

# FOREST PRODUCTS

Their Sources, Production, and Utilization

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McGRAW-HILL BOOK COMPANY, INC.

NEW YORK TORONTO LONDON

1950

THE AMERICAN FORESTRY SERIES  
WALTER MULFORD, CONSULTING EDIT

**FOREST PRODUCTS**  
Their Sources, Production, and Utilization

## The American Forestry Series

HENRY J. VAUX, *Consulting Editor*

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WALTER MULFORD was Consulting Editor of this series from its inception in 1931 until January 1, 1952

## FOREST PRODUCTS

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## PREFACE

Forests constitute one of the most valuable assets that may be possessed by a nation. Their inherent worth is based on the products and benefits they yield continuously when managed as crops and given sufficient protection against fire and other destructive agencies. Wood-producing and wood-using industries rank high in the economic life of nations favored with adequate and productive forests. Although wood is the major raw material of the forest, a great variety of other products from trees and associated vegetation has permitted the establishment of many highly specialized industries. Since forests are a renewable resource, industries based on continuous conversion of forest products contribute to a stable foundation for the economic development of communities.

The range of usefulness of forests is not, of course, confined to the utilization of material products. Water conservation, protection of soil against erosion, recreational facilities, and a multitude of other advantages associated with forests are also important. Forest managers, while striving to obtain the maximum yield of marketable products, should also recognize the other benefits and services that forests can render to a community and to a nation as a whole. Consideration of these latter benefits, however, is not within the scope of this book.

Because of the diversity of products and the numerous methods and processes employed in their conversion, a complete exposition of forest-products utilization would fill many volumes. Space limitations, particularly in connection with a textbook, necessitate a compromise between the breadth of subject matter covered and the extent to which individual topics may be considered. In preparing this text, therefore, the authors have attempted to place major emphasis on the more important phases of forest-products utilization. Basic concepts have been stressed; detailed costs and statistics have been largely excluded because they are usually obsolete before a book comes off the press.

It has been said that a textbook may be likened to a pair of crutches; it assists the tyro until he can walk alone in his chosen field. Once basic principles are mastered, he can, through further study combined with practical experience, become proficient in any specialized field that may attract him. This book contains basic information. The selected references at the end of each chapter point the way to further specialization.

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It is hoped that the reader will broaden his knowledge and understanding of each subject by taking advantage of the opportunities afforded by these references.

In developing this text, the authors have availed themselves freely of the advice and the criticism of men actively engaged in procurement, conversion, and utilization of the products described. It is a privilege to acknowledge our indebtedness to all these people and the organizations they represent.

Special acknowledgments are made to E. R. Deutche, of the Louisville Cooperage Company, H. S. Cunliff, of the Pioneer Cooperage Company, and R. F. Lovejoy, of D. Lovejoy and Sons, for illustrations and information on cooperage; to Dr. J. P. Wentling for data and photographs used in the chapter on round timbers; to Dr. C. S. Schopmeyer, U.S. Forest Service, for historical literature on naval stores; to A. R. Shirley, Georgia Agricultural Extension Service, and C. E. Ostrom, U.S. Forest Service, for information and illustrations, and to Dr. Eloise Gerry, U.S. Forest Products Laboratory, I. F. Eldrege and J. G. Osborne, U.S. Forest Service, for reviewing the manuscript dealing with naval stores.

I. E. Knapp, U.S. Bureau of Agricultural and Industrial Engineering, supplied data on the continuous gum still, and W. P. Lawrence, of The Champion Paper and Fibre Company, furnished information on sulfate turpentine and tall oil. Don Brouse and T. R. Truax, U.S. Forest Products Laboratory, have reviewed parts of the manuscript dealing with veneer and plywood manufacture. Dr. E. C. Jahn, N.Y. State College of Forestry, furnished data on wood plastics, while P. W. Robbins, Michigan State College, assisted with data on maple-sirup production.

Grateful acknowledgment is due S. H. Lorain, U.S. Bureau of Mines, for reviewing the chapter on mine timbers, and V. G. Peterson, Red Cedar Shingle Bureau, for a critical review of the material on shingles and shakes. To R. F. Rommel and Dr. Raphael Katzen, Vulcan Copper and Supply Company, and Dr. E. F. Kurth, Oregon Forest Products Laboratory, our thanks are due for reading the manuscript on wood saccharification. Dr. J. Alfred Hall, Pacific Northwest Forest and Range Experiment Station, offered valuable suggestions in connection with the manuscript for the chapter on wood residues and the related problems of wood utilization research.

Appreciation is also expressed to R. W. Jenner, Cliffs Dow Chemical Company, and Dr. E. F. Kurth for reviewing the manuscript on carbonization and destructive distillation of wood. The very helpful criticisms and suggestions of H. W. Morgan, Weyerhaeuser Timber Company, in the preparation of the manuscript on pulp and paper are greatly appreciated. G. V. Chapman, of the Drexel Furniture Company, and George Lamb, of



the Mahogany Association, contributed information and illustrations used in the chapter on veneer and plywood.

The authors are grateful to all manufacturers, associations, and individuals who furnished tabular and illustrative material used in this text. In each instance special acknowledgment accompanies such material; the credit line is our recognition of such assistance.

Any suggestion that will make this book more useful to people who are interested in this field will be sincerely welcomed.

THE AUTHORS

*January, 1950*

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**Part I**

**ECONOMICS OF FOREST UTILIZATION**

## CHAPTER 1

### TIMBER RESOURCES AND THEIR IMPORTANCE IN THE ECONOMY OF THE UNITED STATES

Timber has played a major role in the growth and development of the United States. It has been estimated that 2,400,000 million board feet of lumber were cut between 1776 and the advent of the Second World War; enough to build 52,000,000 urban homes, 12,000,000 farmhouses, 2,000,000 schools and libraries, 650,000 churches, and 450,000 factories. During the same period the forests also supplied 11,000,000,000 fence posts, 10,000,000,000 railroad ties, 450,000,000 telephone and telegraph poles, 6,000,000,000 cords of fuel wood, and 150,000,000 tons of paper pulp.<sup>2</sup> Without timber, this country could not have attained its present stature so rapidly.

#### I. TIMBER RESOURCES OF THE UNITED STATES AND THEIR UTILIZATION

For approximately 200 years following the erection of the first sawmill in the United States in the early 1600's, timber supplies were considered inexhaustible. As early as 1819, however, there appeared dire warnings of depletion, and as late as 1922 official government pronouncements predicted imminent timber famine. Neither view has proved correct, although depletions of growing stock in most parts of the country have reduced timber resources below desirable levels. Of even greater significance, the quality of timber has been lowered to the point where many primary industries requiring high-quality logs are finding it difficult to obtain adequate supplies. Regionally, drastic steps are required in some instances, but nationally there appears to be sufficient timber to meet immediate needs. Many adjustments are needed, however, to bring all commercial forest lands, both public and private, into the highest possible productivity, to grow the type of forests required to furnish a balanced supply of raw materials for all wood-consuming industries, and to provide a reserve capable of meeting all emergencies. Fortunately, the realities of economic forces are pointing to the need for permanency of timber ownership. In times past it has not always been economically feasible for mill owners to retain ownership of forest lands. Now large segments of the industry realize that permanent ownership and the management of forest lands on a sustained-yield basis

offer the only sure means of survival. Thus it seems that forces are now in motion that have promise of providing a *realistic* solution to the problem of present and future timber supplies and a balanced national timber budget. But forestry costs money. In most private timber enterprises the costs of sound timber management must come from profits derived from the sale of wood products. The problem is, therefore, to utilize as completely and efficiently as possible all available timber supplies that can be grown on the forest lands of the nation. Attainment of these two broad objectives will make the growing of trees more profitable and encourage better forest practices throughout the country.

To accomplish these goals it is necessary to know the quantity, quality, form, and location of the timber resources available for utilization. Careful planning with respect to all these factors is essential prior to establishing even the simplest wood-using enterprise. Also, the time has come when consideration of the sociological aspects of industrial developments can no longer be ignored. The many ramifications of this topic are beyond the scope of this text. The reader is referred to the selected references at the end of this chapter for more complete presentations of national forestry problems, including complete statistical data on growth and drain, major uses, and future requirements of wood in the United States. An understanding of these factors and of the manner in which they are interrelated is essential to all utilization planning.

#### A. MAJOR USES OF WOOD IN THE UNITED STATES

The latest complete data on wood used for all purposes in the United States are provided by a joint canvass made by the U.S. Forest Service and the Bureau of the Census for the year 1940.<sup>5,6</sup> It is unfortunate, in a sense, that more recent data are not available. On the other hand, comparative figures for 1940 are probably more representative of normal conditions than current production and consumption data that reflect the influences of wartime disruptions and the postwar boom in forest products and building materials.

Nevertheless, it does not appear desirable to publish obsolete statistics, particularly since complete data on past lumber production, the amount of wood used in construction and in manufacture, and other pertinent facts are available in numerous publications. Selected reference 4, at the end of this chapter, is an excellent *compendium* of numerous succinct tables dealing with the lumber and related industries.

B. FUTURE REQUIREMENTS FOR WOOD BY WOOD-USING INDUSTRIES,  
1950 THROUGH 1955

The prediction of future lumber requirements is always fraught with uncertainties, but such estimates are necessary from time to time in order to provide bases for future planning. The authors are fortunate that the U.S. Forest Service has just completed an extensive survey of potential timber requirements for the years 1950 to 1955.<sup>8</sup> With the vast resources

TABLE 1-1. POTENTIAL ANNUAL REQUIREMENTS FOR PAPER AND PAPERBOARD,  
WOOD PULP, AND PULPWOOD, 1950 TO 1955 <sup>a</sup>

Item	Paper and paperboard, M tons	Wood pulp, M tons	Pulpwood, M cords	Total fiber required, pulpwood equivalent	
				M cords	Per cent
Total requirement . . . . .	28,000 <sup>b</sup>	17,890	21,751	28,929	100
Estimated imports <sup>c</sup> . . . . .	4,000 <sup>d</sup>	2,000	1,500 <sup>e</sup>	8,678	30
Domestic production . . . . .	24,000	15,890	20,251	20,251	70

<sup>a</sup> Reproduced by the courtesy of the U.S. Department of Agriculture, Forest Service. Potential Requirements for Timber Products in the United States. Report 2 from A Reappraisal of the Forest Situation. 1946.

<sup>b</sup> Includes 17,090,000 tons for domestic paper and paperboard and 800,000 tons for other pulp-containing products.

<sup>c</sup> Chiefly newsprint, equivalent to 4,000,000 cords of pulpwood, on the basis of 1 ton paper equals 1 cord pulpwood.

<sup>d</sup> Equivalent to 3,178,000 cords of pulpwood. Converted on the basis: 200,000 tons groundwood at 0.91 cord per ton; 800,000 tons sulfite at 1.82 cords per ton; 1,000,000 tons sulfate at 1.54 cords per ton.

<sup>e</sup> Total of all imports in pulpwood equivalent.

available to the U.S. Forest Service, this new publication is without doubt the most authoritative work on the subject that is available. Even so, as is unavoidable in estimates of this kind, it has been necessary to qualify many statements and to base the predictions on certain basic assumptions.

Basic assumptions made in the study were (1) that national productivity, as a result of full employment, will remain high, *i.e.*, 95 per cent of the labor force will be actively engaged in production and services; (2) that the national level of output of goods and services, in terms of 1944 prices, should reach 200 billion dollars within the period 1950 to 1955; and (3) that 1950 to 1955 is sufficiently removed from postwar reconversion and, at the same time, not too far in the future to permit a reasonable estimate of timber requirements under the stated assumptions. It is recognized, of course, that

## ECONOMICS OF FOREST UTILIZATION

TABLE 1-2. POTENTIAL ANNUAL REQUIREMENTS FOR TIMBER PRODUCTS  
IN THE UNITED STATES, 1950 TO 1955 <sup>a</sup>

Product	Potential requirements		Estimated drain of domestic timber, <sup>b</sup> million cu. ft.	Estimated drain from trees of saw-timber size <sup>b</sup>	
	Unit of measure	Quantity, millions		Per cent	Million bd. ft.
Lumber (total) <sup>c</sup> . . . . .	bd. ft.	42,500	8,670	98.9	44,345
For construction (total) . . . . .	bd. ft.	31,500			
New residential (nonfarm) . . . . .	bd. ft.	11,000			
All other new (nonfarm) . . . . .	bd. ft.	8,500			
Farm, including maintenance and repair . . . . .	bd. ft.	6,500			
Railroad construction <sup>d</sup> . . . . .	bd. ft.	2,300			
Lumber for use in mines . . . . .	bd. ft.	500			
All other maintenance and repair . . . . .	bd. ft.	2,700			
For use in manufactures . . . . .	bd. ft.	5,000			
For use in shipping . . . . .	bd. ft.	6,000			
Railroad ties, hewed . . . . .	Number or units	22	238	98.5	1,084
Fuel wood . . . . .	Cords	63 <sup>e</sup>	1,836	37.6	3,066
Pulpwood . . . . .	Cords	29 <sup>f</sup>	1,660	70.2	5,784
Poles . . . . .	Number or units	5.7	91	90.0	318
Piling . . . . .	lin. ft.	38	29	100.0	114
Fence posts . . . . .	Number or units <sup>g</sup>	600	480	25.7	492
Veneer logs and bolts . . . . .	bd. ft. <sup>h</sup>	2,400	566	98.5	2,837
Cooperage stock . . . . .	bd. ft. <sup>h</sup>	775	183	98.8	919
Mine timbers, not sawed . . . . .	cu. ft.	220	220	35.6	312
Wood for hardwood distillation . . . . .	Cords	0.5	34	35.0	53
Logs and bolts for all other uses . . . . .	bd. ft. <sup>h</sup>	1,000	236	100.0	1,200
Cordwood for all other uses . . . . .	Cords	5	350	35.0	529
Total all products . . . . .	.....	.....	14,593	82.7	61,053

<sup>a</sup> Reproduced by the courtesy of the U.S. Department of Agriculture, Forest Service. Potential Requirements for Timber Products in the United States. Report 2 from A Reappraisal of the Forest Situation, 1946.

<sup>b</sup> For converting factors see U.S. Department of Agriculture, Forest Service. The Management Status of Forest Lands in the United States. Report 3 from A Reappraisal of the Forest Situation, 1946. Table 25.

<sup>c</sup> Lumber tally.

<sup>d</sup> Includes sawed ties, car lumber, maintenance, and repair.

<sup>e</sup> It is estimated that 27 million cords (43 per cent) might be cut from sound, living trees.

<sup>f</sup> It is estimated that the equivalent of 9 million cords may be imported in paper, wood pulp, and pulpwood. Domestic pulpwood requirement is estimated at 20 million cords.

<sup>g</sup> It is estimated that 20 per cent might be cut from cull and dead trees, 480 million posts from sound living trees.

<sup>h</sup> Log scale.

actual consumption of forest products may be influenced by economic conditions that cannot be predicted with any great degree of assurance at this time.

The over-all estimates contained in the study are quoted as follows:

The estimated potential requirements add up to about 15 billion cubic feet of timber annually. . . . This includes between 42 and 43 billion board feet of lumber, 63 million cords of fuel wood, 20 million cords of pulpwood (domestic only) and about 2½ billion cubic feet in other products. These quantities would apparently meet the needs of a prosperous nation amply but not extravagantly.<sup>3</sup>

Tables 1-1 and 1-2 show the composite results of the study. The factors affecting the estimated requirements of individual uses are of considerable interest, and readers are urged to consult the original publication for this information.

### C. TIMBER REQUIREMENTS AT THE END OF THE CENTURY

The U.S. Forest Service is faced with the extremely difficult task of predicting for some years in advance the expected drain on national timber resources. This is necessary to arrive at a national plan of forest management that will assure adequate future supplies of timber, of the proper quality, for all possible uses, plus a reserve for emergencies such as war. An attempt has been made in the publication that has been under discussion<sup>3</sup> to forecast potential requirements 50 years hence. This estimate will not be discussed in detail, but it is interesting to note that the total estimated drain on domestic timber 50 years hence is expected to be only slightly more than was predicted for the period 1950 to 1955, or 15,576 million cubic feet as compared to 14,593 million cubic feet.

Neither of the above estimates has taken into consideration the larger volumes of wood, now largely unused, that might be utilized by various chemical processes being developed that have a reasonable chance of success within the next 50 years. History has shown that countries with depleted timber supplies ultimately adjust their national wood budgets to remaining stands, plus any importations that can be obtained at reasonable cost. If large-scale chemical uses are found for wood in this country, it is possible that our timber resources 50 years hence will be inadequate to meet all demands, even if intensive forest management is practiced by that time. This is indicative of the urgent need for planning of the type exemplified by the 50-year forecast under discussion. Time may demonstrate that this estimate is not accurate, but it most certainly is a step in the right direction.

On the basis of present knowledge, it seems likely that sound forest



management policies, plus more complete and efficiently integrated wood utilization, may, together, assure adequate timber supplies for the future. The uncertainties that lie ahead point to the need for a greatly accelerated program of national planning in both forest management and wood utilization.

## II. THE RELATIVE IMPORTANCE OF THE WOOD-USING INDUSTRIES

It is difficult, if not impossible, to determine accurately the relative importance of one industry in terms of other industries. The U.S. Department of Commerce, Bureau of the Census, issues the only comprehensive statistics with which various industries can be compared.<sup>11</sup> Excellent as this information is, it falls short of providing complete information on some industries. There are numerous reasons for this, among them being (1) the necessity of combining some industries in order to avoid disclosing the identity of certain individual companies, and (2) for the sake of simplifying the census, the necessity of classifying each establishment as a whole in some one industry, according to its product of chief value, although, in many instances, a single establishment may manufacture more than one product. For example, it is impossible to determine how many wage earners listed under the pulp and paper industry are engaged in cutting and transporting pulpwood or employed in the cut-up mill. Further, many small wood-using industries are classified under miscellaneous industries in a manner that makes it impossible to determine what percentage of the total production in the classification is made from wood; examples of such classification are "Pianos and Musical Instruments," "Sporting Goods," "Pens and Pencils," "Signs," and "Patterns."

It seems desirable, however, that the reader have some concept of the relative magnitude of the lumber and wood-using industries. Table 1-3, based on figures of the Department of Commerce, Bureau of the Census, shows that in 1939 the lumber and wood-using industries ranked fourth in number of establishments, fifth in the number of wage earners, seventh in the total amount of wages paid, tenth in the cost of materials, tenth in value of products, and ninth in value added by manufacture. These figures indicate that the lumber and wood-using industries ranked between seventh and eighth in the national standings in 1939.

Although no comprehensive comparative figures have been released since 1939, data on the numbers of wage earners for 1945<sup>12</sup> show that the lumber and wood-using industries dropped from fifth place in this category in 1939 to sixth place in 1946. In 1939 the lumber and wood-using industries ranked ninth among the major industries with respect to value added by manufacture (Table 1-3). In 1946, even though the lumber and wood-

TIMBER RESOURCES

			(one year)			energy and contract work, thousands	products, thousands	Rank	manufacture, <sup>b</sup> thousands	Rank
Food and kindred products..	51,448	1	823,693	3	\$ 913,985	2	\$7,062,039	1	\$10,618,026	1
Textile-mill products and other fiber manufactures..	6,444	9	1,082,602	1	908,379	3	2,108,926	3	3,930,678	4
Apparel and other similar products made from fabrics and similar materials	20,206	3	751,377	4	654,402	6	1,943,677	6	3,325,015	6
Lumber and timber basic products and furniture and finished lumber products <sup>c</sup>	19,977	4	654,183	5	585,119	7	1,145,199	10	2,389,782	10
Paper and allied products...	.....	.....	.....	.....	.....	.....	1,149,666	9	.....	.....
Printing and publishing and allied industries.....	24,878	2	324,535	9	493,616	8	.....	.....	2,578,464	8
Chemical and allied products.....	9,203	6	.....	.....	356,176	9	1,854,140	7	3,733,658	5
Products of petroleum and coal.....	.....	.....	.....	.....	.....	.....	2,278,486	5	2,953,973	7
Leather and leather products.....	.....	.....	327,633	8	.....	.....	.....	.....	.....	.....
Stone, clay, and glass products.....	7,024	8	287,524	10	.....	.....	.....	.....	.....	.....
Iron and steel and their products, except machinery.....	8,994	7	966,367	2	1,313,633	1	3,635,871	2	6,591,530	2
Nonferrous metals and their products.....	5,600	10	.....	.....	.....	.....	1,748,592	8	2,572,854	9
Electric machinery.....	9,506	5	522,980	6	335,820	10	.....	.....	3,254,174	6
Machinery, except electric.....	.....	.....	398,963	7	748,288	4	.....	.....	.....	.....
Automobiles and automobile equipment.....	.....	.....	.....	.....	646,406	5	2,725,396	4	4,047,873	3
									1,322,476	8

<sup>a</sup> Source: U.S. Bureau of the Census, Statistical Abstracts of the United States, Table 923. 1947.  
<sup>b</sup> Value of products less cost of materials, containers, fuel, purchased.  
<sup>c</sup> Lumber and timber products.

using industries again showed increase over 1939, they had dropped to thirteenth place in the relative standings. This indicates that they have failed to keep pace with advances made in other industries. Extremely high prices of lumber and wood products since the war may have played a part in this decline.

### III. THE STABILIZING INFLUENCES OF FORESTS AND WOOD-USING INDUSTRIES

The numerous values obtained from forests before they are harvested are every bit as important in our national economy as the final products derived from wood. Thus the two are interdependent and cannot be separated in a discussion of their importance and the stabilizing influence they exert. This is particularly true when it is recognized that wise and profitable wood utilization can assure the perpetuation of forests at a high level of productivity. The same principle applies to government and private ownership. The products from government-owned forests, as well as from private forests, must eventually be sold to justify the existence of the forests, except in those instances where they are set aside primarily for watershed protection, recreational activities, or other specialized uses.

Since this text is devoted to the subject of wood utilization, space does not permit a complete discussion of the benefits derived from forests alone. An example may serve, however, to demonstrate the need for discussing the relationships that exist between the products obtained from forests and the forests themselves. Coal is an invaluable resource, but until it is mined it contributes nothing to the national economy, other than to serve as a reserve supply of energy and other products. The difference between this and the case of forests is immediately apparent when the numerous values obtained from forests before they are harvested are considered.

#### A. THE STABILIZING INFLUENCES OF FORESTS

Values derived from forests that are not directly related to wood products include (1) controlling erosion and stream flow, (2) providing range for livestock, (3) maintaining wildlife, and (4) providing suitable areas for recreation. It has been stated that approximately one-half the forested areas of the United States exert a major watershed influence and that another one-quarter exert a moderate influence. Forested watersheds retard runoff, protect potable water sources, retain water for irrigation, increase supplies of hydroelectric power, reduce erosion, and help prevent disastrous floods that affect rural and city populations alike. In the great livestock-raising regions, particularly in the West, the industry is depend-

ent upon forested areas for summer range. Without this source of feed, meat, leather, and wool would be more costly than they are at the present time. Wildlife, when properly managed, does not interfere with the livestock industry and fulfills some of man's need for recreational activities. Forested areas, with their mountains, streams and lakes, trees and wild flowers, fish and game, lead all other areas in their spiritual and recreational appeal. And recreation is vital in all walks of life.

Forests are beneficial in another way. They usually occupy land that is *unsuited, or poorly suited*, for other purposes. Experience has shown that the remaining forest lands are, *for the most part, unsuited* for agriculture. In fact, replacement by forests is the only efficient utilization of marginal farm lands, particularly those that have been abandoned. Forests, then, *provide their many services* on what might be called a noncompetitive basis; and they still provide products of inestimable value.

The general benefits derived from forests are shared by all. This is the justification for extensive Federal ownership of forested regions, particularly where multiple-use management is essential to the national welfare. But private ownership, too, can profit from multiple-use planning. Some or all of the inherent values of forests, such as livestock range and recreational activities, can be utilized, through proper management, to reduce the costs of private forestry. In either case, intelligent multiple-use management is essential to the perpetuation of all these values in their proper proportions.

The above is an extremely limited discussion of the stabilizing influence of forests. The subject merits a good deal more study, and every student of wood utilization should have a thorough grasp of the relationships that exist between forests and the final products that stem from them. The selected references at the end of this chapter will provide a starting point for such a study.

#### B. THE STABILIZING INFLUENCE OF THE WOOD-USING INDUSTRIES

The direct benefits of the wood-using industries are derived from the useful goods they produce and the employment they give to large numbers of workers and the industries that serve them. Less direct, and again rather closely affiliated with the forests themselves, are the opportunities that stable wood-using industries afford in balancing the economic and social development of rural communities. Wood-using industries provide farmers with off-season employment in adjacent forests and wood-using plants and direct returns through the sale of forest products from farm woodlots. Farm populations are heavy users of forest products for homes, barns, fence posts, containers for shipping farm produce, and many other

uses; and the presence of wood-using industries creates local outlets for farm products. They also create a tax base in rural areas where farm properties would otherwise be called upon to bear the entire tax burden. Stable wood industries are essential to the success of many other major industries. To mention only a few, railroads, mining, and communications depend heavily on forest products for their success.

All the benefits that can accrue from the presence of forests and the industries that obtain their raw materials from them are effective in full measure only under intelligent, long-range planning in sustained-yield forest management. All the elements of these values exist in only a very few of our forested areas at the present time. They have been lost temporarily in those areas where unwise exploitation has left ghost towns in the wake of timber depletion. Exhaustion of forests in many areas has resulted in the decline of agriculture, the abandonment of railroads, migration of farm workers to urban centers, and community decadence. Wood-using industries based on sustained-yield management, on the other hand, can form the nuclei of stable communities, with established service industries, permanent social institutions, and normal municipal growth based on permanent values. Such communities stabilize agricultural pursuits by providing local markets for farm products. Other industries, indirectly dependent on forest products, are attracted to permanent communities of this character. Their stability is a bulwark against depressions and a means of reducing migrations to urban areas.

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## CHAPTER 2

### WOOD RESIDUES AND THE RELATED PROBLEMS OF WOOD-UTILIZATION RESEARCH

The term *wood waste* requires careful definition. It is often used loosely. Conservationists sometimes consider as waste every part of a tree not converted to lumber or some higher use. Under such a classification, tops of trees left in the woods and mill residues used as fuel are called waste. Many lumbermen, on the other hand, give little thought to tops and limbs for which no markets exist under any particular set of economic conditions. They also view sawmill residues as a logical fuel for the generation of steam at the mill, although, in some cases, higher uses might be found for the material that is burned. To arrive at a reasonable definition of wood waste it is necessary to examine some of the factors that play a part in determining the marketability of wood residues generated in the forest and at wood conversion plants. The most important of these factors are time and place.

In colonial times timber was often considered an obstacle to agriculture, and valuable species like oak and walnut were sometimes felled and burned when land was cleared, since there were no markets for oak and walnut logs in those days. The same situation existed in all our frontier settlements. It is conceded that such practices were wasteful in the light of present standards, but much unwise exploitation of timber resources still occurs in spite of conditions that permit more complete utilization. Even now, our best forestry practices are considered wasteful by Europeans. It is a question of time and economic development; the practice of forestry in Europe is several centuries older than it is in this country. Countries that have experienced timber scarcity recognize the wisdom of maintaining forest lands in a high state of productivity and of utilizing every portion of a tree to the highest possible degree.

Time and place often combine to dictate the extent of wood utilization. A sawmill located near a large settlement might, at one stage in the regional development, dispose of all of its residual wood and sawdust for fuel at a reasonable return. At the same time, a mill located some distance from the settlement might be unable to dispose of its residues in this manner because the cost of transportation would preclude a profit. This situation could, however, be reversed. A pulp mill might be erected adjacent to the isolated

mill, providing it with even more profitable outlets than the fuel market of the city mill. If, because of more extensive timber supplies, a group of diversified industries, such as fiberboard plants, plywood plants, and others, should be located in the vicinity, the more isolated mill might find highly profitable uses for all its residues, while the city mill might make no great gains in utilization. The proximity of the pulp mill and the development of new processes, such as the hydrolysis of wood to produce wood-sugar alcohol and molasses, might also make profitable the harvesting of logs and tops formerly left in the woods. Thus, place and time would have a great influence on the extent of utilization of residues in the instances cited. Fluctuations in economic conditions also have a marked influence on the extent to which residual materials are utilized. In times of unfavorable market conditions, it may not pay to transport sawdust to a fuel market or slabs to a fiberboard plant. When prices are at a low level, it often does not pay to haul marginal materials from the forest, and more material is left unused. A recent example from the Douglas fir region may serve to illustrate this point. The demand for lumber was active during the Second World War and prices were high. This resulted in the removal of logs that would have been unprofitable on any previous market. "Wood logs," previously left in the woods, were a common sight in mill ponds. The demand was so active, in fact, that relogging of cutover lands and salvage logging on old burns gained much impetus.<sup>6,9</sup> With the first break in prices after the war, these activities stopped abruptly; mill operators went into the woods to "reeducate" their bucking crews to prepare for removal only those logs considered profitable under the new price structure.

The foregoing examples are only a few of many combinations of circumstances that can have an effect on the degree of utilization of residues at any time or place or under changing economic conditions. They serve, however, to illustrate the need for careful thinking in expressing the meaning of wood waste.

The U.S. Forest Service has defined wood waste in a recent publication as follows: "Throughout this report the term waste wood means wood material from the forest which does not appear finally in marketable products other than fuel wood, regardless of whether it is economically or technologically feasible to utilize it."<sup>15</sup>

The Society of American Foresters recognizes the following definitions:

*Waste.* 1. On a logging operation, that portion of the tree which has merchantable value but is not utilized.

2. Waste at a sawmill is that portion of the log having merchantable value which is not utilized. Sawdust and refuse used for fuel, and those portions of logs, slabs, edgings, and trimmings used for lath, shingles, cooperage, and other products are not waste.



*Merchantable.* 1. Used to designate the portions of trees or stands which can be profitably marketed under given economic conditions.\*

Voorhies<sup>16</sup> has defined sawmill waste as that portion of the sawlog that does not appear as lumber, and net waste as all waste that remains after deductions have been made for fuel, lath, pickets, and other products.†

For this chapter, the following definitions will be used:

1. *Waste wood is marketable wood of any form that is not used at the highest level available to a given logging or manufacturing operation, under current economic conditions and at the current stage of technological development.* Marketable wood that is not used for any purpose comes within the scope of this definition.

2. *Wood residues are all forms of wood that cannot be marketed at a profit from a given logging or manufacturing operation, under current economic conditions and at the current stage of technological development.*

The Forest Service definition quoted above views wood residues from the standpoint of the conservationist, labeling as waste all parts of trees that are not converted to salable products, irrespective of whether or not it is economically feasible to convert them. From a long-range standpoint this is tenable, and no one can object to the goal that this definition expresses. All elements of the wood-producing and wood-using industries, including the Forest Service, should be directing every effort toward more complete utilization of materials now destroyed or not utilized to the greatest economic advantage. From the standpoint of the national economy, tops left in the woods and sawdust destroyed by burning because there is no market constitute grave waste, but individual operators cannot be expected to harvest or manufacture such materials at a loss when no profitable markets exist or when no processes have been developed to utilize them to advantage.

Genuine wood waste, however, has been tremendous. Many sawmills

\* Forestry Terminology. Society of American Foresters, Washington, D.C., 1944.

† Webster's New International Dictionary defines the noun waste as "(1) The action of wasting, or state of being wasted: useless expenditure; as *waste* of time. (2) Superfluous or rejected matter: refuse." Neither meaning fits the case in question very well. If lumber is needed, and there is no market or profitable use for tree tops, it does not seem logical to classify the wood they contain as a *useless expenditure* of material. Neither does it seem reasonable to call sawdust used as fuel at a sawmill *superfluous* or *rejected matter*, or *refuse*. There has been, and there still is, a good deal of *wasting* of the timber resource, in the true sense of the word. But it does not cover all the cases to which the term is commonly applied. In the minds of many people the word *waste* connotes *profligacy*, and stigma may be attached to acts and procedures for which there is no immediate remedy.

Perhaps a more appropriate word is needed. Webster defines the word *residue* as "That which remains after a part is taken, separated, removed, or designated; remnant; remainder; rest." This seems to fit the case better.

have destroyed, and still are destroying, slabs and much other material that would have yielded vast quantities of short lengths of clear wood that could have been converted to salable commodities<sup>2,3</sup> (see Figs. 2-1 and 2-2). It is rather generally agreed among its more progressive leaders that the lumber industry has lacked vision and has failed to take advantage of



FIG. 2-1. Typical open-pit burner in a western Oregon sawmill. Bark, sawdust, slabs, and edgings are burned for lack of profitable markets. (From *Bull. Series 17. Engin. Expt. Sta., Oregon State College.*)

technological developments in other fields. One leader in the industry<sup>4</sup> stated recently:

Probably one of the simplest ways to improve our product is to improve the tools by which the product is produced. This involves research in equipment and methods. Although tremendous improvement has taken place in logging methods in the last 15 years, no like improvement has taken place in the equipment of conversion. Let me ask you a question. How new is your band mill, and in what respect does it vary from grandpappy's mill? I can tell you. With the possible exception of antifriction bearings, improved carriage design, and faster set works, fundamentally there is no change.

Strangely enough, the industry is not often criticized for its archaic methods of manufacture, production control, and inspection. Instead it is censured for failure to utilize materials that cannot be put to profitable use by the small operator. The exact reason for this is not known. Perhaps it is because logging, even under the best forestry practices, often has

the appearance of spectacular waste and because sawdust piles are so often located in plain sight along public highways. Equally great wastes and residues are common but little publicized. Unused lignin offers an example. About one-third of the weight of wood is made up of lignin. No extensive, profitable uses have been found for this substance, and its chemical nature is not fully known. According to Brauns,<sup>1</sup> pulp mills in the United States "waste" about 2½ million tons of lignin each year; sawmills about 7½ million tons. He points out further, however, that 30 mil-



FIG. 2-2. Sawmill trim accumulated at a medium-sized Douglas fir mill. (From Bull. Series 17, Engin. Expt. Sta., Oregon State College.)

lion tons of wheat, rye, and flax straw, cotton and cornstalks, and the herbaceous parts of other crop plants also are not utilized. Some of these materials are plowed under, adding values to the soil. This is not a high form of use. Its value is equal only to the cost of an alternate soil conditioner and plant food, which is comparable to using sawdust for fuel. No profitable bulk uses have been found that will provide sufficient returns to warrant the collection of lignin from field crops at the present time. The same applies to the lignin residues of pulping operations.

Research has succeeded in solving similar residue problems in other industries. Codfish livers were considered offal for years, until research discovered the vitamin values they contained. This paved the way for an extensive expansion of the fishing industry. The livers of nonedible fish that are present in great quantities, and often a nuisance in the nets of fishermen, were found to contain even higher quantities of valuable oils and vitamins. The list of such examples is endless, and the part played by re-

search in this and similar cases points the way to the solution of the present problems of the lumber industry.

Until only recently the level of research in the lumber industry was far below the general industrial average. Even with the impetus given wood research during the Second World War, it still does not approach the intensity of developmental research now being practiced by the metal, chemical, and plastics industries, many of whose new products are in direct competition with wood. There are reasons for the dearth of research in the lumber industry. It is made up, to a large extent, of numerous individual units, each too small to support research of its own. Many of these small firms are banded together into loosely knit associations, whose primary aims have been advertising and sales promotion. A few associations have accomplished effective research on a small scale, but they have been the exception. Living in the past, most of the operators and associations have failed to appreciate the need for *imagination* and research to keep abreast of the advance made by competitive industries. Quoting again from C. D. Dosker, Chairman, National Lumber Manufacturers Association Committee on Products and Research,

A study of the downward trend of the average per capita consumption of lumber should indicate to this great industry of ours the need of putting back into the soil of markets those vital elements on which this industry can grow, those elements which will prevent the sterility of our markets. The continued decline in the use of lumber should indicate to this industry its great need for research, and we must not be lulled into security by a wartime and postwar reconversion demand for our products. We are living in a fool's paradise, and we all know this to be true. But time is growing short and we should know that it is wise, in times of plenty, to prepare for the famine.<sup>4</sup>

A few large timber companies, particularly in recent years, have established sizable research laboratories. The experience of such companies points the way to the resolution of the wood residue problem. Large companies, having integrated operations based on permanent sustained-yield timber holdings, not only can afford research; they can reduce residues materially through the diversity of numerous utilization units. Such an operation may contain separate units for the manufacture of lumber, paper pulp, fiberboard, plywood, fuel briquettes, and bark-conversion products.<sup>7,12</sup> This permits segregation of raw materials by species, size, and quality and utilizing each at its highest economic level. At the same time, residues can be distributed to specialized plants designed to convert them into useful products. As new processes are added, residues are even further reduced. By the development of entirely new processes, higher uses may be found for residues previously utilized for another purpose; or for the utilization of materials now considered worthless, such as wood containing decay. The

process of integration can be carried on indefinitely through the discovery of new processes and the improvement of old methods, until all values inherent in trees are realized.

Integrated units of the foregoing type are relatively few in number. Nevertheless, because of their large size and efficiency, they are the source of a rather high percentage of the total lumber cut in this country. Unfortunately, however, there are thousands of small- and medium-sized mills that are left, for all practical purposes, without benefit of research. Most mills in this category have little prospect of obtaining the capital necessary for the establishment of integrated operations. More often, they even lack the possibility of obtaining a sustained-yield unit. As time passes, the onus of waste is resting more and more heavily upon these small owners. Being financially incapable of applying technological advances to their operations, they continue to generate outright waste or to utilize residues at a very low level, long after higher economic uses have been developed. The situation is not hopeless, even for these small operators, but its correction will require new thinking and aggressive action. Research is one of the answers, not only in the development of new processes, but also in the improvement of existing practices. Among the problems requiring immediate consideration are (1) improvement in sawmill machinery and handling techniques, (2) improvements in the quality of lumber itself, (3) adoption of production-control methods used in other industries, (4) development of building techniques that will utilize lumber more efficiently, and (5) the application of modern market-survey techniques. Such research could easily be provided by trade associations and public agencies.

Some industries expend as much as 10 per cent of total sales value for research, but 2 to 3 per cent probably approaches the average. It is doubtful if the lumber industry, as a whole, spent more than 0.2 to 0.5 per cent for research prior to the Second World War, and the average has not increased appreciably since that time. Not all wood-using industries have suffered from lack of research. Pulp companies have been aggressive in sponsoring research, not only in the technology of the chemical processes involved, but in harvesting methods, cut-up mill and barking practices, the utilization of new species, waste reduction, and sustained-yield forest management. Their technical laboratory \* is one of the finest research institutions in the country, and the industry has sponsored much academic and public research. The same has been true to a lesser extent in the fiberboard field. The research activities of the Masonite Company are an outstanding example. The lumber industry could well follow the lead of these closely allied industries.

\* Institute of Paper Chemistry, Appleton, Wisconsin.

Residue and waste-utilization plants sometimes work against the goals of forestry and the best interests of the nation. Though originally planned for the utilization of residues, some plants of this type become so large that they compete with sawmills for sawlogs in the race for sufficient raw materials to maintain themselves. The hardwood dimension-stock industry offers another example. Numerous mills, originally designed to produce dimension stock from sawmill residues, now find it more profitable to use lumber as their raw material. The same thing has been true of pulp mills in some regions. It is poor national economy to use sawlogs capable of producing structural materials for low-quality fiberboard and for paper pulp that can be made from tops or from inferior species. Here, again, classification of raw materials is essential to the balanced production of all commodities stemming from wood. Without intelligent planning, the goals of forestry and the general welfare of the wood-using industries may suffer. The goals of forestry and wood utilization are identical in basic principle, a fact often forgotten by lumbermen and foresters alike. The aim of foresters should be the sustained-yield management of all forests with a view to producing as much high-quality timber as possible, together with enough other wood to supply the needs of all the wood-consuming industries that complete the pattern of integrated utilization. The aims of the wood-using industries should be much closer utilization, more intensive remanufacture, greater diversification, and more complete integration, all of which will reduce waste to a minimum. If these aims can be achieved, the future of the lumber industry can be assured and uncertainty can be replaced by stable and permanent production and employment.<sup>8</sup>

It is hoped that this chapter will impress on all students of wood utilization, if nothing else, the great need that exists in the lumber industry for progressive leadership, imagination (in both management and research), and intelligent nation-wide planning. Only in this way will it emerge from its present status of a low-value raw-material industry to become the highly diversified and specialized industry that it could and should be.

#### I. SOURCES OF RESIDUAL AND WASTE WOOD

The major sources of residual and waste wood are (1) wood left in the forest after logging, and (2) residual and waste wood generated in the manufacture of primary products such as lumber, veneer, and shingles. Other sources include secondary manufacturing operations of all kinds, planing mills, materials unutilized during building construction, and many minor sources. Bark is not usually included in estimates of residues, but perhaps it should be. The bark of some species appears to offer just as great potentialities for utilization as some forms of residual wood. The sum of wood

residues and wood actually converted to salable products is called the commodity drain on the nation's forests. An added drain, called the noncommodity drain, results from fire, decay, and insects. In 1944 the noncommodity drain was approximately 12 per cent of the commodity drain.

#### A. LOGGING

Residual wood generated in logging consists of trees not cut because of poor form, mechanical defects, and decay, tops and limbs, trees damaged or destroyed in logging, and residual trees destroyed during slash disposal. The amount of wood destroyed or unused after logging depends on species, age and composition of the stand, logging methods used, type of terrain, primary product for which the logs are being harvested, distance of the producing area from its principal markets, size and location of conversion plants, and many other factors. A few examples will serve to illustrate the more important of the foregoing factors. According to U.S. Forest Service estimates,<sup>15</sup> 88 per cent of the wood left in the forests after logging comes from felled trees, the remaining 12 per cent from damage to the residual stand. Wood residues from the softwoods logged in the Pacific Northwest amount to 67 cu. ft. per 1,000 ft. of lumber produced, while in the case of some heavy-topped hardwoods in the Lake states, the amount may reach 130 cu. ft. Logging damage in the Douglas fir region is much greater in the old growth than in second-growth stands, owing in part to the greater breakage that occurs in felling large, defective trees. The primary product has a marked effect on the amount of material that is left in the woods. Losses in preparing fence posts, fuel wood, and round mine timbers for the market are small compared to the preparation of sawlogs, peeler logs, cooperage stock, shingle bolts, and other primary commodities. Seventy-two per cent of the cubic volume of a tree cut for cooperage is lost; for hewed cross-ties, 70 per cent; for lumber, 68 per cent; for veneer, 66 per cent.<sup>15</sup> The great distance of the Douglas fir-producing area from its principal markets has an influence on the amount of wood left in the forest. High freight rates to Eastern markets make profitable the harvesting of only the higher grades of logs. Consequently, logs that would be utilized to advantage in other parts of the country cannot be transported from the woods and manufactured into lumber at a profit. Small isolated operations in all parts of the country tend to leave more material in the woods because they lack the facilities for more complete utilization. Proximity to fuel markets makes possible the utilization of some logging residues. This use ranges from 10 per cent in some parts of the Eastern states to nearly none on the West Coast. There are a few instances of hardwood logging residues being utilized for pulp and other purposes. As in the case of residual wood at sawmills, cost of transportation is the principal deterrent to more complete

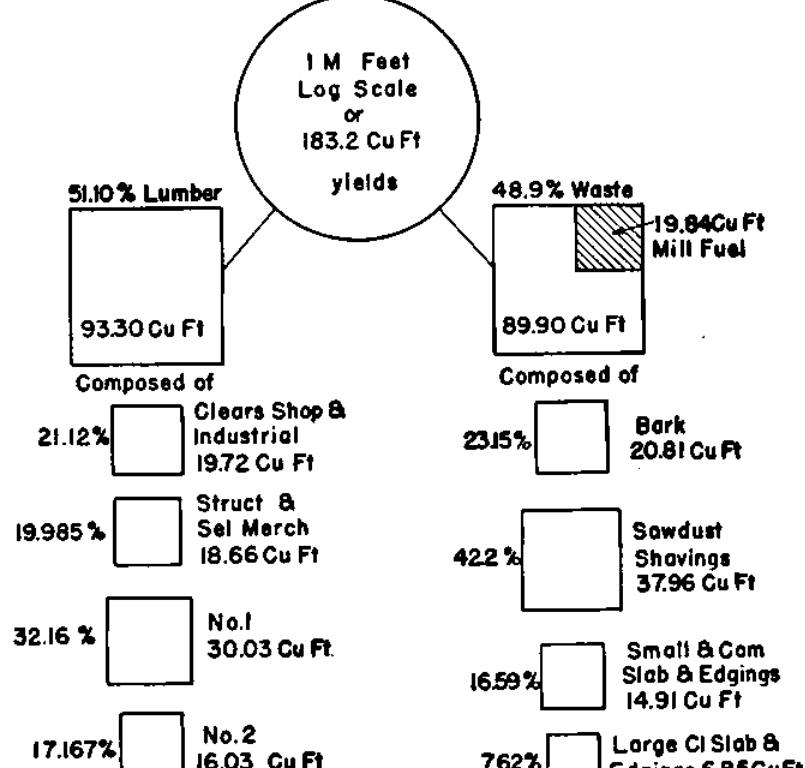
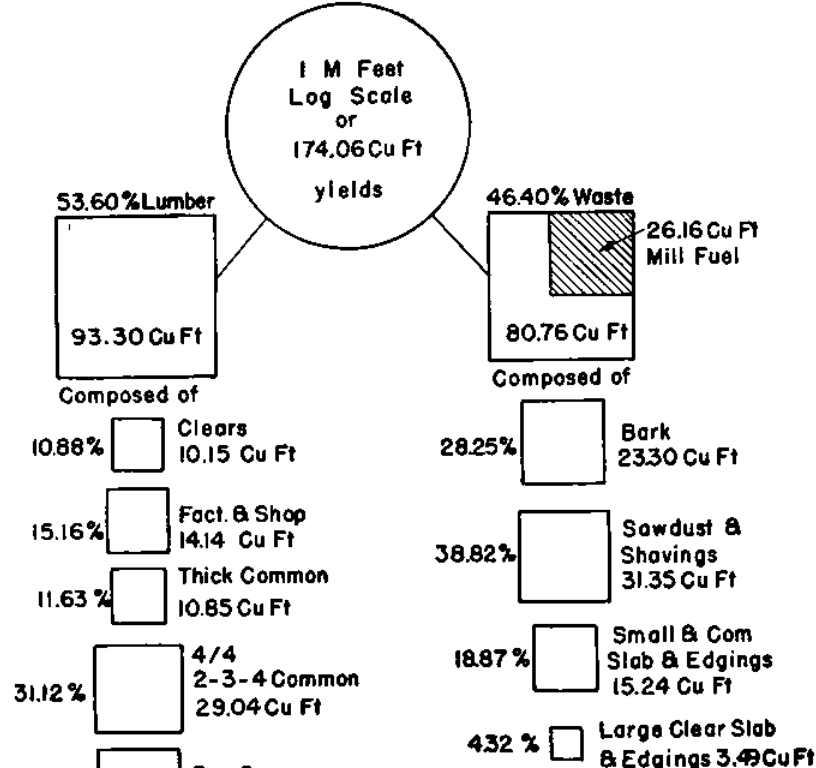
utilization of materials left in the woods. In some regions, because of the scattered distribution of these residues, it will probably be some time before they can be utilized at a profit.

#### B. PRIMARY MANUFACTURE

The most commonly accepted classification of wood residues produced in the manufacture of primary products is as follows: "Primary manufacturing waste includes: (1) Coarse materials like slabs, edgings, and trimmings from sawmills, cores and trimmings from veneer mills, and culled stove bolts from cooperage stock mills; (2) fine materials such as sawdust and shavings from sawmills and other plants; (3) fibers and chemical components lost in making pulp and paper."<sup>15</sup> The last category is not always included in such a classification, although it seems tenable, providing it is recognized that these products are not waste in those cases where no profitable uses exist. The amount of residual wood at primary conversion plants is slightly greater than the amount left in the woods if *pulping losses* and the sawdust and other products sold for fuel are included, and about one-half as much if they are not included. Sixty-three per cent of all wood residues from primary manufacturing operations were used for fuel in 1944, as compared to 6.6 per cent logging residues. On a national basis, approximately 43 per cent by weight of the total timber cut is converted into wood products of all kinds, including wood cut for fuel; 22.5 per cent, in the form of wood residues, is used as fuel; and approximately 34.5 per cent is not used at all.

Coarse materials found at sawmills include slabs, edgings, mill trim, and planer ends. Hogged wood is included in this category because it is produced by chipping coarse material. Fine material consists of sawdust and shavings. Figure 2-3 shows the relationship between lumber recovery and waste and unused wood accumulations as determined for ponderosa pine and Douglas fir in one study.<sup>16</sup> Each primary industry has its own type of wood-residues material. Rotary veneer plants generate log trim, peeler cores, sapwood lost in truing up the log on the lathe, and wood that is lost in trimming out defects and in jointing, breakage, and the like. In fact, wood residues at many veneer plants are almost as great as those produced in the manufacture of lumber. Shingle mills generate residual wood in the form of log trim and waste in producing shingle blocks, "spalts," shingle tow, and so forth. Even in producing round commodities, such as poles, there are unused butts and tops that are removed to improve grade, fine sapwood material removed in barking poles on the recently developed pole-shaving machines, and saw kerf and other wood from framing operations. Many small plants produce characteristic residues in the manufacture of blanks, billets, and cut-up stock for a host of small remanufacturing plants.





### C. SECONDARY MANUFACTURE

The residual wood from primary plants is fairly well concentrated in large manufacturing centers or adjacent to large sawmills, but countless small remanufacturing plants, cabinet shops, and producers of specialties are widely scattered in every part of the country. It is virtually impossible to determine the amount of wood residues they produce. Although the residues in any one small specialty plant are usually low in volume, both the relative and aggregate residues of such facilities are high because many such plants discard a high percentage of wood in the fabrication of high-quality articles. With the exception of the amount used locally for fuel, there is no great immediate possibility of utilizing the bulk of this residual wood for higher uses. The cost of concentrating wastes from widely scattered plants is too great.

### D. CHEMICAL INDUSTRIES

Wood losses incurred in the chemical industries take two forms: (1) wood lost in harvesting and preparing the wood for chemical conversion and (2) losses of lignin and fiber, and dissolved cellulose, hemicelluloses, and extractives. The pulp and paper industry is the principal source of these losses. About 48 per cent of the wood consumed by this industry in 1944 was either left as residues or used for fuel. Of this total, 60 per cent was used for fuel, 23 per cent was lost in the pulping process, and 17 per cent was lost in harvesting the wood and preparing it for pulping. Preparation losses arise from cull material, decay in storage, bark removal, and from fines that are usually burned as fuel. The scarcity of pulpwood in 1944 offers an excellent example of the effect of favorable economic conditions on the utilization of wood residues. High prices, and short supplies in some regions, resulted in the use of material formerly culled and a general reduction in the quality of paper in some instances. The pulping of little-used species increased and is still increasing. It has been estimated<sup>15</sup> that decay losses normally arising from the practice of storing pulpwood in the woods for from 6 months to a year were materially reduced in 1944. Many pulp mills are now barking pulpwood at the mill, instead of in the woods, because of labor shortages and higher labor costs. This makes much bark formerly left in the woods available for fuel.

Wood lost in pulping takes two forms: fiber and dissolved substances. Fiber losses amount to only 7 per cent of the total. With the exception of small losses in bleaching, the remainder consists entirely of dissolved material. While more than half of this residual material finds a low-value use as fuel, it is a vast storehouse of chemical raw materials. More research,

probably, has been directed to finding uses for this unused potential than for any other form of wood residue, and some progress is being made. Dumping these residues in streams as a means of disposal creates serious pollution problems, a fact that has given research in this field a twofold purpose.

The total wood residues generated in distillation and extraction are small in comparison to those of the pulp and paper industry. For the most part, these processes utilize less valuable species or residues of other primary industries. Nevertheless, they generate some residues and in some instances utilize wood at a low economic level. Either no provisions are made to recover acetic acid, methanol, and acetone in many charcoal operations or the recovery methods are primitive.\* Spent chips from the steam and solvent process are an excellent source of fiber for insulating boards, but they are often burned as fuel.

#### E. FIBERBOARD

The extent of losses in the manufacture of fiberboard varies with the process. If a chemical cook is used, some wood constituents are lost by dissolution. Fiber is lost in barking, and some fines escape in the white water. Most fiberboard plants utilize slabs and other residues from sawmills. Some, however, use young second-growth trees and sawlogs. In some instances this is true waste, because the trees are either harvested prior to attaining their maximum growth potential or they are diverted from a higher use.

### II. WOOD RESIDUES AND WASTE WOOD IN THE UNITED STATES

The literature on the amount of residual and waste wood developed in the United States is meager. While intensive surveys have been made of individual primary industries in some producing areas,<sup>16,17</sup> information on a national basis is limited, for the most part, to statistics collected and published by the U.S. Forest Service. These figures, though admittedly based to a large extent on estimates, are of inestimable value to all who are interested in developing means of utilizing wood at the highest possible economic level. Complete data on the amounts of wood residues generated in logging and manufacture, by commodities and by regions, are available in the most recent U.S. Forest Service publication on the subject.<sup>15</sup> For reference purposes, selected data from this publication are presented in Tables 2-1, 2-2, and 2-3. The reader is urged to study thoroughly the original work.

\* See Chap. 18.

TABLE 2-1. WOOD RESIDUES GENERATED BY LOGGING IN THE UNITED STATES IN 1944, BY PRINCIPAL FOREST PRODUCTS, MILLIONS OF CUBIC FEET <sup>a</sup>

Product	Used for fuel	Not used at all	Total	Per cent used for fuel	Per cent not used at all
Lumber . . . . .	167.9	2,090.6	2,258.5	7.4	92.6
Fuel wood . . . . .	.....	199.4	199.4	.....	100.0
Pulp and paper . . . . .	5.0	215.3	220.3	2.3	97.7
Hewed crossties . . . . .	14.9	92.7	107.6	13.8	86.2
Cooperage stock . . . . .	4.9	70.2	75.1	6.5	93.5
Fence posts . . . . .	1.4	17.8	19.2	7.3	92.7
Veneer . . . . .	8.8	140.5	149.3	5.9	94.1
Round mine timbers . . . . .	0.4	21.3	21.7	1.8	98.2
Shingles . . . . .	.....	20.0	20.0	.....	100.0
Other . . . . .	4.4	79.0	83.4	5.3	94.7
Total . . . . .	207.7	2,946.8	3,154.5	6.6 <sup>b</sup>	93.4 <sup>b</sup>

<sup>a</sup> SOURCE: U.S. Forest Service. Wood Waste in the United States. Report 4 from A Reappraisal of the Forest Situation. Report prepared by Robert K. Winters, Gardner H. Chidester, and J. Alfred Hall. 1947.  
<sup>b</sup> Per cent of totals.

TABLE 2-2. WOOD RESIDUES GENERATED BY PRIMARY MANUFACTURING PLANTS IN THE UNITED STATES IN 1944, BY PRINCIPAL FOREST PRODUCTS, <sup>a</sup> MILLIONS OF CUBIC FEET <sup>b</sup>

Product	Used for fuel	Not used at all	Total	Per cent used for fuel	Per cent not used at all
Lumber <sup>c</sup> . . . . .	1,449.0	859.8	2,308.8	62.7	37.3
Fuel wood . . . . .	.....	146.6	146.6	.....	100.0
Pulp and paper <sup>d</sup> . . . . .	55.0	59.0	114.0	48.2	51.8
Hewed crossties . . . . .	.....	15.0	50.8	70.5	29.5
Cooperage stock . . . . .	35.8	2.4	2.4	.....	100.0
Fence posts . . . . .	.....	0.8	110.1	99.3	0.7
Veneer . . . . .	109.3	0.4	3.8	99.5	0.5
Round mine timbers . . . . .	3.4	12.2	25.2	51.6	48.4
Shingles . . . . .	13.0	25.6	108.6	76.4	23.6
Other . . . . .	83.0	.....	.....	.....	.....
Total . . . . .	1,807.5	1,062.8	2,870.3	63.0 <sup>e</sup>	37.0 <sup>e</sup>

<sup>a</sup> Includes residues from both domestic and imported woods.

<sup>b</sup> SOURCE: U.S. Forest Service. Wood Waste in the United States. Report 4 from A Reappraisal of the Forest Situation. 1947.

<sup>c</sup> Excludes secondary manufacturing residues.

<sup>d</sup> Includes only residual wood as such; does not include waste of fiber or dissolved materials.

<sup>e</sup> Per cent of totals.

## ECONOMICS OF FOREST UTILIZATION

TABLE 2-3. RELATION OF WOOD-RESIDUE DRAIN AND PRODUCT DRAIN TO TOTAL COMMODITY DRAIN, MILLIONS OF CUBIC FEET <sup>a</sup>

Product	Total wood residues <sup>b</sup>	Total commodity drain	Wood residues, % of drain	Product drain	Product drain, % of total drain
Lumber <sup>c</sup> . . . . .	4,567.3	6,711.1	68	2,143.8	32
Fuel wood . . . . .	199.4	2,202.8	9	2,002.8	91
Pulp and paper <sup>d</sup> . . . . .	324.9	1,306.3	25	981.4	75
Hewed crossties . . . . .	254.2	363.5	70	109.3	30
Cooperage stock . . . . .	125.9	173.8	72	125.9	28
Fence posts . . . . .	21.6	219.9	10	198.3	90
Veneer . . . . .	259.4	391.7	66	132.3	34
Round mine timbers . . . . .	25.5	225.0	11	199.5	89
Shingles . . . . .	45.2	71.7	63	26.5	37
Other . . . . .	192.0	515.8	37	323.8	63
Total . . . . .	6,015.4	12,181.6	49	6,166.2	51

<sup>a</sup> SOURCE: U.S. Forest Service. Wood Waste in the United States. Report 4 from A Reappraisal of the Forest Situation. 1947.

<sup>b</sup> Sum of wood residues generated in logging and primary manufacture.

<sup>c</sup> Does not include wood residues in the remanufacture of lumber into furniture, construction, etc., estimated at 463 million cubic feet.

<sup>d</sup> Includes only residues in form of wood. Does not include losses of fiber and dissolved substances, nor losses in processing imported pulpwood, estimated at 9.4 million cubic feet.

A knowledge of the amount of wood residues generated, their character, and where they occur is the first step toward an understanding of the problem of more complete utilization.

## III. BETTER WOOD UTILIZATION

For practical purposes, the means of improving wood utilization should be divided into two categories: long-range possibilities, and methods that have good prospects of succeeding under conditions existing at present and in the immediate future. Long-range planning should include (1) basic research on entirely new concepts of wood as a raw material, (2) studies aimed at devising the best means of integrating wood-using industries to obtain the highest economic return and the best balance between essential uses, and (3) research to discover entirely new techniques for the more efficient utilization of wood. Such efforts are one of the primary responsibilities of Federal and other research agencies that are not entirely dependent on the returns from sales of forest products to finance their re-

search activities. Obviously, it is impossible to draw a fine line of responsibility for research, but individual wood producers cannot be expected to assume a large share of basic research costs. All research agencies share the responsibility of applying new developments to the reduction or elimination of residues and waste, and each wood user, whether he has research facilities or not, must adopt all technological advancements that will reduce residues and waste to a minimum. The adoption of new methods is usually slow in an industry made up largely of small enterprises, but in view of the ever-increasing inroads of competition, it seems inevitable that only those operators who obtain the maximum return from the raw material will survive. Under a system of free enterprise, it is axiomatic that industry will adopt without delay any new developments that promise a fair return under existing economic conditions. The problem, then, is balanced research to provide practical solutions for the immediate reduction of bulk residues, and fundamental research that will pave the way to the complete and efficient utilization of every cubic foot of wood that can be produced on the forest lands of the nation.

#### A. LONG-RANGE RESEARCH GOALS IN THE UTILIZATION OF WOOD RESIDUES

Examples of the long-range problems requiring solution are numerous, and a few of them will be discussed. One of the more far-reaching research objectives of the U.S. Forest Products Laboratory at Madison, Wisconsin, is the conversion of wood into a liquid source of chemical raw materials through hydrogenation or other processes. This would have obvious advantages, particularly if plants using the process could be located adjacent to large concentrations of timber and waste materials. Logs are costly to ship for any distance, but a liquid raw material can be piped or shipped by tank car to any part of the country for conversion. A recent statement<sup>14</sup> concerning this development is as follows, under the heading Hydrogenation of Wood:

It has been shown from pioneer research and work now in progress at the Forest Products Laboratory that lignin dissolved in organic solvents or suspended in water can be made to react with hydrogen gas at elevated temperatures and pressures in the presence of various metallic catalysts. Among the products of the reaction are several new cyclic alcohols that had never been previously described in the literature. These show promise as plastic solvents, antiknock agents for motor fuel, and toxic agents. By varying the hydrogenation conditions, phenolic compounds are obtained that may find uses in plastics and complex neutral oils, together with a plastic-like residue. Wood waste or chips can also be hydrogenated in aqueous suspension to produce soluble lignin decomposition compounds and a cellulose pulp residue. This is a possible new pulping process that will be studied further by the

Forest Products Laboratory. Under more severe hydrogenation conditions the cellulose can be converted to glycerine and sugars. In this case the entire wood is converted to liquid products.

Lignin is still an enigma to the wood chemist and to most of the chemical industries that use wood as a raw material. Finding profitable uses for this substance is one of the major problems of wood utilization. No other wood constituent has received so much research attention. Progress is being made, but much basic work is still needed.

The destructive distillation of wood yields products such as tars, acetic acid, and methanol.\* In general, less than half the dry weight of wood is recovered as charcoal and salable distillate.<sup>15</sup> The cellulose and hemicelluloses are broken down, and only a small part is recovered. If the lignin is separated from the carbohydrate portion, its distillation produces nearly the entire original yield of methanol from wood and approximately half the charcoal.

It is evident that the process is wasteful of the cellulose and hemicelluloses. There is a clear-cut need for research to devise less wasteful means of obtaining the products now derived from destructive distillation. The tars also merit attention, particularly when softwood is the raw material. They have little value at the present time, yet it seems likely that careful research might disclose values that are not now apparent.

There is a tremendous need for an inexpensive adhesive having properties comparable to the better present-day synthetic resins that will set rapidly at room temperatures. Such a discovery would extend the benefits of gluing techniques to many small enterprises, because initial investments in gluing equipment would be so greatly reduced. The lamination of rafters, beams, and numerous other structural members would become a relatively simple matter. This would result in great savings of raw material, since it would make possible the low-cost fabrication of laminated products from small pieces of residual wood from a variety of primary industries. Even laminated railroad ties with wear-resistant surfaces are a possibility. Boat-building would be greatly simplified and costs reduced. Major adhesive manufacturers are engaged in active research in this field, but all wood-research agencies should contribute to this important project.

Until new adhesives of the type described above are developed, there will be a continued need for information on radio-frequency dielectric heating. This method is particularly useful in gluing certain types of curved veneer products and laminated beams that are too thick to be glued in conventional hot presses. It is also useful for gluing up furniture core stock, box ends, and other built-up products from small pieces of residual

\* See Chap. 18.

wood. Although costly for many applications, this process is gaining increased attention from wood-fabrication industries and deserves a place in the list of projects requiring research attention.

The microbiological utilization of wood waste also deserves long-range research consideration. McElhanney<sup>10</sup> states the problem as follows:

Investigations have already shown that thermophilic bacteria are capable of attacking cellulose with the formation of valuable organic chemicals such as formic, acetic, lactic, and butyric acids. Microbiological methods have the advantage of simplicity, do not require expensive equipment, and can be carried out on a large scale. This field seems worthy of further investigation. Attempts should be made to isolate organisms from the digestive tracts of wood-eating insects and the rumen of animals capable of digesting cellulose. In addition to bacteria, protozoa might be worthy of investigation. All of these organisms are of interest not only in relation to the formation of valuable chemicals from cellulose, but also because of their high protein content. It is conceivable that sufficient protein material could be produced in the fermentation of wood waste to act as a binder for the conversion of wood waste into structural boards.

While having only an indirect influence on reductions of residues, seasoning and the practice of wood preservation have a salutary effect in lessening the drain on forest resources. Continued fundamental research in these fields is, therefore, justified and desirable.

Research is also needed to find uses for wood containing decay, which is present in large quantities in some regions, particularly in the overmature stands of the Pacific Northwest. Exploratory work is needed to determine the constituents of the bark and wood of all species, including those not now utilized for lumber and other products. The cork in Douglas fir bark, as a possible substitute for imported cork, offers one example; tannins from numerous species, another. The possibility of extracting useful resins from wood chips prior to pulping and fiber manufacture, and many other prospective extraction processes also merit consideration.

The hydrolysis of wood cellulose to produce industrial ethyl alcohol, wood molasses, or yeast is a long-range project that is approaching the stage of realization. It offers an excellent example, however, of the many problems that must be solved in launching a new industry. The process is feasible from the technological standpoint, but many economic factors are still undetermined. Accurate cost data must be obtained, and the effect of such a process on the cost of wood residues must be evaluated; competition from other sources of alcohol, some of them as new as wood hydrolysis, is uncertain, and increased uses for molasses and yeast must be developed. The extension of stock-feeding experiments now in progress at several agricultural experiment stations is necessary, as is further research on the by-products of the wood saccharification process.



It is encouraging that research in long-range potentialities has increased substantially since the Second World War. It is hoped that the lumber industry will avail itself of the results of these efforts to a far greater extent than it has in the past.

#### B. IMMEDIATE APPLICATION OF KNOWN METHODS

Research aimed at the reduction of residues through the application of existing knowledge is an outright challenge to the wood-using industries. Although wood research has been meager in comparison with the research efforts of many other industries, it is still far ahead of the capacity of the lumber industry to apply known improvements. As pointed out previously in this chapter, this condition stems from the lack of industry-owned applied research facilities capable of converting the results of basic findings to product and process development. This is the general situation; there are some examples of progressive enterprises, large and small, that have taken advantage of research to improve utilization, increase profits, and perpetuate their operations by decreasing the drain on their supply of raw material. The rest of the industry must follow these examples. It is not a case of the complete dissolution of the lumber industry if this is not done, but it is one of elevating it from a one-product raw-material industry, earning low returns, to a multiple-product manufacturing industry that obtains profits all the way to the consumer.

It is not possible to generalize on residue-utilization methods, because the amount, character, and location of residues and waste vary too much with species, regions, primary products, types of conversion plants, distances to markets, and many other factors. Each case requires separate analysis in the light of some or all of these variables. The possibilities of improvement on the basis of present knowledge are numerous, and a few examples will be given to illustrate some of the more obvious avenues of approach.

1. **Wood Now Left in the Forests.** The greatest opportunities for reducing the amount of wood left in the forests are found in the Pacific Northwest and in the South, where large sawmills are still found. Both of these regions afford the stability of wood supplies required for the establishment of chemical utilization enterprises. Pulp and paper mills are taking much more material from the forests than formerly. Portable chippers, designed to prepare unused forest wood for utilization, are in the experimental stage. Chemical utilization offers the best ultimate possibilities, but other steps are being taken to reduce residues accumulating during logging. In the Pacific Northwest, the ever-increasing replacement of high-lead logging by tractors has resulted in material reductions in losses from broken and damaged trees. Lighter yarding equipment has made it possible to harvest

economically small material that was too costly to remove with the heavier equipment formerly used. "Prelogging" and "relogging," encouraged by high log prices in recent years, have aided in reducing the amount of material left in the woods in the Pacific Northwest. Portable mills, designed to utilize trees and logs left by conventional logging methods, have had the same effect. Considerable research is in progress in the Pacific Northwest and at the U.S. Forest Products Laboratory to find profitable uses for wood containing decay and logging residues and to devise cheaper and more efficient harvesting and transportation methods. Much progress is being made in the South along lines of integrated utilization, particularly on large holdings, and many improved harvesting techniques have been introduced in recent years.

Efforts to increase the utilization of wood left in the forests should not be limited to the foregoing regions. Although concentrations of residues are smaller in other regions, they should not be neglected. Many small but permanent wood-using enterprises now leaving wood on the ground in the forests could well give consideration to integrated operations. There are numerous opportunities for small-scale plant expansions that will reduce residues and increase profits. The Northeast Wood Utilization Council, New Haven, Connecticut, is making excellent progress in this field.

**2. Residual Wood at Manufacturing Plants.** Of all the sources of residual and waste wood, that generated in the manufacture of lumber offers the most promising opportunities for immediate utilization at a higher level. Perhaps the greatest waste in the lumber industry is the practice of producing full-length lumber, only to be cut up into small products, when thousands of tons of clear pieces in the form of slabs, cuts from crooked logs, trim, and edgings are used for fuel or burned outright. There are countless articles that can be manufactured from such material, often at a greater profit than the lumber itself. The main thing that is needed is a new outlook, an outlook that envisions products other than lumber as the final product of a sawmill. Some enterprising individuals are making substantial profits from the manufacture of broom handles, garden and surveyor's stakes, chair spindles, oak wedges, adding-machine-tape rolls, toys, ladder rungs, tool handles, mouse traps, molding, door rails, and an endless list of such products from sawmill residues. But the number of companies so engaged is too small and the amount of such material being burned is too great. Supplying secondary remanufacturing plants with blanks and dimension stock offers another large outlet for wood residues.

The edge-gluing of sawmill residues to produce furniture and door cores, kitchenware, chair bottoms, box ends, ironing boards, and numerous similar items also offers great possibilities. This use is increasing, but there is room for much greater expansion. One of the authors recently purchased

a small folding ironing board in one of the largest ponderosa pine-producing cities in the West. The board, fabricated of edge-glued 1-in. yellow poplar, was shipped, perhaps, from some Southeastern state. Ponderosa pine is an excellent wood for ironing boards; yet much wood comparable to that from which this board had been made was being burned daily in the waste burners of the local mills. More sawmills could well enter this field or at least furnish the raw material to remanufacturing plants.

The box-and-crate industry is one of the largest consumers of wood in this country, and much of the raw material it uses comes from full-length boards and cants. Much wood that is now hogged for fuel or destroyed could be used for this purpose. The Wooden Box Institute, San Francisco, California, has been more alert to this possibility than has the lumber industry and is engaged in constructive research along these lines. High-speed slicers that produce box-shook veneer from short lengths of wood have been introduced recently and have already contributed to the reduction of residues at some western sawmills.

The building industry has accepted lumber as produced for years without contributing significant advances in the use of wood for construction purposes. There is evidence to indicate that many wood structures are over-designed and that substantial savings of wood could be effected by improvements in present designs. The same applies to lumber grades. Excessively high quality is often demanded where lower grades would serve just as well. Indirectly, this results in leaving logs containing large quantities of low-grade lumber in the woods, because such lumber is often produced at a loss. Revisions of grade standards would provide increased outlets for this material. Improved design would no doubt permit the increased use of shorter lengths, as well. The lumber industry cannot depend on architects and construction engineers for improvements in design. Fabricators of competitive building materials have been exceedingly active in this field, and they supply complete data on design factors for their products. The lumber industry, as a whole, has too long neglected this type of selling activity though it offers potential lucrative dividends. One of the exceptions is the Timber Engineering Company, affiliated with the National Lumber Manufacturers Association, which has recently entered this field and is making good progress.

The production of fiber products from sawmill residues also offers immediate prospects for reducing wood residues. Much wood, not usable for any other purpose, can be reduced to fiber to produce the filler for asphalt roofing materials and for the manufacture of insulating and hard-pressed fiberboards. The volume of fiberboards from all sources has increased more than 120 times in the last 10 years, and there is no reason why residual wood cannot be the raw material for a large part of this output. High

concentrations of residual wood at sawmills offer a cheaper source than corn and sugar-cane stalks now used extensively for these products.

The problem of residues in most primary wood-using industries is comparable to that of sawmills, although the character of residues may differ somewhat. Cores constitute a rather large proportion of the residues at veneer plants. Much of the volume of the cores left by standard production lathes can be salvaged by the installation of "pony" lathes to cut the cores to the smallest possible diameter. If no pony lathe is available, the cores from the larger lathes can be cut into 8-ft. lumber; yet much of this material is cut into short lengths for fuel wood. Clipper waste can be reduced to fiber, but little of it has been used for fiberboard to date. The waste from veneering operations could easily be used for fiber cores in products not requiring high strength. This would extend supplies of veneer for more exacting uses and lengthen the life of plywood and veneer operations.

The foregoing examples are only illustrations of the many challenging opportunities of utilizing residues at primary manufacturing plants by known methods. It cannot be repeated too often that greatly accelerated research and a conscientious effort on the part of the lumber industry are needed to put the utilization of large quantities of unused wood on a practical and profitable basis.

**3. Wood Lost in Chemical Processes.** Chemical utilization offers the greatest promise for the future conversion of wood residues into useful products, but prospects for immediate savings are less spectacular. In the pulp and paper field, some improvements can be made in present pulping practices and steps can be taken to reduce losses in harvesting pulpwood. Research is showing the way to the use of inferior species for pulp. The use of sawmill residues and even wood containing decay is on the increase, particularly in connection with integrated operations. Hydraulic barkers and whole-log chippers are reducing residues, and many pulp mills are remodeling their wood rooms to accommodate shorter logs and smaller material. In a few instances, wood from thinnings and improvement cuttings is being utilized. The practice of segregating logs for various grades of paper is resulting in better utilization. Losses of cellulose can be reduced by milder chemical treatments and by semichemical pulping. All these developments should be adopted as widely as possible throughout the entire industry. The conversion of the wood sugars in sulfite waste liquors to ethyl alcohol or yeast should also be practiced to the full economic limit.

The wood-distillation and steam-and-solvent extraction processes are in need of intensive and extensive research. Some immediate improvements can be made in the former by increasing the recovery of condensable materials and in the latter by finding more profitable uses for spent chips. Increased demands for charcoal may accelerate activities of the distillation

industry, but competitive factors indicate a decline unless entirely new principles are evolved.

More attention could well be paid to the removal of extractives from various woods prior to use for other purposes. Chips from highly resinous woods might be extracted profitably prior to pulping. The solvent seasoning process developed by the Western Pine Association, Portland, Oregon, and now in the pilot-plant stage, extracts resins and seasons the lumber in the same operation. It is reported that lumber can be dried with fewer defects, that color and paintability are improved, and that valuable resins are recovered. If successful commercially, this process may lead the way to similar developments for the extraction of other species. The extraction of the bark of numerous species shows promise of profitable returns. As an example, barks of many species contain tannins in commercial quantities that are not utilized, yet this country imports large quantities of these important chemicals.\*

#### IV. SUMMARY

The steps required to reduce wood residues will be summarized to focus attention on the important problems that must be solved. The responsibilities for the necessary action will also be discussed.

Of primary importance is the assumption of responsibility by the lumber industry for the applied research necessary to assure that the industry keeps pace with technological developments in all fields of science. Federal, state, and educational agencies should continue and even accelerate their present research activities, both in fundamental and applied fields, but the principal responsibility of applying fundamental results and of developing new products and processes rests squarely upon the lumber industry. The plastics and metal industries do not depend on the results of outside agencies when they develop new products that compete with wood. They do the research themselves. The manufacturers of steel joists and door frames do not wait for architects to suggest new uses for the materials they manufacture. They design them and provide architects and builders with specifications and dealers with advertising information, and they are selling their products at the expense of wood. No one should know the properties and potentialities of wood better than the people who are engaged in the business. It is up to them to launch an applied research program, to support the constructive efforts of all wood-research agencies, and to see that public funds commensurate with the importance of the industry are expended for wood-utilization and forestry research. Such research should include market and economic surveys, customer acceptance tests, and cost analyses, as well as searches for new techniques and improvements in

\* See Chap. 22.

present equipment and manufacturing methods. Some liaison is needed between public and industrial research, and means should be provided to disseminate technical knowledge as widely as possible to all wood-using industries. If the wood-using industries provide sufficient research facilities of their own, there is little doubt that they will be well informed of all research that can be applied to advantage to practical problems.

Another factor of great importance is the more complete integration of all wood-using industries. This is a complex problem requiring action on a national as well as a regional basis. It is closely associated with the sustained-yield management of forest lands, the management policies of Federal agencies having jurisdiction over forest lands, and the interrelationship of the timber requirements of the various types of wood-consuming industries. The pattern of integration is increased efficiency, the reduction of residues through the proper segregation and allotment of raw materials to the highest use, and provision of sufficient raw materials for balanced production to all interdependent units. Large companies having sufficient timber to establish sustained-yield units are already making rapid progress in this direction. Not only do they have the permanence provided by a continuing supply of raw material, but also they have the resources to provide new processes, some of them very costly, that make more complete utilization possible.

The problem is not so simple in the case of small enterprises. Many of them have no prospects whatever of obtaining sustained-yield holdings. Without such backlogs of timber, the large investments required for fiberboard and chemical utilization units cannot be justified. Yet integration is more important to these small enterprises than it is to large companies with assured futures. Without it, many of them will be eliminated by the competition of the more efficient integrated organizations. In a recent survey of sawmills in Lane County, Oregon, the county producing the most lumber in the leading lumber state in the country, only 53 mills out of 238 in operation in August, 1947, expected to be in operation 10 years from that date.\* Cooperative pooling and segregation of raw materials and distribution on the basis of the most efficient and profitable use would help in some localities. Research, again, is the answer for isolated sawmills and other woodworking industries that lack full opportunities for integration. Many residue-using processes often cost more than the unit producing the residue. Research should, therefore, be directed toward methods of utilizing small accumulations of residues. Some progress is being made along these lines, but more effort is needed.

Increased activity in forest management and related research is just as

\* Oregon Forest Products Laboratory, Corvallis, Oregon. Unpublished Report.

important as improving the standards of utilization. Economically sound sustained-yield units should be expanded materially, and there is an acute need for bringing all forest lands of the nation into the highest possible state of productivity. Certainly the waste of unproductive forest lands is just as great, if not greater, than the waste now found in the manufacture of forest products. Farm woodlands, on the whole, are badly in need of regeneration, and every effort should be made by all agencies involved to increase the yield of wood from this large source of timber supplies. Quantity, however, is not the only factor. Forest management should aim for balanced production, with sufficient supplies for all uses. Particular emphasis should be given to supplying the high-quality logs required by lumber, veneer, and other important primary industries.



FIG. 2-4. Refuse burner of the Great Southern Lumber Co., Bogalusa, Louisiana. The use of this burner was discontinued in 1924, through utilization of the sawmill refuse in the manufacture of paper. The inscription on the burner reads "Bogalusa Plant of Great Southern Lumber Co. Refuse Burner Born October 1, 1908 Died July 4, 1924. Every day during my life of sixteen years I consumed daily 560 cords of waste material or a total of 2,688,000 cords. I cost \$75,000, but my fire has destroyed \$1,344,000 worth of what was formerly considered waste. The complete utilization of the sawmill refuse in the manufacture of paper has my fire forever extinguished."

Above all, solving the problem of wood residues demands a realistic approach, combined with the marshaling of all technological resources available to the wood-using industries and to the agencies interested in their welfare. All possible advances must be analyzed in the light of existing economic conditions. It would be folly to put complete reliance on one process to solve the problem. If all the 108.9 million tons of waste and residual wood generated in logging and manufacturing in the United States in 1944 were converted to alcohol at 55 gal. per ton, the total would be nearly 6 billion gallons of alcohol; nearly 10 times the peak wartime production year. Obviously, it would be impossible to convert all residues to alcohol, but the example serves to indicate the need for thinking in terms of balanced utilization of residues. The problem, then, is one of concerted action against all sources of residues and the adoption by industry of as many diversified

methods and end uses as have chances of success under existing economic conditions. The ultimate goal is exemplified in the caption on the refuse burner pictured in Figure 2-4.

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## CHAPTER 3

### THE RELATION OF WOOD PROPERTIES TO WOOD UTILIZATION

Wood is one of the oldest known structural materials in the world. It is also one of the most versatile materials among the major industrial raw products of modern times. The future of wood in many industries, however, will depend to a large extent on its ability to meet the more exacting demands of mass-production methods in competition with other industrial materials. In spite of considerable research that has marked the past few decades, efficient wood utilization is still hampered by the relative inadequacy of basic engineering data \* and the persistence of many well-entrenched prejudices and misconceptions. These prejudices arise largely from the failure to recognize the complex nature of wood and the extent to which it determines wood behavior under different conditions of service.

Some of the most common reasons for the unsatisfactory performance of wood are traceable to the selection of wrong species, the use of timbers in inadequate sizes or in wrong grades, poor construction methods, disregard for effects of changes in moisture content on dimensions and shape of wood products, and failure to protect wood properly against decay, insects, and other destructive agencies. For example, although it is well known that untreated wood is subject to decay if placed in moist locations favorable to the growth of fungi, builders frequently disregard this fact and place untreated wood in direct contact with soil or fail to provide adequate ventilation that would ensure rapid drying once wood becomes wet. Neglect to take into consideration the differences in strength and in working and finishing properties of different species leads to selections of materials unsuited for intended uses.

Proper selection of a wood for any given use requires, first of all, an appraisal of the requirements of that use. It is only after these requirements are thoroughly understood that a species of timber with characteristics most nearly meeting these specifications may be selected. Usually more than one species may be satisfactorily employed, the choice being governed by considerations of cost and availability, as well as by technical properties of the woods. For instance, baseball bats are made of ash and

\* Likewise, a great deal of the available research data has not reached the wood users and fabricators.

also of southern yellow pine. Ash bats are stronger and heavier but are also more expensive; hence in children's bats, where strength and toughness requirements are not great, less expensive southern yellow pine can be employed to advantage. The foremost requirements for ladder stock are strength and lightness; spruce and Douglas fir are commonly used, but the latter species is preferred when high strength is called for, even though the weight factor is sacrificed.

The problem of acquiring fundamental information about wood is admittedly not very simple, mainly because of the extreme variability and complexity of its anatomical structure and chemical composition. This complexity and variability of composition accounts for a wide range of differences in the physical and chemical properties of wood, not only among different species but also within the same species and even among pieces from different parts of the same tree. The proper utilization of wood, therefore, requires a thorough understanding of (1) properties which, within certain limits, are common to wood regardless of the source; (2) specific properties characteristic of a given species and responsible for its suitability for certain uses; (3) degree of variability which may be expected within the same species and the extent to which such variability may affect the specific uses of that species.

#### A. PROPERTIES COMMON TO ALL WOODS

In addition to its abundance and renewability, the principal factors which distinguish wood from other materials, especially in its adaptability for building purposes, can be summarized as follows:<sup>2</sup>

1. Wood is fairly light in weight and therefore is easy to handle; when dry, it can be transported for long distances at relatively low cost. Unless saturated with water, most native species of wood will float.

2. Wood is easily worked into various shapes with simple tools and relatively little skill.

3. Because of its porosity and the nature of cell-wall substance, wood is one of the few major raw materials that can be easily fastened together with nails and screws.

4. The porous nature of wood is also responsible for its ability to hold paints and other finishes.

5. Wood is strong for its weight, and when dry and free from defects, pound for pound it compares quite favorably in strength with steel and other structural materials.

6. Wood is a poor transmitter of heat, sound, and electricity and therefore is a good insulating material.

7. Wood expands and contracts little with changes in temperature.

8. Wood absorbs shocks and vibrations better than most competing materials and is therefore preferred for such uses as wagon axles, spokes, railroad ties, and ball bats.

9. Wood does not rust and resists the action of acid and salt water better than most other materials.

10. The defects present in wood can frequently be detected on the surface, thus permitting rejection or necessary allowances for their weakening effect.

11. Some woods are ornamental, requiring no other treatment except that which will bring out the natural figure to the best advantage.

12. Wooden structures can be taken apart easily; the salvage value of wood is high, compared to its original cost.

13. Wood neither crystallizes nor becomes brittle, like metals, nor loses its cohesive characteristics, like concrete, when subjected to low temperatures.

14. Wood generally gives warning before it fails, a fact of prime importance in various structural members, such as bridge and mine timbers.

In addition, because of its fibrous structure and chemical composition, wood can be reduced by relatively simple means into pulp, which can then be formed into sheets of various thicknesses or converted into such products as rayon, transparent films, or plastics. Finally, wood is an important raw material for various chemical industries.

It must be clearly recognized, however, that wood also possesses a number of characteristics which limit its usefulness. Principal among these are:

1. Wood cannot be extruded or rolled into new shapes. Extension in length must, therefore, be accomplished by gluing or by the use of metal fasteners.

2. Wood is limited in hardness and strength. There are, as yet, no commercially successful methods by which its hardness can be materially increased without changing its character; sufficient strength, however, usually can be obtained by using pieces of proper size.

3. Wood is a hygroscopic substance and therefore its moisture content varies with changes in atmospheric humidity. The changes in moisture content of wood are accompanied by changes in dimension and in strength properties. The dimensional changes due to loss or gain in moisture, moreover, are unequal, as normal wood shrinks but very slightly along the grain, considerably across the grain, then  $1\frac{1}{2}$  to 3 times as much tangentially as radially.

4. Wood, unlike other structural materials, decays and is subject to damage by insects. The life of wood, however, can be considerably prolonged by treating with preservatives.

5. Wood burns, and once ignited it will give off combustible gases which

tend to increase the temperature and maintain combustion even after the original source of heat has been withdrawn. It will also ignite spontaneously if exposed to a temperature of about 275°C. The fire hazard in wooden structures can be considerably minimized by proper construction and by the use of materials made fire-resistant by injection of suitable chemicals. Furthermore, while untreated wood burns readily, it loses its strength gradually, the loss of strength depending on the extent of carbonization that has taken place.

6. Wood is variable in strength. Not only do different species differ from each other in various strength properties, but great variations in strength also exist within the same species and frequently even in pieces cut from different parts of a tree. Moreover, strength properties in a given piece of wood vary, depending on the direction of grain.

7. Most woods split easily along the grain, due to peculiarities of their anatomical structure.

#### B. CHARACTERISTIC PROPERTIES OF DIFFERENT SPECIES

The basic properties of wood discussed in the preceding paragraphs are not possessed in an equal degree by all species. There is great variation among woods in appearance, weight, and hardness, in strength properties, amount of shrinkage, penetrability, ease of working under tools, ability to take paint, glue, and nails, length and size of cells, and reaction to pulping agents, as well as in a number of other physical and chemical properties. Some species may also be distinguished by properties not found in other species. In the proper utilization of wood, therefore, the choice of species for a given purpose should be based on a combination of the properties desired.

This relationship can be best illustrated by a few examples. For instance, both red and white oak possess the required hardness and strength properties for use as bridge stringers or railroad ties, but if used untreated, white oak is preferred because it is characterized by natural durability not found in red oak. If treated with creosote or other effective preservative, red oak can be made fully as durable as white oak; red oak, however, is much easier to impregnate with preservatives because of the open condition of springwood pores, which in white oak are heavily occluded with tyloses, making this wood quite impervious to liquids, even when they are applied under pressure. On the other hand, the same natural impermeability of white oak, coupled with the necessary strength and good working properties, is responsible for its extensive use in tight cooperage, for which purpose red oak is less suitable unless specially treated to increase its liquid-holding efficiency.

Ash and hickory combine strength with good bending qualities which make these woods outstanding for bent work; at the same time, ash and hickory possess the required toughness and good finishing characteristics which account for their extensive use in the manufacture of tool handles. The natural figure, rich color, and uniform texture of mahogany, combined with strength, durability, and good finishing qualities, have made it a favorite furniture wood, either as solid lumber or as a veneer. The close and uniform texture and hardness which are responsible for the ability of persimmon and dogwood to remain smooth under constant wear are the reasons for selecting these woods for shuttles and bobbins, while uniform texture, softness, and low shrinkage, combined with considerable strength and ease of working with tools, account for the extensive use of white pine for pattern stock.

Douglas fir is widely used for structural purposes because it combines strength with durability and is available in large sizes. Good gluing properties and fairly low shrinkage are important considerations in the choice of chestnut, cottonwood, and red alder for core stock, while the acid-resistant qualities of Port Orford cedar was one of the reasons why it was the principal species used in the manufacture of battery separators, when sufficient supplies of this wood were available.

Good screw- and nail-holding ability is a prerequisite of wood used for boxes and crates, but really satisfactory wood for shipping containers should also be strong, light-colored, not too heavy, and free from objectionable odors, taste, and stains. Ease of working, combined with satisfactory finishing characteristics and the ability to take paint, are important considerations in selecting wood for interior trim. Appearance and finishing qualities of woods dominate their choice for exposed parts in furniture, while ability to stay in place, and gluing and nail- and screw-holding characteristics are the deciding factors in selection of woods for concealed parts of furniture. The long strong fibers of such conifers as the southern yellow pines, spruce, hemlock, and balsam firs are reasons for their use in pulp manufacture; differences in the resin content, however, determine the method of pulping and the appearance and quality of the resulting pulp.

### C. VARIABILITY OF PROPERTIES WITHIN A SPECIES

Not infrequently too much emphasis is placed on relatively small differences among species, while the variability in properties of wood of the same species is largely ignored.

Although lack of uniformity is a property common to all materials to some extent, wood has, perhaps, a greater range of variability than other structural materials. Thus it is essential that the extent and the sig-

nificance of variability in wood properties of the same species be known. It is well recognized that the variability within a species comes largely as a result of environmental influences affecting the growth of trees, including such factors as climate, soil, moisture, and growing space; also it depends undoubtedly on hereditary characteristics, though the latter factor has as yet received but scant attention in the handling of forest trees.

The most readily recognizable instances of variability within a species are differences in appearance and weight, while differences in strength properties and workability, although more difficult to recognize, are frequently of much greater practical significance. Fortunately, however, strength properties of normal wood can quite often be closely correlated with specific gravity and with such easily observable factors as the rate of growth and the relative proportion of springwood and summerwood within an annual increment. The correlation of strength properties with the above-noted factors (particularly with specific gravity of normal wood) allows a fairly reliable basis for selecting the material best suited for a given purpose.

The variability of wood properties within a species is also greatly affected by differences in the moisture content and by the kind, number, extent, and locations of defects. The effect of moisture content on the strength properties of wood, as well as on shrinkage and swelling, general workability, and the nailing, gluing, and finishing qualities of wood, is so great that the satisfactory use of wood depends on a precise understanding of the altered behavior of wood accompanying changes in its moisture content. Although detailed discussion of this topic is outside the scope of this text, it may be noted in passing that as a general rule wood should be dried to a moisture content commensurate with the expected service requirements, *i.e.*, wood should be dried to approximately the moisture content which it will attain in actual service. If the moisture content of wood is so great that a considerable amount of moisture is lost after the wood has been placed in service, corresponding shrinkage, warping, and other drying phenomena must be expected, while wood dried to a much lower moisture content than necessary will pick up additional moisture from the atmosphere, with accompanying swelling and some loss of strength.

The extent to which various defects, such as knots, decay, cross grain, shakes, checks, splits, and sap stain, affect utility of wood is taken into consideration in grading lumber. Grading is largely designed to cope with the effects of variability in the properties of wood of the same species. The underlying principles on which these grading rules are based, as well as the proper use of the grades, presupposes a thorough understanding of the nature of defects and their specific effect on the properties of a wood for given purposes.

It is important to recognize also that considerable equalization of the properties of wood can be achieved by the design of an article and treatment of the wood. Not infrequently better service can be obtained from a well-designed article made of an inferior wood than from a poorly constructed item made of a species with superior characteristics. Differences in decay resistance can be compensated by preservative treatments or by protecting wood against moisture. Adjustments in the speed of machinery or a change in the cutting angle of knives may assist materially in the production of acceptable stock from species with less desirable working characteristics. Substitution of glue for nails or screws may result in a stronger joint with a species low in nail- or screw-holding capacity. Good design and corrective treatments, therefore, may extend considerably the range of species that can be employed for all but the most exacting uses.

#### D. CHEMICAL PROPERTIES OF WOOD

Utilization of wood frequently involves treatments which affect some or all of its chemical constituents. The chemical utilization of wood may be grouped under several headings: (1) pulping, (2) extraction, (3) hydrolysis, *i.e.*, conversion of carbohydrates to sugars, (4) destructive distillation, and (5) various chemical treatments designed to improve the properties of wood. A general understanding of wood chemistry is essential to appreciate fully the basic principles underlying any type of chemical utilization of wood. The discussion which follows is offered, therefore, for the purpose of acquainting the reader with a few of the basic facts of wood chemistry.

Each wood cell consists of a cavity surrounded by a rigid wall. The wall contains two morphologically distinct layers: the *primary wall* on the outside and the *secondary wall* on the inside. All cells are cemented together by a common layer, the *intercellular substance*, also called the *true middle lamella*.<sup>\*</sup> The entire cell wall, including the intercellular layer, consists principally of cellulose, lignin, and hemicelluloses. The bulk of cellulose is found in the secondary wall, while lignin occurs largely in the intercellular layer and primary wall, and to a lesser extent in the secondary wall. Hemicelluloses are thought to be intimately associated with microscopic cellulose units (called *fibrils*), of which the bulk of the secondary wall is built. Some hemicellulose is also found in spaces between the fibrils.

In addition to the three above-mentioned components, a number of extractable substances may also be present. These materials reside largely in the cell cavities; they can be removed with suitable solvents without affecting in any way the composition of the residual wall. Extractable ma-

<sup>\*</sup> Less technically, the term *middle lamella* is applied to the *intercellular substance*, or the *middle lamella* proper, and the *cambial*, or *primary*, walls combined.

terials include, among others, tannins, dyes, resins, essential oils, fats, nitrogenous organic compounds, and traces of organic acids and their salts. When burned, wood yields a small amount of mineral residue, called *ash*.

No exact figures indicating the composition of wood in terms of its different chemical constituents can be given, since these vary within wide limits, depending on the type of wood used, methods of analysis employed, and even the interpretation of analytical data by individual investigators. The approximate composition of wood, however, based on its oven-dry weight, may be given as follows: cellulose, 40 to 55 per cent; lignin, 17 to 35 per cent; hemicelluloses, 15 to 30 per cent; water extractives, from less than 1 per cent in aspen to more than 10 per cent in redwood; ash, about 1 per cent.

Much of the chemical utilization of wood involves the *delignification* of wood, *i.e.*, the disintegration of the middle lamella through removal of a large part of the lignin and other noncellulosic materials and subsequent utilization of the resulting fibrous pulp, which is largely cellulose. Wood pulp thus prepared forms an important raw material for the manufacture of paper, paper boards, and other wood-pulp products, while specially purified forms are used extensively in the manufacture of rayon, transparent films, and to a lesser extent in paints, lacquers, and similar products.

The carbohydrates in wood may be converted into sugars when hydrolyzed with dilute solutions of several mineral acids, and most of the resulting sugars can be fermented to ethyl alcohol. When decomposed by heat in the absence of air, a treatment called *destructive distillation*, wood will give rise to numerous chemical products, chief of which are methyl alcohol, acetic acid, tar products, and residual charcoal. Oils, wood turpentine, pine tar, and pitch are additional products of resinous-softwood distillation.

The above-mentioned industrial uses of wood are based primarily on the utilization of the chemical components of the cell wall or their derivatives. An entirely different type of chemical utilization of wood involves removal of extractives such as tannins, essential oils, and dyes. Examples of such utilization are the extraction of tannin from wood of chestnut or the recovery of wood rosin and turpentine from the stump wood of southern pines by steam distillation. In the above instances the extractive-free wood is frequently converted into wood pulp. In the majority of cases, however, no attempt is made to utilize the residual wood for anything but fuel.

**1. Cellulose.** Chemically, pure cellulose is a complex carbohydrate whose empirical formula is expressed as  $(C_6H_{10}O_5)_n$ . Cellulose is insoluble in water and in the ordinary solvents such as alcohol or ether. It is very resistant to the action of alkalies but can be completely dissolved by strong



acids.\* The purest form of cellulose known in nature is cotton cellulose obtained from the seed hairs of the cotton plant, *Gossypium* spp., more than 90 per cent of which by weight is pure cellulose, or *alpha-cellulose*. In wood, cellulose, as already explained, is associated with other components, chief of which are lignin and hemicelluloses. Moreover, wood cellulose is not all *alpha-cellulose*, but has considerable admixtures of other cellulose-like materials, termed *beta-* and *gamma-celluloses*. These differ from *alpha-cellulose* mainly in being soluble in alkaline reagents. When unpurified wood cellulose is treated with such a reagent (for instance, 17.5 per cent sodium hydroxide), the cellulose swells and a part of it dissolves. The dissolved portion contains the *beta-* and *gamma-celluloses*.† Wood cellulose prepared by commercial methods of pulping may lose as much as 10 to 20 per cent by weight, when treated with an alkali, due to removal of the *beta* and *gamma* fractions. The purity of wood cellulose is therefore judged by its *alpha-cellulose* content, and for many uses, *e.g.*, in the manufacture of rayon, wood cellulose is carefully refined with alkalies to remove its non-resistant portions.

**2. Hemicelluloses.** This is a term which is applied to a group of cell-wall carbohydrates found in more or less intimate association with cellulose and lignin. Technically the hemicelluloses may be loosely defined as those less resistant substances which, though insoluble in hot water, can be removed from the cell wall with either hot or cold dilute alkalies or readily hydrolyzed to constitute sugars or sugar acids by means of hot dilute acids. Theoretically, when hemicelluloses are thus removed from delignified cell walls, only cellulose will be left behind. Actually, however, some of the hemicelluloses are water-soluble,‡ and not all of them are extracted from the cell wall by alkali treatments. In chemical pulping, hemicelluloses are largely removed from the pulp. If acids are involved in pulping, the hemicelluloses are converted into sugars (such as galactose, mannose, and others), which pass into the cooking liquor, and of which 60 to 75 per cent could be fermented into alcohol.§ If alkalies are used for pulping, the

\* Another well-known cellulose solvent in Schweizer's cuprammonium reagent.

† *Beta-* and *gamma-celluloses* can be separated by treating the alkaline solution with acetic acid; the *beta-cellulose* will then form a precipitate, while *gamma-cellulose* will remain in solution. Some chemists believe that *beta-* and *gamma-celluloses* are hemicellulosic materials.

‡ A polysaccharide, *galactan*, found in the wood of western larch (to the extent of 8 to 25 per cent of the dry weight of the wood) may be considered one of these. The *galactan*, extracted with water from the wood, can be hydrolyzed into a sugar—*galactose*—and this, in turn, can be oxidized to mucic acid, which is used in the manufacture of baking powder.

§ Another sugar, *xylose*, is converted in the course of acid cooking into *furfural*, which ordinarily escapes with the steam. However, under suitable conditions it could be recovered as one of the products of wood hydrolysis. *Furfural* is an important solvent and intermediate reagent in chemical industry.

hemicelluloses are converted into acids (largely glucuronic and galacturonic). The function of hemicelluloses in nature is not yet understood, although recently a theory has been advanced suggesting that hemicelluloses may be lignin precursors, *i.e.*, substances from which lignin is formed.

**3. Lignin.** This is the third important constituent of the cell wall. Its exact chemical composition is still unknown. It can be obtained from wood either by removing all carbohydrates by means of a strong acid, leaving the lignin behind in the form of an insoluble residue, or by removing the lignin and some of the more soluble carbohydrates and leaving the resistant cellulose behind and then separating lignin from the resulting solution. Still another method calls for dissolving all constituents of wood in a mixture of formaldehyde and sulfuric acid and then precipitating lignin by diluting the acid solution with water. In any case, it requires very drastic treatment to extract lignin from wood, and therefore there is no certainty that the lignin in its extracted form is at all identical with that found in the cell wall. Furthermore, no two lignin preparations have the same physical properties or the same chemical reactions; likewise, there is considerable evidence to show that the lignin from different species of wood is not identical. This has led to the conjecture that "either the substance known as lignin is a complex mixture of compounds with similar properties but of unrelated chemical structure, or else a mixture of compounds which are similar in structure or have the same basal form but which vary in minor ways."<sup>3</sup>

Whatever its exact chemical nature, lignin will remain a term of convenience to describe the cementing material which is largely removed during chemical pulping of wood, thus allowing the fibers to separate. Lignin extracted from wood in this manner constitutes one of the greatest industrial residues of the present time.\*

Among industrial uses of wood in which lignin is utilized along with other wood constituents are destructive distillation derivatives and lignin plastics. In the former, the lignin fraction of wood gives rise to methyl alcohol and acetic acid, and a portion of the complex mixture of tarry and oily substances, while in the latter lignin serves as a binding agent. A number of aromatic substances are also associated with lignin, among them vanillin and eugenol (the flavoring principle of cloves). Recently, manufacturers of storage batteries have begun to incorporate lignin as a part of negative battery plates, with a resulting tenfold increase of current output in zero weather. Purified lignin, hydrogenated in the presence of a catalyst, has been converted by Drs. S. C. Sherrard and F. E. Harris, of the U.S. Forest Products Laboratory, into a thick, viscous, colorless fluid from which, by

\* Pulp-mill lignin losses amount to several million tons annually.

means of fractional distillation, they have produced methyl alcohol and four new substances. Two of these can be made into plastics; another may be used as a solvent for organic gums, resins, and oils, and has a preservative value; the fourth has adhesive properties. The utilization of extracted lignin is discussed in more detail in later pages under the utilization of sulfite liquor (see Chap. 15). Any real progress toward utilization of the vast amount of lignin available cannot, however, be expected until its chemistry is better comprehended.

**4. Extractives.** Wood extractives, also called the *extraneous components* of wood, are substances which can be extracted from wood by means of a suitable solvent or by steam distillation without affecting the composition of the cell wall. Wood extractives, therefore, are not considered to be an integral part of the cell wall but are thought to reside largely in the cell cavities. Most important of the wood extractives are essential oils, resins, fats, tannins, and natural dyestuffs or their precursors. In addition, there may be found small amounts of organic acids or their salts, the most widely distributed acid in plants being oxalic acid, usually in the form of crystals of calcium oxalate. A few woods are characterized by the presence of alkaloids; for instance, the wood of *Cinchona* spp. contains small amounts of quinine and related alkaloids, while species of *Strychnos* contain traces of strychnine. Finally, small quantities, about 0.3 per cent, of other nitrogenous compounds, thought to be traceable to proteins in the dried protoplasm, are also found in wood. Nearly all woods have small deposits of starch, while some also contain sugars; for instance, the "sap" of sugar maple in the springtime contains up to 5 per cent of sucrose.

Some of these substances, notably tannins, resins, essential oils, and dyestuffs, have considerable economic importance and in a few cases may even constitute the chief value of a given wood. A few examples of such are described in later chapters. By and large, however, no attempt is made to recover these materials. The largest waste of various extractives occurs in the preparation of wood pulp, where they are removed and usually discarded in the cooking liquor, together with lignin and the hemicelluloses.

**5. Inorganic Wood Components.** The residue which remains after complete combustion of wood is called *ash*. In the North American woods analyzed by the U.S. Forest Products Laboratory, the ash content was found to range between 0.2 and 0.9 per cent. The highest ash content reported elsewhere was for the European olive tree, *Olea europea* L., in which sapwood yielded about 5 per cent. The principal components of wood ash are salts of calcium, potassium, and magnesium, while small amounts of sodium, aluminum, iron, and manganese sulfates, chlorides, and silicates are also invariably present. Perhaps the most characteristic component

of wood ashes is potash ( $K_2CO_3$ ), the presence of which explains the value of wood ash as a fertilizer and as a raw material in making soap.

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Part II  
WOOD PRODUCTS

## CHAPTER 4

### ROUND TIMBERS

#### I. POLES

The first commercial telegraph system, constructed in 1844, was a line 40 miles in length extending from Washington, D.C., to Baltimore, Maryland. The wires connecting these two cities were carried on wood poles cut from tree-length logs, the placement of which marked the beginning of a new American forest-products industry, pole production. A few years later the first central telephone switchboard was installed in New Haven, Connecticut. Wires extending from this exchange to the 21 original subscribers were similarly carried on poles. Use of poles in electrical power transmission lines had its inception in 1882, when Thomas A. Edison built the world's first utility power station in New York City and sold power to nearly 100 consumers who had installed electric lighting systems in their homes. By the turn of the twentieth century the nation's pole requirements were greatly augmented by the erection of many municipal electric lighting systems and by the extensive construction and expansion of city and interurban electric-railway systems which required many thousands of poles to support the overhead trolley wires.

From these beginnings our communication and power transmission lines have become a veritable metallic maze of wires linking the nation's nerve centers and extending out from them into many remote rural areas. Today, the poles supporting this vast labyrinth of wire and cable are counted in the tens of millions.

Pole production in the United States currently represents an annual drain of from three to five million trees. Many of these poles are used in the construction of new lines; the others are for replacements of poles no longer capable of giving satisfactory service. Recently the Rural Electrification Administration announced that the pole requirements for its cooperative agencies, in new construction alone, would amount to approximately three million annually for the next 5 years.

#### A. FACTORS GOVERNING THE SELECTION OF POLES

Many of our commercial timber-tree species, for one or more reasons, are totally unfit for use as poles in power transmission and communication

lines. Trees suitable for pole production must have long, straight, full-rounded boles with but little taper. Moderately lightweight woods with high strength-weight ratios are preferable to heavier woods. High-density timbers, while usually possessing excellent mechanical properties, cannot be handled, transported, and erected economically and hence are seldom used. By contrast, many low-density timbers are unsatisfactory for poles because they are weak and brash and are wholly incapable of supporting safely the 50 to 80 wires commonly carried on main trunk lines. Moreover, they are easily damaged by such imposed loads as winds of high velocity or snow and icing along the wires. Unless poles are to be given a preservative treatment before placement in service, they should be cut from timbers known for their durability when in contact with soil. Cheap, perishable woods are often the most expensive in the final analysis, because the frequency with which they must be replaced increases pole-line maintenance costs beyond all reasonable limits. When a preservative treatment is contemplated, timbers which are easily impregnated and which will retain a suitable amount of the toxic when placed in service should be selected. Finally, pole timbers should be readily accessible and available in quantities sufficient to harvest economically and to market at reasonable prices.

#### B. SPECIES USED

If privileged to examine some of the earlier pole-line installations, one would be impressed with the diversity of species used. Chestnut was a prime favorite and used generally throughout the Eastern United States. Quantities of various oaks were also employed locally. Bald cypress, Atlantic (southern) white cedar, and yellow pine \* poles were installed in Southern lines, tamarack and northern white cedar poles were common in the Lake states. Both round and saw-tapered redwood poles were erected in California lines, while in the Northwest western red cedar and Douglas fir poles prevailed. In addition to these, many species such as the ashes, elms, catalpa, black locust, red mulberry, butternut, and even spruces and cottonwoods were used locally; osage orange was employed sparingly through the southern Plains states.

The principal pole woods today are the southern yellow pines, western red and northern white cedars, Douglas fir, and lodgepole pine. Pole production from such secondary species as chestnut, Atlantic white cedar, bald cypress, redwood, and a few others continues, but the annual production for each of these species is much less than that of two or three decades ago. Chestnut poles are now produced from blight-killed but otherwise sound trees that had attained pole size when attacked by the disease.

\* Principally longleaf pine, shortleaf pine, loblolly pine, slash pine, and pond pine

### C. POLE SPECIFICATIONS

In 1941 the American Standards Association released a series of standard specifications and dimensions for each of the major pole-wood species. These specifications serve as a guide in the production of poles and are used by consumers' inspectors for the acceptance or rejection of any or all poles in a shipment. Specification 05.4—1941, American Standard Specifications and Dimensions for Southern Pine Poles, is reproduced here with the full sanction of the Association and serves as a general example for all pole specifications.

#### SPECIFICATIONS 05.4—1941

### SPECIFICATIONS AND DIMENSIONS FOR SOUTHERN PINE POLES

#### 0. INTRODUCTION

These specifications cover southern pine poles which are to be given a preservative treatment. These poles are to be classified in accordance with the table of dimensions which constitutes Part II of this standard.

The length and class of poles wanted and full details of the framing desired shall be stated in the orders.

The details of any marking, including length and class marks, to be placed on the poles shall be in accordance with instructions from the purchaser.

Complete detailed instructions shall be given the supplier in all cases where modifications are to be made in these specifications to meet special requirements.

#### I. SPECIFICATIONS

##### 1. Material Requirements

###### 1.1 Species

All poles shall be cut from live southern pine timber: Longleaf Pine (*Pinus palustris*), Shortleaf Pine (*Pinus echinata*), Loblolly Pine (*Pinus taeda*), Slash Pine (*Pinus caribaea*), and Pond Pine (*Pinus rigida serotina*).

###### 1.2 Prohibited Defects

All poles shall be free from decay, red heart, cracks, plugged holes, and bird holes. Nails, spikes, and other metal shall not be present in the poles unless specifically authorized by the purchaser.

###### 1.3 Permitted Defects

1.31 BLUE SAP STAIN. Blue sap stain that is not accompanied by softening or other disintegration of the wood (decay) is permitted under these specifications.



1.32 **HOLLOW PITH CENTERS.** Hollow pith centers in the tops or butts of poles and in knots are permitted.

#### 1.4 Limited Defects

1.41 **CHECKS.** The top and side surfaces of poles shall be free from injurious checks.

1.42 **SHAKES.** Shakes in the butt surface extending over not more than one-quarter ( $\frac{1}{4}$ ) of the circumference are permitted provided they are at least one (1) inch distant from the edge of the butt. Shakes extending over more than one-quarter ( $\frac{1}{4}$ ) of the circumference are permitted when they are inside of a circle whose center corresponds to the center of the butt surface and whose diameter equals one-half ( $\frac{1}{2}$ ) of the average butt diameter.

Shakes in the top surface whose width does not exceed one-sixteenth ( $\frac{1}{16}$ ) of an inch are permitted provided they do not extend over more than one-half ( $\frac{1}{2}$ ) of the top circumference.

1.43 **SPLITS.** Splits are prohibited in the top surfaces of poles. Splits in butt surfaces are permitted provided that their height from the butt along the side surfaces does not exceed two (2) feet.

1.44 **GRAIN.** No pole shall have more than one (1) complete twist of grain in any twenty (20) feet of length.

1.45 **INSECT DAMAGE.** Insect damage consisting of holes less than one-sixteenth ( $\frac{1}{16}$ ) of an inch in diameter is permitted.

1.46 **KNOTS.** The diameter of any single knot or knot cavity, or the sum of the diameters of all knots and knot cavities in any one (1) foot section shall not exceed the limits set up in the following table. Knots and knot cavities one-half ( $\frac{1}{2}$ ) of an

LIMITATIONS OF KNOT SIZE

Length of pole, ft.	Maximum sizes permitted, in.		
	Diameter of any single knot or knot cavity		Sum of diameters of all knots and knot cavities in any 1-ft. section, all classes
	Classes 1-3	Classes 4-10	
45 and under . . . . .	4	3	8
50 and over . . . . .	5	5	10

inch or under in diameter shall be ignored in applying the limitations for sum of diameters.

Knots one (1) inch or over in diameter, showing discoloration or softness of fiber,

indicating possible decay, shall be neatly gouged to a depth of not more than one-fifth ( $\frac{1}{5}$ ) of the diameter of the pole at the point where the knot is located, to permit determination of the character and extent of decay. The gouging shall be done without unnecessary removal of sound wood, and in such a manner as to insure drainage of water from the hole when the pole is set. *Where such gouging does not completely remove the decay (heart rot), the pole shall be rejected.*

Knots under one (1) inch in diameter need not be gouged unless after trimming the presence of decay is revealed and upon further examination the decay is found to extend to a depth of more than two (2) inches.

When more than one (1) cavity is present in a pole, the sum of the depths of all cavities in the same six (6) inch longitudinal section of the pole shall not exceed one-third ( $\frac{1}{3}$ ) of the mean diameter of that section.

1.47 SCARS. No pole shall have a turpentine face or other scar located within two (2) feet of the ground line.

In other sections of the pole, scars which have been smoothly trimmed so as to remove all bark and all surrounding or overhanging wood that is not completely intergrown with the wood of the body of the pole are permitted, provided

(a) that such trimming does not result in abrupt changes in the contour of the pole surface and that the trimmed scar does not have a depth of more than one (1) inch, except that where the diameter of the pole at the location of the scar is more than ten (10) inches the depth may be one-tenth ( $\frac{1}{10}$ ) of the diameter; and

(b) that the circumference of the pole at any point on trimmed surfaces located between the butt and a point two (2) feet below the ground line is not less than the circumference of the pole at the ground line.

1.48 SHAPE. Poles shall be free from short crooks.

A pole may have sweep subject to the following limitations:

(a) Where sweep is in one (1) plane and one (1) direction only, a straight line joining the surface of the pole at the ground line and the edge of the pole at the top shall not be distant from the surface of the pole at any point by an amount greater than one (1) inch for each six (6) feet of length between these points.

(b) Where sweep is in two (2) planes (double sweep) or in two (2) directions in one (1) plane (reverse sweep), a straight line connecting the mid-point at the ground line with the mid-point at the top shall not at any intermediate point pass through the external surface of the pole.

## 2. Dimensions

### 2.1 Length

Poles under fifty (50) feet in length shall not be over three (3) inches shorter or six (6) inches longer than nominal length. Poles fifty (50) feet or over in length shall not be over six (6) inches shorter or twelve (12) inches longer than nominal length.

*Length shall be measured between the extreme ends of the pole.*

### 2.2 Circumference

Poles shall be classified in accordance with the table of dimensions shown as Part II of this standard. Minimum allowable circumferences at six (6) feet from the

butt, (except for Classes 8, 9, and 10), and at the top, for each length and class of pole listed, are shown in this table. Poles having circumferences which are greater, at the same points of measurement, than those shown for the length and class desired, shall be acceptable, provided that the six (6) foot from butt circumference is less than the minimum given for the second larger class pole of the same length. The top dimensional requirement shall apply at a point corresponding to the minimum length permitted for the pole.

### 3. Manufacturing Requirements

#### 3.1 Bark Removal

Outer bark shall be completely removed from all poles.

No patch of inner bark left on the pole surface shall be more than one-quarter ( $\frac{1}{4}$ ) of an inch in width or more than four (4) inches long.

#### 3.2 Sawing

All poles shall be neatly sawed at the butt along a plane which shall not be out of square with the axis of the pole by more than two (2) inches per foot of diameter of the sawed surface. Beveling at the edge of the sawed butt surface not more than one-twelfth ( $\frac{1}{12}$ ) of the butt diameter in width, or an equivalent area unsymmetrically located, is permitted.

#### 3.3 Trimming

Branch stubs, partially overgrown knots, and completely overgrown knots rising more than one (1) inch above the pole surface shall be trimmed close. Completely overgrown knots less than one (1) inch high need not be trimmed.

#### 3.4 Framing

All poles shall be framed in accordance with the terms of the order before they are subjected to the preservative treatment.

Gains on poles showing sweep or curvature shall be located on the concave side in the plane of the greatest curvature.

All gains on the same pole shall be cut so that their flat surfaces are approximately parallel. Conformance to this requirement may be tested by placing straight edges thirty (30) inches long on the faces of the finished gains so that the ends of the straight edges extend fifteen (15) inches on either side of the center line of the pole. The straight edges in any two (2) gains, when sighted in the direction of the longitudinal axis of the pole, shall not be out of parallel at their ends by more than one-sixteenth ( $\frac{1}{16}$ ) of an inch. Bolt holes shall be bored perpendicular to the faces of the gains.

### 4. Storage and Handling

#### 4.1 Storage

When it is necessary for any reason to hold in storage poles offered under these specifications, they shall be stacked on creosoted or non-decaying skids of such dimensions and so arranged as to support the poles without producing noticeable

distortion of any of them. Poles shall be piled in such a manner as to permit free circulation of air and they shall be supported at all points at least one (1) foot above the general ground level, or any vegetation growing thereon. No decayed or decaying wood shall be permitted to remain underneath stored poles.

#### 4.2 Handling

Pole tongs, cant hooks, and other pointed tools capable of producing indentations of more than one (1) inch in depth shall not be used on poles furnished under these specifications.

### 5. Definitions of Terms

The following definitions shall apply in these specifications:

#### 5.1 Fungous Defects

5.11 **BLUE SAP STAIN.** Blue sap stain is a bluish coloration in the sapwood, caused by the action of certain molds and fungi, that is not accompanied by softening or other disintegration of the wood.

5.12 **DECAY.** Decay is disintegration of wood substance due to the action of wood-destroying fungi. *Rot* and *Dote* mean the same as *Decay*.

5.13 **RED HEART.** Red heart is the incipient stage of a destructive heart rot caused by *Trametes pini* that occurs in the living tree. It is characterized by a reddish or brownish color in the heartwood.

#### 5.2 Insect Defects

5.21 **INSECT DAMAGE.** Insect damage is the result of boring in the pole by insects or their larvae. Scoring or channeling of the pole surface is not classed as insect damage.

#### 5.3 Timber Defects

5.31 **CHECKS.** Checks are lengthwise separations of the wood in a generally radial direction.

*Heart checks* are checks which extend from the pith center of the pole toward but not to the periphery of the pole.

5.32 **CRACKS.** Cracks are breaks or fractures across the grain of the wood.

5.33 **SCARS.** Scars or cat faces are depressions in the surface of the pole, generally elliptical in shape, resulting from wounds where healing has not re-established the normal cross section of the pole.

5.34 **SHAKES.** Shakes are separations of the wood, generally parallel with the annual rings.

5.35 **SPLITS.** Splits are separations between the fibers of the wood extending from surface to surface through the pole.

#### 5.4 Shape

5.41 **SHORT CROOK.** A short crook is a localized deviation from straightness which, within any section of five (5) feet or less in length, is more than one-half

( $\frac{1}{2}$ ) the mean diameter of the crooked section. (See Diagram 3 of the subsidiary drawing entitled "Measurement of Sweep and Short Crook in Poles.")

5.42 SWEEP. Sweep is the deviation of a pole from straightness. (See Diagrams 1 and 2 of the subsidiary drawing entitled "Measurement of Sweep and Short Crook in Poles.")

### 5.5 Miscellaneous

5.51 KNOT DIAMETER. The diameter of a knot is its diameter on the surface of the pole measured in a direction at right angles to the lengthwise axis of the pole.

5.52 LIVE TIMBER. Live timber is that cut from a tree which was standing and living at the time of cutting.

## 6. Subsidiary Drawing

The following drawing (see page 63) is subsidiary to and forms a part of these specifications: Measurement of Sweep and Short Crook in Poles.

### II. DIMENSIONS

#### DIMENSIONS FOR CREOSOTED SOUTHERN PINE POLES

Class.....	1	2	3	4	5	6	7	8	9	10
Min. top circ., in...	27	25	23	21	19	17	15	18	15	12
Length of pole, ft.	Ground line * dist. from butt, ft.	Minimum circumference at 6 ft. from butt, in.								
16	3½	....	....	....	....	21.5	19.5	18.0		
18	3½	....	....	26.5	24.5	22.5	21.0	19.0		
20	4	31.5	29.5	27.5	25.5	23.5	22.0	20.0		
22	4	33.0	31.0	29.0	26.5	24.5	23.0	21.0		
25	5	34.5	32.5	30.0	28.0	26.0	24.0	22.0		
30	5½	37.5	35.0	32.5	30.0	28.0	26.0	24.0		
35	6	40.0	37.5	35.0	32.0	30.0	27.5	25.5		
40	6	42.0	39.5	37.0	34.0	31.5	29.0	27.0	No butt requirement	No butt requirement
45	6½	44.0	41.5	38.5	36.0	33.0	30.5	28.5		
50	7	46.0	43.0	40.0	37.5	34.5	32.0	29.5		
55	7½	47.5	44.5	41.5	39.0	36.0	33.5			
60	8	49.5	46.0	43.0	40.0	37.0	34.5			
65	8½	51.0	47.5	44.5	41.5	38.5				
70	9	52.5	49.0	46.0	42.5	39.5				
75	9½	54.0	50.5	47.0	44.0					
80	10	55.0	51.5	48.5	45.0					
85	10½	56.5	53.0	49.5						
90	11	57.5	54.0	50.5						

\* The figures in this column are intended solely for use whenever a definition of ground line is necessary in order to apply specification requirements relating to scars, straightness, etc.

MEASUREMENT OF SWEEP AND SHORT CROOK IN POLES

DIAGRAM 1. Measurement of Sweep in One Plane and One Direction.

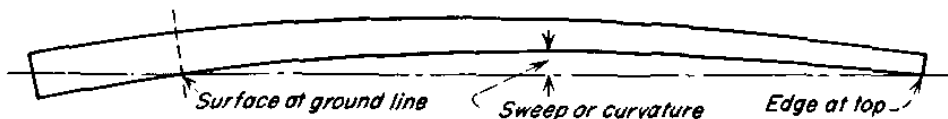
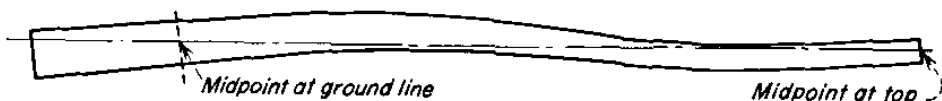
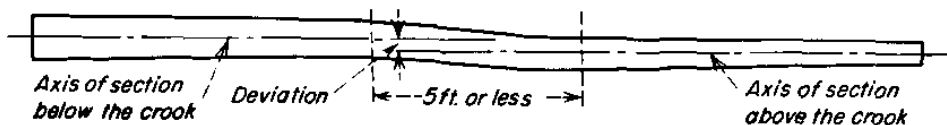


DIAGRAM 2. Measurement of Sweep in Two Planes (Double Sweep) or in Two Directions in One Plane (Reverse Sweep).

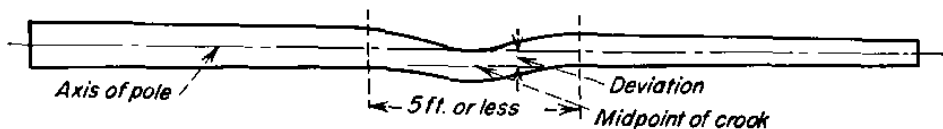


NOTE: This diagram applies to the measurement of double sweep in Western Red Cedar and Southern Pine poles.

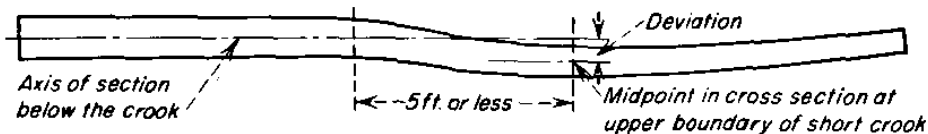
DIAGRAM 3. Measurement of Short Crook (Three Cases Shown).



CASE 1: Where the Reference Axes are approximately parallel.



CASE 2: Where Axes of sections above and below the crook coincide or are practically coincident.



CASE 3: Where Axis of section above short crook is not parallel or coincident with Axis below the crook.

NOTE: The three cases shown under Diagram 3 are typical and are intended to establish the principle of measuring short crooks. There may be other cases not exactly like those illustrated.

## D. POLE DIMENSIONS

Poles are segregated into 10 classes, each class being based on a standardized top circumference. A table of pole dimensions according to length and class is a part of each pole-wood specification. Table 4-1 presents composite data on 30-, 40-, and 50-ft. poles, drawn from the specifications

TABLE 4-1. COMPARISON OF STANDARD DIMENSIONS FOR 30-, 40-, AND 50-FOOT SOUTHERN PINE, WESTERN RED CEDAR, NORTHERN WHITE CEDAR, DOUGLAS FIR, AND LODGEPOLE PINE POLES

	Length of pole, ft.	Ground line dist. from butt, ft.	Class <sup>a</sup>						
			1	2	3	4	5	6	7
			Minimum top circumference, in.						
			27	25	23	21	19	17	15
			Minimum circumference at 6 ft. from butt, in.						
Southern pine	30	5½	37.5	35.0	32.5	30.0	28.0	26.0	24.0
	40	6	42.0	39.5	37.0	34.0	31.5	29.0	27.0
	50	7	46.0	43.0	40.0	37.5	34.5	32.0	29.5
Western red cedar	30	5½	41.0	38.5	35.5	33.0	30.5	28.5	26.5
	40	6	46.0	43.5	40.5	37.5	34.5	32.0	
	50	7	50.5	47.5	44.5	41.0	38.0		
Northern white cedar	30	5½	47.5	44.5	41.5	38.5	35.5	33.0	30.5
	40	6	53.5	50.0	46.5	43.5	40.0	37.0	
	50	7	58.5	55.0	51.5	47.5	44.0		
Douglas fir	30	5½	37.5	35.0	32.5	30.0	28.0	26.0	24.0
	40	6	42.0	39.5	37.0	34.0	31.5	29.0	27.0
	50	7	46.0	43.0	40.0	37.5	34.5	32.0	29.5
Lodgepole pine	30	5½	39.0	36.5	34.0	31.5	29.0	27.0	25.0
	40	6	44.0	41.0	38.0	35.5	33.0	30.5	28.0
	50	7	48.0	45.0	42.0	39.0	36.0	33.5	31.0

<sup>a</sup> No butt requirement in classes 8, 9, and 10.

of the five pole-groups listed. It will be noted that the only variable in this table is the circumference of the poles at a point 6 ft. from the butt. These dimensions have been carefully designed and are based upon the ultimate strength of the species concerned. Thus, regardless of species, poles, class for class, have the same strength characteristics. For example, a Class 2 50-ft. southern pine pole will have essentially the same strength as a Class 2 50-ft. pole of any other of the four species. Class 1 poles have a breaking load of 4,500 p.s.i. when acting as cantilevers, Class 7 poles only 1,200 p.s.i.

#### E. SOUTHERN PINE POLES

The use of the southern pines for poles has increased steadily since 1915, and today these are harvested in greater numbers than any other species. Pine poles are procured throughout the southern pine belt, usually from small scattered tracts of timber and from farm woodlots. Generally a pole producer negotiates directly with the timber owner and cuts only those trees which, in his judgment, are suitable for pole production in the pole class or classes for which he has a market. In some sections poles are cut only in the winter months in order to minimize sporadic bark-beetle outbreaks in the residual stands. At present most poles are cut from second-growth trees of loblolly and shortleaf pines. Second-growth trees of these two species contain large volumes of sapwood, a desirable feature, since sapwood is easier to treat than heartwood and practically all southern pine poles are given a full-length pressure treatment with creosote oil before being placed in service.

Trees selected for poles are felled, cut to specified lengths, then trimmed and barked. The removal of the bark facilitates drying and reduces shipping costs. The peeled poles are then trucked to concentration centers or hauled to railway sidings where they are loaded on gondola or flat cars and sent to treating plants.

**1. Seasoning.** Upon their arrival at a concentration yard or treating plant, poles are segregated according to classes and carefully piled in tiers with stickers, much in the manner of green lumber, and permitted to dry for a period of from 2 to 4 months or until they are thoroughly seasoned. At some plants poles are stored under open sheds or temporary roofs in order to keep off rain and to protect them from the direct rays of the sun. If there is evidence of excessive butt checking, S- or Z-irons are driven into the butts to minimize such damage.

**2. Shaving Poles.** Several treating plants have, as a part of their standard equipment, pole-shaving machines. These machines remove any vestiges of inner bark left on the poles brought in from the woods and



smooth off all knots and other surface irregularities. When handled in this manner the poles are smooth, cylindrical, and much more attractive and are constantly finding more favor with consumers.

Several types of pole shavers are currently employed. In one, a pole is rotated as it is slowly advanced under a series of revolving cutterheads attached to long actuating arms that follow the contour of the pole. In another type, a pole is fed, without rotation, into a machine furnished with cutterheads that revolve about the pole. The depth of cut of either type of machine is easily regulated, and usually no more wood is removed than is necessary to give a pole a clean, smooth finish.

**3. Treating.** As previously indicated, practically all southern pine poles are given a full-length pressure treatment with creosote oil. When properly seasoned, the poles are placed on cars and run into a treating cylinder. One of the empty-cell processes is usually employed, unless customer specification for total retention of creosote is such that a full-cell pressure-treating process is required.\*

Untreated southern pine poles seldom last more than 2 to 5 years in most Southern areas, but a life expectancy of at least 20 years is general for pressure-treated materials.

#### F. WESTERN RED CEDAR POLES

Western red cedar is a tree of gigantic proportions endemic to the Pacific slope and montane regions of northern Idaho and western Montana. The bulk of western red cedar poles comes from the forests of the Idaho Panhandle, since the trees of that particular area are of a size and shape well suited for pole production. Cedar poles are also obtained from the Douglas fir forests on the western slopes of the Cascades in Washington and Oregon. In such instances the pole-size trees are usually removed as a separate undertaking in advance of heavy logging operations. Ordinarily only the younger and smaller trees are harvested; however, cedar poles 130 ft. long are obtainable, and even greater lengths are produced (although rarely).

In the woods operation, trees are felled, cut to proper lengths, trimmed, and barked. Bark crews work immediately behind the fellers, for the removal of the bark expedites seasoning and reduces the activity of beetles and blue-stain fungi. The poles are then skidded to strategic locations where they are decked; from these points they are removed to concentration centers. In Idaho operations, poles are frequently floated to the yards in flumes. Upon their arrival they are carefully inspected, sorted, and

\* For complete specifications relating to the preservative treatment of southern pine poles, the reader is referred to No. 360 in the American Wood-Preservers' Association Manual of Recommended Practice.

permitted to season for a period of from 6 to 9 months before shipment to treating plants.

Western red cedar is an ideal pole wood. It is obtainable in many lengths and has an excellent strength-weight ratio, and its comparative lightness in weight greatly facilitates handling. Pole-size trees seldom have a sapwood layer of more than  $\frac{5}{8}$  in. in thickness. Thus the heartwood, which is exceedingly resistant to decay, comprises about 90 per cent or more of the volume of the pole in the region of the ground line. Because of these conditions untreated poles suffer little from the ravages of decay, and there are many records of western red cedar poles having given satisfactory service for 30 to 60 years even though the perishable sapwood had rotted away within the first few years following their emplacement (Fig. 4-1).

#### 1. Treating Western Red Cedar

**Poles.** Despite the fine service records for untreated western red cedar poles, their life may be prolonged by a treatment designed especially for them. Decay and termite infestations in poles usually have their inception at or slightly below the ground line where conditions are most suitable for the development of wood-destroying organisms; but if these organisms cannot gain entrance in this region, there is usually little likelihood of attack elsewhere along the pole. Accordingly these poles are given a butt treatment only.

The depth of pole embedment, to secure ample anchorage, is a function of its length (see Table 4-1; also specification 05.4-1941, page 62). When the ground line of a pole is established, the surface of the pole for a distance of 1 ft. above and 2 ft. below this line is carefully shaved in order to remove all traces of inner bark left on it after the initial peeling operation at the time of felling. This area, known as the *ground-line area*, is then incised by using machines fitted with steel teeth  $\frac{1}{2}$  in. in length that puncture the pole at regular and frequent intervals about the periphery of the ground-line area. Incising has little effect upon the mechanical efficiency of a pole but greatly facilitates penetration of a preservative.

Following the incising operation, poles are ready for treatment. Several

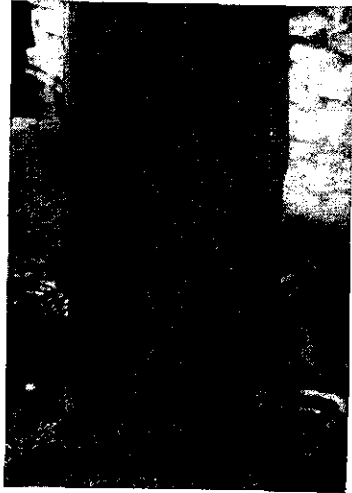


FIG. 4-1. Untreated western red cedar pole. Note that only the sapwood has rotted away after more than 30 years of satisfactory service. (Photograph by J. P. Wentling.)

poles are placed upright in a large open tank fitted with steam coils and usually, for convenience, partially buried in the ground (Fig. 4-2). Hot creosote oil is then pumped into the tank and a level maintained that will ensure a full and adequate treatment of the pole butts. The poles must remain in this tank for a period of at least 6 hours, during which the oil temperature is maintained at 213°-235°F. Following the hot bath the poles are placed in a bath of cool oil \* for a minimum period of 2 hours. Such a

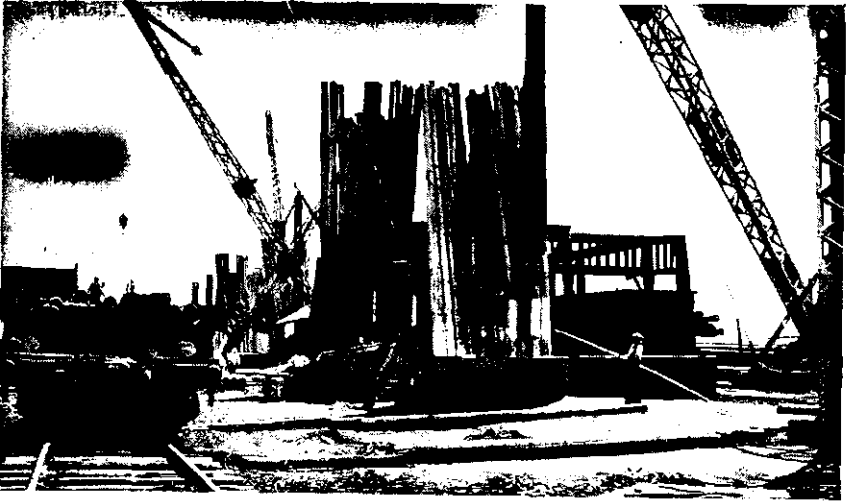


FIG. 4-2. Open-tank treating plant for western red cedar poles. Note shaved ground line region of poles in foreground. (Photograph by J. P. Wentling.)

treatment is usually adequate, and oil retention of at least 35 lb. per cu. ft. of sapwood may be anticipated.

#### G. NORTHERN WHITE CEDAR POLES

The production of northern white cedar poles has declined in the last decade, and today only from 300,000 to 500,000 poles are produced annually. The largest stands of northern white cedar are found in the swamplands of the northern Lake states region, which is the principal pole-production center for this species. The heartwood, like that of its western congener, is exceedingly durable in contact with the soil, and untreated poles have given many years of satisfactory service. The bulk of the poles currently harvested, however, are butt-treated, and their preparation follows the same general pattern as that employed with western red cedar poles.

\* 90 to 100°F.

This cedar never attains the gigantic proportions of the western species, and poles exceeding 55 ft. in length are seldom encountered.

#### H. DOUGLAS FIR POLES

The use of Douglas fir for poles has increased steadily since 1906, but their production is still comparatively limited owing to the ample supply of western red cedar in the same producing areas. Douglas fir is much less durable than cedar, and the poles are usually given a full-length pressure treatment, particularly when their use is contemplated in regions where dry-wood termites are prevalent. The life expectancy of treated Douglas fir poles approximates 20 years.

#### I. LODGEPOLE PINE POLES

Lodgepole pine poles have been produced in ever-increasing numbers since 1923, when the Mountain States Telephone and Telegraph Company, in an effort to find a cheap and continuous source of supply, began experimenting with them in its lines. The size and form of lodgepole pine trees from the northern Rocky Mountain region recommend this species for pole production. The wood of this pine is not particularly resistant to natural wood-destroying agencies, but if the poles are to be used in the northern Rocky Mountain states, an open-tank butt treatment will suffice, and poles so treated normally have a service life of from 15 to 20 years. Lodgepole pine is a very gregarious species, and because of its abundance it is quite likely that it will be a pole-producing species of considerably more importance in the future.

#### J. FUTURE OF THE POLE INDUSTRY

In many of our metropolitan areas, particularly in congested and business districts, the telephone pole has been replaced by the underground conduit. Ornate reinforced concrete and metal poles now support street lights in many cities, and the trolley wires for electric busses and streetcars are hung from columns fabricated of similar materials. High-power transmission lines thread their way across the nation on poles and towers of latticed steel. There seems to be little likelihood, however, that these structures will ever become serious competitors of wood poles, for in most instances wood poles are still the cheapest means of carrying wire. Looking to the future, the development of rural electrification promises to create a steady pole market. New construction and replacements in existing lines will continue at a normal rate for many years to come.

## II. PILES

In the restricted sense, a pile is a heavy timber (usually in the round) driven in the ground for use as a support or a foundation. Through common usage the term also is now used to designate round timbers used in trestles, overpasses, bridges, and similar structures, where they merely rest upon a solid footing. Piling is a collective term used to describe an indefinite number of piles; the term is also applied to structures consisting principally of piles.

There are no statistics available concerning the production of piling in the United States, but it is reliably estimated that the number of round timbers used each year for piling closely approximates the number used for poles. Piles are harvested, seasoned, and treated similarly to poles; the same species are used, and in some operations segregation of poles and piling is effected following inspection and selection of the cut at the concentration yards. In the South, pine piling is obtained largely from woodlots. Douglas fir and western red cedar are the principal pile species along the Pacific rim; in the East and South, yellow pine, eastern larch, oaks, cypress, and chestnut are those used in greatest abundance. In recent years coastal fisheries off the New Jersey coast have used untreated hickory piling from which nets are strung.

### A. FACTORS GOVERNING THE SELECTION OF PILING

The same general considerations employed in determining the suitability of a species for pole use may be applied to piling. In addition to these, pile timbers must also have good shock resistance and the ability to absorb heavy hammer loads imposed upon them during emplacement. End brooming from the incessant pounding of the hammer is often excessive in some of the softer woods. This type of failure under the pile driver does not militate against the use of such woods, however, as this objectional characteristic is readily overcome by fastening metal collars about the head of the pile before it is driven. Some operators claim that broom is less evident with steam than with drop hammers. Piles with excessive sweep are objectionable since they are not only difficult to drive but are usually incapable of carrying the loads for which they are designed. A rule-of-thumb procedure is to cull out any pile in which the central axis falls outside the pile.

### B. PILING SPECIFICATIONS

In 1939 the American Society for Testing Materials released standard specifications for round timber piles under A.S.T.M. designation D25-37. These are reproduced here with the full approval of the Society.

STANDARD SPECIFICATIONS FOR ROUND TIMBER PILES<sup>1</sup>

A.S.T.M. Designation: D 25—37  
Adopted, 1937<sup>2</sup>

This Standard of the American Society for Testing Materials is issued under the fixed designation D 25; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision.

*Scope*

1. These specifications cover round timber piles to be used untreated, or treated by standard preservatives.

NOTE. Where sawed timber is used as piling, such as heavy sheet piles, appropriate specifications should be selected from the Standard Specifications for Structural Wood Joist and Plank, Beams and Stringers, and Posts and Timbers (A.S.T.M. Designation: D 245) of the American Society for Testing Materials.

*Kinds of Wood*

2. (a) The purchaser shall specify the kind or kinds of wood he desires, and shall designate the kinds he desires for preservative treatment.

NOTE. Commonly used species are cedars, chestnut, cypress, Douglas fir, larch, oaks, pines, spruces, and tamarack.

(b) Piles of different kinds of wood shall be delivered in separate lots.

*Use Classification*

3. Timber piles are classified in these specifications under three general divisions according to the use intended, as follows:

(a) Class A. Piles suitable for use in heavy railway bridges and trestles. The minimum diameter of butt assumes the use of load-bearing timber caps 14 in. in width.

(b) Class B. Piles suitable for use in docks, wharves, highway work, and general construction. The minimum diameter of butt assumes the use of load-bearing timber caps 12 in. in width. When timber caps are not used, as in the case of piles under masonry foundations, the sizes given for Class C piles are recommended.

(c) Class C. Piles suitable for use in foundations which will always be completely submerged, for coffer-dams, falsework, and sundry temporary work.

<sup>1</sup> Under the standardization procedure of the Society, these specifications are under the jurisdiction of the A.S.T.M. Committee D-7 on Timber.

<sup>2</sup> Prior to their present adoption as standard, these specifications were published as tentative from 1915 to 1920. They were adopted in 1920, published as standard from 1920 to 1930, but withdrawn and republished as tentative from 1930 to 1937, being revised in 1934 and 1935.

## CLASS A AND CLASS B PILES

*General Quality*

4. Except as hereinafter provided, Class A and Class B piles shall be free from any defects which may impair their strength or durability as piling, such as decay, redheart, splits in piles to be treated, or splits longer than the measured butt diameter of piles not to be treated, twist of grain exceeding one-half of the circumference in any 20 ft. of length, unsound knots, numerous knots or holes, or shake more than one-third of the diameter of the pile. Piles which have been scored for turpentine shall be accepted, provided such scar does not exceed 36 in., and provided the scoring is of recent date showing the scar to be entirely sound and free from insect damage.

*Knots*

5. Sound knots will be permitted in Class A and Class B piles, provided they are not in clusters. The diameter of a sound knot shall not be greater than one-third of the minimum diameter of the pile at the section where it occurs, and shall not exceed 4 in. for piles 50 ft. and under in length. For piles over 50 ft. in length, knots between the section at mid-length and the butt shall conform to the limitation prescribed for piling under 50 ft. Between mid-length and the tip, single knots up to 5 in. in diameter will be permitted, provided they do not exceed one-half the minimum diameter of the pile at the section where they occur. The diameter of a knot shall be measured at right angles to the length of the pile.

*General Requirements*

6. (a) Sound Timber. Class A and Class B piles shall be cut from sound, live trees, except that fire-killed, blight-killed, or wind-felled timber may be used if not attacked by decay or insects. Piles shall be cut above the ground swell.

(b) Tip. The tip shall be sound.

(c) Butt End. The butt end shall be sound except in cedar piles, which may have a pipe or stump rot hole not more than 1½ in. in diameter.

(d) Taper. Piles shall have a gradual taper from the point of butt measurement to the tip.

(e) Surface Finish. All knots and limbs shall be trimmed or smoothly cut flush with the surface of the pile. The butt and tip shall be sawed square with the axis of the pile, or the tip may be tapered to a point not less than 4 in. in diameter if directed by the engineer in charge.

*Sapwood*

7. (a) Piles for Use Untreated. Piles for use without preservative treatment shall have as little sapwood as possible, and when used in exposed work, the diameter of the heartwood shall not be less than eight-tenths of the actual diameter of the pile at the butt.

(b) Piles for Treatment. Piles for use with preservative treatment shall have no sapwood restrictions, but preferably shall contain as much sapwood as possible.

In southern pine the sapwood thickness shall not be less than  $1\frac{1}{2}$  in. and in Douglas fir and larch not less than 1 in. on the butt end.

#### *Peeled Piles*

8. (a) Piles shall be peeled of bark, including the inner skin, soon after cutting so that the piles are smooth and clean. Care shall be taken to remove as little sapwood as possible while peeling the bark. The sapwood shall not be injured by unnecessary axe cuts. These piles shall be designated as piles for treatment.

(b) No pile shall be considered as thoroughly peeled unless all of the rough bark and at least 80 per cent of the inner bark which remains on the pile shall have been removed. In no case shall any piece of inner bark be over  $\frac{3}{4}$  in. in width or over 8 in. in length, and there shall be 1 in. of clean wood surface between any two strips of inner bark.

#### *Diameter*

9. (a) It is recommended that the diameters of piles measured under the bark shall conform to the requirements shown in Table 1, subject to a permissible variation of minus  $\frac{1}{2}$  in. in any diameter in not more than 25 per cent of the piles of that diameter.

(b) The diameter of a pile in cases where the tree is not exactly round shall be determined either by measuring the circumference and dividing the number of inches by 3.14, or by taking the average of the maximum and minimum diameters at the location specified.

#### *Length*

10. All piles shall be furnished cut to any of the following lengths, as specified: 16 to 40 ft. in multiples of 2 ft., and over 40 ft. in multiples of 5 ft. A variation of 6 in. in length shall be allowable, but the average length in any shipment shall be equal to, or greater than, the specified lengths. The length of each pile shall be legibly marked on the butt end with white or black paint.

#### *Straightness*

11. Piles shall be free from short or reversed bends, and free from crooks greater than one-half of the diameter of the pile at the middle of the bend. In short bends, the distance from the center of the pile to a line stretched from the center of the pile above the bend to the center of the pile below the bend shall not exceed 4 per cent of the length of the bend, or  $2\frac{1}{2}$  in. A line drawn from the center of the butt end to the center of the tip shall lie within the body of the pile.

### CLASS C PILES

#### *General Quality*

12. Class C piles shall be of sound, live timber that will stand driving, and need not be peeled if they are to be used without preservative treatment. They shall be free from decay and other imperfections such as bad knots and shakes which will



materially affect their strength. Piles which have been scored for turpentine shall be accepted, provided such scar does not exceed 36 in., and provided the scoring is of recent date, showing the scar to be entirely sound and free from insect damage.

TABLE 1. DIAMETERS OF THREE CLASSES OF PILES

Length, ft.	Class A and Class B piles (these differ in size only)						Class C piles <sup>a</sup> (these differ from classes A and B in size and quality)		
	Class A			Class B					
	Diam. 3 ft. from butt, in.		Min. diam. of tip, in.	Diam. 3 ft. from butt, in.		Min. diam. of tip, in.	Diam. 3 ft. from butt, in.		Min. diam. of tip, in.
	Min.	Max.		Min.	Max.		Min.	Max.	
Douglas fir and southern pine piles <sup>b</sup>									
Under 40.....	14	18	10	12	20	8	12	20	8
40 to 50 incl....	14	18	9	12	20	7	12	20	6
51 to 70 incl....	14	18	8	13	20	7	12	20	6
71 to 90 incl....	14	20	7	13	20	6	12	20	6
Over 90.....	14	20	6	13	20	5	12	20	5
Black oak, chestnut, cypress, pin oak, post or burr oak, red oak, white oak, or willow oak piles									
Under 30.....	14	18	10	12	18	8	12	20	8
30 to 40 incl....	14	18	9	13	20	8	12	20	8
Over 40.....	14	18	8	13	20	7	12	20	6
Cedar piles									
Under 30.....	14	22	10	12	22	8	12	22	8
30 to 40 incl....	14	22	9	13	22	8	12	22	8
Over 40.....	14	22	8	13	22	7	12	22	7

<sup>a</sup> In Class C piles, a minimum diameter (at cutoff) of 10 in. may be specified for lengths of 20 ft. and under.

<sup>b</sup> Where larch, lodgepole or Norway pine, spruce, or tamarack piles are specified, their dimensions shall correspond to the requirements shown for Douglas fir and southern pine.

*General Requirements*

13. (a) *Tip.* The tip shall be sound.
- (b) *Taper.* Piles shall have a gradual taper from the point of butt measurement to the tip.
- (c) *Surface Finish.* All knots and limbs shall be trimmed or smoothly cut flush with the surface of the pile. The butt and tip shall be sawed square with the axis of the pile, or the tip may be tapered to a point not less than 4 in. in diameter if directed by the engineer in charge.

*Sapwood*

14. Sapwood requirements shall be identical with those for Class A and Class B piles as specified in Section 7.

*Peeled Piles*

15. The requirements for peeled piles shall be identical with those for Class A and Class B piles as specified in Section 8.

*Diameter*

16. The methods of measurement of diameter and the permissible variations in diameter shall be identical with those for Class A and Class B piles as specified in Section 9. The recommended sizes are given in Table 1.

*Length*

17. The requirements for length shall be identical with those for Class A and Class B piles as specified in Section 10.

*Straightness*

18. The requirements relating to straightness shall be identical with those for Class A and Class B piles as specified in Section 11.

### III. POSTS

Fence posts are used principally on farms, and in many rural areas they are obtained chiefly from local farm woodlots. The 280,000 farms in North Carolina alone require more than 15 million posts annually, while approximately 460 million units are needed yearly on the farms of the nation. Many thousands of additional posts are used in fences along public highways and railroad right of ways and in regions where livestock and dairy enterprises are expanding. Where large-scale land-management practices are in effect, fencing is needed for adequate area control. The current annual consumption of fence posts in the United States is placed at 600 million units, of which nearly 40 million are given a preservative treatment.

## A. SPECIES USED

In the days before fence posts were treated to prolong their service life, post production was restricted largely to those woods known for their resistance to natural destructive agencies. Timbers such as chestnut, black locust, osage orange, white oak, red mulberry, sassafras, catalpa, redwood, bald cypress, and various cedars were among those principally used. In fact, farmers, through their local, state, and Federal farm agencies, were encouraged to establish plantations of certain of these species to produce their own post requirements.

Untreated posts of chestnut, black locust, osage orange, and the several cedars, provided they include only thin outer layers of sapwood,\* may be expected to last for at least 20 to 30 years under normal conditions of embedment and exposure. White oak, catalpa, redwood, red mulberry, and a few other species have a life expectancy as posts of from 10 to 20 years. By contrast, posts of white ash, beech, birch, maple, black gum, spruce, hemlock, fir, and second-growth yellow pines, unless given a suitable preservative treatment, are usually badly decayed and often riddled with termites within 2 to 4 years after their placement in the ground.

The availability of durable post woods in some localities has diminished to the point where supply no longer keeps up with demand. It is not at all surprising, therefore, to find facilities both in cities and on farms for the treatment of nondurable species. In fact, it is becoming a usual practice, especially in many parts of the South, to treat all woods, regardless of durability, because their service life can be extended by introducing toxics into the sapwood.

## B. HARVESTING POSTS

As indicated previously, a large portion of the fence posts produced in the United States are obtained from farm woodlots. Many others are by-products of logging operations where tree tops and large limbs are cut from the slash and trimmed to post sizes. In many sections of the country, but particularly in the South where young forests of second growth predominate, thinnings in sizes too small for pulpwood often provide a large number of posts, the sale of which more than pays for the cost of such operations. In recent years post producers and distributors have made their appearance in several forest regions, but notably in the Southern states where there is relatively cheap stumpage of a variety of species. While a farmer cuts most of his posts in the winter months when his farming activ-

\* Sapwood of practically all species is quite perishable in contact with soil; hence posts containing large volumes of sapwood have a comparatively shorter service life.

ities are at a minimum, the commercial fence-post producer operates from 200 to 300 days a year. His operations are mechanized as much as possible, both in the woods and at his concentration yards, in order to ensure volume production. Portable power saws and mechanical barking machines are usually a part of his equipment. He also commonly operates one or more treating plants.

Trees selected for the production of posts are felled, trimmed, and cut to proper lengths. Most round posts are produced in lengths of 7 and 8 ft. (maximum 20 ft.) with top diameters of from 3 to 6 in. Trees of larger diameters are commonly halved longitudinally or occasionally even quartered. The posts are peeled either at the point where the trees are felled or at concentration yards. Peeling facilitates drying and reduces the danger of insect and fungal infestations.

Hand-rived posts are made from large western red cedar and redwood logs too severely damaged in felling during logging operations to be used for saw timber.

Sawed posts are favored in some localities. These are manufactured from rectangular cants such as 4 x 8's and 5 x 10's. In using such materials it is customary to rip them lengthwise on a slight diagonal, thus providing a taper.

### C. PEELING

The facility with which bark may be removed varies throughout the year. Spring peeling is preferable, since with the renewal of growth there is a layer of immature cells between bark and wood which are easily ruptured. Bark removal during the winter months is usually fraught with difficulty. Hand peeling has been the standard procedure for years. Such an operation is laborious, time-consuming, and, in these times of high wages, expensive. An experienced peeler can handle 100 to 200 posts a day, depending upon his skill and the ease with which the bark can be removed. Hand-peeled posts, however, are seldom perfectly cleaned; hence treatment with a preservative may be only partially effective.

**1. Mechanical Barkers.** Within the past few years, particularly in localities where there are a number of large commercial fence-post producers, it has been found expedient to remove the bark by mechanical means. In some production centers portable mechanical barkers are skidded from one cutting area to another. Others are set up and operated only at post concentration yards. Three types of mechanical barkers are in current use.

*a. Drum Barkers.* Machines of this type operate on the same principle as rossers used in wood yards of pulp mills. They consist of motor-driven drums approximately 9 ft. long and 5 ft. in diameter. In one design the

axes are eccentrically mounted to provide greater tumbling and sliding action. Side walls of the drums are made either from old, perforated boiler plates or of closely spaced channel irons. In an operation the drums are loaded to about 85 per cent of capacity (80 to 100 posts), and then set in rotation at 25 to 35 r.p.m. The tumbling and rubbing action of the poles against one another quickly dislodges the bark, which falls out through the slots or perforations in the walls provided for this purpose.

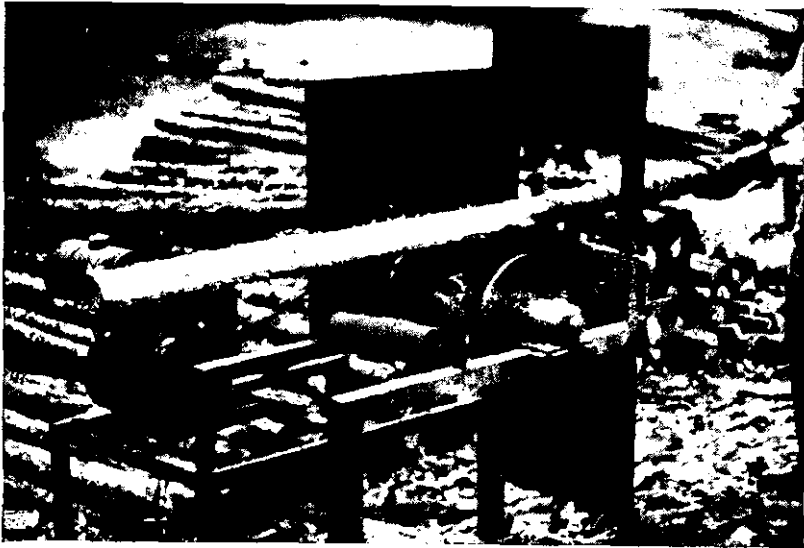


FIG. 4-3. Post chain barker. (U.S. Forest Service photograph.)

Southern pine and spring- or summer-cut hardwood posts may be drum-peeled in 12 to 25 minutes. Such machines have a daily capacity of from 900 to 1,600 posts, depending upon post size, season of cutting, and operators' efficiency. Late fall- or winter-cut hardwood posts cannot be satisfactorily drum-peeled. The cost of drum peeling varies from  $1\frac{1}{4}$  to  $1\frac{3}{4}$  cents per post.

b. *Hammering Machines.* Two types of hammering machines are in current use. One of them is the hammer barker specifically designed for rossing pulpwood. This machine consists principally of a power-driven shaft to which are bolted a number of small hammers. In its operation, posts are mechanically fed and rotated against the flying hammers, which literally beat off the bark. This machine has a daily capacity of about 3,000 posts, but because of its high initial cost and higher operating costs, it can be used economically only on large-scale post-production operations.

The second type of hammering machine is called a *chain barker*. The essential part of this machine is a large iron spool (Fig. 4-3) with several short pieces of heavy logging chain bolted between the flanges. This assembly is mounted upon a frame in such a way that posts may be advanced over it. Bolted to the frame are also properly located feed rolls to carry the posts over the barker. In chain barking the spool is rotated at 700 r.p.m. At this speed the chains, which are slack when at rest, fly outward



FIG. 4-4. Lathe-type barker. (U.S. Forest Service photograph.)

from the spool to strike and remove the bark. Feeding and rotating of the posts are accomplished manually. Such a machine has a daily capacity of from 300 to 400 posts.

*c. Peeling Machines.* These machines differ from other barkers in that bark is actually peeled rather than knocked off by mechanical means. Two general types are recognized. One is essentially a diminutive pole shaver with a floating, rotating cutterhead of similar design. The other is a modified lathe. This is a portable machine readily moved from one woods operation to another. In reality this is more than a barking machine, as it removes not only bark but wood as well, and the finished post is a smooth cylinder of wood much like a core from an expended veneer bolt. Figure 4-4 is an illustration of the lathe-type barker. A post to be peeled is placed between two chucks which automatically center it. The post is then

slowly rotated against a high-speed shaft furnished with a series of staggered cutters. Four men are required to operate a machine of this type, which can peel 120 to 200 posts an hour.

Lathe-peeled posts have smaller volumes than do tapered poles of comparable length and top diameter, hence are lighter in weight and require less of a preservative. Savings in shipping costs alone have been reported to be as much as \$100.00 per car. On the other hand, it is questionable if posts with small volumes of sapwood should be lathe-peeled if a preservative treatment is contemplated, since heartwood of most species is difficult to treat adequately with the common open-tank methods of treatment.

#### D. SEASONING

Experiments conducted by the U.S. Forest Service have led to the conclusion that little or nothing is gained by seasoning posts unless they are to be treated. A seasoned post, once it is in the ground, picks up moisture in the soil until it is in equilibrium with it. To obtain good penetration and absorption of a preservative, however, posts should be thoroughly seasoned before impregnation, unless treated by the osmose method.

Posts should be open-piled or ricked in pens to permit the free circulation of air about them. In such species as the oaks, care must be taken to avoid excessive checking. Better posts of these particular species are obtainable if they are cut and seasoned during the fall and winter months when drying progresses at a slower rate. Most posts can be thoroughly air-seasoned in from 60 days to 6 months, depending on diameter, season when cut, and prevailing atmospheric conditions.

#### E. METHODS OF TREATING

Several methods are employed in treating posts, but the one most universally used is the open-tank immersion in hot and cool creosote baths. There is nothing better than a full-length pressure treatment, but the additional expense involved is not always warranted, as posts given conventional open-tank treatments with creosote oil have a life expectancy of more than 20 years under average conditions of exposure. In some regions it is customary to treat merely the butts; in other locations, especially in warm humid localities, full-length treatments are recommended. Open-tank treatments of posts are similar to those described for the treatment of cedar poles, although the equipment need not be so elaborate. Treating tanks are erected on many farms and consist merely of an oil drum or iron tank built over a firebox. A small privately operated treating plant con-

structed near Hertford, North Carolina, erected in 1947 at a cost of \$3,300,\* has a capacity of 400 to 450 posts daily.

#### F. COST CONSIDERATIONS

Untreated fence posts, depending upon their size, kind of wood, availability, and region of production, cost from \$0.10 to \$1.00 each; treated posts, on the other hand, bring from \$0.35 to \$1.50 or more each, contingent upon their method of treatment and amount of toxic retained. Perishable woods used as posts, which are not infrequently devoid of heartwood, often have a service life of only 3 to 5 years. Posts made from woods known for their durability may last from 10 to 20 years if they include large cores of heartwood. Adequately treated posts, regardless of species, may be expected to give as much as 20 to 30 years of service.

It is well for a consumer to ascertain what materials are available for his fence lines and the life expectancy of those materials in his locality. He should also determine the relative costs of both treated and untreated poles, and if he uses the latter, what his replacement costs may be. With these data the most economical installation consistent with his needs can then be determined. If the price for treated materials can be reasonably expected to exceed the purchase and replacement costs of untreated posts, say for a period of 20 years, there is little real justification for using treated stocks.

Under many circumstances, however, the use of treated posts will effect an appreciable saving to the consumer. This statement is readily borne out by Smith and Hertzler<sup>10</sup> in their study of the fence post requirements in North Carolina. They report (1946) that small untreated fence posts with a service life of about 5 years may be procured at a cost of from 10 to 20 (average 15) cents apiece. Thus the annual cost of these posts is about 3 cents apiece. By contrast, treated posts are priced at from 35 to 60 cents each but have a life expectancy of from 20 to 30 years. From these figures it is evident that the annual cost of treated posts is about 2 cents each and the additional costs of installation (replacement) over a period of 20 years are reduced by more than 80 per cent, which, in these days of high wages for unskilled labor, represents a worth-while saving in cash.

\* For detailed information on plant layouts, methods of treatment, and treating schedules, the reader should consult the several carefully selected references appearing at the end of this chapter.



## G. POST SUBSTITUTES

Iron and even concrete posts have made their appearance on farms and are serving efficiently for support of wire barriers. Their initial costs are greater than those of wood and their service life seldom exceeds that of the fully treated wooden article. Their occasional use will continue, but it is quite improbable, because of consideration of initial cost, that they will ever seriously compete with fence posts on the vast majority of American farms.

*Remark.* Many mine timbers are also used in the round. These are discussed in Chap. 5, Mine Timbers.

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## CHAPTER 5

### MINE TIMBERS

#### I. USES OF MINE TIMBERS

The term *mine timbers* is a collective designation denoting a variety of forms of wooden supports used in the construction of tunnels, shafts, and other mine openings and chambers. Fay<sup>2</sup> defines *timber* as "any of the wooden props, posts, bars, collars, lagging, etc., used to support mine workings" and *timbering*, as "the timber structure employed for supporting the face of an excavation during the progress of construction." The word *timbering* is sometimes applied to concrete, masonry, and steel supports as well as to those made of wood, but the general term *ground support* is considered preferable when referring to all types of supporting structures. This chapter will be restricted, in the main, to ground supports made of wood, as well as to other types of wood products used in connection with mining.

The subject of mine timbers is one of considerable importance in the forest economy of the United States, the consumption of wood for this purpose being exceeded only by lumber, fuel wood, pulpwood, railroad ties, veneer logs, mine timbers, and fence posts, in the order given. A cursory knowledge of mining methods and mining terminology is necessary to an understanding of the timber requirements of the industry.

#### A. PURPOSE OF MINE TIMBERS

In the first place it is necessary to understand the purpose of mine timbers. When an underground excavation is made, whether it be horizontal, vertical, or a large chamber, the removal of the ground \* deprives the surrounding sides and top of the opening of its former support. After an excavation has been made, the exposed surface, if composed of crushed or loose material, starts to slough away, or, if it is hard rock, breaks away from the back along fracture planes. This material will eventually "arch" and support itself, in most instances, but if the back is not supported immediately, this process of caving becomes cumulative until a large chamber

\* The term *ground*, as used in the mining industry, denotes the rock formations in which a mining operation is being conducted.

has been formed. In solid, unfractured rock, no caving may take place, and the roofs of even large chambers may stand indefinitely without the use of internal supports.

Obviously, the amount of timbering that can be placed in a mine opening many hundreds of feet below the surface of the earth would be totally inadequate to support the tremendous weight of overlying strata. The primary purpose of timbering is, therefore, to prevent loose material, blocks, or slabs from falling and damaging equipment, injuring workmen, and plugging passageways. Timbering also provides a firm foundation for machinery in soft ground, a base for car rails, linings for elevator shafts, and numerous other uses.

The amount and character of timbering varies widely in different types of ground. Weaknesses caused by faults, fissures, bedding and cleavage planes in rock strata, blasting fractures, seepage, etc., may even dictate the use of several different methods and intensities of timbering in the same mine. Even after the ground around an excavation has "set," pressures may be great. Such pressures may be either vertical or lateral, or both. Substantial timbering is required to keep some tunnels open, and large timbers are sometimes broken in a matter of days. In some cases, tunnels must be abandoned and alternate passages cut in areas where pressures are less severe. Although less common, some mines require floor timbering to prevent heaving.

## B. MINING TERMINOLOGY

Colloquialisms are common in mining terminology, and many of the terms used are not to be found in the dictionary. To complicate matters further, the same term may have different meanings in various mining regions. Some of the more common mining terms are defined by Fay <sup>2</sup> as follows:

*Adit.* A nearly horizontal passage from the surface by which a mine is entered and watered. In the United States an adit is usually called a *tunnel*, though the latter, strictly speaking, passes entirely through a hill and is open at both ends. Frequently also called drift, or adit, level.

*Cage.* A frame with one or more platforms for cars, used in hoisting in a vertical shaft. It is steadied by guides on the sides of the shaft.

*Crossbar.* A horizontal timber held against the roof to support it, usually over a roadway; a collar.

*Crosscut.* 1. A small passageway driven at right angles to the main entry to connect it with a parallel entry or air course. 2. A level driven across the course of a vein or in general across the direction of the main workings or across the "grain of coal."

*Drift.* 1. A horizontal passage underground. A drift follows the vein, as distinguished from a crosscut, which intersects it, or a level or a gallery, which may do either. 2. In coal mining, a gangway or entry above water level, driven from the surface in the seam.

*Gob.* Any pile of loose waste in a mine.

*Lagging.* Planks, slabs, or small timbers placed over the caps or behind the posts of timbering, not to carry the main weight, but to form a ceiling or a wall, preventing fragments of rock from falling through.

*Level.* A horizontal passage or drift into or in a mine. It is customary to work mines by levels at regular intervals in depth, numbered in their order below adit or drainage level, if there be one. Rarely applied to coal mining.

*Pillar.* 1. A solid block of coal, etc., varying in area from a few square yards to several acres. 2. A piece of ground or mass of ore left to support the roof or hanging wall in a mine.

*Raise.* A mine shaft driven from below upward; called also *upraise*, *rise*, and *riser* (Webster). An opening, like a shaft, made in the back of a level to reach a level above (Standard). The term is in general usage at mines in Western states.

*Shaft.* An excavation of limited area compared to its depth, made for finding or mining ore or coal, raising water, ore, rock, or coal, hoisting and lowering men and materials, or ventilating underground workings. The term is often specifically applied to approximately vertical shafts, as distinguished from an incline or inclined shaft.

*Stope.* An excavation from which the ore has been extracted, either above or below a level, in a series of steps. A variation of step (Standard). Usually applied to highly inclined or vertical veins. Frequently used incorrectly as a synonym of room, which is a wide working space in a flat mine.

*Stull.* 1. The top piece of a set of mine timbers. 2. A timber prop supporting the roof of a mine opening.

### C. MINING METHODS AND TYPES OF TIMBERING

A mine may consist of a simple horizontal tunnel driven into the side of a hill by a prospector, a complicated interconnecting system of underground shafts, levels, crosscuts, drifts, pumping chambers, stopes, and rooms located hundreds of feet below ground, or any degree of development between these two extremes. An open pit of the type used in strip or surface mining is also called a mine.

Open-pit mines use little or no timbering, mine ties constituting the principal item of wood consumed. A relatively small number of mines excavated from solid rock require comparatively small amounts of timbering. Most mines, however, require considerable quantities, the amount and kind depending on the character of the ground, the method of mining, the length of time the mine openings must be kept open, and other factors.

**1. Timbering Open Rooms.** The simplest form of timbering consists of single posts, or props, mounted with or without sills and topped either with caps or headboards. The cap may take the form of two wedge-shaped pieces of wood that can be driven together to assure a tight fit between the prop and the area of roof that it supports. Such props are most common in flat mines, such as coal mines, where they constitute the largest single item of wood consumption.

2. **Timbering Tunnels, Drifts, and Crosscuts.** The timbering in tunnels, drifts, and crosscuts may vary from simple, one-piece tunnel sets to complicated eight-piece arched sets used in ground that swells when exposed to air and moisture. Probably the most common form of timbering is the three-piece tunnel set used in drift and crosscut construction. This type of tunnel set consists of three principal members: two posts and one cap (Fig. 5-1).

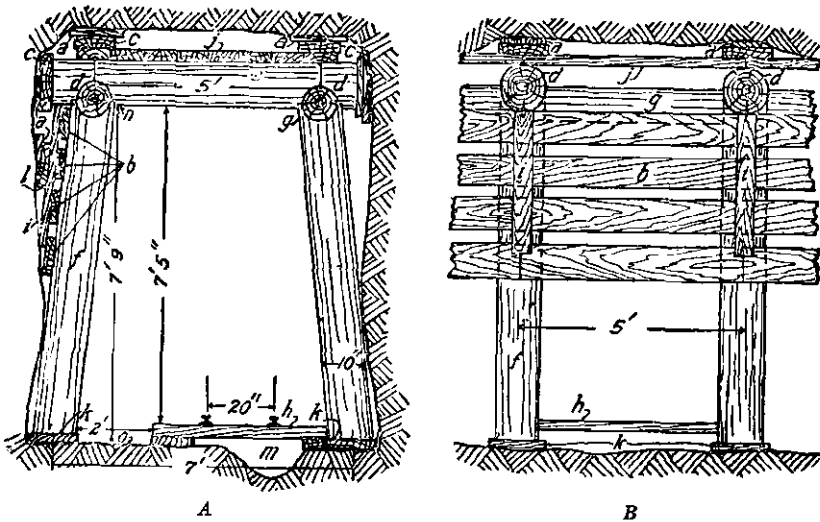
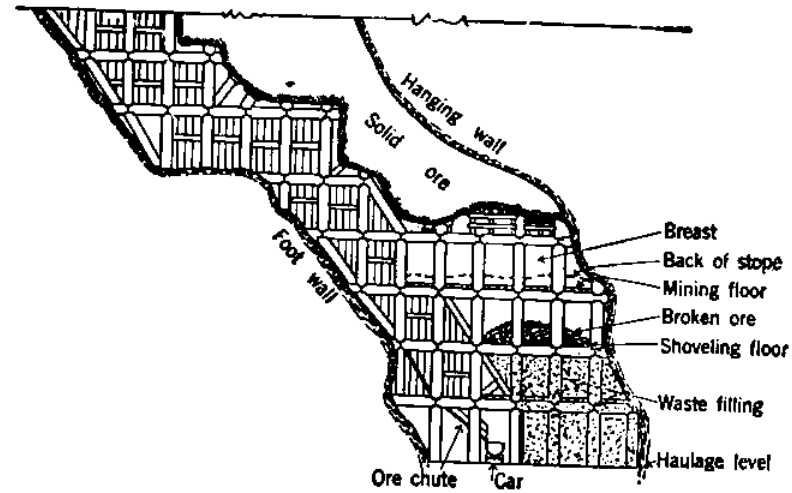
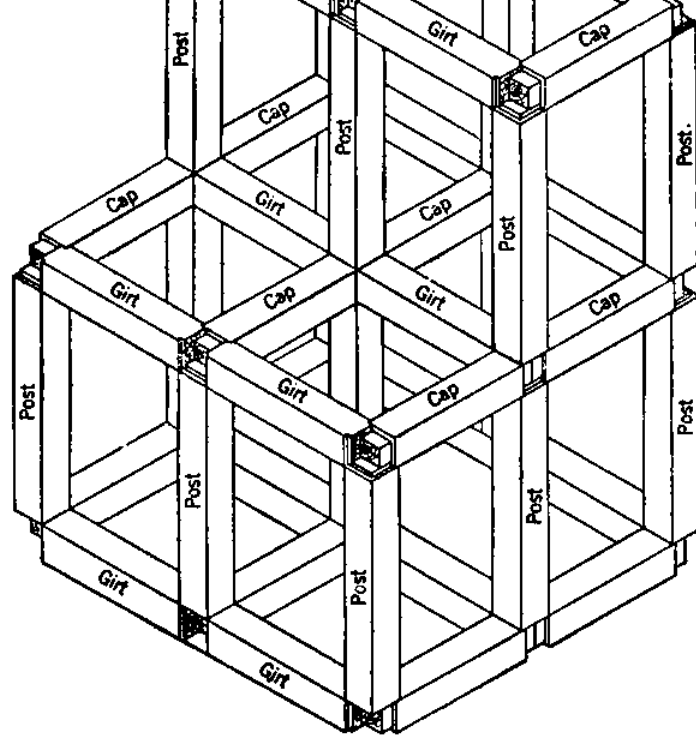


FIG. 5-1. Three-piece set for timbering a drift: A, front view of set; B, side view of set; a, wedge; b, lagging; c, headblock; d, butt cap; e, cap, round; f, post, round; g, girt; h, tie; i, bridge piece; j, top lagging; k, footboard; l, block; m, ditch; n, bottom of cap; o, bottom of drift. (Courtesy U.S. Bureau of Mines.)

The sets form the major framework of tunnel timbering. Additional protection is required to prevent the caving of loose material between the sets. This is accomplished, where necessary, by placing poles, slabs, or sawed lumber on top of the caps and on the outsides of the posts, between the posts and the tunnel walls. This is called *lagging*; that above the caps being known as *top* or *working-floor* lagging, that at the sides being called *side* or *gob* lagging. The construction of *chutes*, used for the loading of ore or waste into mine cars, consumes rather large quantities of heavy stull timbers and plank.

3. **The Square-set Method of Timbering Stopes.** The square-set method is widely used in timbering stopes and rooms. Fay<sup>2</sup> defines a *square set* as follows: "A set of timbers composed of a cap, girt, and post. These members meet so as to form a solid 90-degree angle. They are so



MINE TIMBERS

framed at the intersection as to form a compression joint and join with three other similar sets." A diagrammatic sketch of square-set timbering is shown in Fig. 5 2A; a vertical transverse section through a typical square-set stope is shown in Fig. 5-2B.

a. *Joints Used in Constructing Square Sets.* The most common method of joining the component members of a square set is shown in Fig. 5 3. This is the *step-down* or *Rocker 4-8-12* method used extensively in the copper

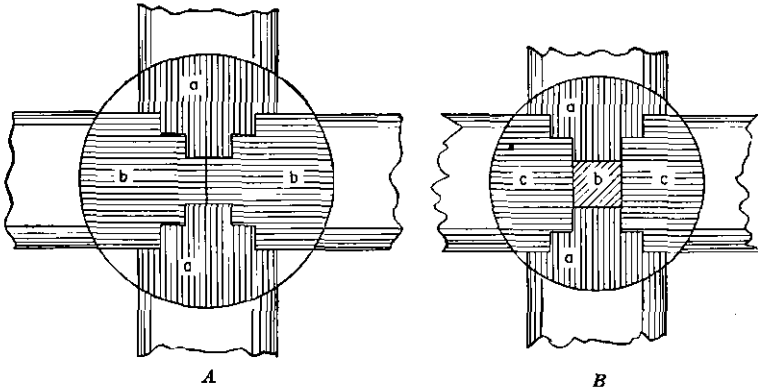


FIG. 5-3. Vertical sections of the joint in the Rocker method of framing square-set timbers: a, post; b, cap; c, girt. (Courtesy U.S. Bureau of Mines.)

mines in Butte, Montana. This joint has many advantages over the former butted posts and square and bevelled framing.

#### D. AVOIDING TIMBER WASTE IN MINES

It has been estimated that as much as 85 per cent of all timber used underground is employed in temporary working spaces. It has also been reported that at least two-thirds of this timber is abandoned in a relatively short time, often while the wood is still sound. This estimate gives due allowance for timber quantities known to be salvaged, including mine ties. Much of this waste is unavoidable, yet more emphasis on salvage procedures would undoubtedly result in large savings. At least, that has been the case in Europe where the matter has been given a good deal more thought. The development of methods that require less timber and of more efficient salvage operations has resulted in substantial savings of timber in Europe. The fact that much of the timber cannot be salvaged, however, dictates certain requirements that mine timbers must meet, the most obvious being the lowest possible cost consistent with strength properties that will provide maximum safety.

## II. THE CLASSIFICATION AND CHARACTERISTICS OF MINE TIMBERS

### A. CLASSES OF MINE TIMBERS

Mine timbers fall into two general groups, round and sawed, the former constituting somewhat more than half the total amount of timber used. Split and hewn timbers also are used to a limited extent. Cost is the principal factor governing the selection of mine timbers. Sawed timbers are used for most more or less permanent installations, such as headframes, entry and shaft timbers, haulageways, certain types of lagging, tipples, trestles, ore bins and chutes, pumping stations, and mine ties. Square timbers have certain advantages, notably ease of framing and the more workmanlike job of construction that can be accomplished. When the square-set method of timbering was originated, it was considered impossible to obtain the desired strength with round timbers. The development of better joints, such as the Rocker joint (Fig. 5-3) dispelled this belief. Now round timbers, usually untreated, are used almost exclusively where the duration of working in a mine is less than the life expectancy of treated wood, and for nearly all temporary timbering where it is impossible to salvage the timbers as the workings advance.

Rapraeger<sup>14</sup> shows that round timbers and sawed timbers of the same cross-sectional area have virtually the same strength but that round timbers have two slight advantages in this respect. The axis of a round piece is almost always parallel to that of the component fibers, whereas sawed material is often cross-grained as a result of improper sawing. Knots can be expected to have less effect in reducing strength in round timbers than in sawed material, since in the former they are usually smaller. The above is based on two assumptions: (1) that the round members can be fastened together as securely as sawed timbers; and (2) that the volume of sapwood will not be reduced by decay during the service life of the timber.

### B. QUALITIES DESIRED IN MINE TIMBERS

Wood for use as mine timbers should possess the following qualities:

1. Strength
  - a. High stiffness and compressive strength
  - b. Lack of brashness
  - c. High strength-weight ratio
2. Durability
3. Availability
4. Low initial and low maintenance costs

Strength is, of course, of vital importance, since the safety of workers is at stake. Stiffness and compressive strength, both parallel and at right



angles to the grain, are essential. Most mine props are used as columns, although they may be used as beams under various types of loading. Bearing strength is also important, particularly since the joints most commonly used depend on side bearings to sustain superimposed loads as well as to maintain tight joints. Brashness, which results in timbers breaking at reduced loads and without warning, cannot be tolerated. Cross or spiral grain or combinations of the two, if present to the extent of weakening timbers beyond safe limits, are also dangerous.

The total output of a mine is often governed by the efficiency and capacity of the hoisting system, and the transportation of supplies into a mine is a large part of the total cost of operation. The weight of wood used for timbering is, therefore, of the utmost importance, since wood for timbering represents a large part of the material that must be moved in many mines. Direct labor costs are also involved, since most timbering must be placed by hand under unfavorable working conditions. The preference for Douglas fir over western larch in the Rocky Mountain mining region is an example of the effect of weight in the selection of a species. The properties of the two species are essentially equal for use as mine stulls, yet western larch usually enjoys only second choice because of its greater weight. Thus light weight, consistent with adequate strength, is an important property in species used as mine timbers.

The importance of durability varies with the length of service required of timbering. In temporary locations it may not be a factor at all. In semipermanent installations the wood used should have sufficient durability to ensure protection from decay for the expected life of the operation. Where long service is required, preservative treatments are essential and ease of treatment may be of greater importance than natural durability. This subject will be covered more fully in a discussion of wood preservation that will appear in following paragraphs.

Availability and cost may be interdependent factors. If timber supplies are available at or near the mine site, the initial cost of wood is usually far less than that of substitute materials. This is the case in most mining areas in the United States, but there are exceptions. Sometimes mines must compete for supplies of costly timbers that are more valuable for other uses. Low-quality supplies may be expensive because of scarcity. In some arid regions even strength properties may be secondary to availability, making it necessary to utilize local species in order to obtain any timbers at all. In most mining regions, however, adequate supplies of relatively low-cost species are available.

The high cost of maintenance is one of the disadvantages of wood for use as mine timbers. This objection is valid when untreated wood is used in permanent installations and must be replaced frequently because of decay

or excessive wear. Often this difficulty can be overcome by preservative treatment. The objection is not applicable in temporary workings or in stopping and other locations where no attempt is made to salvage the timbering.

### C. ADVANTAGES OF WOOD AND SOME COMPARISONS WITH SUBSTITUTE MATERIALS

The advantages of wood over substitute materials are numerous and they presage the use of wood timbering at rather permanent levels of consumption per ton of coal or ore mined. Brush,<sup>1</sup> in 1938, reported that 4 per cent or less of wood had been displaced by steel and concrete at that time. These substitutes have found logical uses in specialized installations, particularly where permanence and fire resistance are factors. Even so, it is expected that wood will continue to be used extensively, even in the one-third of mine construction that is considered permanent in nature. Post-war shortages of steel indicate that this condition may exist for some years.

The advantages of wood over other materials are (1) relatively low initial cost, (2) availability, (3) favorable strength-weight ratio, (4) gradualness of failure, giving warning of impending danger, (5) adaptability because of ready workability, and (6) sufficient durability for most short-term requirements. Cost, availability, and safety are probably the most important advantages of wood over substitute materials.

The initial cost of wood is far less than that of substitute materials. This is important, since at least two-thirds of all mine timbers are either *not* salvageable or are used for only short periods. Availability is often a factor in cost, but stulls can be shipped for considerable distances and still maintain favorable price margins. The fact that treated timbers cost no more to ship than untreated timbers is also a factor, since the former have sufficient service life to compete with steel under all but the most unfavorable conditions. Considering the average life of permanent installations in a mine, the cost of maintaining treated materials may not be significantly higher than the upkeep of steel, which must be painted at regular intervals to prevent deterioration. Opinion differs on this point, however; figures are available to support the contention of lower over-all costs for both materials. The fact remains that wood is suitable, and often preferred, for most mining operations. It costs less for most uses and is available at or adjacent to most of the important mining regions of the United States.

The strength-weight ratio of wood compares favorably with that of steel and concrete. The stiffness of wood is also a factor in withstanding the high pressures produced by earth movements. According to Hornor and Tufft,<sup>2</sup>

Steel is strong, but under excessive pressure lacks the tenacious resistance to failure shown by timbers. Steel fails by buckling; and once failure has set in, buckling usually proceeds rapidly, whereas a mine timber under pressure exceeding its strength usually fails gradually. Concrete also fails rapidly when loaded beyond its carrying capacity. Neither of these materials gives appreciable warnings of failure.

Adaptability, attributable to a large extent to workability, is an outstanding advantage of wood. It has a marked effect on timbering costs, particularly in temporary workings. Steel tunnel sets designed for temporary workings lack the flexibility of wood in situations that require ready adjustments to variations in the size of tunnels. Also, the joints are usually more difficult to assemble underground. Because of the higher initial cost of steel, losses are greater when timbering is buried as a result of cave-ins. The waters found in many metal mines and some coal mines are highly corrosive. In such places steel suffers a fate similar to that of wood timbers subjected to decay in warm, humid mines, and rapid corrosion may make the use of steel costly. Steel timbering may last indefinitely, however, in comparatively cool, dry mines, with only a minimum of maintenance in the form of occasional coats of protective paints. Durability, because it is so closely related to wood preservation, will be discussed under that heading.

Steel timbering was once hailed as the solution to the rising costs of wood stulls, but its extensive use has never materialized. Both steel and concrete have, however, become standard materials for certain locations in mines, particularly in the coal mines of the Eastern United States. Tipples, steel or cast-iron supports for main haulageways, shaft bottoms, and pumping stations and, to some extent, shaft sets and drift sets, are among the common uses of steel at the present time.

Concrete is most commonly used for machinery foundations, headframes, shaft collars, shafts and linings for shaft and hoisting stations, as a lining for shafts to exclude water, for sumps and the walls of pumping stations, for fire walls, and, rarely, for precast shaft sets and stringers. It is sometimes used for the construction of pillars in large stopes and to reinforce natural pillars to prevent them from falling or crumbling. The most important uses of steel and concrete are for the construction of headframes, shaft and adit openings, and other surface structures where the prevention of fires is vital.

From the foregoing it can be seen that wood, steel, and concrete all serve useful purposes in mine construction, each being adapted to special applications on the basis of inherent properties. There seems little doubt, however, that wood will continue to dominate the mine-timber field. Its favorable properties, low cost, and availability, combined with its adaptability to the

short-term requirements of most mining operations, provide advantages that will be difficult to overcome unless prices of substitute materials can be reduced considerably below present levels.

#### D. PRESERVATION OF MINE TIMBERS

The principal disadvantage of wood for use as mine timbers is its lack of durability, *i.e.*, its inability to resist the attacks of insects and wood-destroying fungi. Insects often attack underground timbers, particularly unpeeled stulls, but the total damage produced does not approach that caused by decay. The decay problem is more critical in mines than it is above ground because the warm, damp atmosphere in most mines provides optimum growth conditions for many wood-destroying fungi. Under such conditions, nondurable woods may have a service life of only 1 year, and even naturally durable woods, such as white oak and the heartwood of Douglas fir and the southern yellow pines, may last only 3 or 4 years.

As mentioned previously, durability is not a point of issue in the case of timbers that cannot be salvaged. The situation is quite different, on the other hand, when wood is used in permanent and semipermanent structures such as entry shafts and headframes, haulageway timbers, raises, ore bins and chutes, pumping stations, and similar installations. Even though the use of steel and concrete for such structures is increasing, wood is still used extensively. This poses the problem of frequent replacement costs versus wood preservation. For semipermanent construction, the selection of naturally durable species may be sufficient to assure adequate life. In most cases, however, preservative treatment is the only means of reducing replacement costs and providing the service life required in permanent locations. Tests over a long period of time have demonstrated repeatedly the economy of treated mine ties and timbers. Hunt and Garratt<sup>10</sup> give an excellent analysis of savings that can be effected, both for mine timbers in particular and treated wood in general, yet the amount of treated wood used in mines has increased only slightly through the years. This indifference to the advantages of treated wood for use in permanent construction, both above and below ground, is difficult to understand. The application of preservatives to surface structures, as well as for miscellaneous mill equipment, has also been ignored for the most part. Hornor and Tufft<sup>8</sup> state that approximately 80 per cent of replacements of mine cars and trucks, concentration tables, tanks and flotation machines, and similar items are caused by decay. They estimate that only about 15 per cent of the total wood consumed is used in permanent openings, which are expected to have an average life of 12 years. The average life of untreated timber, where not subject to crushing or destruction by mechanical wear, is ap-

proximately 3 years, or even less in some cases. The implications are obvious: untreated material would have to be replaced at least three times, if not more often. Properly treated timbers will last 10 to 20 years. Increases in costs over the use of treated timber are significant, since the cost of replacement is often double that of the original installation or more. The increased drain on available supplies of suitable stulls must also be considered. Wood preservation cannot be justified from the standpoint of economy in the many temporary structures used in mining. There can be no question, however, of the far-reaching benefits that would accrue to the mining industry from the intelligent application of wood-preservation practices.

**1. Selection of Mine Stulls.** The selection and handling of stulls and sawed material prior to placement in a mine may have marked effects on the service that can be expected. With respect to selection, Hunt<sup>8</sup> states, "Selection of timbers without consideration of the grade and possibilities of preservative treatment may result in the shipping of timber for long distances when more suitable material is available locally." Timber is usually selected on the basis of species and the reputation it may have for strength and durability. This is not enough in many cases. Low-quality material of a desirable species may be less suited for mine timbers than good-quality material from an inferior species. A knowledge of structural grades and the relationship of grade to strength values is essential. Joyce<sup>12</sup> has worked out some interesting tables in which steel and wood timbers are compared under the types of loading encountered in supporting the roofs of mines. A further factor in the selection of stulls is the assurance that they are sound and not already infected by decay-producing fungi. Ordinarily this dictates immediate delivery to the mine, since logs left on the ground in the woods usually decay rather rapidly, particularly in the summer months.

**2. Peeling.** Peeling is one of the best means of protecting stulls from deterioration during storage. Unless immediate use is assured and the expected service life is extremely short, all round timbers should be peeled as soon as cut or shortly thereafter. Peeling expedites seasoning and reduces materially the possibilities of insect damage both prior to and after installation. The elimination of insects has double benefits, because the spores of fungi find ready access to the interior of wood through insect borings. Numerous experiments have shown that peeled stulls last longer than those that are installed with the bark on. In spite of such experiments, much timber that could be peeled to advantage is put in place without removing the bark.

**3. Seasoning.** Proper seasoning of mine timber has several advantages. Seasoned timbers are slightly stronger than green timbers and it has been

shown that properly seasoned wood gives longer service than unseasoned timbers. The difference is not great in extremely wet locations but may be appreciable in well-ventilated, comparatively dry mines. Seasoning is, of course, desirable prior to preservative treatment. The saving in weight brought about by seasoning represents distinct savings in freight and handling and in hoisting costs at the mine.

**4. Storage of Mine Timbers.** In spite of the high cost of mine timbers, outright losses of large volumes of wood have been observed at many mines as a direct result of improper storage. Too often costly timbers are dumped or stacked in large piles on damp, poorly drained soil without any thought being given to the prevention of decay. Piling methods that prevent deterioration also promote seasoning. Proper storage and seasoning methods are the same as for other forest products. The important factors to consider are a properly drained storage yard, elevation of the piles above the ground, and provision of sufficient space to assure adequate circulation of air around each piece of timber in the pile. The increasing costs of stulls are focusing the attention of mine operators on better storage practices, but much improvement is still to be desired.

**5. Preservative Treatments.** Any of the standard preservatives are satisfactory for the treatment of mine timbers.<sup>10</sup> The choice of a particular treatment will depend on the length and character of service the treatment is required to perform, the species to be treated, the location of the mine with respect to treating facilities, the cost of treatment, the extent of fire hazard in a given mine, and other factors. It is sufficient to say, for the purposes of this chapter, that the judicious use of any proved wood preservative will result in material savings to the mine owner.

**6. Other Causes of Deterioration.** Decay probably causes more than half the timber failures which occur prior to the normal abandonment of mine openings, but breakage and crushing and, to a lesser extent, mechanical wear and fire also cause the destruction of mine timbers. Decay, of course, contributes to losses from breakage and crushing. Crushing and mechanical wear of sound timber can be reduced by proper engineering. Losses caused by fire, although smaller than those caused by other destructive agencies, are of vital importance from the standpoint of human safety and, because of this, a matter of concern to anyone interested in the use of wood in mines. Direct losses of timbers as a result of fires are usually small as compared to lost operating time and the cost of fighting the fire and of putting the workings back in operating condition. Most serious of all is the ever-present danger of loss of life, which can be staggering in a serious mine fire. Wood, being inflammable, is suspect from this standpoint. Steel and concrete serve a useful purpose in mine construction, both above and below ground, because they are not inflammable.

Probably the best method of eliminating the danger of fire from wood timbering is to resort to fire-retardant treatments. Unfortunately, such treatments are still too costly for general use, even though they can be combined with a wood preservative. Other methods consist of spraying timbers with concrete (*Guniting*) and other noninflammable materials. *Guniting* has given good service in some mines. The use of concrete and steel headframes and other units at the mouths of shafts, where fires are particularly dangerous, and at all other critical points is effective in reducing the fire hazards of mines. The use of large quantities of wood is inevitable, as has already been pointed out, and special precautions must be taken to reduce the dangers of fire. Among these are the use of efficient sprinkler systems, the exercise of great care in the installation of electric wiring, adequate ventilation to prevent the accumulation of explosive dusts, avoiding carelessness with miner's lamps, blasting fuses, combustible fuels, and the like, and providing ample fire-fighting equipment. Decayed wood is more combustible than sound wood. Thus a good preservative has a secondary advantage of aiding in the reduction of fire hazard. Some preservatives, however, or the solvents in which they are applied, increase the inflammability of wood, at least temporarily. This must be considered in selecting a preservative.

Wood no doubt contributes to the spread of fires in a mine, particularly the smaller pieces used for lagging, but once a fire has started, failure of heavy wooden members progresses rather slowly. Steel and concrete will fail rapidly at the temperatures encountered in a major fire. Heavy wood timbers will char on the outside but retain a large part of their strength for a much longer time. The timbers may fail eventually, but the time gained to fight the fire may be instrumental in saving endangered lives.

#### E. PRODUCTION OF MINE TIMBERS

The production of mine stulls is almost invariably carried on apart from standard logging operations. Sometimes the stull cutters follow other logging operations, taking the smaller trees, but more often they operate in young stands, cutting the trees that will meet mine specifications. This is true both in the hardwood regions of the East and the softwood areas of the West. In Idaho some stands cut for lumber during the depression have been relogged for stulls. There are a few instances of stulls having been supplied from thinnings and improvement cuttings, but such cases are rare. For the most part, stull production is carried on without consideration of the aims of sound forest management and often in direct conflict with such aims.

Supplies of round timbers, except in unfavored areas, are most commonly

obtained from nearby forests, and most of the sawed material comes from local mills. In a recent report <sup>8</sup> it is stated that the anthracite mines of Pennsylvania obtain about 90 per cent of the round timbers and 75 per cent of the sawed material they use from the 15 counties of the anthracite region of the state. This situation is the general rule in the mining areas of the United States. In certain parts of Montana, the Southwestern states, and a few other regions not favored with suitable timber stands, appreciable quantities of timber must be shipped from outside sources. Douglas fir and southern yellow pine timbers are being shipped in increasing quantities to Eastern coal mines. The shipment of treated timbers for considerable distances is becoming more common; *e.g.*, mines in Idaho and Montana are purchasing treated material from treating plants in Seattle and Portland.

There are no standard specifications for mine stulls, and few mines have published specifications. Round timbers are usually cut in accordance with an advance purchase order.<sup>19</sup> In the coal-mining region of Pennsylvania, props may be purchased by the lineal foot according to top diameter, at random by lineal foot and top diameter, or by the ton. The diameters and lengths specified vary with the individual preferences of the mine operators. They are, of course, influenced by the type and size of the ore bodies being mined, the method of mining used, the pressures encountered, and other factors. The requirements of one group of mines in Montana offer an example of the range of stull sizes. Stulls are cut in the woods to log lengths of 11, 14, and 16 ft., about 2 per cent being 14 ft. long, 5 per cent 11 ft. long, and 93 per cent 16 ft. long. The 16-ft. length is the most economical, since it is a standard log length that can be handled with standard logging and loading equipment. It is also the most versatile, because it will produce the following pieces with a minimum of waste: three caps, 5 ft. 4 in., one 7-ft. post, and one 8-ft. 2-in. post; or two 5-ft. 4-in. caps and one 5-ft. girt; or two of these girts and one cap. An 11-ft. stull will cut two caps without waste but is not adapted to the production of posts. The 14-ft. length is even less economical. The majority of the stulls obtained for this group of mines from immature Douglas fir and western larch stands come from trees that give top diameters of 8, 9, 10, and 7 in. in the approximate order given. No single top diameter can be considered ideal, but a tree with a diameter of 12 to 13 in. breast high approaches this. According to Hough,<sup>9</sup> the common practice in the bituminous coal regions is to cut stulls 5 to 15 ft. in length and with a minimum top diameter of 3.5 in. inside the bark. Round props are preferred, but split props up to 8 ft. long will be accepted. Lagging as small as 2 in. top diameter inside the bark is purchased by some mines.

The production of round stulls is much the same in all parts of the



country, although the type of producers involved may vary somewhat. In many parts of the Eastern and Middle Western states, large quantities of stulls are supplied by farmers who work in the woods during the winter months or who harvest trees from their own wood lots. Professional stull choppers are also common, some cutting purchased stumpage, others harvesting props on land owned by mining interests. Jobbers are common; many mines prefer to deal with reliable jobbers rather than with a large number of small producers. In parts of the West, stulls often are cut by loggers in off periods, or the mines may contract for logging with persons who are engaged in stull production as a regular business. Local shortages, the fear of depleted supplies, or competition from other users of logs have prompted some mining companies to purchase timber holdings and have put some mine owners in the sawmill business.

The essential steps in producing stulls are logging, peeling, and seasoning. Some mines will purchase stulls either peeled or unpeeled, seasoned or unseasoned. Peeling in the woods is sound practice, since it promotes more rapid seasoning, reduces shipping costs, and avoids the accumulation of waste bark at the mine site. Peeling is usually done by hand, with spuds. The efficient new barking machines developed by the pole industry would be excellent for this purpose and will, no doubt, be adopted by some stull producers. Peeling by hand is more difficult in the fall and winter than in the spring. It has been reported that the difficulty of peeling frozen logs in the Rocky Mountain region is sometimes overcome by rolling the stulls through a large fire prior to removing the bark with spuds.

Framing of timbers is done at the surface in modern framing plants at most large mines. Preframing of square-set members requires a precision which would be difficult to accomplish in the crowded quarters below ground. Modern sawing equipment, with automatic log-turning devices and mechanical conveyers, is used extensively in the framing plants. Sawed material finds many uses in a mine. In addition to the sawed material used for permanent structures both within the mine and at the ground level, large quantities of wood are used for wedges, lumber and plank for lagging, ladder stock, mine-car material, shaft guides, and many other items. These, in so far as possible, are purchased from local sawmills or produced in the mine company's own mill. Mine ties may be purchased locally or imported from outlying regions, depending on the suitability of species growing in the vicinity of the mine. Items such as shaft guides, which require special grades of structural material, are usually obtained from outside sources.

**1. Species Used.** Oak is the most widely used species for all types of mine construction in the Eastern, Southeastern, and Central states. White oak is preferred because of its greater durability. Depending on available

supplies, red oak, maple, beech, birch, ash, some hickory, and the dwindling supplies of chestnut are other hardwoods commonly used. Some yellow poplar is used for sawed stock. Among the softwoods, hemlock, spruce, and the local pines are used to some extent. The use of Douglas fir and the southern yellow pines is increasing east of the Mississippi River, particularly for structural timbers of all kinds. Available sources of suitable timbers in the Illinois mining area have largely been consumed, remaining sources being of rather low-quality second-growth hardwoods. Much of the timbering consumed in this region comes from Missouri, but some supplies of tamarack and hardwoods are obtained from Wisconsin and Michigan. Here, too, the southern pines and Douglas fir are being used more extensively. The situation is similar in the Lake Superior region, the local supply of high-quality, durable species being very small.

In the West, the Rocky Mountain form of Douglas fir is the most common source of mine timbers. In Colorado this species is supplemented by Engelmann spruce, lodgepole pine, and, less commonly, some of the high-elevation five-needled pines. In some of the more arid locations western yellow pine is the only species that is available in any quantity. In the northern Rocky Mountain area of Montana and the Inland Empire lodgepole pine was once used extensively, but Douglas fir and western larch are now the principal species. Lodgepole pine, western yellow pine, and some spruce are used in areas where local supplies of the preferred species are unavailable. The Southwestern states depend to a large extent upon locally grown western yellow pine, but supplies of this species must be augmented by importations from other states. Local supplies of durable species of suitable quality are decreasing in some regions. Under proper forest management practices, such as have already been demonstrated as practicable, this situation could be corrected in most cases.

**2. Costs of Mine Timbers.** A detailed discussion of stull, prop, and mine-timber prices has purposely been eliminated from this chapter. Since there are no standard specifications for mine timbers, cost comparisons are difficult without the establishment of complicated conversion factors. Further, there are no comprehensive analyses of costs available since 1938. Current prices are inflated and would probably be obsolete in a very short time if included in the text at this time.

## F. ANNUAL REQUIREMENTS AND TRENDS

Comparatively speaking, the use of wood as mine timbers is a rather unproductive form of wood utilization because so little value is added to the raw material prior to its ultimate use. The use of wood for mine timbers is, nonetheless, an important factor in our national economy, consuming as

it does between 2 and 3 per cent of the national cut and being exceeded in consumption only by lumber, fuel wood, railroad ties, fence posts, and pulpwood.

The normal requirements for mine timbers for the period 1938 to 1945 were estimated by Brush<sup>1</sup> in 1938 to be approximately 250 million cubic feet, 130 million cubic feet of which was round and split material. The other 120 million cubic feet was sawed material, representing about 550 million board feet of lumber. This quantity included all wood used underground, track ties, car material, and that required above ground for structures directly employed in mining operations. Wood for dwellings and offices was excluded from the estimate. A more recent estimate<sup>16</sup> published in 1946 has placed the requirements for round timbers at 220 million cubic feet and the consumption of sawed material at approximately 500 million board feet for the period from 1945 to 1955. These figures indicate a reversal of the prewar trend toward the use of higher percentages of sawed over round material. This is attributed to the increased mechanization of mines. A study of the wood requirements of the anthracite mines of Pennsylvania<sup>5</sup> indicates the same trend.

The amount of wood used per ton of ore or coal mined varies with the type of material being mined. For example, in 1935 the total amount of wood used, in cubic feet per ton of ore mined, was as follows: iron ore, 0.158; bituminous coal, 0.382; "other metals," 0.603; anthracite coal, 0.740. The consumption of "all mines" was 0.426 cu. ft. per ton of ore.<sup>1</sup> The relationships between the consumption of wood in the various types of mines are maintained in the 1946 estimates mentioned above, but they show a decrease in the proportion of sawed material, an increase in the amount of round material, and an over-all increase in the total amount of wood used per ton of ore. It was Brush's opinion in 1938 that an increase in the use of sawed wood could be expected. Even though this has not been borne out in postwar findings, the situation that exists now may not be normal. The high postwar cost of sawed material has probably been a factor in this change of trend.

Coal mines use approximately 80 per cent of the wood used in mining; Pennsylvania, West Virginia, and Kentucky, in the order named, lead all other states by wide margins. As mentioned previously, oak is the predominant species used. Of the wood used in coal mines the distribution is approximately as follows: 80 per cent for single props, 15 per cent for caps or crossbars, and 5 per cent for shaft and repair timbering. In most metal mines the percentages of timbers used for shafts, tunnels, and square sets are much greater, single props being used much less frequently.

The consumption of wood in mines varies directly with ore production, which, in turn, is sensitive to general economic conditions. Prior to the

First World War, mining expanded rapidly in keeping with the tremendous industrial development of the times. It was further stimulated during the war years, suffered a heavy decline after the armistice, recovered in 1923, and rose again to a fairly steady level until the depression years, when the total output of all mines fell considerably below the 1905 level. By 1935 production had recovered to the level of approximately one-half of the 1928 total. The heavy demands of the Second World War again stimulated production, and again there was a sharp drop at the end of hostilities as a result of labor unrest, scarcities of essential materials, and other factors. As this is written, production is again on the increase, and it may again reach the peaks attained in 1918 and 1928. With prospects of full employment at home and a comprehensive aid program abroad, it seems likely that ore production may continue at relatively high levels for several years, at least. If so, there is every prospect that wood will enjoy a position of heavy demand. The competition for supplies from badly needed house construction and other uses for wood has raised the cost of mine timbers to high levels in some regions. This may encourage the use of substitutes at higher levels than previously realized, but steel, too, is in short supply and very costly. On the other hand, impending petroleum shortages may accelerate the production of coal for its conversion to liquid fuels by the Fischer-Tropsch and similar processes. Eventually, of course, there is the possibility that the development of atomic energy may have far-reaching effects on the amount of coal that is mined.

Prior to the Second World War there were several factors tending toward reductions in the amount of wood used in mining. For the most part, these trends have been intensified since the war. They are (1) increased salvaging of timber from abandoned workings because of the increasing costs of timbers in most localities, (2) increased use of machinery such as conveyer systems, which eliminate the need for mine ties, (3) increased use of strip, or surface, mining, (4) the substitution of steel and concrete for wood, and (5) the increased use of treated lumber. The primary consideration in each of the trends listed above is the reduction of labor costs; labor costs are even greater than they were prior to the war when the above trends began to be manifested. Actually, none of these trends has had a significant effect in reducing the amount of wood used in mining, but it is expected that inroads may materialize if labor costs remain at the postwar level for an appreciable length of time.

#### •G. RESEARCH IN MINE-TIMBER UTILIZATION

There are virtually no records of research designed to reduce the amount of wood used in mines or to improve mine structures constructed of wood.

It seems unlikely that applications of wood to mine needs have reached a zenith of perfection that makes further improvements unnecessary. Certainly this is not true in other industries in which wood is one of the basic raw materials used. Even wood railroad ties, which have withstood the competition of substitutes since the earliest days, are now under close scrutiny by numerous research agencies. Progress has been made in wood preservation and in fire-resistant treatments, but these improvements have resulted from interest generated in other fields. Some wartime research on mine guides, sponsored by the Office of Production Research of the War Production Board, is a notable exception to the general lack of research mentioned above. As reported by Schrader,<sup>15</sup> this study demonstrated that laminated mine guides, made to replace high-density, straight-grained material that could not be obtained during the Second World War, were superior to the clear material previously used. It was believed that their superiority would probably offset the increase in cost involved. Improvements in fastenings used to connect mining timbers, perhaps by the adaptation of modern timber connectors, would also seem to offer an excellent opportunity for successful research.

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## CHAPTER 6

### RAILROAD TIES

Railroad ties are classified, depending on use, in three categories: (1) crossties, (2) switch ties, and (3) bridge ties. Crossties, or sleepers, as they are sometimes called, are the beams that support railroad rails on the road-bed; switch ties support the rails and frogs at switches; and bridge ties, laid on bridge and trestle stringers, support the track on these structures. Switch and bridge ties are usually sawed, but crossties are either hewed or sawed. Sawed and hewed crossties may be faced on two opposite sides or they may be faced on four sides. Formerly most crossties were hewed, but now approximately 55 to 60 per cent of the total annual production is sawed. The proportion of sawed ties varies in different parts of the country; in the West the proportion of sawed ties is greater, but in the Northeast the proportion of hewed ties is greater. The old-time tie maker, or "tie hack," with his broadax is slowly yielding his function to portable and stationary sawmills.

#### A. ADVANTAGES OF WOOD AS A TIE MATERIAL

Because of its resiliency, strength, economy, availability, electrical resistance, noncorrosive qualities, sound-absorbing ability, spike-holding capacity, and nonelectrolytic properties, wood is the outstanding material used for ties by steam and electric railroads. Although more than 2,500 patents are reported to have been granted for substitutes for the wood crosstie, none of these substitute materials has offered a serious challenge. Of the estimated 992,437,654 crossties in maintained tracks of Class I line-haul railways \* in 1949, 91.99 per cent were of treated wood, 7.99 per cent were of untreated wood, and 0.02 per cent were of materials other than wood, principally steel and concrete. In 1949, 213 ties of material other than wood, costing \$1,977, were laid in new and previously laid tracks by Class I railways in the United States.<sup>7</sup> The average cost of these ties was \$9.28 apiece.

In 1949, Class I railways placed, in new and previously laid tracks, about

\* Class I line-haul railways include those whose annual revenues total one million dollars or more. These roads own approximately 95 per cent of the track mileage and employ about 98 per cent of all railway wage earners in the United States.

32,926,175 wood crossties, 95 per cent of which were treated with preservatives. The average cost of untreated crossties was \$1.47 each, and the average cost of treated crossties was \$2.79 apiece. In addition to the crossties laid, nearly 131 million board feet of switch and bridge ties were placed in new and previously laid tracks during 1949. Table 6-1 indicates the quantities of ties replaced by Class I railways in the years 1940 to 1949, inclusive, for previously laid tracks only.

TABLE 6-1. TIES REPLACED IN PREVIOUSLY LAID TRACKS BY CLASS I RAILWAYS 1940 THROUGH 1949<sup>a</sup>

Year	Untreated wood crossties, thousands of pieces	Treated wood crossties, thousands of pieces	Other than wood crossties, thousands of pieces	Wood switch and bridge ties, M bd. ft.
1940	6,326	37,294	1	145,553
1941	5,763	41,461	1	144,600
1942	4,618	43,998	b	136,944
1943	3,909	41,530	b	124,097
1944	3,134	44,897	2	137,780
1945	2,629	41,283	b	130,520
1946	2,133	35,429	b	106,205
1947	1,982	35,307	b	108,159
1948	1,818	35,024	b	119,932
1949	1,410	28,875	b	107,793

<sup>a</sup> Source: U.S. Interstate Commerce Commission, Sixty-Third Annual Report on the Statistics of Railways in the United States. 1951.

<sup>b</sup> Fewer than 1,000 pieces.

### B. DISADVANTAGES OF WOOD AS A TIE MATERIAL

Although wood has advantages that make it the favored tie material, it has several disadvantages, the principal of which are:

1. It is subject to attack by wood-destroying fungi.
2. It checks and splits in seasoning, particularly in "boxed-pith" pieces, where the pith is within the cross section of the tie. Checking in boxed-pith ties is unavoidable because of the difference in tangential and radial shrinkage of wood. Sawed and hewed ties from small trees and ties sawed from the centers of large logs exhibit this fault. Pith-free, flat-grained ties are usually not subject to severe checking, and they are likely to have greater spike-holding power because, in normal tree growth, the annual



rings become narrower as the distance from the pith increases. This usually means that the wood directly under the rails is more dense, for the top of the tie is always considered to be the wide face that is farthest removed from the pith, whether the pith is present or not. For these reasons, the flat-grained, or "half-moon," tie is preferable to any other form.

3. It burns. Engines using coal as a fuel must dump cinders and ashes at designated places because of the fire hazard. Ties at these points are often burned.

4. It is subject to mechanical wear. Crossties that have been given treatment with excellent preservatives often wear out and must be replaced before they decay. This mechanical wear is thought to be largely due to the actual abrasion of the wood by the movement of the steel tie plates or rails over the surface of the tie, particularly when sand gets between the wood and the metal. To a lesser extent, crushing of the wood fibers contributes to mechanical failure.

### C. FACTORS THAT PROLONG THE LIFE OF WOOD TIES

Railroad companies are endeavoring to prolong the service of ties by adopting various practices that reduce decay, mechanical wear, breakage, spike-pulling, lateral thrust of spikes, and seasoning defects, such as splitting and severe checking.

It is significant that approximately 88 per cent of the ties in maintained tracks of Class I railways are now of treated wood and that several railroads have no untreated wood ties in their tracks. The Chicago, Burlington, and Quincy Railroad, in 1909 and 1910, laid ties of 20 species in test tracks. Some of the ties were untreated, some were treated with zinc chloride, some were treated with a mixture of zinc chloride and creosote, and others were treated with creosote only. The average life of the untreated ties was found to be 5.6 years; that of those treated with zinc chloride, 15.5 years; that of those treated with zinc chloride and creosote, 18.8 years; and the estimated life of those treated only with coal tar creosote, 29.1 years. These data are averages for all species combined. Individual species varied widely from the average. Table 6-2 gives the average life of 20 species of untreated ties and the approximate number of times that two methods of preservative treatment will increase the average life of these species.

Mechanical wear is being reduced by the use of larger steel tie plates under the rails and by adzing the tops of the ties so that the tie plate will have the maximum bearing surface. The old-style, small, corrugated tie plate is being replaced by the heavy, larger, flat plate.

Breakage is being reduced by the use of larger ties, by the use of better ballast, and by better maintenance of roadbed conditions.

Spike-pulling is being minimized by boring holes prior to preservative treatment and by the use of screw spikes. A spike driven into a bored hole of the proper size offers greater resistance to pulling than one driven into solid wood, because the wood fibers exert greater end pressure against the spike; they are not bent down as is the case when the spike is driven into solid wood. Also, in order to obtain better spike-holding capacity, some railroads are specifying that the top one-fourth of the thickness of the tie

TABLE 6-2. AVERAGE LIFE OF UNTREATED TIES AND APPROXIMATE NUMBER OF TIMES THAT TWO PRESERVATIVE TREATMENTS WILL INCREASE AVERAGE LIFE OF CERTAIN SPECIES <sup>a</sup>

Species	Average life in years for untreated ties	Approximate number of times that two preservative treatments will increase average life of untreated ties	
		Coal-tar creosote, full-cell process, 10 to 12 lb. per cu. ft. absorption	Zinc chloride, Burnett process, ½ lb. per cu. ft. absorption
White oak.....	11.1	2.2	1.5
Chestnut.....	9.7	<sup>b</sup>	<sup>b</sup>
Cypress.....	8.3	2.9	2.2
Pin oak.....	6.3	4.7	3.1
Hickory.....	5.5	4.5	3.6
American elm.....	5.3	5.8	3.3
Red oak.....	5.3	5.3	3.1
Yellow poplar.....	5.3	4.1	2.6
Loblolly pine.....	5.3	5.1	2.3
Tamarack.....	5.1	4.9	3.4
Ash.....	5.1	3.8	3.5
Beech.....	5.0	6.5	3.2
Hemlock.....	4.9	4.1	3.4
Sugar maple.....	4.7	5.8	3.9
Red gum.....	4.1	7.4	2.9
Soft maple.....	3.6	7.0	3.8
Yellow birch.....	3.6	7.6	3.8
Tupelo gum.....	3.5	8.4	4.2
Sycamore.....	3.3	10.5	4.1
Cottonwood.....	2.9	11.2	<sup>b</sup>

<sup>a</sup> Adapted from Report of 34th Annual Inspection of Chicago, Burlington and Quincy Railroad Experimental Ties. *Wood Preserv. News*. January, 1944.

<sup>b</sup> No data.

shall be of *compact wood*. This provision is applied to ties made from coniferous species, and it calls for an average of six or more annual rings per inch along any radius in this section of the tie. Some railroads specify, in addition to the ring count, that each annual ring in the top quarter of the tie shall contain at least one-third summerwood; or, if the section has four to five rings per inch, the tie shall have one-half or more summerwood in each annual ring.

Resistance to lateral thrust of spikes is secured by specifying ties with compact wood in the top quarter of the thickness, by the use of a tie plate which is perforated for the spikes and which has a shoulder that meets the outside edge of the base of the rail, and by the use of special tie plates that have flanges that extend down the sides of the tie. These special plates are bolted to the tie through the flanges.

Antichecking irons, though not entirely satisfactory, are being used to retard checking and splitting during the seasoning process. Common forms of these devices are the *S*, *C*, *Beegle*, and *crinkle* irons. Severely split ties are being salvaged by the use of bolts, by squeezing the parts together and applying metal straps around the end of the tie, and by the use of spiral metal dowels made of twisted square iron bars that are driven into a bored hole of a size that will ensure a tight fit.

Deterioration of ties because of fungus attack during the seasoning period prior to preservative treatment is being reduced by better methods of piling and better yard sanitation. Many railroads have adopted 1 by 7, 1 by 8, or 1 by 9 piling in tie-seasoning yards. In this method, 7, 8, or 9 ties are laid edge to edge on two parallel stringers that are set on permanent foundations. The tops of the stringers are on a level plane. Two ties are placed on top of this first layer of 7, 8, or 9 ties at right angles to the layer and at the ends of the layer. Next, another layer of ties is placed above these two ties; then only one tie is placed at one end and at right angles to this second layer. The third layer is placed on top of this one tie so that it is in a sloping position. After the third layer is in place, a single tie is then placed across it, at its lower end, and the fourth layer is then added. The next "sticker" tie will be placed on top of the fourth layer at the end opposite the sticker tie upon which the fourth layer rests. This alternation of sticker ties continues until the pile is completed.

There are two principal advantages to this method of piling. The first is that there is less wood-to-wood contact between the ties in the pile, and the second is that a pile of this type will contain more ties for the same height than one that uses two sticker ties between the layers. That is, if a 1 by 9 pile contains 100 ties, a 2 by 9 pile of the same height will contain only 86 ties.

## D. PRINCIPAL SPECIES USED FOR TIES

Species that are suitable for crossties include the ashes, balsam fir, beech, birches, catalpas, cedars, cherry, chestnut, cypress, Douglas fir, elms, gums, hackberry, hemlocks, hickories, larches, locusts, maples, mulberry, oaks, pines, poplars, redwood, sassafras, spruces, sycamore, and walnut. Formerly, when untreated ties were used and railroad traffic was *not so heavy and fast as it is today*, natural durability, cost, and availability were the principal considerations in selecting a species for crossties. The more durable and softer woods, such as cedars, cypress, redwood, and chestnut, gave good service when not subjected to severe mechanical wear. Now, however, factors such as resistance to mechanical wear, crushing, spike-pulling and lateral displacement of spikes, bending strength, and ease of treatment with preservatives are making the harder and denser woods preferable. The economy of using treated ties has been demonstrated so thoroughly that few untreated ties are being laid. Thus the item of natural ability to resist fungus attack is secondary and the ability of the wood to take preservatives is of primary importance.

Of the nearly 38 million crossties given preservative treatment <sup>4</sup> in 1951, species ranked as follows in percentage of the total number:

<i>Kinds of wood</i>	<i>Per cent</i>
Oak.....	36.8
Douglas fir.....	11.5
Gum.....	10.7
Southern pine.....	9.0
Larch.....	3.7
Lodgepole pine.....	1.0
Ponderosa pine.....	0.9
White fir.....	0.7
Cypress.....	0.2
Maple.....	*
Hemlock.....	*
Elm.....	*
All others.....	25.5

\* Less than 1/10 of 1 per cent.

Red oak is now considered by many to produce the most satisfactory tie to meet present conditions because of the ease with which it may be treated and its superior combination of desirable physical and mechanical properties. Of the oaks given preservative treatment, more than half the total is red oak.

## E. GENERAL SPECIFICATIONS FOR CROSSTIES

Although some railroads publish separate specifications for ties, the following American Standards Association specifications<sup>1</sup> are followed rather closely. With certain exceptions, ties must be free from defects that would impair the strength or durability of the wood, such as decay, large splits, large shakes, large or numerous holes and knots, and cross grain having a slope of more than 1 in. in 15 in. In cedar and cypress ties, a limited amount of pipe or stump rot and peckiness will be permitted; in chestnut, "bark disease" caused by the chestnut blight [*Endothia parasitica* (Murr.) A. & A.] will be allowed when it is not more than  $\frac{1}{4}$  in. in depth.

The rail-seat areas on a tie are important sections. These areas are located between 20 and 40 in. from the mid-length of the tie on each end of standard-gauge ties and between 15 and 25 in. from the mid-length of the tie on each end of narrow-gauge ties. Defects such as large knots (greater in average diameter than one-fourth the width of the tie) may be accepted when they are located between the ends of the tie and the rail-seat areas. Ties that are to be used untreated may contain sapwood if it is not more than one-fourth the width of the tie at the rail-seat areas. Ties having sapwood in excess of this amount should be given preservative treatment and are designated as "sap" ties; the others are designated as "heart" ties.

Ties are divided into two general classes on the basis of necessity for preservative treatment for satisfactory performance. Class U ties may be used untreated, and Class T ties should be treated. Each of these general classes is subdivided into four groups in order to permit tie manufacturers to pile several species together when the purchasing railroad will permit such grouping. The grouping in each class of ties is as follows:

## CLASS U—"HEART" TIES THAT MAY BE USED UNTREATED

<i>Group Ua</i>	<i>Group Ub</i>
Black locust	Douglas fir
White oaks	Pines
Black walnut	Larches
<i>Group Uc</i>	<i>Group Ud</i>
Cedars	Catalpas
Cypresses	Chestnut
Redwood	Sassafras
	Red mulberry

## CLASS T—TIES THAT SHOULD BE TREATED

<i>Group Ta</i>	<i>Group Tb</i>
Ashes	"Sap" cedars
Hickories	"Sap" cypresses
"Sap" black locust	Balsam firs
Honey locust	"Sap" Douglas fir
Red oaks	Hemlocks
"Sap" white oaks	"Sap" larches
"Sap" black walnut	"Sap" pines
	"Sap" redwood
	Spruces
<i>Group Tc</i>	<i>Group Td</i>
Beech	Butternut
Birches	"Sap" catalpas
Cherry	"Sap" chestnut
Gums	Elms
Hard maple	Hackberries
	"Sap" mulberry
	Poplars
	"Sap" sassafras
	Sycamore

All ties must be straight, cut square at the ends, free of bark, well sawed or hewed, and must have tops and bottoms parallel, within certain tolerances. A tie will be accepted when (1) a straight line along the top from the mid-point of the width of one end to the mid-point of the width of the other end lies entirely within the tie and (2) when a straight line along a side from the mid-point of the thickness of one end to the mid-point of the thickness at the other end lies everywhere more than 2 in. from the top and bottom of the tie. The top and bottom of the tie are considered to be parallel if any difference in the thickness at the sides or ends does not exceed  $\frac{1}{2}$  in. A tie is not well hewed or sawed when its surfaces contain score marks that are more than  $\frac{1}{2}$  in. deep or when its surfaces are uneven.

Lengths, widths, and thicknesses specified are considered to be met when they are within the following limits: lengths not more than 1 in. shorter and not more than 2 in. longer than the specified length; widths not more than  $\frac{1}{4}$  in. narrower and not more than 3 in. wider than that specified; and thicknesses not more than  $\frac{1}{4}$  in. thinner and not more than 1 in. thicker than the specified thickness. Ties more than 1 in. but not more than 2 in. thicker than the maximum ordered are accepted as one size lower than the largest tie ordered. Thicknesses and widths are determined at the rail-seat areas, but the dimensions of the tie are not aver-

aged. Width determinations are made on the top of the tie, and for this purpose, the top of the tie is considered to be the narrower of the two horizontal faces or the face with the narrower or no heartwood when both horizontal faces are of the same width.

Standard lengths of narrow-gauge ties are 5, 5½, 6, 6½, and 7 ft.; standard-gauge ties are 8, 8½, and 9 ft. long.\* In cross-sectional dimension, seven standard sizes of ties are recognized:

Size	Thickness, in.	Width on top, in.
0	5	5
1	6	6
2	6	7
3	6	8
4	7	8
5	7	9
6	7	10

These dimensions apply to ties that are sawed or hewed on top, bottom, and sides as well as to ties that are hewed or sawed on top and bottom only. In standard-gauge ties, sizes 0 and 1 are not acceptable when sawed or hewed on top, bottom, and sides. In the case of ties that are hewed or sawed on top and bottom only, a 7-in.-thick by 7-in.-wide tie may be accepted as a size 3 tie. If the railroad wishes to have 7 by 7 ties kept separate from 6 by 8 ties in size 3, it should designate the 7 by 7 ties as size 3A.

#### F. ADVANTAGES OF SAWED AND HEWED TIES

Sawed ties have several distinct advantages not possessed by hewed ties. Their principal advantages are:

1. There is less waste of raw material in the manufacture of sawed ties. Much material that would be wasted in the form of chips in hewing can be converted into lumber by sawing. It has been estimated<sup>2</sup> that at least 35 per cent of a tree converted into hewed ties is wasted.

2. Sawed ties are more uniform in size, particularly when sawed on four sides. This means a saving in transportation costs per tie, because a greater number can be loaded into a given car. At the preservation plant, a greater number of ties per charge can be put into the treating cylinder and it is

\* Some railroads now do not use ties less than 9 ft. long, and others are considering adoption of the 9-ft. tie.

possible to determine more accurately the amount of preservative needed to attain a given absorption per cubic foot of wood.

3. Ties sawed on four sides are less expensive to replace in tracks because there is less disturbance of the ballast in the process of removing the old tie and placing the new one.

4. Ties sawed on four faces usually have less sapwood than hewed ties.

5. Sawed ties are more easily adzed and bored prior to preservative treatment because of the parallel faces.

6. In the absence of adzing, sawed ties provide a better bearing surface for the tie plates and rails.

Hewed ties have several advantages, the chief of which are:

1. Hewed ties are likely to be more straight-grained than sawed ties coming from a mill that does not saw its logs parallel to the bark.

2. For a given size classification, a tie hewed on two faces has a greater volume of wood than a tie with four sawed faces. This advantage is lost when comparing hewed and sawed ties that have the same number (whether it be two or four) of hewed or sawed faces.

3. Hewed ties often have more sapwood than sawed ties, and because sapwood absorbs preservatives more readily than heartwood, the hewed ties are easier to treat.

#### G. CROSSTIES REQUIRED PER MILE OF TRACK

One mile of track requires from 2,600 to 3,328 crossties, depending on the size of tie and the service the road must render. Class I railways use an average of 2,994 ties per mile.

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## CHAPTER 7

### WOOD FURNITURE

Furniture may be defined as decorative and utilitarian furnishings, usually restricted to movable articles, for homes, houses of worship, and public and private buildings. On the basis of use, five arbitrary groups of furniture may be distinguished: (1) household furniture; (2) partitions, shelving, cabinet work, and store and office fixtures; (3) office furniture; (4) public-building furniture, including public-conveyance seats; and (5) laboratory, hospital, barbershop, and beauty-parlor furniture. The first group represents approximately 77 per cent; the second, 10 per cent; the third, 7 per cent; the fourth, 4 per cent; and the fifth, 2 per cent of the total manufacturers' value for all furniture produced in the United States. Because wood household furniture alone represents somewhat more than half the total value, this chapter will deal principally with this class of furniture.

#### I. TYPES OF HOUSEHOLD FURNITURE

Household furniture can be classified on the basis of use, such as dining-room, living-room, library, bedroom, kitchen, porch, camp, hall, juvenile, furniture-in-the-white, built-in, and miscellaneous.

Using this classification, Table 7-1 indicates the percentages, based on manufacturers' prices, for all types of household furniture produced in the United States.

A limited quantity of bentwood furniture is made and used in this country. Hickory, ash, elm, hackberry, and oak are popular woods for bentwood furniture. Chairs, stools, and settees are virtually the only kinds of bentwood furniture produced in the United States or imported for consumption. Bentwood chairs are usually used in places of public assemblage and only occasionally as household furniture. A somewhat general classification divides them into (1) staple, or lower grade, chairs and (2) high-grade chairs. Some bentwood chairs were imported in prewar years, principally from Poland, Danzig, and Czechoslovakia. Importers usually bought the chairs unassembled or only partially assembled and maintained factories in this country for setting them up. Most American manufacturers of bentwood chairs make other kinds of furniture also. Virtually no bentwood furniture is exported, but occasional shipments to

Canada and Mexico contain a few bentwood chairs. Bentwood chairs are sold throughout the United States, and the principal markets are New York, Chicago, Philadelphia, Boston, and Pittsburgh. These five localities distribute from 50 to 60 per cent of the combined total of domestic manufactures and imports.

TABLE 7-1. PERCENTAGES OF DIFFERENT TYPES OF HOUSEHOLD FURNITURE PRODUCED, BASED ON MANUFACTURERS' SELLING PRICES <sup>a</sup>

Type	Wood, %	Metal, %	Fiber, <sup>b</sup> %	Totals, %
Upholstered furniture:				
Living-room and library . . . . .	27.03	2.41	0.13	29.57
Dining-room chairs <sup>c</sup> . . . . .	0.88	0.01	<sup>d</sup>	0.89
Other than upholstered furniture:				
Living-room and library . . . . .	15.00	0.90	0.07	15.97
Bedroom . . . . .	23.71	1.72	0.03	25.46
Dining-room . . . . .	10.05	0.29	<sup>d</sup>	10.34
Kitchen . . . . .	3.87	2.79	0.06	6.72
Porch and lawn . . . . .	0.60	1.40	0.29	2.29
Camp . . . . .	0.40	0.40	0.01	0.81
Hall . . . . .	0.07	0.01	<sup>d</sup>	0.08
Juvenile . . . . .	1.08	0.03	0.04	1.15
Furniture-in-the-white . . . . .	0.12	<sup>d</sup>	....	0.12
Built-in furniture . . . . .	2.07	0.01	0.04	2.12
Miscellaneous and unspecified . . . . .	3.15	1.27	0.06	4.48
Total . . . . .	88.03	11.24	0.73	100.00

<sup>a</sup> Based on Household Furniture: A Statistical Handbook. *Indus. Ser.*, 8, Bureau of Foreign and Domestic Commerce, U.S. Department of Commerce. June, 1944.

<sup>b</sup> Includes reed, willow, and rattan.

<sup>c</sup> Not generally considered by the trade as belonging to the upholstered furniture classification.

<sup>d</sup> Less than 0.005 per cent.

In the summer of 1946, a new type of high-grade functional furniture was placed on the market. This type of furniture is built in interchangeable units, based on dimensions that are in multiples of 6 in. These units are designed so that they may be easily added to, rearranged, and assembled into many combinations to suit the needs and tastes of the user. Such functional furniture should meet the hearty approval of many furniture users, particularly homemakers.

## II. FOREST MATERIALS USED IN HOUSEHOLD-FURNITURE MANUFACTURE

Many forest materials are used by the furniture industries, not only in furniture proper, but also in finishing and preparation for shipment.

Wood, of course, constitutes the largest proportion of the forest products so used.

#### A. WOODS USED IN FURNITURE

Wood is used in furniture in several forms: as solid lumber, as core stock in panels, as cross-banding veneer in panels, as face veneer, as plywood, as laminations in heavy parts, and as round saplings, peeled or unpeeled, depending on the kind of furniture.

In 1928, approximately 1,364,000,000 bd. ft. of wood in the forms of lumber, veneer, plywood, logs, and bolts were used in furniture manufacture; in 1933, this quantity had dropped to about 746,600,000 bd. ft., but in 1940 approximately 1,421,705,000 bd. ft. were used. In 1940, native hardwoods supplied 86.1 per cent, native softwoods accounted for 10.8 per cent, and foreign woods made up 3.1 per cent of the total wood used for furniture. The 10 principal species used in 1940 and their relative rankings are as follows:

<i>Species</i>	<i>Per cent of total</i>
Red gum.....	20.2
Yellow poplar.....	14.8
Maple.....	10.2
Tupelo.....	8.3
Birch.....	7.2
Oak.....	6.9
Chestnut.....	3.3
Douglas fir.....	3.1
Red alder.....	2.6
Ponderosa pine.....	2.6

Most of the wood used for furniture is in the form of lumber for solid parts and core stock, but appreciable quantities of veneer from several species are used for cross-banding. Veneers of yellow poplar, red gum, chestnut, and birch are used in this manner. Approximately 25 per cent of the black walnut and about 3½ per cent of the oak used for furniture is converted into veneer, principally face veneer.

Several American trees produce decorative furniture woods. Stumps of certain black walnut and bald cypress trees produce highly figured veneers that are used for decorative purposes. Veneer from bald cypress stumps is sold as "faux satiné." Some burls of black cherry, bigleaf maple, California laurel (also known as Oregon myrtle), and redwood are converted into ornamental veneers. Holly wood is used for inlays because of its light color. Certain sugar maple trees produce "bird's-eyes" which create a distinctive figure in lumber and veneer cut from the tree stem, and occasionally the trees produce lumber and veneer with a curly grain. California laurel tree

stems are also converted into lumber and veneer for decorative furniture. This wood is now enjoying a deserved popularity for restaurant, store, and office furniture and fixtures on the Pacific Coast. Beautiful "quilted maple" veneer is produced by the stems of a few bigleaf maple trees. Veneer from the irregularly colored heartwood of red gum, known as "figured red gum" in the United States and sometimes as "satin walnut" in foreign trade, is often matched to form ornamental designs.

Many imported woods are used in small quantities in the manufacture of furniture. Most of them are used for veneers and inlays in cabinets. Some species are imported in the log, as well as in lumber and veneer forms, and are converted in this country.

**1. Wood as a Furniture Material.** Wood has many things in its favor for use in furniture: (1) it is easily worked with hand and machine tools; (2) it may be satisfactorily fastened together with adhesives, dowels, nails, and screws; (3) it is strong for its weight, enabling the fabrication of strong parts possessing agreeable proportions without incurring excessive weight; (4) damaged wood usually is easily repaired; (5) it is comparatively noiseless when struck; (6) it is a poor conductor of heat and therefore does not feel very hot or very cold when touched, although its temperature may be considerably above or below body temperature; (7) no other material possesses such natural beauty, with variations in figure and color that blend, although the shades of color and the contours of pattern are seldom, if ever, identical; (8) pieces of wood that are not, in themselves, ornamental may be given attractive finishes; and (9) no other material, as it grows old in service, enhances its beauty by taking on a dark color and rich appearance, such as the patina of old wood furniture.

While wood has many advantages, it is not a perfect substance. In its natural state, it has two very objectionable features: (1) it shrinks and swells with changes in moisture content, and (2) it has the property of absorbing or releasing moisture with changes in atmospheric temperature and humidity. These two properties, working in unison, are the basic causes of most of the problems encountered when wood is used as a furniture material. They account for many of the defects developing in the seasoning of the raw material, and they are responsible for the splitting and checking of large surfaces, for the failures of many glue joints between veneer and core stock in panels or between structural members, and for the sticking of doors and drawers in humid weather. Elimination of these faults would relieve wood of its principal criticism. These effects can be ameliorated, but not removed, by drying wood to the average moisture content it would assume while in service; by giving all surfaces moisture-resistant coatings where possible; by using cross-banding veneer between core stock and face veneers of panels; by using plywood; and by using moisture-resistant ad-

hesives, some of which impregnate thin layers of veneer, thereby reducing their tendency to shrink or swell with changes in atmospheric conditions. The use of modified woods that have high dimensional stability is a distinct possibility, but their high cost has precluded intensive use for furniture up to the present time.

Wood, of course, enjoys a record of centuries of excellent service, and this is a powerful influence in maintaining its popularity; but in order to perpetuate this approval, every effort must be made to better its behavior in service. If such improvement is not forthcoming, wood may yield its position to more satisfactory substitutes that may be developed.

#### B. OTHER FOREST PRODUCTS USED BY THE FURNITURE INDUSTRY

In addition to lumber, veneer, and plywood for furniture parts, lumber and plywood are also used for shipping crates and cases; wood excelsior is used for packing pads; paper is used for wrapping; fiberboard cartons are used for packing some furniture items; Spanish moss, crin vegetal, sponge rubber, and rubber-coated materials are used for stuffing upholstered pieces; and such items as turpentine, wood alcohol, rosin, and other derived forest products are used in wood finishes.

Plastics are finding some application in furniture manufacture. Not only are plastics being used for ornamental trimmings and upholstery materials, but also large surfaces are sometimes covered with sheets of plastics thoroughly bonded to the wood parts, and ribbons of plastic materials are being used to some extent to replace willow, reed, and rattan in camp, lawn, and porch furniture. It is improbable that functional furniture made entirely of plastic materials will constitute a serious threat to wood, although novelty items have already appeared on the market.

#### III. MANUFACTURE OF WOOD HOUSEHOLD FURNITURE

The use of modern woodworking machinery has greatly reduced labor requirements, time, and manufacturing costs, thereby making good furniture available in large quantities at reasonable prices, and it has made possible a parts-fabricating precision that cannot be equaled by human hands. Modern furniture manufacture consists largely of fabricating individual parts in quantities and assembling them into identical pieces of furniture. It is difficult, however, for a furniture factory to standardize on any particular design, especially in the higher grades of furniture. The factory must be equipped to produce a varied line of goods.

At least some household furniture is manufactured in virtually every state in the Union. Leading states and the approximate percentages of the

total household furniture produced, based on manufacturers' selling prices, are as follows:

<i>State</i>	<i>Per cent of total</i>
North Carolina.....	12.0
New York.....	10.5
Illinois.....	9.0
Indiana.....	8.5
Virginia.....	7.0
Pennsylvania.....	6.5
California.....	6.0
Michigan.....	5.5
Massachusetts.....	5.0
Ohio.....	4.0

#### A. FACTORY PROCESSES

Wood, as a raw material, is brought to the factory principally in the form of lumber. This lumber is usually edged and segregated into standard lumber grades at the producing sawmill, but where transportation costs are not excessive, round-edge, log-run lumber is sometimes purchased. The chief standard grade of hardwood lumber consumed by furniture factories is the combined grade of No. 1 Common and Selects. This grade applies to at least 50 per cent of the total hardwood lumber used. Other grades consist largely of Firsts and Seconds and No. 2 Common. The principal thicknesses of lumber purchased are  $\frac{3}{4}$ ,  $\frac{5}{4}$ ,  $\frac{6}{4}$ , and  $\frac{8}{4}$  in., mostly air-seasoned.

There is a growing tendency for factories to purchase hardwood dimension stock in order to avoid costly freight charges on useless material and to reduce the amount of equipment needed in the plant. Hardwood dimension stock may be purchased in three forms: (1) as rough, green, or air-dried blanks of standard sizes, (2) as kiln-dried and surfaced blanks of standard sizes, and (3) as semimachined or even completely machined furniture parts. The first type of hardwood dimension stock necessitates kiln drying, with its attendant degrade, and almost complete machining at the factory. Stock of the second type is much more satisfactory, because it is already dried, less waste is incurred, and less machine work has to be performed. The practice of buying semimachined and completely machined parts will increase as hardwood dimension-stock plants install modern equipment for better seasoning and greater precision in manufacture to meet exacting specifications.

Veneers for faces, cross-banding, and fabrication of plywood parts are delivered to the factory in boxes and crates.

To complement the following description of wood household-furniture

manufacture, the flow sheet shown in Fig. 7-1 has been prepared. It covers the usual processes encountered in most factories making living-room, dining-room, and bedroom furniture. The flow sheet does not cover every detailed step in the manufacture of such furniture, but it does give the principal operations. Likewise, it cannot be said to apply to a particular factory, because it represents a composite of practices, some of which are not in vogue at all plants.

A brief explanation of the flow sheet begins with the delivery of lumber and veneer by railroad or auto truck to the furniture factory. The crated and boxed veneer is placed on shelves in a heated storage room in order to keep it from absorbing too much moisture. Lumber is loaded onto kiln trucks directly from the railroad car or auto truck whenever possible; otherwise it is piled in a storage yard to await kiln drying. When yard storage of lumber must precede kiln drying, great care must be exercised to pile the stock so that it will not warp, check, split, stain, or decay. Most lumber is air-seasoned when it reaches the factory, but a few factories are equipped to handle lumber green from the saw.

The seasoning operation, for best results, requires good kilns and a skillful operator. It is one of the most important steps in making good furniture and in conserving raw material through reduction of degrade in seasoning. Lumber should be dried to the proper moisture content for the use intended, the moisture content should be equalized so that it is uniform throughout the thickness of the stock, and the lumber should be relieved of internal stresses, preferably before it is taken from the kiln, so that it will not change shape in fabricating operations. The two latter objectives may be accomplished by a suitable conditioning treatment in the kiln. Equalization of moisture content plus a cooling period of a day's duration following removal from the kiln will materially reduce the development of chipped, torn, and raised grain when the lumber is machined. After the lumber has been dried, conditioned, and cooled, it may be unplied from the kiln trucks in a dry storage shed or it may be unloaded onto factory trucks for transfer to the cutting room.

In the cutting room, thick lumber may be resawed into thinner stock before proceeding to the cutoff saw. At the cutoff saw, a skilled operator cuts the lumber into lengths suitable for various furniture parts. It is his duty to convert the greatest possible percentage of each board or plank into usable sizes as well as to eliminate defective portions. He must know the permissible defects in every furniture part in order not to waste raw material by trimming too much.

Pieces produced at the cutoff saw are then conveyed to a self-feeding, straight-line rip saw for further removal of defect and for assembly of sets

of pieces to be glued together to form blanks for furniture parts. The rip-saw operator must also exercise great care in avoiding excessive ripping and wastage of raw material.

In some furniture factories the operations of crosscutting and ripping are reversed in order, but the majority of plants seem to prefer to crosscut first and then to rip. In the interest of reducing waste in these operations, it would be better to segregate the lumber into two classes: (1) that in which the greater yield is obtained by crosscutting and then ripping, including those pieces that show no greater yield by being ripped first, and (2) the balance that gives the greater yield when first ripped and then crosscut. A second point upon which there is variation in practice is the first planing of the lumber. Some plants prefer to plane the stock prior to the crosscutting and ripping operations; others use a straightening planer after the blanks have been glued. A third difference in procedure concerns stock that is to be used for bent parts. Most plants use air-dried stock for bending, but others kiln-dry the stock to between 15 and 20 per cent moisture content. For convenience, the flow sheet indicates the latter practice. Squares for bent, turned parts go directly from the rip-saw to the turning department, and flat, solid stock goes to the planers and final machining department. Many plants do as much preliminary machining on bent-wood parts as possible before sending the stock to the bending department. Low-moisture-content squares for turned parts go from the rip-saw to the turning department.

Returning to the usual practice, the exceptions having been discussed, stock leaves the rip-saw and usually goes to the glue jointer where the edges are straightened, and possibly tongued and grooved, for the purpose of making good joints when glued. For some uses, stock leaving the modern straight-line rip-saw may be glued without jointing. The stock is then taken to the glue room, where glue is spread on the edges of the pieces by putting them over a roll glue spreader. They are then usually placed in a revolving glue-clamp carrier to set, although some furniture factories are now using high-frequency dielectric heating for this purpose.

When the glue is set, the rough blanks are taken to a straightening planer for *face-jointing and sizing*. *Slightly twisted pieces fed into this machine* will come out perfectly flat and surfaced on both sides. The first part of the machine has a planer head on the lower side and a flexible feeding arrangement so that the blank will be pulled into the machine without altering its shape. While so held by this feeding device, the lower part of the blank is planed off to get a straight, smooth surface. The second part of the machine has a top planer head and sectional feed rolls to accommodate the possible uneven, rough surface of the blank. This top planer head



removes the excess material, bringing the blank to uniform thickness. The use of such a planer is largely made possible because of the adoption of better seasoning practices that produce less severely warped lumber.

After leaving the straightening planer, the blanks go through a finishing or cabinet planer for a final surfacing. Material to be veneered is taken from the finishing planer to the veneer department, and other material goes to the final machining department. Before discussing the treatment of wood in the final machining department, the veneer department should be considered.

Veneer from the storage shelves is put through a veneer redrier \* to bring it to proper moisture content for gluing. From the veneer redrier, the stock goes to the veneer clipper for the purpose of cutting it to proper lengths and widths for the various products to be made. Veneer for irregular-shaped products is often cut with a bandsaw. Veneer from the clipper is stacked and taken to the jointer. The modern veneer jointer has a traveling bed that carries the stacks of veneer forward, under uniform pressure, to two high-speed cutterheads. The first head does the rough jointing and the second the final jointing, making the edges of the veneer sheets smooth and straight.

Veneer pieces that are to be matched are usually run through a taping machine that binds them together with a thin paper strip, making the taped pieces of desired widths to be glued to panels. In some plants, however, tapeless splicers, which apply and set the adhesive automatically, are used to glue the veneer sheets edge to edge.

In gluing veneer to panels with cold-setting liquid adhesives, the face veneer is laid flat and a sheet of cross-banding veneer is run through a double-roll glue spreader that coats both sides. The glue-covered cross-banding veneer is laid on top of the face veneer with its grain at right angles to the face veneer, and the center core is placed on top of the cross-banding veneer with its grain parallel to that of the face veneer. The second cross-banding is run through the glue spreader and is laid on top of the core stock, with its grain at right angles to that of the core stock. Finally, a second face veneer or backing veneer is laid on top of the cross-banding so that its grain runs in the same direction as that of the first face veneer. This process is repeated for other panels until a stack of proper height is assembled for the power press, which may be mechanical or hydraulic. These stacks are placed on top of a retaining plank, which rests on short I-beams, and another retaining plank is placed on top of the stack. Short I-beams are then placed on top of this retaining plank. This combination is then put into the power press, and binding turnbuckles are hooked onto vertical pairs of I-beams. When the stack has received sufficient pressure the turnbuckles

\* For a fuller discussion of veneers, plywood, glues, and veneer driers see Chap. 8.

are tightened and the press is opened up. The stack is then hauled to a space where it is allowed to remain for a sufficient time to allow the adhesive between the veneer and other panel components to set. This procedure requires considerable time and storage space, and it is not unreasonable to expect that some plants will install high-frequency dielectric heating equipment to obtain greater production.

Plywood may be made in a similar manner, and in instances where curved parts are to be made, the various layers of veneer are put into suitable rigid forms. These various-shaped forms consist of male and female parts, usually made of laminated wood. As a result of the advances in the manufacture of plywood molded in autoclaves, some factories are now purchasing molded plywood parts from plywood companies.

After the adhesives have set for the proper period, the turnbuckles are released, and the panels or plywood parts are then redried so that the sanding and finishing operations may be performed. The redried parts are then sent to the final machining department.

In instances where glue joints of high water resistance are desired, high-temperature-setting liquid glues are used, or dry film resin adhesives may be interleaved between the assembly components and set in a hot press or by high-frequency dielectric heating.

The surfaced blanks from the finishing planer and the products of the veneer department are machined in numerous ways in the final machining department. Simple panels are put through a double-end cutoff saw twice to cut them to exact lengths and widths and to square the edges and corners perfectly.

Edges of table tops, for example, may be given molded edges on a shaper by clamping them to forms or patterns of the desired contours. The hand shaper consists of a smoothly milled iron table that has a motor-driven cutterhead extending through and above it. Knives of various shapes are inserted into the upper part of this cutterhead, and the edge of the form, to which the top is fastened, is pushed against the circular base of the cutterhead, below the knives. The form is held against this base and moved until the whole perimeter of the table top has been molded.

An automatic shaper for small parts is equipped with a revolving turntable to which a form of suitable contour is fastened. This form is so designed that several small pieces may be cut at each revolution of the table. Air-operated clamps hold the pieces while they are being shaped by a motor-driven cutterhead suspended from an arm which follows the contour of the pattern or form attached to the revolving turntable.

Other items may be put through a double-end tenoner for the purpose of making tenons on both ends; parts requiring mortising are sent to mortisers of various kinds. Drawer sides and ends may be sent to a dado ma-

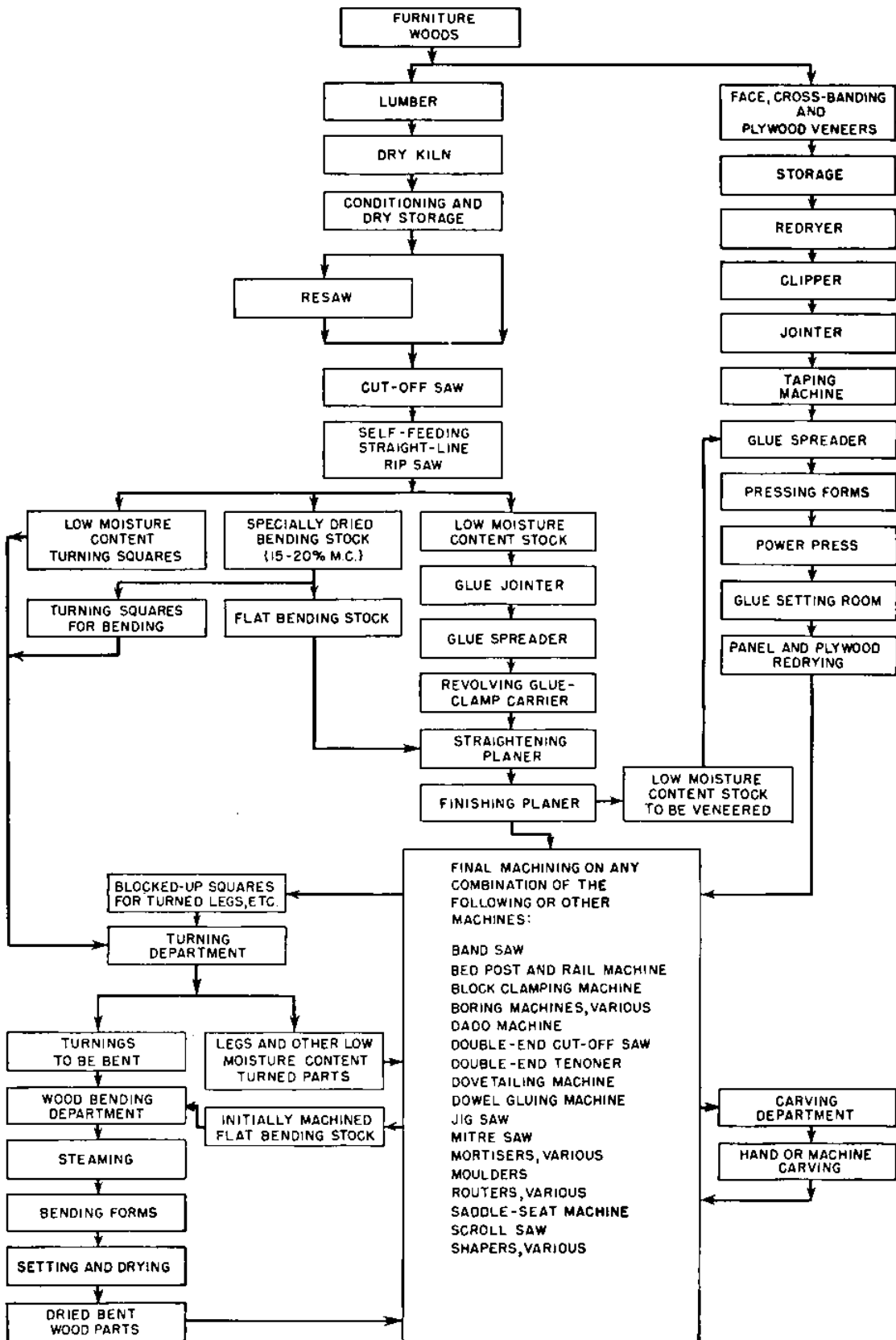


FIG. 7-1. Flow sheet for wood furniture manufacture.

(Continued on page 125.)

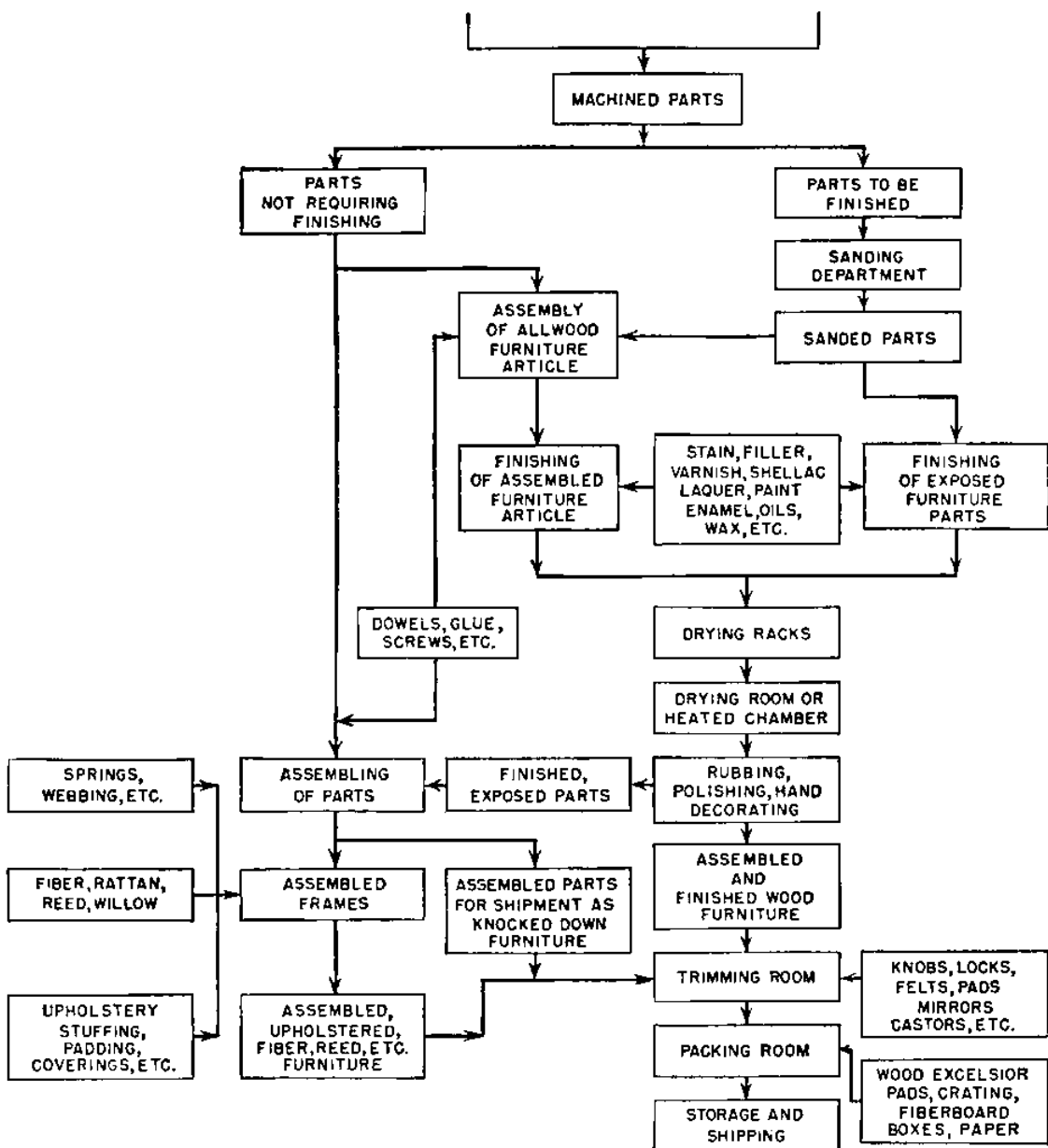


FIG. 7-1. (Continued.)

chine for the purpose of cutting the grooves which will hold the drawer bottom, and for high-quality furniture, they will be sent to a dovetailing machine for dovetailing operations on the ends. Pieces requiring boring for dowels are sent to multiple-spindle boring machines when several holes are to be drilled. Irregularly shaped pieces are cut on scroll saws and jigsaws, and pieces for mitered joints are cut on an adjustable miter saw.

Panels requiring open scrollwork can be sent to a router for cutting out the openings. The panel in this instance will be clamped to a jig having grooves of the proper contours on its underside. A steel pin is set in the router table directly beneath the cutting spindle, and this pin extends upward into the grooves of the jig.

Chair seats of the saddle type are put through a saddle-seat machine. In this machine, the seat is pulled under a cutting head, having knives of the proper shape, by means of a traveling bed equipped with lugs. The cutting head is raised and lowered by a cam that is synchronized with the motion of the feed bed so each seat is perfectly shaped automatically.

It is not feasible to describe all the operations performed in the final machining department. Let it suffice to say that there are many other machine tools for the purpose of making various parts and that there is a tendency to install machines that are designed to perform many of the operations formerly done on individual machines. For instance, there is a double-end tenoner that has attachments for sanding, dovetailing, corner-rounding, lock joints, miter joints, dado work, tapering, and making several parts from a single piece.

Some work from the final machining department has to be sent to other departments, such as the carving department. Table legs that are to be turned with bulbous sections or in curved shapes are usually built up by gluing blocks to surfaced squares. The block-clamping machine in the final machining department is used for this purpose. Bent furniture parts are usually machined as much as possible before being sent to the bending department.

In the carving department, one encounters single- and multiple-spindle carving machines for the purpose of eliminating as much hand carving as possible. In certain instances a limited amount of hand carving may be done. Multiple-spindle carvers are equipped with as many as 24 spindles. In using such a machine, the operator moves a tracer over the contour of a sample hand carving and each carving spindle cuts into a blank piece, duplicating the artist's work. The product of the multiple-spindle carver is usually completed by hand by master carvers on a single-spindle carver.

The turning department is equipped with various turning lathes, ranging from hand lathes to fully automatic lathes. Hand lathes are used, ordinarily, for turning samples and odd work, where comparatively few pieces are required. One automatic lathe, the back-knife lathe, holds the material between a high-speed revolving headstock and tailstock while a knife of the desired shape operates on the work from the back, moving in and out, as determined by the contour of the work, governed by a master cam. Another automatic lathe holds the work between a very slowly revolving headstock and tailstock while a cutterhead equipped with knives of the desired shape revolves at high speed. The contour of the knives is the counterpart of the shape to be turned. The slowly revolving work is pushed toward the cutterhead. Other lathes are employed for fluted and rope-twist work.

Some material from the turning and final machining departments goes to the *bending department* for the purpose of making bent parts. Here the wood is usually steamed at a temperature of about 212°F. for about 1 hour per inch of thickness. Although steaming is the principal treatment used for bent parts, hot water and hot sand are occasionally used, and in recent years attempts have been made to devise other methods of softening the wood to reduce or eliminate breakage.\*

In present commercial practice, after the wood has been steamed, it is placed in bending forms and dried. Some of the bent parts are then ready for sanding and finishing, but others may have to go back to the final machining department for additional working.

Completely machined parts are now ready for sanding, finishing, and assembly into furniture. The sanding department includes a sponging bench, where certain parts are sponged with a mixture of water and a small amount of glue. This operation raises the grain of the wood prior to sanding, so that the sanders will leave the wood in the best condition for finishing.

The various types of sanders include, among others, the drum, stroke, hand-block, molding, variety, disk, oscillating-spindle, and special turning sanders. Some factories manufacturing high-grade furniture sand virtually all parts, but it is not altogether necessary to sand hidden parts. The flow sheet indicates the sanding only of parts to be finished.

Furniture is finished to beautify and to protect the wood. In modern practice, the completely assembled article may be finished as a unit or exposed parts may be finished separately. With new finishes and equipment, the task is simplified greatly. Much furniture is finished in spray booths, where the finish is applied by spray guns operated by compressed air. Stains and fillers are often applied by dipping the parts into vats to save time and to ensure coverage of all sections. Automatic rubbing machines and motor-driven hand-rubbing machines are in general use.

The flow sheet indicates the assembly of finished furniture in three forms: (1) the completely assembled all-wood article, (2) the assembly of parts for shipment as knocked-down furniture, and (3) the assembly of upholstered or fiber, rattan, reed, and willow furniture. Some unfinished furniture, principally in the cheaper grades, is also sold.

\* Urea and urea compounds have been tried as agents to facilitate bending, but they have not proved to be satisfactory in some respects and are not generally employed in the furniture industry at present. Another method tried in England involves the use of natural or synthetic tannins in media such as salts of chromic acid, iron salts, alum, phenols, and aldehydes; addition of an organic solvent, such as amyl acetate, to the tannin solution is said to give improved results.

### B. WOOD LOST IN FURNITURE MANUFACTURE

The manufacture of wood furniture entails a great deal of loss in raw material. Some furniture parts contain less than 50 per cent of the wood necessary for their manufacture. Much of this loss is unavoidable because of (1) artistic shapes required in solid parts; (2) trimming of veneer for panels, particularly when fitches of sawed or sliced veneers are purchased; (3) matching of veneer, especially when unusual designs are sought; and (4) inability to use the entire piece of lumber purchased under regular grading rules because of losses from defects, saw kerf, shavings, and the impossibility of converting all the remaining clear material into usable cuttings of required sizes. The purchase of hardwood dimension stock or completely machined parts by the furniture factory does not solve the wood-loss problem. The same losses are merely transferred to the hardwood dimension-stock factory. The furniture factory, however, does not have to pay freight on useless material when it buys hardwood dimension stock and machined parts.

One operator quotes an average loss of approximately  $33\frac{1}{3}$  per cent of the rough lumber taken from the yard and an average loss of about 12 per cent in air-seasoned hardwood dimension stock. The loss of material in green hardwood dimension stock averaged more than 12 per cent. The loss from hardwood dimension stock, while usually considerably less than the loss from lumber, occasionally reaches 25 per cent.

Much loss of raw material can be prevented by (1) proper piling in the storage yard, (2) better kiln-drying equipment and more skillful kiln operators, (3) more careful handling and elimination of unnecessary handling, (4) reduction of spoilage by obtaining better equipment and skilled employees, (5) elimination of oversized blanks for parts, and (6) using extreme care in handling veneers.

### C. SOME FEATURES OF GOOD FURNITURE CONSTRUCTION

Much of the quality in furniture lies in unavoidably concealed construction points, such as the type of adhesive used, the fit of a mortise-and-tenon joint, the kind, number, and placement of dowels, the moisture content of the various wooden parts at the time of assembly, and the internal stresses existing in the lumber when it leaves the dry kiln. Rarely can any of these things be ascertained by examining a completely assembled and finished piece of furniture. On these points, the purchaser generally has to rely on the reputation and integrity of the manufacturer. There are several visible evidences of good craftsmanship characteristic of high-grade furniture, on which the purchaser can estimate quality.

1. Very few nails will be found in *good furniture*.
2. The sides of drawers will be dovetailed into both the front and back panels.
3. Drawer bottoms will have substantial thickness and will be *dadoed* into the sides and ends of the drawer.
4. The drawer will slide easily and will be treated with a moisture-retardant coating.
5. Center slides on the bottoms of drawers will be fastened to front and back cross rails and glued to the bottoms of the drawers.
6. Bedroom and dining-room furniture will have thin panels between the drawers for dustproofing.
7. The back of a cabinet will be fitted into grooves in the sides rather than being fastened with nails.
8. The legs of chairs, beds, tables, and cabinets will set squarely on a level floor.
9. Corner blocks, glued and screwed to the rails, will strengthen joints at the *points of leg attachment* on chairs and tables. Absence of corner blocks or substitution of nails for screws in corner blocks are evidences of inferior construction. Corner blocks are not required when bentwood legs are socketed into the rim of a chair seat.
10. The back posts of chairs will be of bentwood or, if sawed from lumber, they will be cut in such a manner that the lower portion will contain a sufficient amount of longitudinal grain so that the bottom of the post cannot be broken off easily.
11. Rungs or stretchers between the legs of chairs will be in *sufficient* number to give ample bracing.
12. Table tops will be attached to the legs and rails in such a manner that they are permitted to shrink or swell without splitting the base.
13. Carved furniture will have the carvings actually made in solid wood rather than having carved wood blocks or molded compounds glued to the surface of the wood.
14. Veneered panels of a cabinet will have adjacent pieces of face veneer matched, and no piece of face veneer will be spliced to attain the required length in high-quality furniture.
15. *Joints* will be inconspicuous, indicating that care was exercised in sanding, finishing, and polishing.
16. Fine furniture will possess no glossy or shiny finish.

#### D. "BORAX" FURNITURE

"Borax," a colloquial term of speculative origin, has two connotations when applied to household furniture. In one sense it refers to cheap,



poorly constructed, offensively styled, and showy furniture. "Borax" furniture is often characterized by flashy combinations of many materials, useless ornamentation, and shiny surfaces. The second use of the term, "borax," refers to vigorous and unscrupulous sales practices in retailing such furniture. Most sales of this nature are made to installment buyers.

### E. VENEERED VERSUS SOLID FURNITURE

Purchasers often hesitate in making a choice between veneered and solid wood furniture, largely because of unfamiliarity with furniture construction and the characteristics of these two types. Briefly stated, either may be highly satisfactory or highly unsatisfactory. Construction methods and the quality of materials in the structure are all-important. Figure 7-2 shows a veneered dresser body.

Usually the following advantages are ascribed to furniture of solid wood:

1. Surfaces cannot loosen, blister, or peel off, as may be the case with improperly constructed veneered surfaces.

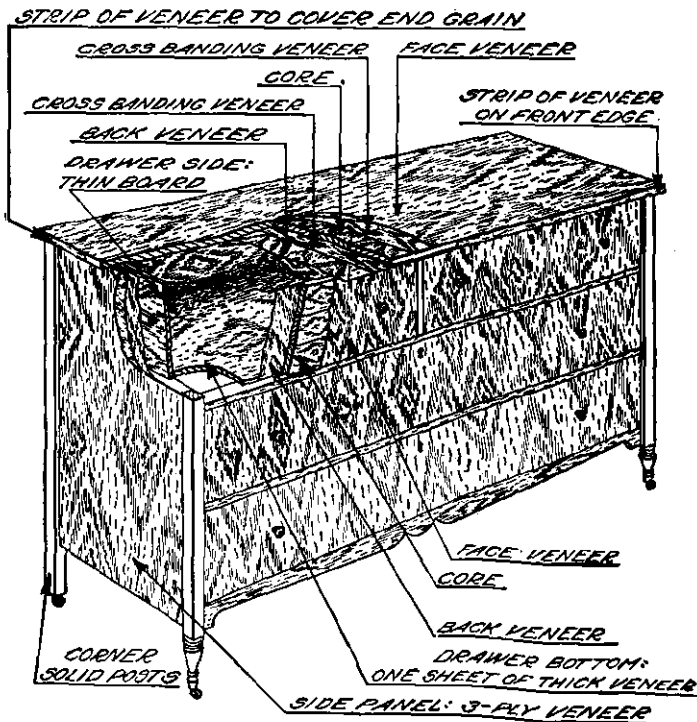


Fig. 7-2. Sectional view of medium-grade dresser body, showing use of veneers

2. Surfaces can be sandpapered heavily or even planed off when such furniture is to be refinished.

3. Solid wood can be carved, which is impossible in veneered construction unless special provisions have been made.

4. If chips are broken off, the same kind of wood is exposed.

5. Solid wood, when worn down, does not change in figure or appearance.

6. The owner has personal satisfaction in knowing that the article is constructed throughout of the kind of wood visible at the surface.

The advantages of veneered construction in furniture may be summed up as follows:

1. In some respects, a plywood panel is stronger than a solid piece of wood of the same thickness.

2. The use of cross-banding or plywood reduces the tendency of panels to shrink, swell, warp, split, and check.

3. Curved surfaces made of laminated wood are superior in strength to those made of solid wood, are less wasteful of raw material, and may be veneered to give a continuity of figure not attainable by the use of solid wood.

4. Highly figured woods, often cross-grained and therefore unsuited to use in thick sizes because of the resulting uneven shrinkage, can be used for thin face veneers.

5. Because of the thinness of highly figured face veneers, several consecutively cut pieces can be matched to produce symmetrical figures that are impossible of attainment in solid wood.

6. Valuable woods used for face veneers would make furniture prohibitive in cost if used in solid pieces.

7. Veneered construction permits better utilization of wood. More people may enjoy the beauty of rare woods of limited supply when these are used as face veneers, and cores of panels may be made of softer, lighter, and cheaper wood than can be used for solid wood construction.

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## CHAPTER 8

### veneers and plywood

The art of veneering is nearly as old as civilization itself and actually antedates the birth of Christ by more than 1,500 years. Exquisitely designed and skillfully fabricated pieces of plywood furniture found in the tombs of the Pharaohs give silent testimony to the dexterity and artistry of the ancient Egyptian cabinetmaker. A number of the essential features of a modern plywood panel were found in the headboard of a bedstead reputed to have belonged to the grandparents of Tutankhamen's wife. Made of laburnum wood and lavishly embellished with gold and precious stones, it was as sound as though it were made but yesterday. How the wood was cut into thin, delicate sheets of veneers or what was the nature of the adhesive that stood the tests of 35 centuries, however, is still a matter of speculation.

In the years that followed, Assyrian, Babylonian, and Roman craftsmen, influenced by the Egyptian stylists, made several significant advances in the use of veneers. The Romans developed the art of matching figured veneers to produce unusual decorative effects as well as beautiful patterns of warmth and charm. In his "Natural History," Book XVI, Pliny revealed that the rootwood of certain species was often used, thus indicating that the ornamental value of stump wood and rootwood has long been recognized. He also recorded that among the many personal treasures of Julius Caesar, the one held in highest esteem was a beautifully veneered table.

During the Middle Ages, oppressive ecclesiastical and political orthodoxy effectively stifled creative thinking, cultural interests, and practice of the arts, but toward the end of the seventeenth century a revival of learning became manifest, and in the years that followed some of the world's finest masterpieces in sculpture and painting were created. Interest in wood-working and marquetry was reborn, and in 1769 Riesener completed for Louis XV his "Bureau du Roi," said by many in authority to be the finest specimen of veneered furniture of all times. The eighteenth century witnessed the peak in period stylings and with it the creations of such renowned craftsmen as Duncan Phyfe, Hepplewhite, Chippendale, Sheraton, and the Adams brothers.

Until the middle of the nineteenth century the finest furniture was hand-

made, and into each piece went all the skill, ingenuity, artistry, and pride of the master. Quality, not quantity, was his watchword. The work was slow, painstaking, and laborious, the furniture costly and available only to the wealthy.

About 1840, furniture manufacturers began to mechanize their shops in order to produce goods on a mass-production basis. In some of these plants quality was readily sacrificed for quantity. Ornate inlays and a variety of highly figured veneers were applied over a poorly fabricated article merely for the purpose of concealing shoddy workmanship. Eventually this practice affected adversely the sale of all veneered furniture, because buyers began to regard such merchandise as an inferior substitute for comparable articles constructed of solid wood. This concept is still held by many uninformed even today. Our leading dictionaries do little to dispel this view, defining veneer as "a layer of more valuable or beautiful material over an inferior one."

Veneering as practiced today, however, needs no defense, but rather an intelligent understanding of the principles, purposes, and advantages of veneered construction. Wood technologists, engineers, chemists, and designers working together harmoniously have pooled their knowledge and skills to produce a superior product. This is plywood. How it is made, its advantages over solid wood, and its many and diverse uses will now be reviewed.

#### A. VENEER AND PLYWOOD DEFINED

Veneer is a thin sheet of wood of uniform thickness produced by peeling, slicing, or sawing logs, bolts, and flitches. Plywood is a well-established trade term applied to composite wood panels composed of an odd number of sheets of veneer that are bonded together with a suitable adhesive in such a manner that the grain directions of the adjacent plies are at right angles to one another.\* The simplest plywood panel is a three-ply assembly. The inner layer is designated as the *core* to distinguish it from the two outer sheets, the *face* plies. In three-ply construction, the grain direction in the core is at right angles to that of the face plies. A five-ply panel is comprised of five layers of wood in which the grain directions of the core and faces all parallel one another. On each side of the core is a sheet of veneer bonded in such a manner that the grain lies at right angles to that of the core or faces. These sheets are known as *cross bands*. Panels composed of seven, nine, or more plies are similarly constructed.

The term *plywood* is applied also to panels in which a lumber core of some

\* A few specialty types of plywood, comprised of an even number of plies, are also manufactured. The grain direction of the individual layers in composites of this type is specified by the designer.

predetermined thickness is used in place of the conventional veneer core. While plywood is in reality a form of laminated construction, the term laminates as applied to wood is descriptive of multi-ply panels, beams, and other structures in which the grain directions of all component parts comprising the assembly are parallel.

## B. REASONS FOR VENEERING

With the exception of containers such as baskets, crates, boxes, drums, and a few specialty products where veneers are used per se, the principal use of thin sheets of wood of this sort is in the production of plywood panels.

It is a well-known fact that solid wood will withstand much greater stress along the grain than across it. This makes it exceedingly difficult, if not impossible, to design a solid wooden member with equal strength properties in all directions. Likewise, dimensional changes in solid lumber, occasioned by fluctuations in moisture content, are not equal in all directions. While wood shrinks or swells but little along the grain, its dimensional instability across the grain is much greater. Moreover, dimensional changes in the tangential plane are about twice as great as those in the radial direction. However, by bonding together an odd number of sheets of veneer in such a manner that the grain in adjacent layers is at right angles, the unbalanced internal stresses may be practically equalized. The resulting panel is characterized by much greater dimensional stability than one of similar size made of solid lumber and by strength properties that are nearly equal in all directions.

The chief advantages of plywood panels over those of solid wood of the same dimensions may be summarized as follows: (1) greater uniformity in strength properties along the width and length of the panel; (2) reduction and equalization of shrinkage and swelling; (3) increased resistance to end-checking and splitting; and (4) if properly constructed, little or no tendency to twist or warp. In addition, veneered construction permits the broader use of expensive woods and is the only practical way of *matching figures* to bring out the most striking and realistic results. Plywood construction allows the fabrication of curved and irregular surfaces, impossible to achieve with solid wood.

## I. VENEERS

### A. MANUFACTURE OF VENEERS

There are at present five methods employed in the manufacture of veneers. Prior to the twentieth century all veneers were produced by sawing. In this process logs were first cut into fitches, and the fitches in turn were

reduced to thin sheets of wood by driving them against a circular saw. This was both an expensive and wasteful procedure, since much of the best and clearest wood in a log was removed as slabs and more than half the potential veneer in the flitches was reduced to sawdust in the cutting operation. Veneer saws long since have been largely replaced by modern rotary lathes, and less than 5 per cent of all veneers now manufactured in the United States are sawed.

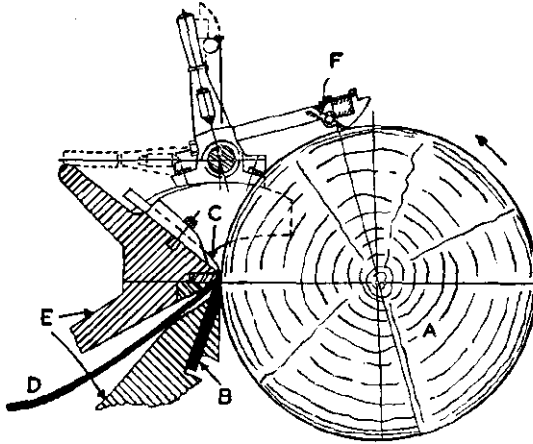


FIG. 8-1. Diagrammatic sketch of modern veneer lathe.

**1. Rotary-cut Veneer.** Today nearly 90 per cent of all veneers manufactured are rotary cut. In this method of cutting, a bolt of wood of predetermined length is held by two chucks and centered on a lathe. When in place the bolt is turned against a stationary knife extending across its length. Figure 8-1 is a diagrammatic sketch of the modern lathe. The bolt (A) turning in a counterclockwise direction strikes the knife (B); while the pressure bar (C) holds the wood firmly against the cutting edge at the instant of cutting. The knife carriage (E) automatically advances the knife into the revolving bolt at a given speed, thus controlling the thickness of the sheet. The resulting veneer (D) passes out through a slot in the knife carriage. In rotary cutting, a bolt is literally unwound (much as one might unroll a bolt of wrapping paper), and the veneer is produced in a long, continuous ribbon of wood. Giant lathes capable of peeling logs 12 to 16 ft. in length are used in a few plants. More commonly, however, logs suitable for the manufacture of veneers are sawn into peeler-bolt lengths of from 24 in. to 8 ft. and turned on smaller lathes.

The surface of veneers, to be suitable for gluing, must be clean and

smooth. Experience has taught the producer that better sheet surfaces are obtainable from woods of moderate density if the bolts are steamed or steeped in hot water for several hours before they are peeled. Certain woods, however, such as basswood, yellow poplar, Douglas fir, spruce, and cottonwood produce better veneers if they are "cold-cut," since fuzzy, fibrous veneer surfaces are not unusual if the wood of these and similar species is subjected to preparatory heating. When bolts are heat-conditioned the bark is ordinarily removed after the cooking process.

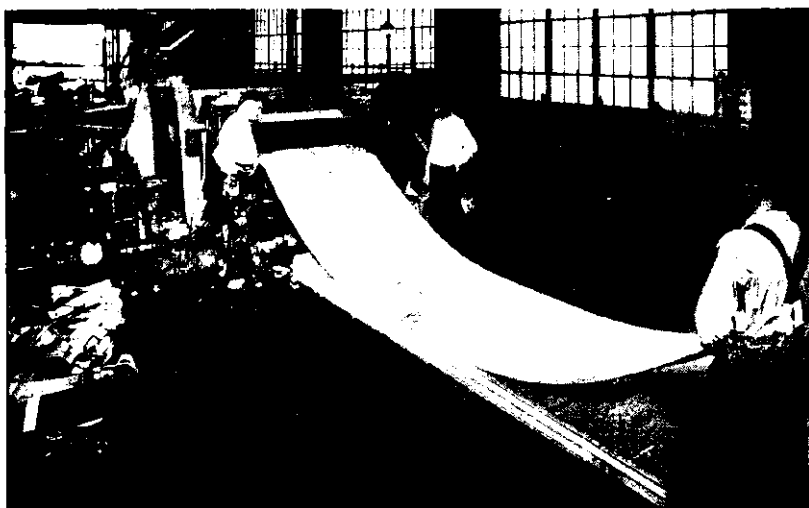


FIG. 8-2. Producing rotary-cut veneer. (Courtesy Wood Mosaic Co., Louisville, Kentucky.)

Rotary veneers are manufactured in thicknesses ranging from  $\frac{1}{64}$  to  $\frac{1}{4}$  in. The interplay of forces produced by the pressure bar and the wedging action of the knife causes a sheet of veneer to bend sharply away from the bolt as it is cut, and as a result of this excessive bending, many small longitudinal cracks and checks often develop on the under side of the sheet. The thicker veneers ( $\frac{1}{8}$  in. and up), if unrestrained, have a tendency to assume the peripheral curvature of that part of the bolt from which they were cut. When such a sheet of veneer is forcibly flattened, the upper side is subject to compression stresses while the lower side is under tension. The knife checks are then often discernible particularly at the edges of the sheet. The surface of the veneer having these checks is called the *loose side*, the other is known as the *tight side*. Veneers of this sort are commonly termed *one-face veneers*. When one-face veneers are used for face and back plies of plywood panels, the loose side is always on the glue line unless it has to be



reversed to match grain or figure. It is possible to cut thin veneers without the subsequent development of checks in the lower surface when excessive pressure is exerted by the pressure bar. Veneers of this sort are termed *tight-cut*. If the pressure on the bar is relaxed, the fibers in the wood are easily ruptured and *loose-cut* veneers result. Loose-cut veneers have much less tendency to bow than do tight-cut sheets. To aid the manufacturer in keeping track of the tight side of veneers throughout subsequent operations, a scribing device on the lathe (*P* in Fig. 8-1), a pencil or crayon, marks the sheet as it is cut. This mark may be sanded out or trimmed off later in the finishing of the plywood panel.

Rotary cutting is the cheapest means of producing veneers, and the bulk of the veneers cut in this manner are of the *commercial* variety. Commercial veneers are those which are used largely in the fabrication of articles where strength rather than figure is of primary concern. However, the lathe is a versatile tool, and many types and grades of veneers ranging from coarse, cheap materials used for berry boxes, citrus crates, and egg cases to the expensive and highly figured face veneers of black walnut, bird's-eye maple, and tamo \* used in paneling are rotary-cut.

When a ribbon of rotary-cut veneer leaves the lathe it passes over a series of table rolls which convey it to a clipper. Here major defects are cut out and the ribbon clipped into veneer sheets of standard widths.

a. *Veneer Winding.* It has been a common practice for several years in some European mills to rewind rotary-cut veneer on spools or reels as it leaves the lathe. This method of handling has begun to find favor in American mills, and within the past few years reel banks have been installed in some of the more progressive American plants.

The reel is a metal shaft with a wooden facing inserted in a heavy metal frame in front of the lathe. It is driven by a special differential speed mechanism which permits uniform winding as the veneer leaves the lathe. When the reel is full it is removed by a crane or other suitable device to the reel storage immediately behind the clipper. Where reeling is practiced there is less likelihood of slowdowns at the lathe because of clipper holdups. Clipping can be done independently of the lathe, and better inspection and clipping thus may be assured.

2. *Stay-log Cutting.* This is merely a modification of rotary cutting and was developed primarily for producing fancy face veneers from quarter-fitches and irregularly shaped materials such as burls, crotches, and stumps.

A stay-log is a long, flanged steel casting mounted in eccentric chucks of a conventional lathe. To produce veneer, a fitch or section from a stump, crotch, or burl is securely fastened to the flange with several heavy lag screws, and then turned against the knife. Large fitches and even half-

\* Japanese ash.

bolts mounted and cut in the manner illustrated (Fig. 8-3) are called *half-round cut*. The manner in which the bolt in Figure 8-4 is mounted produces *back-cut veneer*. Back-cut veneers obtained from stump wood and crotches are usually handsomely figured because fiber alignment in materials of these kinds is very irregular. In fact much fiber is often cut across rather than along the grain with the result that the sheets of veneer are very brittle and special care must be exercised in handling them.

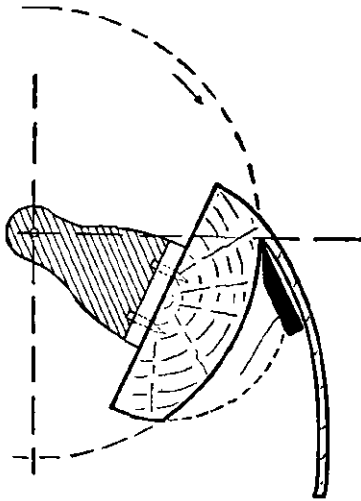


FIG. 8-3. Diagrammatic sketch of half-round stay-log cutting.

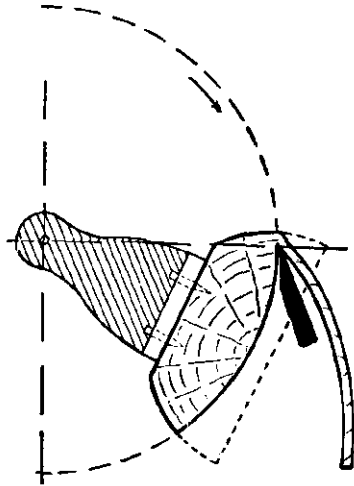


FIG. 8-4. Diagrammatic sketch illustrating back-cutting.

Stay-log cutting permits the manufacture of wider sheets of veneer than it is ordinarily possible to produce in conventional slicing operations described in section 4.

**3. Cone-cutting.** Cone-cutting produces circular sheets of veneer by taper-peeling a bolt in a manner similar to that of sharpening a wooden pencil. The contact angle of the knife determines the degree of taper, the approximate width of the sheet for a bolt of a given diameter, and the number of revolutions the bolt must make to produce a completely circular sheet. Only a very small amount of veneer is produced in this manner, as such veneers are ordinarily "short-grained" and hence quite brittle. Beautiful "wheel" or stellate figures result, and the veneers are used in the fabrication of panels for fancy, circular table tops.

**4. Sliced Veneers.** Veneer slicers were developed in an effort to eliminate the wasteful practice of sawing. With numerous improvements of the original slicing device, many of the figured woods that were formerly sawed

into face veneers are now cut on slicers. While slicers can be employed to produce veneers of all types, they are used largely for cutting only figured woods for face stocks.

Sliced veneers are usually cut in lengths of from 12 to 16 ft., although cutting is not restricted to these sizes. Logs to be used for the production

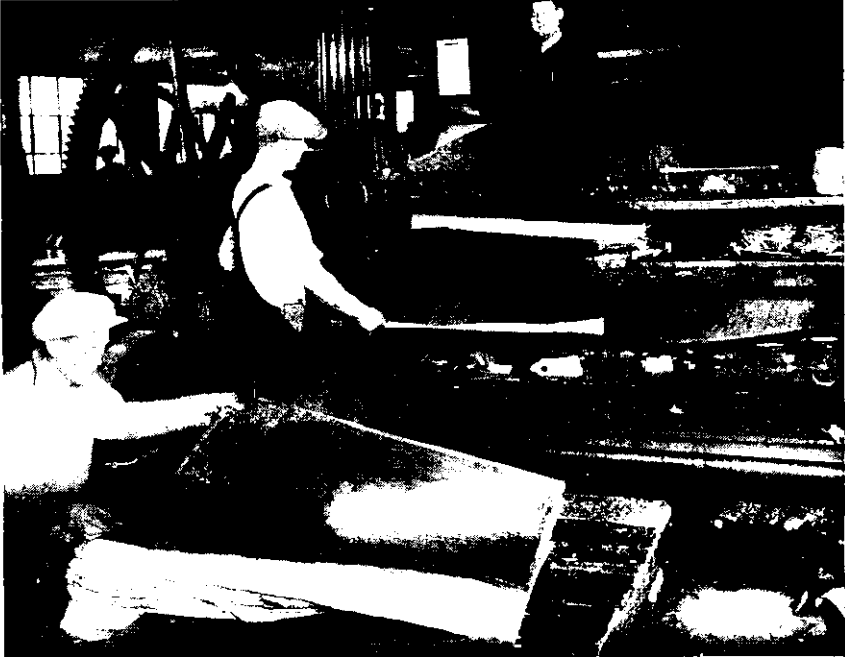


FIG. 8-5. Stay-log cutting of a walnut stump. (Courtesy Wood Mosaic Co., Louisville, Kentucky.)

of sliced veneers are first halved lengthwise on a circular or bandsaw and then not infrequently cut into smaller fitches at the option of the producer. An experienced and skillful operator is usually in charge of preparing such fitches. Upon inspection of an opened log he must be able to visualize the type of figure it possesses and to indicate how it is to be fitched in order that this figure may be best brought out in the veneers subsequently cut from it. If in his judgment radial slicing is desired, the half log is further reduced to six or eight fitches for the production of quartered veneers, obtained when the slicing is parallel to the wood rays and at right angles to the growth rings. If, on the other hand, "flat-cut" veneers\* are to be

\* Flat-cut veneers are made by slicing half-sections of logs. In such a case both quarter-grained and flat-grained figures are commonly present in the same sheet.

sliced, no further flitching is ordinarily required. Before the actual slicing operation begins it is necessary to soften the stock in steam or hot-water vats in a manner similar to the treatment of bolts for rotary cutting.

The most commonly used slicer in the veneer plants of the United States is the vertical type. In practice a flitch is firmly "logged" to a heavy metal bedplate which is fastened to two angling slides set in a heavy metal

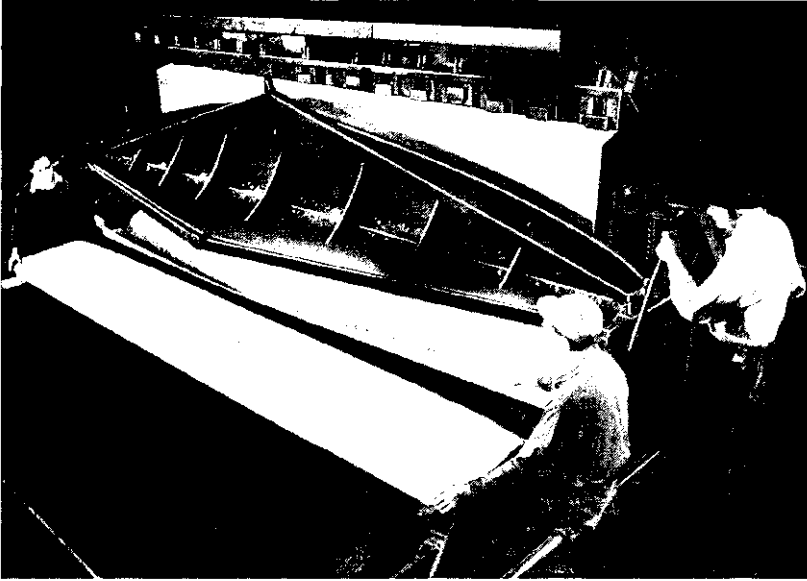


FIG. 8-6. Slicing a mahogany flitch. (Courtesy The Mahogany Association, Chicago, Illinois.)

frame. The flitch is driven down against a pressure bar and knife, and the resulting sheet passes out through a slot in the knife carriage in a manner similar to that of a rotary lathe. On the up stroke of the flitch, the knife carriage moves forward and thus is in position to slice off another sheet with the next cutting stroke. The angling slides give the flitch a slight lateral movement as it advances toward the knife. This makes for smoother veneers, since the cutting action is somewhat along the grain of the wood rather than directly across the fibers. Such a shearing action is particularly helpful in producing smooth surfaces when woods with curly, wavy, or interlocked grain are sliced. Horizontal slicers work on the same principle except that the flitch travels in a horizontal plane in approaching the knife.

There are also several special types of slicers designed largely for produc-

tion of battery separators and shooks for fruit, vegetable, and cheese boxes and crates and similar containers.

When slicing face veneers, the sheets from a given flitch are turned over as they come from the knife and stacked consecutively, exactly in the order cut. Such a bundle is also called a *flitch*; in subsequent handlings it is regarded as a unit, and special care is exercised to preserve sheet sequence at all times. The reasons for this will be explained later.

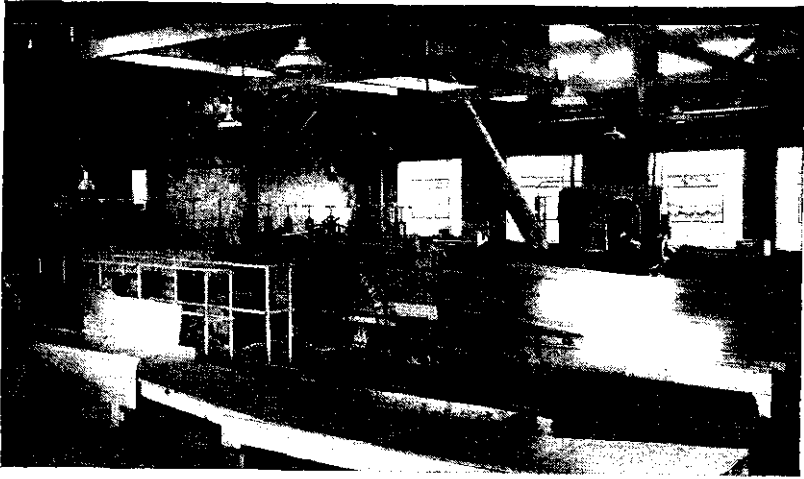


FIG. 8-7. Battery of veneer saws. (Courtesy Wood Mosaic Co., Louisville, Kentucky.)

As in rotary veneer, the side of a sliced veneer next to the knife contains numerous fine checks. Therefore, whenever possible, care must be taken to spread glue on the open face; in matched veneers, however, in order to produce a balanced figure, some pieces must be glued open face up.

**5. Sawed Veneers.** As previously indicated, little veneer is produced by sawing at the present time. Ordinarily, sawing is restricted to cabinet woods that are either highly refractory and unsuitable for slicing (ebony, oaks, satinwood, knotty eastern red cedar) or that cannot be softened in cooking vats without impairing their color. Woods with appreciable tannin are commonly sawed, since hot tannin extracts coming in contact with a knife impart objectionable iron tannate stains to the wood. Port Orford cedar and basswood slats for venetian blinds and Spanish cedar (*Cedrela odorata* L.) shooks for the manufacture of cigar boxes are commonly sawed.

The modern veneer saw is known as a *segment saw*. It consists of a heavy metal tapering flange (mounted on an arbor) to which are bolted several thin, steel saw segments along its periphery. In this way the kerf is con-

siderably less than that of a conventional circular saw blade of similar size. Despite this, about half of a fitch is reduced to sawdust in the production of  $\frac{1}{20}$ -in. veneer.

**6. Veneer Thicknesses.** Veneers are cut in a wide variety of thicknesses ranging from  $\frac{1}{110}$  to  $\frac{3}{8}$  in. Most of the rotary veneers are either  $\frac{1}{7}$ ,  $\frac{1}{8}$ ,  $\frac{1}{10}$ ,  $\frac{1}{16}$ , or  $\frac{1}{20}$  in. thick. During the Second World War, rotary-cut mahogany veneers  $\frac{1}{64}$  in. in thickness were used in the manufacture of wing skins for aircraft. Sliced veneers usually range from  $\frac{1}{20}$  to  $\frac{1}{40}$  in., but the bulk of face veneers so cut are either  $\frac{1}{20}$  or  $\frac{1}{28}$  in. in thickness. The very thin sheets of Spanish cedar used to wrap fine cigars individually and some other specialty veneers are often only  $\frac{1}{100}$  to  $\frac{1}{110}$  in. thick.

Sawed veneers vary from  $\frac{1}{4}$  to  $\frac{1}{32}$  in. in thickness, with  $\frac{1}{20}$ -in. stock being the most common.

## B. VENEER DRYING

Freshly cut veneers are ordinarily very wet and in that condition are wholly unsuited for gluing. Moreover, while green they are readily susceptible to the attack of molds, and of blue-stain and wood-destroying fungi. It is necessary, therefore, that excessive moisture be removed from them as rapidly as possible, consistent, of course, with good drying practices. Exception to this general rule may be found in the basket industry. Since wood is much more pliable when it is wet, it may be bent to much sharper curvature without danger of rupture. Hence the basket manufacturer commonly works with wet veneers and dries them only after the product is fabricated.

Several methods for drying veneers are in common use. The selection of one of them for any given plant is usually dependent upon the ultimate use of the stock, and the facilities available to the manufacturer.

**1. Air Drying.** The cheap grades of rotary (and occasionally sliced) veneers used for fruit and vegetable crates, egg cases, and packing-case materials are sometimes dried in the open. In such instances they are dried merely enough to prohibit the growth of fungi and to reduce shipping weight. When air drying is practiced, the sheets are laid up between tiers of stickers or loosely stacked on end in finger racks in order to permit free circulation of air over their surfaces.

**2. Loft Drying.** A loft is a well-ventilated room with or without humidity control. Wet sheets of veneer are hung on clips from rafters or edge-stacked in finger racks. Here they remain until the moisture content stabilizes at from 12 to 15 per cent. In drying thin sheets of the order of  $\frac{1}{20}$  in. in thickness, only a day or two is required to bring the moisture content down to within these limits.

3. **Kiln Drying.** The conventional progressive-type lumber kiln is also used in drying veneers; usually several sheets are bulked between each tier of stickers. One plant in North Carolina producing  $\frac{1}{8}$ -in. rotary red gum veneer bulks 10 sheets between stickers and dries them to a 6 per cent moisture content in 48 hours.

4. **Veneer Driers.** At the present time most veneers are dried in carefully designed and engineered driers that permit of rapid and uniform

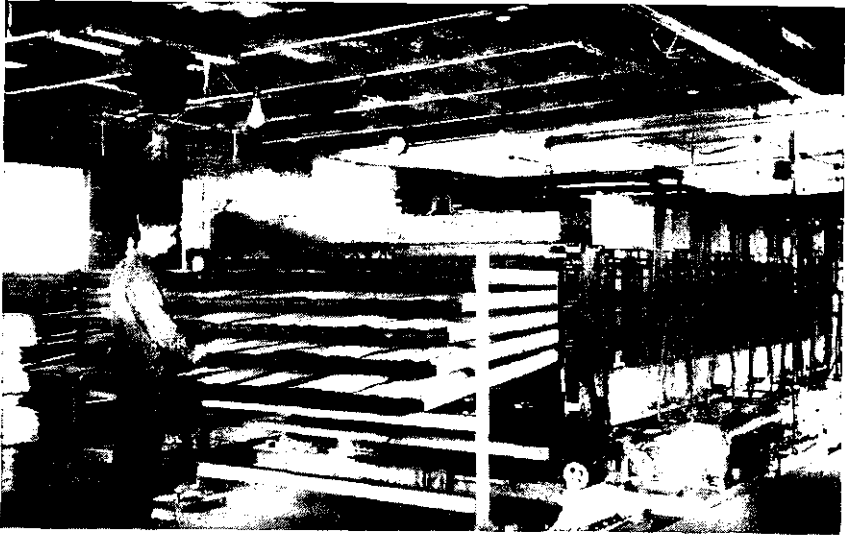


FIG. 8-8. Five-deck conveyor drier. (Courtesy Merritt Engineering and Sales Company, Inc., Lockport, New York.)

seasoning without adversely affecting the sheets. Two types of such equipment, *viz.*, conveyer driers and hot-plate driers, are in common use.

Conveyer driers are chambers 50 to 100 ft. or more in length, fabricated of sheet metal and suitably provided with heating equipment and two to six banks of power-driven rolls or belts to move the veneers longitudinally through them. The rapidity with which veneer passes through driers of this sort is dependent upon numerous variables such as (1) original moisture content of the wood, (2) manner in which veneers were cut, (3) veneer thicknesses, (4) degree of dryness required, and (5) efficiency and length of the drier itself.

Hot-plate driers consist of a bank or battery of heated platens. Sheets of veneer are placed on the upper faces of the platens and then the platens are brought together to keep the sheets flat while drying. During the drying interval the platens are intermittently opened and closed to allow

moisture to escape as it is driven from the wood. Driers of this kind are very effective, but they have a smaller capacity than those of the conveyor type. However, when floor space is at a premium they are to be preferred.

Still another type of modern drier combines the use of platens and conveyers. In installations of this kind, paired rolls alternate with heated platens and the veneers are advanced by the rolls to each succeeding pair of platens. Good flat veneer is produced in this manner, but these driers lack the high capacity of continuous types.

### C. THE VENEER INDUSTRY

A large variety of woods, both foreign and domestic, is utilized in the manufacture of veneers, but more than half the total annual American output is comprised of red gum (sweet gum) and Douglas fir. In considering the industry as a whole it is necessary to note that a distinction is made between the *hardwood-* and *softwood-*veneer industries because of the marked differences in utilization of their products. In the hardwood-veneer industry a further distinction is made between (1) face veneers, (2) commercial veneers, and (3) veneers for containers.\*

**1. Face-veneer Manufacturers.** These usually limit their activities to the production of sliced, sawed, or stay-log fancy face veneers from carefully selected logs, burls, crotches, and stumps. Such materials are usually handsomely figured and are used as facings for plywood panels employed in the fabrication of furniture and pianos and for interior decorative paneling.

There are more than 50 manufacturers of face veneers scattered through the Ohio and Mississippi river valleys and adjacent territories, the Lake states, and in large cities along the Atlantic seaboard.

The manufacturer of face veneer cuts his raw materials as received and builds up sizable inventories which are stored in well-ventilated warehouses. After a flitch is cut and the veneers dried, the sheets are bulked in sequence and the flitch is given an identifying number. Samples, normally consisting of three sheets, one taken from near the top of the flitch, one from about the middle, and another from near the bottom, are marked with the identification number of the flitch, total square-footage content of veneer, and the number of pieces included in the package. These samples are then sent to salesmen who sell the entire flitch based upon these samples. The importance of preserving sheet sequence of face stocks now becomes evident. The buyer, upon examining the sample sheets, can determine the

\* The discussion of the hardwood-veneer industry is based in part on "The Veneer Industry," Educ. Ser. 2. The Veneer Association, Chicago, Ill.



degree of uniformity of figure in the entire fitch and its suitability for his needs. A uniform figure is essential to the manufacturer who matches veneers to produce highly figured panels. A prospective buyer can also determine length, width, and thickness of sheets, variation in color, and smoothness of cut from properly selected samples of this kind.

In normal times some 80 or more kinds of face veneers are offered to the trade. Importation of exotic woods was greatly curtailed during the Second World War, and many stocks have long since been exhausted; several new species, however, have been introduced in the postwar era.

**2. Commercial-veneer Manufacturers.** Commercial veneers, or "utility" veneers, are those used for cross bands, cores and backs of plywood panels, and concealed parts of furniture such as drawer bottoms, case and mirror backs, and dust sealers. These are rotary-cut and are made from several species of domestic hardwoods. Manufacturers of commercial veneers are usually located near adequate supplies of suitable timber. Beech, birch, maple, and basswood veneers are produced in large quantities in Wisconsin, Michigan, and New York. Red gum (including sap gum), yellow poplar, cottonwood, tupelo, sycamore, and oak veneers are made in many Southeastern plants from the Ohio River region to the Atlantic and Gulf coastal plains.

Unlike the manufacturer of face veneers, the manufacturer of commercial veneers cuts on order, in which species, thickness, sheet size, and grade requirements are specified. A few plants, however, restrict their production to sheets of standard size. Most commercial veneers are sold to furniture, piano, or radio manufacturers who make their own plywood or to plywood plants that build stock panels or manufacture panels to customer specifications. In several instances a veneer plant is but a part of a large mill manufacturing plywood panels, in which case the entire output of veneer is consumed in the fabrication of panels within the mill.

**3. Container-veneer Manufacturers.** A wide variety of cheap veneers suitable for crates and packing cases, hampers, fruit and vegetable baskets and kits, meat, butter, and picnic dishes, cheese boxes, drums and hoops, and other similar items are classed as container veneers. Plants manufacturing them are usually established proximate to adequate supplies of cheap timber and suitable markets.

**4. Softwood-veneer Manufacturers.** The production of softwood veneers is concentrated along the Pacific rim, where a number of large and modern plants are engaged in the production of Douglas fir, Sitka spruce, ponderosa pine, sugar pine, and western white pine veneers. While the vast bulk of these veneers is rotary-cut, some quarter-grain Douglas fir and Sitka spruce veneers are also made. In the Southeastern United States, bald cypress and some of the southern yellow pines are used to a very lim-

ited extent in the production of core stock for use with hardwood face veneers.

More than 80 per cent of all softwood veneers manufactured in the United States are made from Douglas fir. The Douglas fir industry has made tremendous strides during the past decade, and in the year preceding V-E Day had expanded its facilities to the point where it was capable of producing more than seven billion square feet of veneer annually.

Douglas fir veneer is used almost entirely for the fabrication of structural and interior plywood. Some container veneers are manufactured of Sitka spruce and western pines. These find a ready market in the citrus industries of California and with the hard and soft fruit growers of the Pacific Northwest.

## II. PLYWOOD

### A. MANUFACTURE OF PLYWOOD

The manufacture of a plywood panel consists of (1) preparing faces, cross bands, and cores; (2) edge-gluing narrow pieces to form large sheets when required; (3) lay-up and spreading of adhesive; (4) pressing the glued lay-up into a panel; (5) drying the panel; and (6) finishing the panel.

**1. Preparation of the Stock for Gluing.** Unless veneers are dried to a very low moisture content and used immediately, it is customary to redry them when they are removed from storage prior to the gluing operation. Redrying is accomplished ordinarily by means of platen driers, consisting of a series of smooth, flat, steam-heated platens which alternately close and open to allow moisture to escape from the surface of the wood. More recently the progressive platen driers, already described, have also been successfully employed for redrying. Veneers are usually redried to 5 per cent of moisture or less if liquid glues are used. In the case of fragile veneers such as burls and crotch, the moisture content is rarely reduced below 10 per cent. When sheet glue, such as Tego film, is used, the moisture content of veneer should range from 10 to 12 per cent in order to ensure an adequate flow of the resin during the bonding cycle.

The next operation consists in trimming the veneers to dimensions somewhat longer and wider than the finished product. With the less expensive face veneers, as well as in the case of the core and cross-banding materials, the rough ends and edges may be most economically trimmed with a band or a circular saw, using bundles of sheets approximately 1 in. in thickness in one trimming operation. The more expensive face and back veneers are cut to dimensions by means of veneer clippers, in which usually one sheet is trimmed at a time.

The clipping operation requires considerable judgment on the part of the

operator, since the value of fancy face veneers depends largely on the figure they will produce. In cutting face veneers the clipper operator must keep in mind six general classifications into which face veneers fall. The *one-piece face* consists of a single unmatched sheet of veneer. The width of one-piece face veneer, if sliced or sawed, is limited by the width of the flitch, while in *rotary-cut veneer*, face veneers of any width can be had. The *two-piece, center-matched face* (also called *book-matching*), is produced by splicing two pieces of veneer of equal width in such a manner that a bilaterally symmetrical figure results. The balanced effect of figure is obtained by reversing one sheet of veneer in order to bring the corresponding part of the design together at the center; this necessitates having one half of the veneer loose side up. *Balanced joints*, as the term indicates, are veneers cut so that when two or more sections are joined they will form a symmetrical figure. Contrasted with that are *random joints*, *i.e.*, pieces which are used unbalanced for figure. *Faces selected for color* are faces in which either light or dark colors are desired; the remaining portions of the veneer sheets are either used for backs or wasted. *Sap no defect* is a term which indicates that the lighter colored sapwood in the veneer sheet is allowed in the face.

For plywood backs two general grades are recognized: (1) the *sound back*, *i.e.*, veneers free from defects but unselected as to color and figure; (2) the *reject back*, used in places concealed from view, *e.g.*, the underside of table tops. Such backs will include a number of defects, the kind and number of which are usually written into the buyer's specifications.

The clipped sheets of veneer are next put through an edge jointer to ensure perfectly tight and imperceptible joints in the finished plywood. Usually a stack of veneers, 1 to 8 in. in thickness, is *jointed in one operation*. The usual type of veneer jointer is equipped with a rapidly revolving traveling cutterhead, containing up to 16 knives. Some manufacturers prefer to use a combination of jointer and clippers, which cut all four sides in one operation.

The face veneers are then taken to the matching table. Considerable experience and patience, as well as artistic ability and imagination, are required to produce the best effect in matched veneers.

When the matcher selects two pieces of veneer to be joined, he butts them together along their dressed edges and holds them firmly in place with gummed tape or with a film of glue spread along the joint. This operation is known as *splicing* and may be done manually but is accomplished more efficiently on specially designed machines known as *splicers*, two general types of which are now in current use.

In a tape-splicing machine two sheets of veneer to be spliced are fed through a paired series of live rolls, the shafts of which are angled in such a manner that the two pieces of veneer are butted firmly together as they

pass across the table. Suspended above the table is a roll of gummed tape. This tape is passed over a moistening device and under the rolls to the joint. An electrically heated roll sets and dries the tape while it is pressed firmly against the veneers. If in the manufacture of a panel three or more pieces of veneer are required to attain sheet width, a workman, the off-bearer, slides the pair of taped pieces back across the table to the operator who, in turn, tapes a third piece to the sheet. In this way sheets of large widths consisting of several individual pieces are readily made. Tape may be either of cloth or paper. It is invariably applied to the "finish side" of the sheet, later to be sanded off the panel during finishing operations.

The tapeless splicer is a more recent development and permits the joining of individual sheets of veneer without the use of tape. Its chief advantage over the tape machine lies in the fact that there is no tape to sand off the faces of panels after their manufacture. There is also a notable saving in tape costs. Tapeless splicers are very similar in design to the conventional tape machines. In one type, the edges to be joined are led over a glue spreader just in front of the heating rolls. In another, the edges of sheets are precoated with a suitable adhesive prior to joining. When fed into the machine the coated edges of the veneers pass over a formaldehyde wick or one with some other suitable moistening agent and are then bonded in the usual manner as they pass through heated pressure rolls.

A core may be a single sheet of veneer, several sheets of veneer suitably bonded together, or lumber. The best core woods are those of moderately low density and good dimensional stability. Uniformity of grain and ability to take glue are other important considerations. When lumber is used in making cores, edge-grained stock, because of its greater stability, is to be preferred over flat-grained stock. In high-grade plywood the most common woods are yellow poplar, red gum, birches, soft maple, and sound, wormy chestnut.

The stock for lumber cores is usually dried to a moisture content of about 5 per cent, then surfaced and ripped into strips  $\frac{3}{4}$  to 4 in. in width. All major defects are removed in the resaw operation. The strips are edge-glued together and placed in clamping devices until the adhesive has set. In some of the more modern plants use is made of continuous core-making machines. Machines of this sort have been "on the job" designs, and several of them are very efficient and economical to operate. Lumber cores usually absorb appreciable moisture from adhesives during the lay-up, hence must be redried after glue is cured.

Cross bands are used to balance and equalize stresses in plywood, and they play a significant role in reducing warpage and dimensional changes occasioned by fluctuating atmospheric conditions. Cross bands also minimize checking in thin faces which, if they were bonded directly to a thick

core, would be unable to withstand the mechanical stresses developed during periods of excessive swelling or shrinkage. Yellow poplar is regarded by many in authority as the best American cross-band material.

**2. Spreading.** The next phase in plywood manufacture is the bonding together of the various elements to form a panel. This is accomplished by spreading an adhesive on the faces of core or cross bands or interleaving

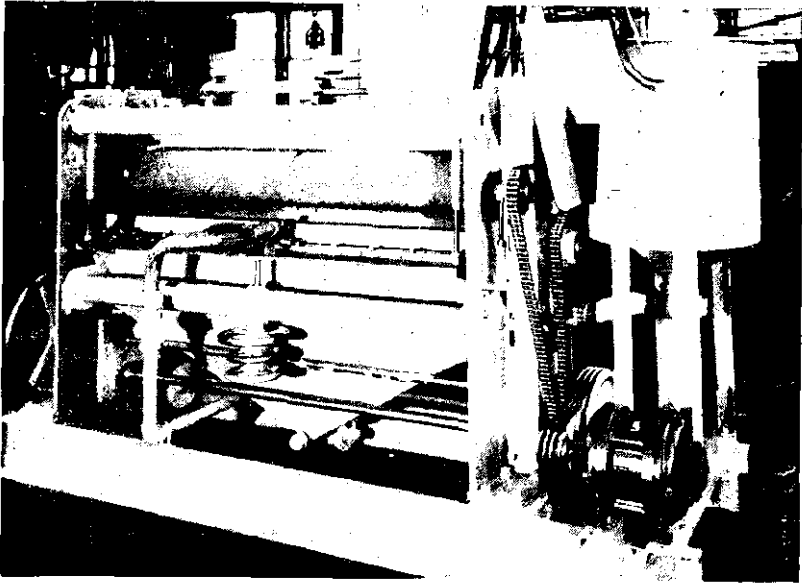


FIG. 8-9. Glue mixer and spreader. (Courtesy Merrill Engineering and Sales Company, Inc., Lockport, New York.)

the individual layers of wood with sheets of dry glue film and then pressing them firmly together with or without heat as required until the glue is cured. In small operations, liquid adhesives may be brushed on by hand, but in plants of large capacity the operation is mechanical. Figure 8-9 illustrates a modern mechanical glue spreader. Fundamentally it consists of two power-driven rollers, each of which rotates in a bath of an adhesive. The rollers may be adjusted to accommodate veneers of varying thicknesses. The supply of glue to the rollers is controlled by means of an adjustable pressure bar or doctor blade, and any liquid adhesive with good spreading characteristics may be used in machines of this and similar design. As the veneers pass through the spreader they are laid up in conformance with good manufacturing procedures, and the resulting assemblies are then placed in presses until cure of the adhesive has been effected. Full explan-

tions of lay-up and pressing techniques are presented in subsequent sections under cold-pressing and hot-pressing procedures.

**3. Adhesives.** Adhesives suitable for the manufacture of plywood and laminated structures must be of such a nature that they may be easily and uniformly spread over large surfaces, and if extenders are used, be compatible with them. They must not impart objectionable stains to veneers, particularly to face stocks, nor should they lose their bonding capacity with age after cure. They must also resist insect attack and the action of bacteria and fungi. In many instances it is also mandatory that they be highly water-resistant. Relative costs are also important, and in some instances these alone will influence a manufacturer in his choice of an adhesive. Comparatively few adhesives possess all these qualifications, but there are several in any one class that are suitable for particular applications.

Six classes of adhesives are currently used in plywood-panel construction, *viz.*, (1) animal glues, (2) starch glues, (3) vegetable-protein glues, (4) blood-albumen glues, (5) casein glues, and (6) synthetic-resin adhesives. A seventh class, the liquid fish glues, may be added, although their use in plywood manufacture is limited largely to repair work.

Animal and fish glues, and perhaps also blood-albumen glue, are of rather ancient origin. In fact, it is only in the past 40 years that serious competition to animal glues has developed in American woodworking industries. Starch glues appeared on the market about 1908, while casein adhesives were developed on a commercial basis during the First World War. Vegetable-protein glue, a soybean derivative, appeared on the market about 1923. Blood-albumen glues have been popular in European shops, but they have enjoyed only limited use in the American industry, and then they were restricted largely to use in the manufacture of water-resistant panels. The first of a large and now diversified series of synthetic-resin adhesives was placed in American markets about 1935. The Second World War saw the rapid development of resins of this type, and in the short space of a dozen years their use in the American plywood industry has become quite general. It would be erroneous to conclude, however, that synthetic resins have entirely replaced other types of adhesives, since large quantities of animal, starch, protein, and casein glues are consumed annually in many plywood fabrication plants.

*a. Animal Glues.* Animal glues are derived from the hides, bones, and fleshings of cattle, horses, sheep, and other beasts; they are usually offered to the trade in sheet, cake, flake, or powdered form. In preparing animal glue for use, the dry glue should be poured slowly into pure cold water, using a ratio of glue and water in accordance with the manufacturer's specifications. When possible the mixture should be permitted to stand

overnight. After softening in this manner the mass must be heated in a double boiler or jacketed gluepot at a temperature not to exceed 140°F. and maintained at this or a slightly lower heat level during gluing operations. Experience has revealed that best results are obtained when the surfaces to be bonded are preheated or at least the workroom is maintained at about 80°F. during the bonding period. Animal glue is essentially an all-purpose glue, in spite of certain inherent weaknesses. Joints made of animal glues are far from being waterproof or heatproof, although under normal atmospheric conditions, joints bonded with a good grade of such an adhesive will give many years of satisfactory service.

b. *Starch Glues.* Starch glues, known in the trade also as vegetable glues, are water-soluble materials made largely from starch obtained from the roots of cassava (*Manihot utilissima* Phol., et al.), which are also the source of commercial tapioca. Starch glues, for the most part, are offered to the trade either in the form of a dry powder composed of blended grades of cassava flour with incorporated converting chemicals or as a flour or blend of flours to which the consumer adds a quantity of caustic soda at the time of mixing in accordance with the manufacturer's recommendations. When dry and properly protected, these glues have an almost indefinite storage life. They are cheap and very simple to prepare for use. The cured glue produces tough, strong joints of enduring strength, except when high humidities prevail. Under unfavorable conditions of exposure, starch glues are also readily subject to the ravages of insects and fungi. Vegetable glues are thick, viscous fluids wholly unsuitable for brush or spray, hence must be used with mechanical spreaders. Since they set up quickly at room temperatures, the assembly time\* should never exceed 15 minutes if maximum bond strength is mandatory. Good joints are obtained with pressures of from 75 to 100 p.s.i. Elevated temperatures are not required for curing adhesives of this kind, and the bonded materials may be removed from press or clamps in safety after 8 to 16 hours, depending upon the degree of wetness of the adhesive at the time of spreading. In most instances it is necessary to redry panels made with starch glues because of excessive amounts of water introduced into the wood at the glue line in the spreading operation. Redrying may be done either in low-temperature kilns or by open-piled air drying until test specimens reveal that the moisture content of such panels is 6 to 10 per cent.

c. *Casein Glues.* Casein glues, as previously indicated, were developed commercially during the First World War, although the use of casein as an adhesive has been traced back to the Middle Ages. Casein, a derivative of skimmed milk, is obtained by adding a quantity of acetic or some other

\* The elapsed time between beginning of the spread and application of full pressure on the joint.

acid to milk and heating the mixture to about 100°F. This procedure sours the milk and permits rapid separating of the curd and whey. The curd is thoroughly washed and dried and then reduced to the consistency of wheat flour. Proprietary casein glues are offered to the trade as dry powders consisting of a standardized mixture of casein, hydrated lime, and certain alkaline solutions or salts. There are numerous glues of this sort, each compounded for some specific use; *e.g.*, some will permit of long assembly periods, while others may be more highly water-resistant. In use they are merely mixed with water in proportions recommended by the manufacturer.

A second group of casein adhesives, the *wet casein mixes*, are made by the plywood manufacturer by mixing raw casein powder with water, lime, and other ingredients to make a satisfactory adhesive for his particular needs.

The casein glues are suitable for many purposes. Many formulations are highly water-resistant, but joints made of them weaken materially if subjected to prolonged immersion in water; hence this type of adhesive is not a suitable bonding agent for boat hulls or for construction continuously exposed to excessively high humidities. Like starch, casein is also an organic material which will deteriorate in the presence of certain fungi unless fortified with suitable toxic agents. Best results are obtained with assembly periods of 20 minutes or less. About 6 to 8 hours of press or clamp time and pressures of from 75 to 100 p.s.i. are required to develop good bond strength. Casein glues are somewhat more versatile than most wood-bonding adhesives. They may be mixed and spread at considerably below normal room temperatures. They also exhibit good gap-filling characteristics and therefore are capable of producing good bonds on rough surfaces, even when the glue line itself is excessively thick. Because of their alkalinity they are especially suited for bonding oily woods such as teak and the southern yellow pines.

*d. Soybean Glues.* Soybean glues made their appearance about 1923, and by 1926 manufacturers of structural Douglas fir plywood were using them in ever-increasing quantities. The best formulations are very water-resistant, and their cheapness is another point in their favor. Soybean glues are supplied as yellowish powders and are comprised of soybean meal in admixture with hydrated lime, caustic soda, sodium silicate, and a water-proofing ingredient. Plywood manufacturers preferring to prepare their own liquid mix procure the various ingredients from reputable sources and blend them in accordance with schedules they themselves have developed.

Soybean glues have none of the tacky properties exhibited by adhesives previously mentioned but more nearly resemble wet plaster or cement in their flow characteristics. They are readily applied, however, in mechanical spreaders and may be cold-pressed or hot-pressed, at the discretion of



the manufacturer. Thick, paste-like mixes, *mastics*, are also used if hot-pressing is employed. Mastics may be spread mechanically with characteristically grooved rolls which deposit many small, continuous beads of glue on the surface of the wood. Later these flow together with the application of heat and pressure.

Veneers to be bonded with soybean glues should have a very low moisture content, preferably below 5 per cent. If cold-pressed, a maximum assembly period of 25 minutes is permissible; when hot-pressing is employed, the allowable assembly time should not exceed 15 minutes. It is recommended that from 60 to 70 lb. of liquid glue be used per 1,000 sq. ft. of glue joint in cold-pressing, whereas 50 lb. of glue appears to be adequate when plywood is hot-pressed.

*e. Blood-albumen Glues.* Blood albumen, or dried blood, an important by-product of abattoirs, has been used with varying degrees of success as the basic constituent of a highly water-resistant glue and as an extender for other adhesives such as soybean, casein, and more recently some of the synthetic resins. Blood-albumen glues were developed with the advent of the First World War in an effort to obtain moisture-resistant adhesives suitable for aircraft fabrication of that period. Comparatively little glue of this type has ever been used in the United States, although substantial tonnages of dried blood were being exported to the Scandinavian countries and neighboring states prior to the Second World War.

Blood-albumen glues, if properly blended, offer great resistance to both hot and cold water but must be hot-pressed to form satisfactory bonds. The small number of hot presses<sup>10</sup> available in the United States prior to 1935 was probably a prime limiting factor in the use of glues of this type. Inherent disadvantages of glues of this sort are that their bond strength is appreciably affected in aging and that to date no suitable means has been devised whereby they may be mixed dry with other essential chemicals and placed on the market as proprietary adhesives that may be easily prepared for use by merely mixing with water in the correct proportions. There are numerous mixes for these glues which include, in addition to the dried blood, such chemicals as ammonium hydroxide, paraformaldehyde, and hydrated lime.\* Dried blood used as an extender in casein glues definitely improves their water resistance, but when similarly used with phenol-formaldehyde resins, the bonds, although wholly satisfactory for many purposes, are nevertheless somewhat inferior to those made with unadulterated resin.

*f. Synthetic-resin Adhesives.* Synthetic-resin adhesives were used first commercially in European plywood plants, and it was not until 1935 that

\* For details of blood-albumen glue formulations see T. D. Perry, *Modern Plywood Adhesives*, Chapter 7, Pitman Publishing Co., New York.

Tego, a phenol-formaldehyde resin in dry sheet form, became available in commercial quantities in the United States. This was followed by several other types of resin adhesives. During the Second World War the production of synthetic-resin adhesives was greatly expedited, and today there are many formulations of the several basic types available to the trade. Their acceptance and utilization by the woodworking industries of America has become so general that old-line, well-established manufacturers of animal, starch, casein, and soybean glues are now marketing many resin compositions under their own trade or brand names.

The synthetic-resin adhesives are of either the *thermosetting* or the *thermoplastic* types. Thermosetting adhesives are those which, when cured under heat and pressure, "set" or harden to form films of great tenacity and strength. The reactions during the curing cycle of such adhesives are irreversible, *i.e.*, upon total cure, repeated applications of heat will in no way soften the bonding matrix. By contrast, thermoplastic adhesives are those which remain soft until cooled. The reaction is reversible to the extent that upon reheating the resin will again soften, only to harden once more as it is cooled.

Up to the present time thermoplastic-resin adhesives have had only a limited application in the plywood industry, where they have been used successfully in making molded panels by the bag-molding process. Resin adhesives of this sort are chiefly of the polyvinyl butyral and vinyl acetyl types. They cure at room temperatures and form good bonds with less pressure than is usually required for the thermosetting adhesives. There are a number of factors, however, that seriously limit their use. They have no great heat resistance, and bonds are materially weakened in situations where atmospheres surrounding them approach 150°F. Some also have tendencies to creep and flow, which make them totally unsuited for many plywood applications. Perry<sup>13</sup> indicates that their use in the fabrication of models and mock-ups is very advantageous, since the designer may release and reset parts or pieces of his creation at will. It appears, however, that there is little likelihood of thermoplastic-resin adhesives ever becoming serious competitors with thermosetting types in the plywood industry.

There are two very important classes of thermosetting-resin adhesives currently employed in the American plywood industry, *viz.*, (1) the phenol-formaldehyde series and (2) the urea-formaldehyde group. Resorcinol-formaldehyde and melamine-formaldehyde resins are suitable for bonding wood but because of their higher costs are used only in limited quantities and then usually for special applications.

As previously indicated, the first phenol-formaldehyde resin used in the United States was marketed in dry sheet form. Upon close examination one finds that it actually consists of a very thin sheet of tissue-like paper

suitably coated on both sides with uncured resin. When it is placed between two layers of wood and hot-pressed, moisture released from the wood softens the resin and subsequently facilitates its penetration into the interstices of the elements being bonded. Phenol-formaldehyde-resin adhesives are now available in either liquid or powder form. The liquid resins may be spread as received or diluted with solvents and mixed with extenders in accordance with manufacturer's recommendations. The powder forms are prepared for use by mixing them with water, alcohol, acetone, or combinations of these solvents, in proportions recommended by the manufacturer. Some few formulations call for a catalyst, but usually it is not necessary to employ one with resins of this sort. The earliest phenol-formaldehyde-resin adhesives required comparatively high temperatures (260 to 320°F.) to effect their cure in a reasonable period of time; later, warm-setting phenolics (110 to 240°F.) were placed on the market, and even more recently, cold-setting (70 to 110°F.) resins of this type have been made available to the consumer.

It is beyond the scope of this discussion to describe the many types of phenol-formaldehyde-resin adhesives on the market today. Some have been developed especially for bag-molding work, others to permit of long assembly periods necessitated by difficult fabrication, a few have been formulated especially for use in radio-frequency bonding, while still others have been compounded to resist the corrosive action of sea water.

Extenders or fillers are used sparingly with these resins. Walnut-shell flour or dried blood appear to be more compatible with the phenolics than do the amylaceous (starch or flour) types of extenders.

Temperature, allowable assembly periods, press time, and pressure requirements for phenolic-resin adhesives vary with their source. Users of such adhesives should adhere strictly to the manufacturer's recommendations for best results. Resins of this type are particularly well suited for primary gluing operations, *i.e.*, in the production of flat and molded plywood. When properly cured in keeping with good manufacturing procedures, they form excellent heat-, water-, and fungi-resistant bonds of great strength and endurance.

Urea-formaldehyde-resin adhesives were developed as the result of industry's insistence on a resin-type adhesive with a wider sphere of usefulness than the hot-setting phenolics then available and one that would cure at a much lower temperature. The earliest formulations of this type required curing temperature of about 200°F., but shortly thereafter the so-called "cold-setting" ureas made their appearance. To the manufacturer unable or unwilling to obtain hot-press equipment, here was an adhesive of the resin type that could be used with the physical facilities at his disposal. It should be clearly borne in mind, however, that the term "cold-

setting" is a relative term, as, in the restricted sense at least, there is no real cold-setting resin. The polymerization or total cure of any resin film is merely a time-temperature relationship; thus those that will cure at room temperature in 8 to 16 hours will also completely polymerize in a matter of minutes at higher levels of heat.

The urea resins are offered to the trade in powder or liquid form, usually with separate catalyst or hardener. In some of the more recently developed dry urea resins, the catalyst is incorporated. There are many proprietary resins of this kind on the market today. Some are compounded expressly for use in cold-pressing, while others are specially prepared for hot-press work. As a group, and except in instances where maximum bond strength is requisite, urea resins are usually extended with varying amounts of rye or wheat flour or occasionally with tapioca-starch flour. Large quantities of extender will, of course, lessen strength and durability of bonds, but where they may be used with safety they also reduce glue-line costs. Straight urea bonds are not adversely affected by cold water or the presence of fungi; however, they deteriorate to some degree in hot water or at high temperatures. It has been determined that the urea resins fortified with melamine produce bonds of excellent strength and durability, and a number of such formulations are now available to the consumer.

The resorcinol-formaldehyde-resin adhesives were introduced to the plywood industry in 1943. They are usually supplied in liquid form with separate catalyst and were first among phenolic-type adhesives capable of cure at room temperatures. These adhesives are considerably more expensive than the straight phenolic resins. During the Second World War they were used to a limited extent in secondary gluing in aircraft and watercraft. Recently they have been used in laminating large structural members. Perry<sup>12,13,14</sup> indicates that they are readily adaptable for use with radio-frequency heat.

Melamine-formaldehyde-resin adhesives have a limited use in plywood fabrication. They exhibit, except for color, many of the physical characteristics of the phenolics, particularly with respect to heat resistance and durability. At present they are offered to the trade in dry powder form, since liquid mixes have been found to be very unstable. They are readily cured at low temperatures and are compatible with most of the common extenders. At present their cost, which is higher than that of either the urea or phenolic types, is a limiting factor in their use.

*g. Extenders.* These are usually cheap, inert materials commonly added to certain liquid resins, particularly those of the urea type with which they are very compatible, to increase their bulk. Extended resins may be spread over significantly larger areas than those that are not extended and not only

reduce materially glue-line costs but also, in many instances, stop "bleed-through" of the resin as well. The common extenders are wheat and rye flour and walnut-shell flour; tapioca flour is also occasionally used. Soluble dried blood is sometimes added to some of the phenolics to improve their flow characteristics. This substance acts not only as an extender but also as a supplementary bonding agent when hot-pressed in the conventional manner. It has been determined that the stability of powder resins with incorporated catalyst may be improved if a small quantity of extender is added to the mixture. Many adhesives extended with 10 parts of flour to 100 parts of resin appear to develop bonds equal in durability to the unextended resin. Mixtures containing as much as 100 parts of flour produce bonds of better-than-average water resistance and strength. Resins extended with more than 150 parts of flour may be made at great sacrifice in water resistance and for purposes of economy. No proprietary resin adhesive, however, should be extended without first consulting the manufacturer for his recommendations.

**4. Panel Assembly.** The amount of an adhesive, *i.e.*, the thickness of spread required to produce good plywood, varies with the type of bonding agent employed. In spreading, an adhesive should cover the entire joint area uniformly and completely and be devoid of air bubbles and foreign matter. It is consistent with good gluing practice to use no more than the required minimum of an adhesive in making a joint. A surplus of glue in no way improves joint strength; in fact, thick glue lines should be avoided, as they are usually more dangerous than glue lines with insufficient spread. When starch glues are used, the spreader rollers should be so adjusted that 1,000 sq. ft. of glue-line area may be spread with 75 lb. of the liquid mix. Spreads of 60 to 75 lb. are recommended for casein and 60 to 70 lb. for soybean. From 30 to 40 lb. of straight or extended resin is the usual spread for urea-type resins, while 25 to 35 lb. is ample for those of the phenolic type. Directions for spreading are furnished by the supplier and should be carefully adhered to for best results.

The elapsed time between the beginning of a spreading operation and the application of full pressure upon the glue lines of a plywood panel or batch of panels pressed simultaneously is known as the *assembly time*, or *period*. The rapidity with which an adhesive begins to "set up," or cure, is of primary importance to the manufacturer of plywood. If there is an appreciable hardening of the glue on the surfaces of the wood before full pressure is applied to the joint, flow of the bonding agent is retarded, thick glue films result, and in consequence adhesion is greatly reduced. Similarly, if the glue is too thin and it is not permitted to thicken somewhat before pressure is applied, excessive "squeeze-out" and excessive absorption of the resin by the wood occurs and a starved joint results. It is readily ap-

parent that careful control over assembly is mandatory if high-grade plywood is to be produced. Maximum assembly periods for the starch glues should never exceed 15 minutes. Casein adhesives have a maximum assembly period of about 20 minutes, but better results are obtained in half that time. Soybean glues permit of a 15- to 25-minute assembly period if cold-pressed, 5 to 15 minutes if hot-pressed. The assembly period for the synthetic-resin-type adhesives varies from a few minutes to several days, depending upon the characteristics of the resin employed.

**5. Pressing.** After the veneers are spread in accordance with good shop practice, the plywood assemblies are ready for pressing. Depending upon the type of adhesive used, pressing may be accomplished at room temperature or at raised temperatures. The former is known as *cold-pressing*, the latter, *hot-pressing*. Cold-pressing generally is practiced with starch, casein, animal, and most soybean adhesives and with some of the urea-type resins. Hot-pressing equipment is used in curing blood-albumen and a few soybean glues, several urea-type resins, and the phenolic-type resins. While resorcinol-formaldehyde resins will cure at room temperatures, better bonds are obtained if they are hot-pressed.

There are two general types of cold presses, *viz.*, hand-screw presses and power presses. Hand-screw presses are used in small shops or (in large plants) for special work where production is limited or where the panels are of such an irregular size that power presses are not practical. Sandbags, lead shot, or lead bars are occasionally used for small lots.

Among the several different power presses to be encountered, the hydraulic press, the power-screw press, and the combination power-screw-hydraulic press are the most common. Hydraulic presses depend upon the action of one or more hydraulically operated rams to lift the lower platen, thus closing the press and applying the pressure. Power-screw presses are equipped with heavy, threaded strain rods upon which the upper platen travels to open or close the unit and to apply or release the pressure as may be required. The combination power-screw-hydraulic press makes use of the mechanical-screw system to open or close it and the hydraulic ram to apply pressure. All types are furnished with pressure gauges. In cold-press plywood manufacture, pressures range from 100 to 200 p.s.i. or more, depending upon the kind of wood and the type and consistency of the adhesive employed.

In charging a press the panels are stacked on a strong retaining board. When thick panels are pressed, each assembly is usually placed upon a *caul board*, usually a piece of three-ply,  $\frac{3}{8}$ -in. plywood with waxed surfaces, or a sheet of aluminum. If thin panels are made, two to five or occasionally more assemblies may be placed between cauls. Caul boards are used to assure panel flatness and to guard against injury to the adjacent panel faces

while under pressure. A stack of panels large enough to fill the press to capacity is placed on I-beams resting on the lower platen. A top retainer and second set of I-beams is placed on top of the stack. As the press is closed, retainer clamps are adjusted over the beams' flanges and taken up as pressure is applied. Once full pressure is attained the clamps are given a final adjustment, whereupon the press is opened and the bundle removed.

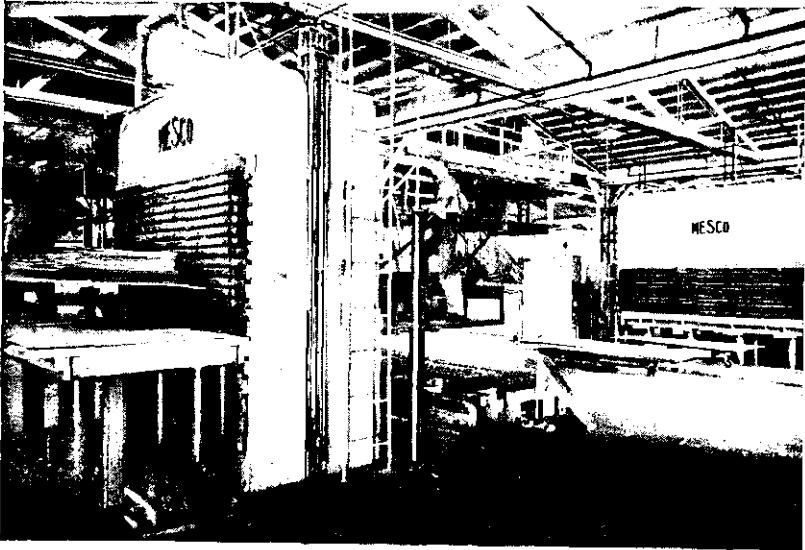


FIG. 8-10. Hot-pressing plywood panels. (Courtesy Merritt Engineering and Sales Company, Inc., Lockport, New York.)

The retaining clamps are left on until the adhesive is thoroughly set up, a period which may vary from 8 to 24 or more hours, depending upon the type of bonding agent used. The bundle is then broken and the panels sent to inspection and finally to the finishing departments.

Figure 8-10 illustrates a modern multiplaten hot press. The press is usually hydraulically operated and the platens internally heated. When hot-pressing is practiced, each panel is laid up between two thin cauls which are usually made of aluminum. A single panel, or occasionally two of them with their cauls, is placed upon each platen. As soon as the press is charged the platens are closed and full heat and pressure are developed as rapidly as possible. Presses of this sort will bond wood satisfactorily in from 2 to 30 minutes, depending upon the thickness of the stock, the distance of the glue line farthest removed from the heat source, the nature of the adhesive, and the curing temperature employed. Platen temperatures

of from 300 to 350°F. are usually employed, and pressures range from 100 to 275 p.s.i., depending upon the species used. Mechanical loaders used to expedite press charging are standard equipment in most hot-pressing departments.

When a press is opened the hot panels are removed, stacked, and permitted to cool and condition for several hours before they are finished. The metal cauls, which are also very hot when removed from the press, must be cooled before they are used in subsequent operations, since a hot caul would cause the bonding agent to pre-cure before full pressure could be applied, thus forming a joint of questionable integrity.

**6. Radio-frequency Bonding.** In recent years radio-frequency heat has been used to cure synthetic-resin adhesives. The underlying principles in the use of high frequency for bonding wood are comparatively simple. According to Berkness,\* all matter is composed of molecules, which in turn are composed of atom combinations. Atoms consist of electrical particles. Each has a positive charge about which negatively charged electrons revolve in fixed orbits. When these atoms are subjected to a high-frequency field, the electrical particles of the atom are alternately attracted and repelled by the rapidly changing dielectrical field. This periodic orbit distortion results in friction which manifests itself as heat.

When a combination of a wood and an adhesive is placed in such a field, the adhesive reaches polymerization temperature while the wood is relatively cooler than it would be in a conventional hot press. In fact, in high-frequency gluing, higher temperatures usually prevail in the glue lines than in the wood facing them, since there is no transfer of energy from a hot platen across a layer or layers of wood to the glue lines. Thus temperatures attained in glue lines are independent of the thickness of stock being bonded, and the curing period for a stack of assemblies 4 in. or more in thickness will be essentially the same as that of a stack only a fraction of an inch thick. In conventional hot-press work, a total thickness not exceeding 1 in. is considered the practical limit.

The use of high-frequency heat in gluing plywood is attended with several advantages. Shorter press times and lower surface temperatures prevail. Actual loss of moisture from the panel is slight, hence conditioning of panels following bonding is unnecessary and there is no necessity for time lapses between bonding and the next succeeding operation. Bonding time is greatly reduced, since bulky stacks may be pressed with the same facility as those containing only two or three panels. Volume production is easier to maintain in plants employing high-frequency heat in bonding.

A number of furniture manufacturers are using high-frequency equip-

\* Berkness, I. R. The High-frequency Method for the Gluing and Drying of Wood Thermal Engineering Corporation. 1940.



ment in their plants. The tendency for flashover and subsequent scorching of panels, a serious drawback to the use of this equipment, has been largely overcome by recently developed resins, prepared specially for use in high-frequency gluing.

**7. Molded Plywood.** Panels with single or double curvature, such as those used in aircraft skins, hulls of small boats, or in some of the most

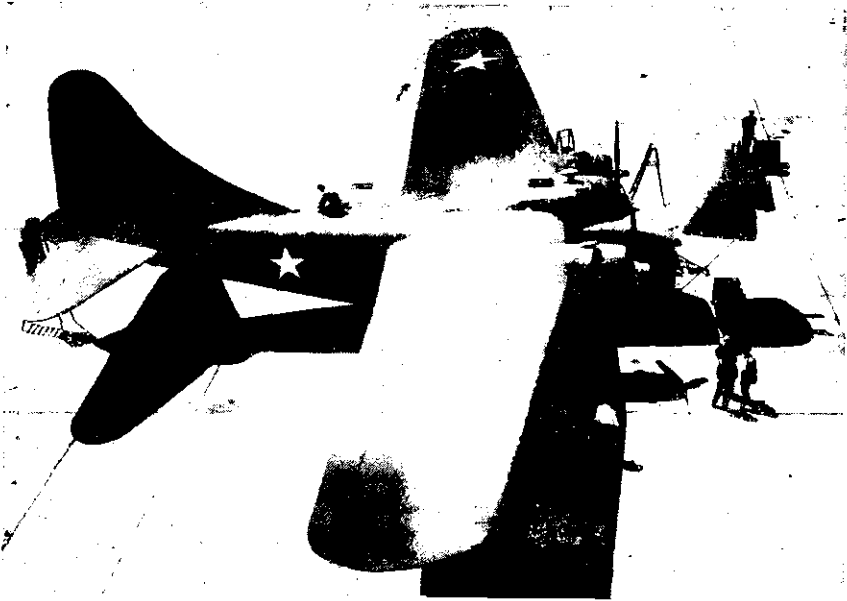


FIG. 8-11. The C-76 airplane, with molded plywood skins. (Courtesy Curtiss-Wright Corporation, Columbus, Ohio.)

modern furniture designs, cannot be made with ordinary pressing equipment. Thus molding techniques have been devised which make use of thermosetting resins and of fluid pressures.

In one molding process, veneers interleaved with film glue or veneers coated with an uncured resin are formed over a male mold of wood, metal, or ceramic material and temporarily held in place with wire staples, tape, or by other suitable means. Such an assembly is then placed in a large flexible rubber bag from which the air is immediately expelled. As the vacuum is drawn, the bag presses firmly against the veneers, causing them to conform to the contour of the die. The deflated bag and its contents are then placed in a large steel autoclave where steam, hot water, or both are admitted under pressure. Adequate fluid pressure is brought to bear in this way over the entire assembly and the heat cures the resin. At the

completion of this cycle the molded item is removed and the operation repeated.

A somewhat similar process employs the use of a female mold. In this instance veneers are laid up along the inner face of the mold and covered with a rubber blanket that is attached to the die. The air is then expelled beneath this covering in order to press the veneers firmly into place. The assembly is then handled in a similar manner to that described above. There are several variations of these two methods for molding panels of unusual shape and contour. In one of these, veneers are laid up in a female die and a flexible bag placed within the assembly is inflated to bring the veneers into proper contour. Heat may be supplied either from within the bag, from some heating element surrounding the mold, or by the use of high-frequency equipment. In recent years many ingenious methods have been developed at individual plants to mold small plywood panels or parts for use in particular products.

#### B. PANEL TREATMENT FOLLOWING PRESSING

Plywood which is made with aqueous glues and then pressed, particularly when cold-pressed, absorbs moisture from the glue. Hot-pressing veneers with an excessive moisture content should be avoided, since steam will form and become trapped in the panel. When the presses are opened, steam pressures built up in this manner will cause the panels to explode. The amount of moisture so absorbed depends on several factors, *viz.*, (1) original dryness of the veneers; (2) thickness of the individual plies; (3) water content of the adhesive; (4) thickness of the glue line; (5) whether glue was hot or cold at time of spread; and (6) elapsed time between spreading and pressing.

Other things being equal, the drier the veneer the more water it will absorb from the glue. Thinner plies will absorb a higher percentage of water based on the dry weight of the ply; however, thicker plies may actually absorb greater amounts of water.

**1. Redrying Plywood.** In cold-gluing, except for plywood made of very thin plies, more moisture is ordinarily added to the wood adjacent to the glue line. Unless this absorbed moisture is allowed to equalize, subsequent drying of the plywood will result in a number of defects, such as warping, checking, open joints, and glue-line failures. It is therefore necessary that the moisture content of plywood be equalized throughout the panel and also be brought to a level suitable for the subsequent use of the product. It is ordinarily assumed that 10 to 15 per cent moisture in the finished plywood is satisfactory for service in the open air, while for interior use in heated buildings the moisture content of plywood should be 7 to 8 per cent.

and somewhat lower for the product intended for furniture manufacture.

On the basis of experiments in kiln-drying aircraft panels, the U.S. Forest Products Laboratory recommends a constant temperature of about 120°F. and a constant maximum relative humidity which will permit the stock to dry down to the moisture content desired, with minimum injury to the material and the maximum of convenience and economy of operation. Temperatures in excess of 120°F. will decrease the drying time but are prone to lower the quality of the plywood by increasing warping, checking, and opening of joints.

The length of time required to dry plywood depends largely on its moisture content and the total thickness of plywood, as well as the number and thickness of the constituent plies and the type of wood. Panels dried from very high to very low moisture content should be dried more slowly, to prevent warping and other drying defects. The actual drying time with three- and five-ply panels ranges from 8 to 24 hours. In a few instances mechanical veneer driers and hot-plate presses have been used for redrying thin plywoods with relatively high moisture content. This method has the advantage of speed but involves the use of expensive equipment.

Plywood glued in hot presses does not require redrying after gluing, but good practice calls for a conditioning period to provide for equalization of moisture content. In some shops it is common practice to sponge or spray the panels as they are removed from the press in order to restore surface moisture.

**2. Finishing Panels.** Unless all plies were trimmed to exact size before gluing, the panels are trimmed after redrying. In some mills the first straight edge is obtained with a hand jointing machine, the panels then passed over a variety saw, set to produce the desired width, and finally through a trim saw for trimming the ends. In a plant equipped with power-driven sizing saws having two saws for cutting both edges in one operation, the hand jointing and the variety-saw operations are eliminated. A power-driven trim saw may be set at a right angle to the sizing saws, so that sizing and trimming of panels are accomplished in one operation.

The finishing of plywood frequently involves the sanding of faces to remove tapes, rough spots, and unevenness in thickness. Great care should be exercised to sand both faces evenly, as the difference in thickness of the faces would destroy the symmetry of construction and lead to distortion with changes in moisture content; furthermore, faces sanded too thin will not finish well and are likely to show the glue line. For sanding, either the endless belt or the drum type of machine may be used, the final cleaning of high-grade plywood usually being done by means of the belt sander.

After sanding, the panels undergo a final inspection and grading. The

panels containing surface imperfections, such as checks, splits, or pitch pockets, are sent to the patching room, where these defects are removed and sound pieces of veneer inserted. When this is expertly done, such patched panels are fully as strong and serviceable as sound, unpatched plywoods. The graded plywood is stored piled solid in heated conditioning rooms until needed. It is customary to lay the panels with the faces toward each other when they are crated for shipment.

### C. CURVED PLYWOOD

Plywood will bend more satisfactorily than solid lumber of the same thickness. In one forming method the veneers are bent before the glue hardens. The assembly is clamped tightly over the curved form and pressure is maintained until the adhesive sets. A variation of this method is to machine the lumber base to any desired curve, using the reverse concave form to apply the pressure. This method can be used for production of compound curves.

A different method for bending thin plywood is provided by the Elliott bending machine, in which the plywood is passed between heated rollers in a manner similar to that employed in curving steel plates for cylinders and boilers. Finally, plywood may be curved by means of flexible bags; a method which is especially suited for production of irregularly shaped objects.

### D. SPECIAL PLYWOODS AND LAMINATES

In addition to conventional plywood described in the foregoing pages, there are also a number of special plywoods and veneer laminates which deserve mention.

**1. High-density Wood.** It has been known for some time that by compressing wood it is possible to improve many of its physical-mechanical properties. Practical application of this principle, however, has only been achieved since the development of the thermosetting synthetic-resin adhesives.

Normal pressures used in gluing wood, ranging from 75 to 200 p.s.i., are accompanied by compression not exceeding 10 per cent of the original thickness of the plywood assembly. If, however, veneers are impregnated with a synthetic resin and then bonded under pressures ranging from 500 to 2,000 p.s.i., considerable compression results, with, of course, a corresponding increase in density. Material of this kind (which may be laid up with either cross or parallel laminations), developed at the U.S. Forest Products Laboratory, was originally designated as compregnated wood and later as *compreg*. At present *compreg* and several closely related materials

are manufactured under a variety of trade names such as Pluswood, Superpressed Plywood, Improved Wood, and Tegowood.

Compreg is made by impregnating thin sheets of dry veneer with a water-soluble, specially prepared, resin-forming formulation. Following impregnation the sheets are removed from the bath, laid up and hot-pressed. Heat has a plasticizing effect upon lignin, and wood treated in this manner will compress much more readily, for a given unit pressure, than one untreated. By varying the intensity of pressure, the resin-treated wood will compress from  $\frac{1}{3}$  to  $\frac{1}{2}$  of its original dimension and increase its specific gravity from approximately 1.0 to 1.40. Compreg may be made in thin sheets or heavy blocks of considerable thickness. Shrinkage or swelling with atmospheric changes is negligible. In fact, tests at the U.S. Forest Products Laboratory revealed maximum dimensional change of only 3.6 per cent after a 50-day immersion in water. It is also highly resistant to mild acids, alcohols, and many other solvents and is not permanently spotted by such materials. Compreg takes on a high luster from the press platens and needs no further finishing. Since the resin permeates the whole panel, surface scratches or mars may be sanded or burnished out without additional treatment. Compreg has excellent mechanical properties except for impact strength, as the large amount of resin present has some small embrittling effect.

The full utility to which compreg may be put is yet unknown. As a panel it is well suited for bar tops, card tables, furniture, and specialty flooring. During the Second World War it was used for airplane propellers, bases for parachute flares, radio antennae masts, dies, small tools, jigs, and in various parts of aircraft. Recent tests\* by the United States Navy have revealed that compreg made of cottonwood is a suitable decking material for aircraft. Compreg picker sticks used in place of those made from hickory are giving satisfactory service in a number of Southern cotton mills.

Tegowood, another densified product, differs from compreg in that thin sheets of veneer are bonded under high pressure with Tego film glue. This material does not appear to have such good dimensional stability or strength characteristics as compreg but is suitable for many purposes.

Impreg is another resin-treated wood developed by the U.S. Forest Products Laboratory. Like compreg it is made of resin-impregnated veneers. After sheet impregnation, the veneers are dried and the resin cures within the individual sheets. These are then laid up in the conventional manner and hot-pressed with a resin adhesive at normal bonding pressures. The resulting product is a superior plywood with good stability and greatly improved resistance to fungi, insects, fire, and weathering.

\* Anon. U.S. Navy Installs Newly-developed Dual Purpose Decking. *Wood Prod* 52:6, 20-22. June, 1947.

Another development in compressed plywood construction is the *differential density material*, in which a plywood product has different densities throughout its length. This is achieved by using veneer sheets of different lengths and assembling them in such a manner that several more veneer sheets are placed at one end or in the middle of the assembly. Since the shorter veneer sheets are cut to different lengths, the number of veneer layers, and therefore the actual combined thickness of the veneer sheets, varies throughout the length of the plywood. The resulting assembly, consisting of veneers and synthetic-resin glue, is compressed between parallel platens to exactly the same thickness, with the result that a plywood material with density varying throughout its length is obtained. Such material could be used in aircraft propellers, where the part nearest to the hub requires high density while the tips must be as light as possible.

**2. Veneer and Plywood Combinations.** Various plywood and laminated products can be made by combining veneers or plywood with fiberboard, paper, or nonwood materials, such as cloth, asbestos, metal, and foamed plastic materials.

An example of veneer-paper combination is a product constructed of kraft paper and veneer. Kraft paper is somewhat stronger across the grain than thin veneer and therefore may be used to reinforce it. The paper is used either as a core, between layers of veneer, or for outside surfaces. Such veneer-paper combinations are used for packing cases, mirror backs, and cabinet partitions. Papreg and Kimpreg, phenolic-impregnated papers, are also suitable facing material for both veneers and plywood. One Southern manufacturer is using a three-ply assembly consisting of a  $\frac{1}{4}$ -in.-veneer core and phenolic-paper faces for draw bottoms and dust-proof boards in case goods.

Any of the pulp fiberboards, such as Masonite or Celotex, can be faced with veneers. Veneers used in this manner generally range from  $\frac{1}{32}$  to  $\frac{1}{60}$  in. in thickness. Sometimes a face veneer is first combined with a high-density fiberboard and the resulting assembly is then glued with a more porous, low-density fiberboard.

Veneer combined with asbestos board finds its widest application for heat protection in radiator enclosures, covering for hot-air ducts, boat and ship partitions, and doors and partitions in slow-combustion construction. Since the primary object of the asbestos-veneer construction is heat resistance, only phenol-formaldehyde adhesives should be used.

A well-known example of the cloth-veneer combination is Flexwood. This is a veneer product used for interior wall finish. Flexwood consists of a sheet of thin hardwood veneer,  $\frac{1}{100}$  to  $\frac{1}{4}$  in. thick, laminated under heat and pressure with a waterproof adhesive to a coarse cotton fabric. The sheets are then processed in a flexing machine and the result is a flex-

ible material with a hardwood surface. Flexwood is manufactured in strips 18 to 24 in. wide and 8 to 10 ft. long; it can be applied to any surface, flat or curved, with a permanent adhesive, much as wallpaper is hung.

Another example of cloth-and-veneer combination is a special type of conveyer belt where the woven fabric supplies flexibility while the veneer produces the desired surface and a degree of stiffness. A similar product is used for guard cages around machinery.

Another product is *woven wood laminate*. In this process the veneer is coated and impregnated with resin varnishes. It is then cut into strips of the desired width and woven into sheets of any size. The woven sheets of veneer are then bonded with some stiffening material under heat and pressure. The resulting sheets are flexible and can be cut with ordinary shears. When mounted on plywood or other solid backing, these panels can be used for desk tops, card tables, bars, walls, and ceilings. They have a glass-smooth surface, unaffected by moisture, alcohol, and most common acids and are resistant to cigarette burns. Various designs are achieved by combination, in weaving, of woods of various color and grain.

Of the many types of metal-faced plywoods now on the market, two outstanding examples are Bonded Metal and Plymetal. Bonded Metal is a bond of wood veneer to a metal underlay. In this process cotton cloth is fused into steel with a zinc solder and then bonded with phenolic-resin sheets to the thin wood veneer. The significance of this product is that although it looks and feels exactly like wood, it can be handled and machined like steel. It is highly fire-resistant. It is believed that Bonded Metal has an enormous field wherever the so-called "grained" metals are used, *i.e.*, in filing cabinets, radio and air-conditioning cabinets, office furniture, automobile dashboards, and the interior of railroad passenger cars. Another potential field for this product is for interior finish in ships.

Plymetal is a lamination of plywood and metal, differing from Bonded Metal in that the plywood is covered with a metal-veneer surface. This product finds wide application in elevator cabs, soda fountains, restaurants and hospitals, truck bodies, boats, and passenger railroad cars.

Veneers or thin plywood bonded to thick, lightweight cores of foamed thermoplastic resins give promise of being suitable materials for insulation and acoustical boards and for lightweight panels for many special uses.

#### E. UTILIZATION OF PLYWOOD

In recent years plywood has gained such popularity and its use has become so varied and diverse that only a general summation of its utilization is presented.

**1. Plywood in Construction.** Perhaps the greatest field of application for plywood is in construction. The ever-growing popularity of plywood in the construction field is largely due to the advantages it offers in comparison with solid lumber. Some of these advantages have already been mentioned, but they are repeated here to emphasize their importance in a building material. Of particular significance are (1) the equalization of strength properties along the length and width of the panel achieved by alternating the direction of grain in successive plies; (2) greater resistance to end checking and splitting, thus permitting nails and screws to be driven closer to an edge than is possible with solid wood; (3) reduction and equalization of shrinkage and swelling; (4) lightness, which makes handling of plywood on scaffolding easy; (5) ease of cutting into any desired shape; (6) applicability for construction of curved surfaces; (7) good nailing and screw-holding capacity; (8) availability in large sizes cut to exact dimensions; (9) adaptability for sheathing purposes; (10) high range of decorative effects possible.

Of the species used for structural plywood, Douglas fir is by far the most important. Douglas fir plywood suitable for construction purposes is made in two types, *interior* and *exterior*. The interior-grade type represents the larger amount of production and consists of plywood with some degree of moisture resistance; it is built to retain its original form and practically all its strength when exposed to occasional but thorough wetting and subsequent normal drying. The exterior type of Douglas fir plywood is intended to retain its original form and strength when wet and dried repeatedly and otherwise subjected to the elements; it is, therefore, suitable for permanent exterior use.\*

Douglas fir plywood is peculiarly suited for concrete forms, and many millions of feet of it are consumed annually for this purpose. Plywood concrete forms are easy to construct and easy to remove; they are strong, yet offer a degree of flexibility which allows construction of curved surfaces. Plywood forms produce even concrete surfaces that require little labor to smooth them off. Douglas fir plywood is equally well adapted to small concrete forms, such as sidewalks, curves of residence foundations, and to gigantic projects such as skyscrapers, dams, or bridges. Finally, the same forms may be reused several times, and then when finally dismantled the plywood still has a salvage value for rough construction.

Douglas fir plywood is extensively used as a roof and wall sheathing and

\* Each type, *i.e.*, interior and exterior, is available in several grades. For complete information consult the latest Commercial Standards for Douglas fir plywood, available through the National Bureau of Standards, U.S. Department of Commerce, Washington D.C.



for floors and subfloors. Although on the basis of square-foot cost plywood is somewhat more expensive than some other forms of construction materials, its availability in large panels cut to exact dimensions allows labor savings which tend to equalize the costs. As a subfloor material plywood has the added advantage that large unbroken surfaces minimize the extent of cracks; it also offers a good nailing surface for flooring. The same advantages apply to the use of plywood as sheathing material, but in order to secure a greater degree of rigidity and strength, the panels must be properly braced and securely nailed to the frame. According to the U.S. Forest Products Laboratory, a rigidity far superior to anything possible with nailing can be obtained by gluing plywood to a frame.

Douglas fir plywood, as well as other types of plywood, finds a wide range of application in interior construction. Plywood is occasionally used as lining to be covered with plaster but more commonly as wallboard used as a combination lining and decorative base; the panels are nailed directly to the studding and joints. When used as a decorative base, plywood offers many finishing possibilities. Panels with hardwood face veneers can be selected according to architectural requirements. If desired they may be stained, painted or enameled, or covered with wallpaper and fabric by first pasting a base of muslin or light paper felt to cover the cracks and take care of slight changes in dimensions that may take place in the walls. Plywood is very well adapted for the modern wall forms requiring curved surfaces and for the fabrication of nooks, partitions, cantilever shelves, etc.

Other household building uses for plywood include the finishing of attics and basements, secondary partitions, closets, and storage rooms. Plywood finds wide application in garages and farm buildings, such as poultry houses and dairy-barn stalls, as well as in office buildings, warehouses, and other industrial buildings. Plywood is a favorite construction material for interior and exterior sheathing, subflooring and roofing, for exposition buildings and similar temporary structures which require speed of construction, maximum safety, high decorative possibilities, and low costs.

In connection with constructional uses of plywood, reference must be made to its utilization in prefabricated houses. Whether made of wood, steel, or other materials, all prefabricated housing systems use a panel as the structural unit. The basic idea of all these systems is that the most difficult part of construction should be done by factory mass-production methods, by which it can be done more cheaply and efficiently, thus offering to the public cheaper and at the same time more scientifically designed housing. A number of model prefabricated houses utilizing plywood as the principal construction material have recently been built throughout the country.

**2. Plywood in Furniture and Cabinetwork.** Plywood is widely used in furniture and cabinetmaking. Some of the principal uses are for tops, table leaves, case backs, drawer fronts and bottoms, mirror backs, foot and head panels in beds, radio cabinets, piano cases, sewing-machine cabinets, fixtures, and seats and backs of auditorium chairs, school and theater chairs, and church pews. In fact, plywood is used in all parts of furniture



FIG. 8-12. A modern buffet constructed with plywood panels. (Courtesy Drexel Furniture Company, Drexel, North Carolina.)

except legs, rungs, frame rockers, and similar solid parts. Furniture plywood is usually made to order in accordance with the manufacturer's specifications as to matching and size. Some furniture manufacturers prefer to buy three-ply panels to be used as a stock on which face veneers are glued at the furniture factory, so that any desired matched effect can be produced as needed. Cabinet work, such as cupboards, closets, bookcases, and medicine chests, provides another large outlet for plywood.

**3. Industrial Uses.** To meet the engineering requirements of light weight with maximum strength, there are on the market a number of metal-faced plywood products. Such panels are used in truck bodies, boats, hospitals, and restaurants; more recently such panels have been used in the construction of streamlined trains. Plywood covered with heat- and acid-

resistant resins is available for use for table tops, office equipment, and wall paneling. Freight-car construction promises an extensive field of use for Douglas fir plywood in the form of car lining, while railroad passenger cars have long offered a market for plywood, for decorative as well as structural purposes.

Plywood made with water-resistant glues is extensively used in all classes of water craft. In small pleasure boats plywood is used as a structural and decorative material, while its use for interior paneling in large ocean liners is rapidly increasing. House-trailer building, although a new field for plywood, already consumes millions of square feet of this product, largely of Douglas fir. The automobile industry still consumes quantities of plywood, although much less than formerly, for floor boards, trunk shelves, and upholstery frames. During the war enormous quantities of plywood were used in airplane and glider construction.

Millwork is another important outlet for plywood, one of the largest items being door panels of all kinds; large volumes of plywood are also used in trunks, traveling boxes, packing cases, and fruit and vegetable baskets and boxes.

An unusual but quite extensive market for Douglas fir plywood is in the motion-picture industry and on the legitimate stage, for construction of stage sets. Toys, woodenware and novelties, bird houses, ping-pong table tops, patterns, bulletin boards and signs, educational and industrial exhibits, and amusement devices are but a few other items on the rapidly expanding list of uses for plywood.

#### F. PLYWOOD PRODUCTION; INDUSTRIAL STATUS

Plywood is manufactured in practically every state in the Union. The state currently leading in the production of this commodity is Washington, where the Douglas fir plywood industry is concentrated. Other leading states in which plywood is manufactured in large volumes are Oregon, Tennessee, North Carolina, Kentucky, Wisconsin, Indiana, New York, Pennsylvania, and Vermont. As in the production of veneers, the plywood industry is divided into two main categories, *viz.*, the hardwood plywood industry and the softwood plywood industry, in the latter of which Douglas fir is the predominating species.

The Douglas fir plywood industry is a large-volume, standardized operation confined to Washington, Oregon, California, and British Columbia, where there are about 40 mills manufacturing over a billion square feet of plywood annually. In fact, 1,800,000,000 sq. ft. of Douglas fir plywood was purchased in 1942, the peak year of the industry; in 1946, 1,390,000,000

sq. ft. was manufactured.\* The majority of the Douglas fir plants are members of the Douglas Fir Plywood Association and operate under trade standards established by the Association. About 54 per cent of the plywood manufactured in the United States is of Douglas fir.

The hardwood plywood industry, by contrast, consists of several hundred manufacturers, ranging from large corporations to small shops of very limited capacity. Hardwood plywood products, for the most part, are custom-made. There is no trade association for the industry as a whole, but the manufacturers as a group follow the inspection, test, and approved methods for plywood fabrication as set forth in the U.S. Department of Commerce Hardwood Plywood Commercial Standard CS35-47.

The aggregate value of American plywood production for the year 1946 has been estimated at something over 60 million dollars.

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\* These figures are given in terms of  $\frac{3}{8}$  in., a three-ply stock.

## CHAPTER 9

### WOOD CONTAINERS

#### I. COOPERAGE

Cooperage is a collective term descriptive of a variety of wood containers consisting of assemblies of staves and heads securely held together with hoops. The term is also used to designate a plant where such containers are manufactured. Barrels, casks, and kegs designed to hold liquids or products processed in liquids are classified as *tight cooperage*. In contrast, similar containers used for packaging dry commodities such as nails, tobacco, chinaware, flour, and a host of other industrial products are called *slack cooperage*. Large tanks and vats made of staves and heads and bound together with metal rods or straps are forms of *heavy cooperage*. Wood pails, tubs, churns, buckets, and other types of container woodenware composed of hoops, staves, and heads or with special tops and bottoms are also regarded as cooperage products.

#### A. HISTORICAL

The origin of the wooden barrel antedates the recorded history of man, and the name of its inventor is shrouded in the haze of time. Archaeologists have revealed that barrels were used by both the ancient Babylonians and the Egyptians, while numerous passages in the Old Testament attest to the fact that barrels of various types were in general use at least several hundred years before the birth of Christ. When the barrel first acquired its bilge \* is also a matter of speculation, although there is evidence that curved staves were used in cooperage manufacture at least before 525 B.C.

Legend has it that the precursor of the stave barrel was a hollowed log with animal-skin headings. Containers of this sort were cumbersome and of limited capacity and were transported with difficulty; hence one may conjecture that the ancient cooper, in an attempt to produce a better vessel, conceived the idea of fashioning a number of hand-carved staves into a cylindrical structure of much less bulk and with proportionally greater carrying capacity. His hoops, probably thongs, served not only to avert

\* Central bulge.

leakage along the stave joints but also to close any checks in the staves themselves that might have developed in seasoning.

During the period of the Crusades (1096-1291) the barrel was introduced into Europe from the Holy Land, and by the fifteenth century barrels of several standard sizes were recognized and subsequently were used as universal means of measure. In 1423, English lawmakers placed the capacity of a hogshead at 63 wine gal. Later, by other imposed statutes, the capacity of a wine barrel was fixed at  $31\frac{1}{2}$  gal.; those for vinegar, eels, and herring at 30 gal.; and those for codfish and honey at 32 gal. Several slack barrels were similarly employed. For example, a barrel of gunpowder was required to weigh 100 lb.; one of soap, 265 lb.; and one of candles, 120 lb.

Early American history is intimately associated with the barrel. Columbus, in preparing for his westward voyage into the unknown, provisioned his ships with food and drink packaged in cooperage. The Puritans, when they founded their colony at Plymouth in 1620, not only brought most of their supplies in coopers' ware but also had the foresight to include among their numbers one John Alden, a journeyman cooper, hired expressly for the purpose of plying his trade in the New World.

Trade was the very lifeblood of the American colonies, and in the years following their settlement, cargoes of codfish, whale oil, molasses, rum, naval stores, tobacco, and other commodities were consigned to London and many other European ports in wooden barrels. In fact, foreign markets were also created for cooperage itself, and large numbers of American-made staves were exported to England, Ireland, Portugal, and Spain.

Time has witnessed many changes in the American cooperage industry. In early colonial days, barrels were made by journeyman coopers who had neither shops nor regularly established businesses but traveled from place to place in the practice of their trade. The cooper fashioned his staves, headings, and hoops by hand; his work was slow, painstaking, and laborious; his production limited to about two barrels daily. The development of the Pennsylvania oil fields during the middle of the nineteenth century created a tremendous demand for tight cooperage, and it was during this period that the first stave-cutting machinery was made available to the manufacturer. Thereafter, machinery rapidly replaced various hand operations in barrel manufacture, and within a few years the industry was mechanized for mass-production methods.

No historical review of cooperage would be complete, however, without brief mention of the curved stave. This structure embodies the principle of the double arch \* and, in the more than 2,000 years that it has been employed in the construction of a barrel, no one has been able to improve upon its basic design from the standpoint of its mechanical efficiency. In a

\* Longitudinally and transversely curved.

properly assembled barrel, the projected planes of all stave joints pass through its longitudinal center line; thus each stave acts as a key. Hence, when an external impact load is applied to a vessel of this sort, the shock is instantly transmitted to all parts of the structure, thus greatly minimizing its damaging effect at the point of contact. In fact, a blow of sufficient magnitude to fracture the staves in a cylindrical barrel ordinarily can be absorbed by a bilge barrel having staves of comparable thickness.

### B. TIGHT COOPERAGE

Tight barrels are designed primarily for holding liquids such as vinegar, fruit juices, sirups, alcohol and alcoholic beverages, mineral and vegetable oils, turpentine, paints, and chemical compounds and for meats, fruits, and vegetables processed in liquids. They are also used for packaging semi-solids like lard and vegetable shortenings, preserved fruits, resins, waxes, pastes, and greases and as shipping containers for such dangerous commodities as gunpowder, corrosives, poisons, and highly inflammable goods.

Several kinds of tight barrels are manufactured; most of them vary somewhat in the details of construction, as each type is designed for a specific use. Those having capacities of less than 30 gal. are known to the trade as *kegs*, whereas those with capacities greater than 60 gal. are called *hogsheads*. The terms *cask* and *tierce* are descriptive of large barrels commonly used for packaging wines, fish, lard, and a few other commodities.

**1. Manufacture of Tight Cooperage.** The component parts of a tight barrel are commonly manufactured at separate and independent plants and in turn are sold to coopers for assembly in accordance with customers' specifications. A few of the larger cooperage houses, however, operate their own stave and heading mills or manufacture their staves and headings at the cooperage. Strap-steel hoops are used almost exclusively on tight barrels.

*a. Staves.* At one time a wide variety of woods was used in the manufacture of tight staves, but today such species as white and red oaks, white ash, Douglas fir, yellow birch, sugar maple, and red gum are principally employed. Trees selected for conversion into cooperage are felled and reduced to flitches suitable for the production of quarter-grained staves that will not exceed a width of more than 6 in. To produce staves of uniform length the flitches are rough-peeled and then equalized. An equalizer (Fig. 9-1) is a device for squaring the flitch and cutting it to the required stave length. It consists of a pair of circular saw blades with a common drive shaft mounted in a heavy metal frame. Following the equalizing operation the flitches can be reduced to staves.

At one time tight staves were made on a stave bucker by forcing rough-hewn stave blanks through a pair of stationary, heavy, curved knives. These were known as "bucked" staves, the manufacture of which was both laborious and wasteful. Because of ever-increasing stumpage values and the need for more efficient manufacturing procedures, the stave bucker has long since given way to the *drum* or *barrel saw*, and today virtually all tight staves are cut with such machinery. The barrel saw (Fig. 9-2) is a steel cylinder with cutting teeth on one edge, mounted on a heavy power-driven shaft and equipped with a manually operated carriage. When a flitch is properly fixed on the carriage an operator pushes it forward into the whirling blade. At the completion of the forward stroke a stave drops into a cradle within the saw and is automatically ejected with the return of the carriage to its original position. The flitch is then

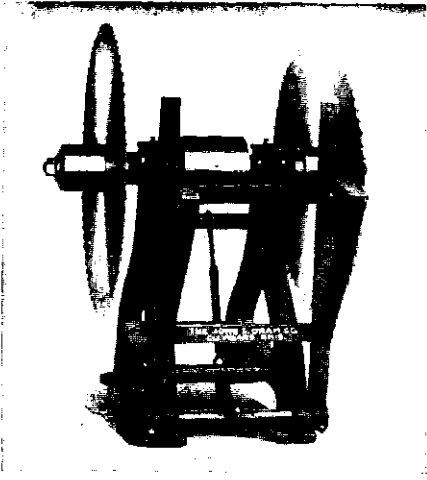


FIG. 9-1. Stave-bolt equalizer. (Courtesy John S. Oram Co., Cleveland, Ohio.)

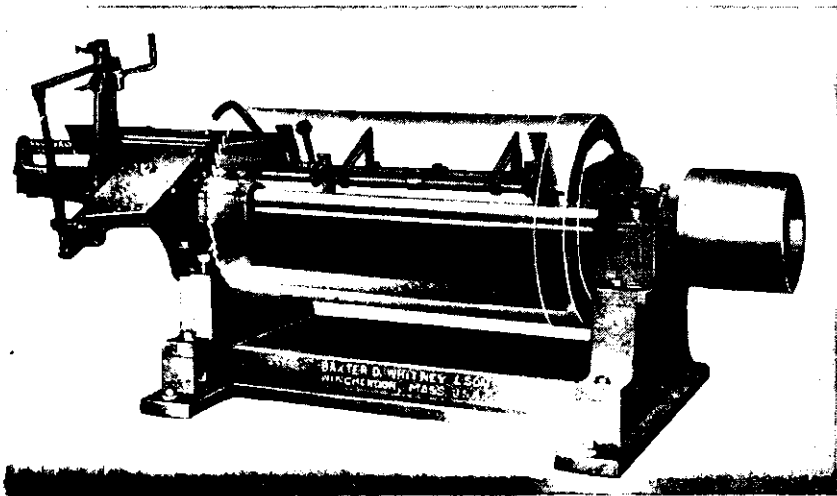


FIG. 9-2. Barrel saw. (Saw blade depicted as transparent in order to show position of stave ejector.) (Courtesy Barter D. Whitney & Sons, Winchendon, Massachusetts.)



positioned for the next cut. Barrel saws are manufactured in several diameters, as the staves cut on any one of them are essentially segments of a cylinder equal in diameter to that of the saw used.

The bilge saw is another type of stave saw but differs from the barrel saw in that it has the configuration of a conventional barrel. Staves cut with this machine have a "built-in" bilge, but owing to the prevalence of short



FIG. 9-3. Cutting pine staves with a bilge saw. Note that in this operation the staves are equalized following their ejection from the saw. (U.S. Forest Service.)

grain which is invariably present in the region of the bilge, they are usually weaker and more readily broken than those of comparable size made on a barrel saw. Thus bilge staves are somewhat restricted in their use, and their production is largely limited to lengths of 24 in. or less, except where strength is not a primary consideration (Fig. 9-3).

The staves as they leave the saw are green and hence must be thoroughly seasoned before being used in barrel assembly. At some mills they are crib-piled in the open or in open sheds and air-dried for several weeks, or even months, and then kiln-dried. At other plants, staves are bulk-stacked for a few days and then seasoned in kilns. Barrels cannot be made with air-seasoned wood because in storage they would continue to dry out, and loose, open joints would result. Staves are ordinarily dried to a moisture content of about 12 per cent. Below this point the wood becomes too brittle

and is easily fractured in rough handling. Upon removal from the kiln, staves are ready to be jointed.

Figure 9-4 shows a typical stave jointer. In its operation, a stave is clamped on a cradle and brought into contact with the jointer wheel by means of a manually operated foot treadle. This wheel has a number of jointer knives set in a dished surface and is thus, upon being rotated, able

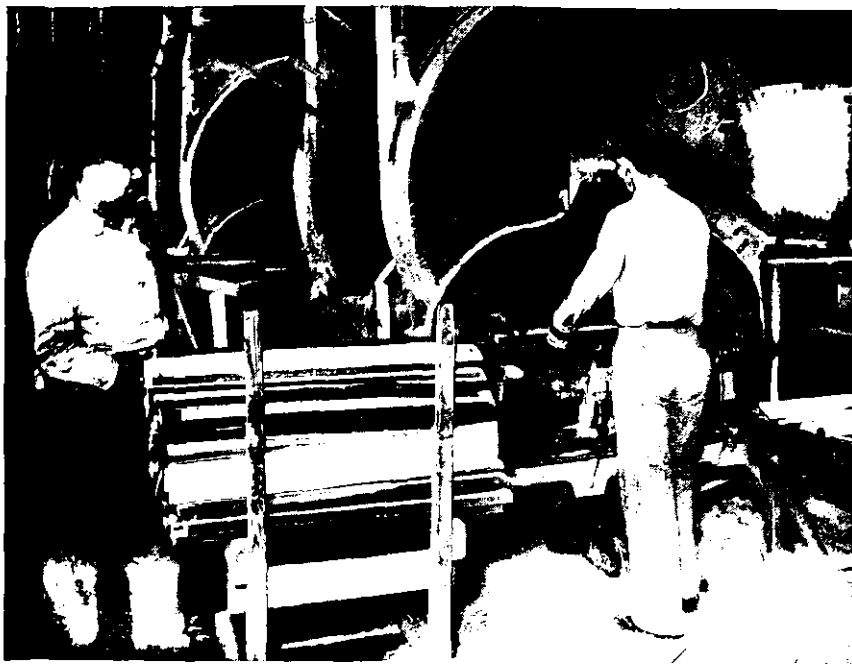


FIG. 9-4. Stave jointing. (Courtesy of the Louisville, Kentucky)

to shape and bevel staves to desired contours. Machines of this sort are manufactured in several sizes in order to accommodate staves of different standard lengths. The jointer wheels, depending upon diameter and kind of staves to be jointed, are furnished with four, six or eight knives and driven at speeds of from 450 to 650 r.p.m. The jointed staves are described in terms of the *difference in width between their mid-section and ends*. Thus half-bilge, three-quarter-bilge, or seven-eighths-bilge staves are those in which the width of the mid-section exceeds that of the end by  $\frac{1}{2}$  in.,  $\frac{3}{4}$  in., and  $\frac{7}{8}$  in., respectively.

*b. Headings.* Woods used for the production of tight staves are suited for the manufacture of tight headings. Bolts or fitches of proper length are cut into headblanks 1 to  $1\frac{1}{4}$  in. thick on heading saws. Like staves, these

blanks, too, must be thoroughly seasoned before they are worked up into finished goods. Following their removal from the kiln, the blanks are dressed, then tongued and grooved or dowel-jointed. A *matcher* selects a number of pieces and assembles them into squares from which the circular one-piece headings are cut. Dry rush or cattail leaves, known as flags, are used to caulk the seams of some dowel-jointed headings, others are edge-

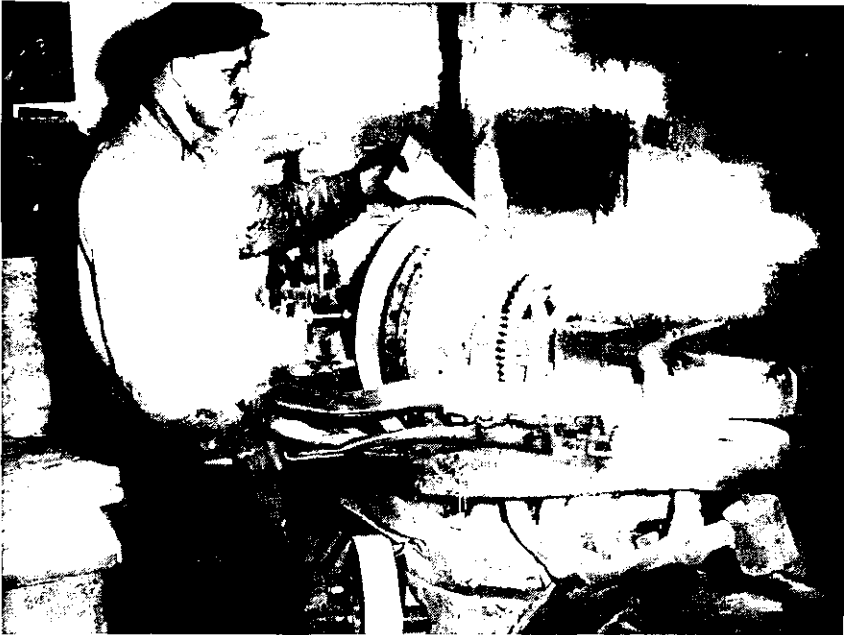


FIG. 9-5. Turning a head for a tight barrel. (Courtesy Pioneer Cooperage Company of Illinois, Chicago, Illinois.)

glued. Squares should never be wider or longer than is necessary to cut out a perfect circular head; in fact, it has been a practice at some mills to pay a bonus to matchers who keep "goosenecks" \* to a minimum.

Figure 9-5 shows a square in the process of being cut into a circular head. The square is held firmly in a vertical position as shown and turned rapidly against a concave saw and a knife. The saw cuts the circular heading on a bevel, and the knife, working behind the saw, cuts the second bevel to meet the first. The finished head is automatically released, and the operator centers in another square. Headings made at mills removed from cooperages are usually made up into bales for shipment, 20 pairs of heads comprising a bale.

\* Trade term applied to waste trimmings of a head-cutting machine.

*c. Hoops.* Hoops of strap steel are used on practically all forms of tight barrels. The cooper ordinarily purchases his hoop stock in the form of flat strips and manufactures his own hoops, such hoops varying from  $1\frac{1}{8}$  to  $1\frac{3}{4}$  in. in width and from 16 to 19 Birmingham gauge in thickness. Machinery is used for coiling, riveting, and flaring the hoops.

**2. Tight-barrel Assembly.** The initial step in barrel assembly is called *raising*. A cooper selects enough staves (but not exceeding a specified num-



FIG. 9-6. Raising tight cooperage. (U.S. Forest Service.)

ber) of random width to form a tight basal circle when placed in a setup. Note in Fig. 9-6 the two heavy, temporary, encircling truss hoops that hold the staves together. This setup is then placed in a tunnel and steamed for 30 minutes at 200 to 210°F. This softens the wood and enables the cooper to draw the tops of the staves together in order to place the top and quarter truss hoops without breaking the staves. The staves are then drawn into position with a steel cable and a windlass; this operation is known as *windlassing*.

At this stage of tight-barrel assembly the staves are fired. Firing should not be confused with charring, as it is essentially a baking process using dry heat. This has a threefold purpose. Firing drives from the staves moisture absorbed during the earlier steaming treatment; it stress-relieves the fibers in the region of the bilge; and finally, it "sets" the staves so that

they will not spring back appreciably when hoops are removed. As a usual practice, a barrel is retained in the firing chamber for about 15 minutes at temperatures ranging from 400 to 500°F. Some coopers employ progressive firing tunnels through which barrels are moved on conveyer chains at a pre-determined rate of travel.

When cooled the barrels are leveled and trussed. Leveling is essentially a tamping operation designed to bring the staves into transverse alignment

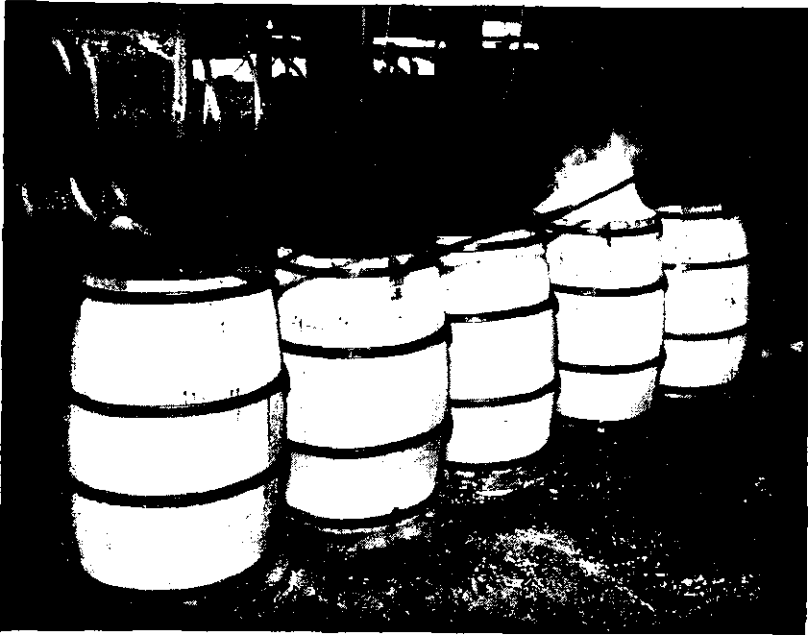


FIG. 9-7. Charring bourbon whisky barrels. (U.S. Forest Service.)

and is done mechanically. In the trussing operation, a leveled barrel is placed on end in a trusser, a machine fitted with several power-driven arms, and the temporary truss hoops are forced down over the sides of the barrel, thus assuring uniformly tight joints.

White oak barrels to be used for aging bourbon whisky are charred internally, following their removal from the trusser. At one time this was done by building a small fire within the barrel. Today gas or oil flames are used by most coopers, since uniformity and depth of char are more easily controlled. Some manufacturers employ a bung protector during the charring operation. This is a water-saturated pad that is held firmly against the mid-point of the bung stave and is used to prevent excessive char at the

point where the bung hole is to be drilled. Whisky-barrel heading must be charred also, and particular care is exercised to avoid burning or charring of the beveled edges. Head-charring is a separate operation accomplished before the heads are seated in the barrel.

Both charred and uncharred barrels are then prepared to receive the heads. In a series of three operations, which the coopers call *working off*, a



FIG. 9-8. Heading-up machine. (Courtesy Pioneer Cooperage Company of Illinois, Chicago, Illinois.)

barrel is placed between two adjustable chuck rings in a multipurpose device known as a *howeling, crozing, and chamfering machine*. First, small knives, much like a diminutive carpenter's gouge, cut a pair of semicircular grooves, the *howels*, on the inside of the barrel, one at each end, 1 to 1¼ in. from the rims of the staves. A second pair of knives cuts a V-shaped groove, the *croze*, in each of the howels. The croze is so cut that the beveled edge of the head may be firmly seated in it to form a strong, watertight joint. A third set of knives then bevels the inner faces of the staves between the howels and the rims of the barrel. This beveled part of the barrel is called the *chamfer* or *chime*; it greatly facilitates head emplacement and prevents

leakage that could occur should small pieces of wood be broken off the stave ends as a result of rough handling of a barrel.

Heads are inserted and seated in the croze, using a heading-up machine, after which the barrels are sanded or smoothed on a special kind of lathe to improve their general appearance. The barrels are then placed in a hooping machine, a device similar to a trusser, where the temporary truss hoops are replaced with permanent ones made of 18- to 23-gauge steel. Special metal hoop fasteners are also used to keep the hoops in position.

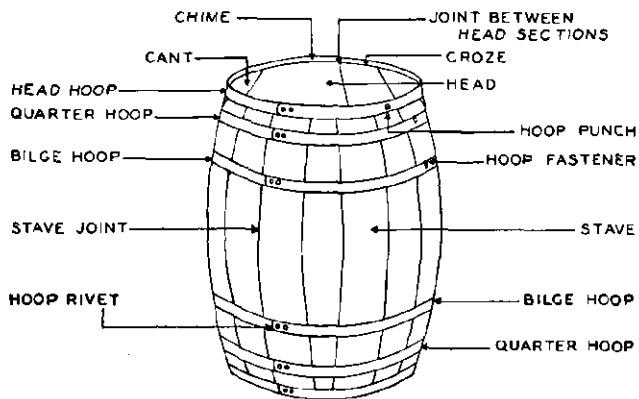


FIG. 9-9. Component parts of an assembled barrel.

The finished barrel usually carries six hoops. The medial pair, the bilge hoops, are driven first, then the quarter and head, or chime, hoops, in the order mentioned. Where maximum strength is of paramount importance, barrels are furnished with eight hoops. Nearly all barrels used in export trade, where rough handling is virtually inevitable, are fabricated with eight hoops; the additional pair, seated between the head and quarter hoops, are called eighth hoops because of their relative position on the staves. The bung hole, if one is required, is driven in the bung stave after hooping up.

To avoid leakage or to guard against contamination of certain liquid commodities, it has been found expedient to coat the inside of a barrel with some inert compound such as paraffin, silicate of soda, or glue. Coatings are not required of all types of cooperage, and the use of any of them is governed by the quality of the barrel used and the nature of the commodity to be packaged. Paraffin linings are used primarily for water-based liquids, such as beverages, brine, fruit juices, sirups, and vinegar. Glue is somewhat water-soluble, however, and should be used only for products containing alcohol solvents and for shellac, lacquers, paints, and certain chemicals. Silicate of soda imparts no taste or odor and makes a suitable lining when

packaging lard, molasses, vegetable oils, meats, and sausage casings. It is also used with many industrial oil-based products such as waxes, white oil, greases, and many chemicals, including caustics.

**3. Kinds of Tight Barrels.** The Associated Cooperage Industries of America, Inc., recognizes, without respect to capacity, eight standard classes of tight barrels, as follows: \*

*a. Bourbon Barrel.* This is the king of the tight barrels and is used largely by distillers for storage of whiskies. When internally charred it is employed for aging of bourbon whisky. Bourbon barrels are made of the finest quality quarter-sawn white oak heartwood staves † and headings. The staves are equalized 34, 35, or 36 in. in length and when thoroughly kiln-dried must be a full  $\frac{3}{4}$ ,  $\frac{7}{8}$ , and 1 in. in thickness, respectively, and cannot exceed a width of more than  $5\frac{1}{2}$  in. For headings, maximum diameters have been set at  $20\frac{7}{8}$  in., and when kiln-dried and dressed they must not be less than 1 in. thick. No multiple-piece head can include more than seven pieces. Cants ‡ less than 3 in. in width at their mid-section and middle pieces under  $2\frac{1}{2}$  in. in width are not permitted.

*b. White Oak Barrel, Sap Clear.* This barrel is also manufactured entirely from quarter-sawn white oak heartwood staves and headings, but specifications are relaxed slightly to permit the acceptance of minor defects which will in no way impair the serviceability of the structure. This type of barrel is used without a lining for packaging alcoholic liquids, liquid chemicals, vinegar, fruit juices, and wines.

*c. White Oak Barrel, Tight Sap.* Barrels in this category are manufactured from quarter-sawn white oak timber. Sapwood with closed pores (tyloses) is allowed. Lined, the barrel is used for such commodities as paints, lacquers, shellac, varnish, oils, alcohol, acids, and sirups. Without a lining this barrel may be used to package meats, fruit juices, and certain beverages.

*d. White Oak Barrel, Sound Sap.* This is another white oak barrel. Staves and heading may include sound sapwood. This barrel is usually lined and used for a host of commodities including liquid chemicals, lard, vegetable and mineral oils, greases, condensed milk, meats, juices, solvents, wines, vinegar, cider, turpentine, and fruit juices.

*e. Red Oak Barrel.* Barrels in this classification are manufactured from red oak timber. Because many of the red oaks have open-pored wood (relatively free of tyloses), the barrels must be lined with paraffin or some other suitable substance, if used for packaging liquid products. Unlined,

\* For complete specifications of these barrels, see The Wooden Barrel Manual, Associated Cooperage Industries of America, Inc., St. Louis, Mo.

† Bucked staves also permitted.

‡ The two outside pieces of multiple-piece headings.



they can be used for lards, greases, and other semisolids; lined, they are used for processed fruits, meats, and vegetables, and a wide variety of industrial oils, solvents, soaps, and similar commodities.

*f. Gum Barrel.* Barrels in this category are made of red gum staves and heads free of defects that will impair the serviceability of the container. Black or tupelo gum staves or headings are permitted only if agreed upon by the purchaser. Minimum thickness for both staves and head pieces has been set at  $\frac{3}{4}$  in. Unlined gum barrels are suitable for packaging semisolids, dry chemicals, powdered dyes, gums, and thick, heavy sirups. When lined they are used for many liquid chemicals, industrial oils, processed meats, fruits, and vegetables, tanning compounds, and similar products.

*g. Ash Barrel.* The ash barrel is manufactured from staves and heads made of one or more of the ashes (pumpkin ash not permitted). Lined ash barrels are used for packaging the same general classes of commodities described under the red oak barrel. Unlined ash barrels are used for processed meats, meat products, and fish.

*h. Douglas Fir Barrel.* This barrel is made on the West Coast with Douglas fir staves and headings. It is used for packaging salmon, processed fruits, and a variety of industrial products. Because this wood readily imparts objectionable tastes to many foodstuffs, the barrels must be lined if used for packaging products destined for human consumption.

**4. Plywood Whisky Barrels.** Whisky barrels of 50 gal. capacity made of 14 interchangeable laminated staves and with plywood headings have been introduced recently to the trade. The staves are made of four-ply, parallel-bonded, rotary-cut white oak veneers; the heads are cut from five-ply stock of conventional design.

**5. Beer Barrels.** The beer barrel is a form of tight cooperage, but because the cooper requires machines specifically designed for the production of staves and heads, it is usually regarded as a separate and distinct container.

The beer barrel, designed as a container for malt beverages, has thicker staves and heads and a much more pronounced bilge than the conventional tight barrel. By government statutes, the capacity of this barrel has been fixed at 31 gal. Half-, quarter-, and eighth-barrels are also manufactured, their capacities being based upon the full 31-gal. container.

Two types of beer barrels are currently available, *viz.*, the solid wooden barrel and the laminated stave barrel.

The solid wooden beer barrel or keg is made with 16 to 21 rived or split white oak staves and white oak heads. The full barrel (31 gal.) requires staves 31 in. in length that must be a full  $1\frac{3}{4}$  in. in thickness at their ends and  $1\frac{7}{16}$  in. thick in the region of the bilge. After the staves are dried and jointed, the barrels are raised in the usual manner. Heads  $1\frac{3}{4}$  in. thick are

used. These thick staves give the barrel excellent strength properties as well as acting as an efficient insulation that materially aids in maintaining proper temperature of beer or ale when in transit. Before barrels are filled with malt beverages, they are lined with gum rosin.

Like the whisky barrel, beer kegs are also now available to the consumer assembled with plywood staves and heads. The staves are dimensioned and interchangeable and only nine are required for each barrel. They are made of seven plies of  $\frac{1}{8}$ -in. rotary-cut hard maple faced with white oak veneers to make a nine-ply structure. The first and fifth maple plies from the outside of the staves are laid up like conventional cross bands.

### C. SLACK COOPERAGE

Slack barrels are used for packaging a great variety of dry commodities for both domestic and export trade. Because of their carefully engineered configuration, they are capable of withstanding greater abuse than other wood containers and are especially suited for overseas shipment where rough handling is inevitable. Their sturdy construction permits repeated use, and in the event of damage, the broken components are easily replaced.

Slack barrels are manufactured in a variety of sizes but vary somewhat in their details, since each type is designed for a specific purpose. In packaging certain foodstuffs, care must be exercised in the selection of the wood, as that of certain species will impart objectionable tastes or discolorations to the contents. The weight of the commodity to be packaged also will not infrequently govern the selection of stave and head stocks as well as the type and number of hoops required. Powdered ingredients such as dried milk and eggs, spices, expensive chemicals, and the like call for moisture-proof, siftproof containers. The best slack barrels are used for such commodities and are made with top-quality tongued and grooved staves and one-piece headings. Plain-jointed staves and multiple-piece headings bound with wire, wood, or beaded steel hoops are suitable for packaging chinaware, nails, unshelled oysters, dried fish, and many other commodities. Used with a paper-bag liner they are suitable containers for many fine, even powdered, ingredients. Because of the number of slack-barrel styles available, one should seek the advice of a competent cooper before packaging a particular product. The cooper is in a position to recommend the best and cheapest container that will meet minimum specifications of the Interstate Commerce Commission, as well as those for export trade.

**1. Manufacture of Slack Cooperage.** Like tight cooperage, the component parts of slack barrels are usually manufactured at separate plants and shipped to cooperage houses for assembly. At one time, slack barrels were bound exclusively with wooden hoops, but in recent years beaded-

steel bands or hoops of iron wire have all but replaced the wooden article. Wooden hoops are still used on some kinds of slack barrels, however, and their manufacture is usually undertaken at plants removed from either stave mills or heading plants. Thin splines of wood (head liners) are nailed to the chamfer of some barrels after the heads are seated, in order to provide greater strength.

*a. Staves.* A large variety of woods, including red gum, beech, birch, maple, elms, hackberry, ashes, sycamore, cottonwoods, black willow, basswood, oaks, black gum, western hemlock, spruces, Douglas fir, and numerous pines, is used in the production of staves. Trees are usually cut into bolts in the woods, and the bolts in turn are shipped to stave mills for processing.

Slack-barrel staves are either sawed or sliced. In the production of sawed staves the bolts and flitches are rough-peeled, equalized, and then cut to desired thickness on a barrel saw. Sliced staves, on the other hand, are made by driving a fitch laterally against a knife ground to a circle of predetermined diameter. Flitches handled in this manner are given a preliminary steaming in order to soften the wood and thus expedite the shearing action of the knife. Properly softened wood will produce smooth, bright staves, but that which is over- or understeamed yields staves of inferior quality. In practice, the flitches are stacked on cars and transferred to steam tunnels where they are steamed for at least 24 hours at pressures ranging from 80 to 110 p.s.i. Some manufacturers prefer to boil their stock in open tanks for several hours, but the steaming process is favored by a majority of operators. Upon their removal from steam tunnel or cooking vat, the flitches are barked and equalized. They are then ready for the slicer.

The slicing machine, known as a *stave cutter*, consists essentially of a receptacle to hold a fitch, the tumbler, and a knife. In its operation a fitch is placed in the tumbler, which is actuated by an eccentric cam, and driven lengthwise across the knife. The fitch is so positioned that staves are cut along the quarter. With each forward stroke a stave is sheared from the fitch. Machines of this character can make 150 or more strokes a minute and are capable of producing 40,000 staves in an 8-hour day, when manipulated by skilled operators.

Hardwood species are well suited for the production of sliced staves. Coniferous woods, on the other hand, not infrequently shatter under the knife following their removal from steam tunnels, and the staves commonly check and warp excessively in drying. For these reasons, bilge and barrel saws are used in the manufacture of softwood staves. When carefully and properly seasoned, the staves are jointed and then bundled for transit to a cooorage.

*b. Heads.* The species enumerated above used for slack-stave production are also suitable for slack-barrel headblanks. The manufacture of slack-barrel heads does not differ essentially from that of tight headings; both one-piece and multiple-piece heads are produced.

*c. Hoops.* It was common practice years ago to use only wood hoops on slack barrels, but when these containers were adopted for packaging a wide variety of farm and industrial commodities, it was necessary to improve the strength characteristics of some kinds of barrels and to provide tighter, even siftproof joints in several others. This led to the use of iron-wire hoops and beaded-steel bands. Today beaded-steel hoops are used exclusively on some barrels. Others are made with beaded-steel head hoops and wire bilge hoops; still others have wood head hoops or wire bilge hoops. Only when maximum strength and tight joints are of little concern are wood hoops used without reinforcement.

Elm, because its mechanical properties are affected but little by the prolonged steaming or boiling that is a necessary step in wood-hoop manufacture, is preferred above all other woods. Hickory, oak, black gum, hackberry, and a few other species are used, but collectively they represent only about 5 per cent of the total wood-hoop output.

Wood hoops are made by sawing or slicing splines from planks of suitable length and thickness. The splines are fed into a machine which planes them, points one end, and laps \* the other. Following this series of operations, the splines are steamed or boiled in open vats for several hours to facilitate bending. Upon their removal from the steam box or vat, and while they are still wet and hot, the splines are fed into a hoop coiler, an ingenious device that bends them into a circle and rivets or staples the pointed and lapped ends together to form a finished hoop of prescribed diameter. When dried they are bundled and consigned to an assembly plant.

Standard wood hoops are  $1\frac{3}{8}$  in. wide and  $\frac{5}{32}$  in. in thickness at one edge and  $\frac{5}{32}$  in. at the other. This wedge-like cross section gives the hoop a slight flare and insures a snug fit against the tapering sides of a barrel. Hoop splines before coiling vary from 5 to 8 ft. in length.

*d. Head Liners.* Head liners are thin strips of elm  $\frac{1}{2}$  in. by  $\frac{3}{16}$  in. in cross section and 12, 14, or 18 in. in length. These are nailed or stapled to the chamfer and are used to keep the heads from slipping out of the croze and to increase the strength of the barrel. Before setting, the liner strips are soaked in water to increase their pliability. Usually two such strips are used with each head, one fastened along the edge of each cant. Head liners are used on all barrels with wood hoops when the net weight of the contents exceeds 250 lb. Barrels furnished with beaded-steel hoops seldom require

\* Makes a lap-scarfed or feathered end to which the pointed end is riveted or stapled when coiling the hoop.

liners unless they exceed 600 lb. capacity. When necessary the liner may be made to extend completely around the circumference of the head.

**2. Slack-barrel Assembly.** The assembly of a slack barrel follows the same general pattern as a tight barrel, previously described. A number of staves that will completely fill the raiser are set in the form, steamed, and windlassed. The assembly is then fired, leveled, trussed, crozed, and chamfered. Heads are set and the final hoops driven. Hoops may be of wood, iron wire, beaded-steel bands, or combinations of these types. If tongued and grooved staves are used, the matching operation is performed in machines designed for the purpose and the barrels are raised in the usual manner.

**3. Kinds of Slack Barrels.** The Associated Cooperage Industries of America, Inc., recognizes nine types of standard slack barrels. Each kind was designed for specific uses, and all types, when properly constructed, meet minimum specifications of the Interstate Commerce Commission and regulations pertaining to export-shipping containers.

*a. No. 1 Barrel.* This is the finest of the slack barrels, and only No. 1 grade staves and No. 1 headings \* are used in its assembly. When sift-proof joints are required or where protection against moisture or contamination is of paramount importance, tongued and grooved staves and heads are used; as an added measure of safety the barrel may be lined with a paper bag. When the barrel must "breathe," plain edge-jointed staves and headings may be used. The No. 1 barrel is used principally for packaging dried milk and eggs, dry paints, soap chips and powders, sugar, salt, spices, chemicals, lime, and similar commodities.

*b. No. 2 Barrel.* Barrels in this category are made with No. 2 grade staves and headings (see grade rules). They are furnished with either plain edge-jointed or tongued and grooved staves, but the heads are usually plain edge-jointed only. This is an excellent container, usually made with four beaded-steel-band hoops when strength is of primary concern. No. 2 barrels are used primarily as shipping containers for many kinds of hardware, including chains, fittings, and valves, and for a wide selection of low-grade chemicals.

*c. Meat-and-poultry Barrel.* This is another No. 2 barrel assembled with plain edge-jointed staves and one head. It is usually furnished with two wood head hoops and four wire hoops, one pair placed below the head hoops, the other near the bilge. This barrel makes an excellent shipping container for dressed poultry and for cuts of beef, pork, and similar commodities.

\* For grading rules see Grade Rules and Specifications, The Slack Barrel Group, or The Wooden Barrel Manual, both published by the Associated Cooperage Industries of America, Inc., St. Louis, Mo.

*d. Glass-and-pottery Barrel.* Other than the fact that this barrel is supplied with two heads, it is identical to the meat-and-poultry barrel described above.

*e. Fish Barrel.* This barrel is used for shipping fish, crabs, and other seafoods. It is made with No. 2 grade plain edge-jointed staves and furnished with one or two heads in accordance with customers' specifications. Various combinations of wire and wood hoops are used, depending on the consumers' preference.

*f. Potato Barrel.* This barrel may be made with dead-cull staves and a No. 2 grade head. Either pine or hardwoods may be used. The potato barrel is furnished with six hoops in one of the following combinations: (1) six wood hoops; (2) four wood hoops and two wire hoops; or (3) two wood hoops and four wire hoops.

*g. Apple Barrel.* The apple barrel is also assembled with dead-cull staves and one No. 2 grade head made of either pine or hardwood. It is usually finished with six wood hoops but may be supplied with two wood hoops and four of iron wire.

*h. Vegetable Barrel.* This is a No. 2 barrel with plain butt-jointed staves and heading, assembled with six wood hoops.

*i. Nail-and-spike Kegs.* These containers are made in a variety of sizes and used for packaging nails, spikes, nuts, bolts, screws, rivets, and similar fastenings. Both staves and heads are made of yellow pine. The barrel is offered to the trade bound either with four beaded-steel bands, or with two such bands and two wire hoops.

**4. Tobacco Hogshead.** No discussion of slack cooperage would be complete without mention of the tobacco hogshead. This is a large straight-wall container used for packaging and storing leaf tobaccos of the kinds used in cigarettes and pipe blends. Each barrel has a capacity of approximately 1,000 lb. of compressed leaf, and more than 550,000 of them are required each fall to handle the tobacco crops of North Carolina and South Carolina alone.

Leaf tobacco purchased in the tobacco belts of the Carolinas, Virginia, and Maryland is removed from warehouses packaged in hogsheads \* and shipped to redrying plants. Upon arrival, the containers are emptied and the leaf is dried so that it may be stored for protracted lengths of time without deterioration. The leaf is then repackaged and trucked to nearby storage sheds where the hogsheads are racked in tiers and the tobacco permitted to age for at least 2 years. At the conclusion of the aging cycle the tobacco is routed to a stemmery where it is again removed from the barrel,

\* Georgia tobacco is usually baled in burlap.

steamed, and stemmed.\* The stemmed leaf is returned to the containers and consigned to a manufacturing plant for final processing.

For years tobacco hogsheads were made with yellow pine or oak staves and heads bound together with wood or metal hoops. These containers received exceedingly rough handling in their circuitous travels from warehouse floors to final processing plants; many of them virtually had to be rebuilt each time they were emptied. Damaged staves, heads, and hoops were counted in the thousands, and cooperage shops were a major department in every tobacco factory. Such damage was regarded as inevitable, and only after labor and material costs began to rise appreciably did the tobacco manufacturers look for a better container. In the late 1930's, a prefabricated hogshead of Douglas fir plywood staves and headings made its appearance, and its general adoption by several of the larger manufacturers suggests that it will one day completely replace the old-style container.

The Douglas fir plywood hogshead is comprised of two interchangeable mats that, when properly mated, form the cylindrical wall of the container. Each mat is made with 15 three-ply staves, each  $\frac{5}{16}$  in. thick,  $42\frac{1}{2}$  in. wide, and 54 in. long. In mat assembly, spacers made of 20-gauge metal are placed between the joints and the 15 staves are then bound with five galvanized-iron bands  $1\frac{1}{2}$  in. wide,  $72\frac{5}{8}$  in. long, and 20 gauge in thickness. Male hinges are riveted at one end of each band and female hinges are similarly attached at the other. Liners (small strips of plywood  $\frac{1}{16}$  in. thick,  $1\frac{1}{4}$  in. wide, and  $45\frac{5}{8}$  in. long) are nailed on the inside of the staves, one at each end, and are used to seat the heads.

The heads for the tobacco hogshead are 46 in. in diameter and are made of  $\frac{7}{16}$ -in. three-ply Douglas fir plywood. An oak spline  $\frac{3}{4}$  in. by  $1\frac{1}{4}$  in. by 11 ft.  $9\frac{1}{4}$  in. is formed into a hoop and nailed on a head piece. This band fits snugly against the faces of the liners when the head is properly seated and protects the ends of the staves against breakage when the heavy, fully packed barrels are upended.

To assemble the prefabricated barrel, two mats are placed side by side and steel pins slipped into one set of mating hinges. The two remaining edges of the mats are then drawn together and similarly pinned. The shell is then upended and the bottom head slipped in at an angle and carefully driven into place. When the barrel has been packed with leaf, three top pins of one hinge row are removed and the top head inserted. A ratchet device is used to draw the hinges together and the pins are replaced. To empty this type of container, it is only necessary to remove the pins from one hinge row.

\* Process wherein the tough, fibrous, midrib (stem) of the leaves is stripped from the blades.

The plywood hogshead has several distinct advantages over the solid wood container: (1) since it is only about two-thirds as heavy (about 100 lb.) as the old-style barrel, there is a material saving in shipping costs; (2) because of its engineered design, damage from rough handling is only a fraction of that previously experienced; (3) all parts of this hogshead are interchangeable, and damaged components are easily and inexpensively replaced; (4) finally, it has a long service life, and it may be used time after time for storage and shipment of leaf tobacco. Barrels of tobacco consigned



FIG. 9-10. The tobacco hogshead: (a) Loaded barrel ready for storage; (b) Removing the two mats. (Courtesy A. E. Wackerman.)

to West Coast cigarette manufacturers can be knocked down and returned to the shipper for reuse. The old-style barrel, on the other hand, had little salvage value outside the tobacco-producing centers, and its disposal was always a problem, since the costs involved in its dismantling, return, and reassembly exceeded the costs of new containers.

#### D. STATUS OF THE COOPERAGE INDUSTRY

The wooden barrel, once the nearly universal storage and shipping container of a variety of dry and wet industrial commodities, is today faced with many kinds of competitive containers. New and improved methods of distribution and selling have had a profound effect on the use of barrels in many industries. Cooperage production reached its peak in 1907, and since then the use of barrels has been in steady decline. In a few instances competitive containers have completely replaced the slack or tight barrel.

**1. Whisky Barrels.** About 1,700,000 new white oak barrels have been used annually for storage and aging of whiskies since the repeal of the



**Eighteenth Amendment.** In spite of the fact that there are now numerous patented processes for expediting the aging of whisky, some of which require no barrels whatsoever, a Federal statute decrees that such beverages must be aged in new white oak barrels. Distillers are also forbidden by law to reuse them for this purpose. Thus it is apparent that until these laws are changed there is little likelihood of competitive containers entering the market, or of a major curtailment in whisky-barrel production.

**2. Beer Barrels.** Prior to the passage of the Eighteenth Amendment, practically all beer and ale was distributed in oak barrels and kegs. When the brewing of these beverages was again legalized in 1933, brewers were unable to procure a sufficient number of barrels to distribute their products and the metal barrel made its appearance.

Time has since witnessed many changes in the merchandising of malt beverages. In 1934 about 25 per cent of the production was distributed in cans and bottles, and by 1941 more than 50 per cent was marketed in this manner. Today, nearly three-quarters of all barreled beers and ales is distributed in metal barrels. Several brewers using laminated barrels have indicated their dissatisfaction with these containers and are discontinuing their use. Improperly laminated staves appear to have open joints between the plies, and brew lodging in these recesses becomes sour. This condition ultimately renders the entire content of the barrel unfit for consumption. In fact, time has shown that metal barrels have a service life equal or superior to the wooden container, and in today's markets cost only half as much as the wooden article.

**3. Wine Barrels.** During the past few years the demand for barrels for use in storage of wine has increased rather than diminished. On the other hand, their use in distributing and marketing such beverages has fallen sharply. More wines are now marketed in bottles and jugs, while bulk shipments are frequently made in glass-lined tank cars or tank trucks.

**4. Oil Barrels.** In the early beginnings of the petroleum industry all crudes were shipped to refineries in wooden barrels. About 1865 wooden tank cars were put into service, and in 1872 the first pipe lines were installed. More than seven million new barrels, in addition to several million used ones, were required by the petroleum industry in 1907, but with the rapidly expanding automotive industry, new methods for packaging and distributing petroleum products were introduced. In 1934, 6 million steel drums, 44 million pails and buckets, and 535 million quart and gallon sealed tins were required. In the same year only 1.5 million wooden barrels were used. Today the wooden oil barrel is employed largely for exporting lubricating oils, greases, and waxes.

**5. Pork Barrels.** The meat-packing industry used more than 675,000 pork barrels in 1909, but 30 years later its annual requirements had dropped

to 200,000 units, despite the fact that much greater quantities of meat were processed for shipment. Today the wooden case has become the pork barrel's principal competitor and may eventually wholly replace the barrel.

**6. Slack Barrels.** There has been a general decline in the use of slack barrels since 1909. Crackers, cement, flour, salt, and sugar, commodities that were once almost entirely packaged in wooden barrels, are now distributed in cloth or paper bags, fiber containers, or wooden cases. Wooden boxes and cases, fiber containers, and baskets, as well as open-weave sacks, have partially replaced wooden barrels as shipping containers for such commodities as tile, glassware, chinaware, pottery, and many fruits and vegetables. Metal drums and multiwall paper bags are being used in ever-increasing quantities by naval-stores producers. Soap chips, while still packaged in barrels, are distributed in ever-increasing quantities in paper-board cartons.

The wooden barrel is preferred in certain producing areas for apples, potatoes, yams, and cabbages. In others, sacks and boxes are preferred. Little competition with other containers has as yet been noted for barrels and kegs used for fish, poultry, nails, hardware, dry paint, chemicals, powdered milk, and corn products.

#### E. CONTAINER WOODENWARE

Woodenware is a collective term applied to some articles of turnery and also to wooden containers such as pails, kits, buckets, tubs, and piggins. These products are generally regarded as forms of tight cooperage, since they are assembled with staves, hoops, and headings and are used for carrying many liquid and semisolid commodities. All these containers have about the same general configuration, yet each has certain features that render it distinctive. A pail, for example, is wider at the top than at the bottom. Metal hoops are used in its assembly, and it is furnished with a wire bail (handle) and with or without a cover, depending on customer specifications. A kit, by contrast, is shaped like an inverted pail, being wider at the bottom than at the top. Kits are hooped with wire or metal straps and supplied with wire bails, and their covers are seated in grooves near their upper rim much like the croze of a conventional barrel. A bucket (or kanakin) is similar to a kit except that both hoops and handle are made of wood and its cover slips over and around the rim. Tub is a large pail with two lateral handles. Large straight-walled containers made with staves and wooden hoops and used for packaging large round loaves of cheese are also designated as tubs. A piffin is a wooden pail with one of its staves extending beyond the rim to form a handle. The piffin obtained its

name from farmers who used it to carry feed to their pigs. It is still used for this purpose in certain rural areas of the South.

Production of container woodenware in the United States had its inception in New England during early colonial times when a demand was created for pails and kits for packaging salted fish. The expansion of the industry kept pace with the industrial development of the colonies, and ultimately containers of this sort were being used for pickles, jellies, salted mackerel and herring, butter, lard, printer's ink, candies, maple sirup, and many other commodities. By 1850, plants had become established in the Lake states, where there was an abundance of white pine and red spruce. The first plant in the Pacific Northwest began operation in 1921, producing pails and kits of Sitka spruce.

The manufacture of the component parts of container woodenware and their assembly is quite similar to that of tight barrels. Like barrels, the general decline in the use of woodenware has been influenced by new and improved methods of commodity distribution, new merchandising practices, and mass production of cheap, serviceable, lightweight containers of fiber, glass, and metal.

#### F. TANKS AND VATS

Tanks and vats fabricated with staves and headings are designated as heavy cooperage. Both staves and the individual pieces comprising the heads are made from lumber. The staves are circled to proper contour by passing planks or cants of predetermined cross-sectional dimensions through a machine that profiles them. Both staves and head pieces are tongue-and-groove jointed. Unlike barrels or woodenware, which are usually assembled at a cooperage, tanks, and often vats, are carefully engineered structures that are designed for specific purposes, and their assembly is usually undertaken at that point where they will be permanently located.

White oak, Douglas fir, bald cypress, and redwood are the woods principally used in the heavy cooperage industry. Because of the growing scarcity of bald cypress, once the prime favorite of tank manufacturers, a great many recent installations have been made using redwood. This species is readily available in large, clear lengths, and this, coupled with its lightness of weight, excellent stability, and natural resistance to decay and many chemicals, combines to make redwood an excellent processing or storage container for a wide variety of industrial products.

In the storage of corrosive materials, wood tanks are often more satisfactory than similar containers fabricated of metal. The petroleum industry, for example, has determined that it is much more economical to

store corrosive sour oil crudes in redwood tanks than in those made of any other structural material; in the pulp and paper industry, wood tanks are entirely suited for the storage of sulfite cooking liquor. Brine processing of onions, olives, sauerkraut, tomatoes, cauliflower, and pickles is usually done in paraffin-lined tanks of from 2,000 to 500,000 gal. capacity. Wood tanks are used for the fermentation and aging of malt beverages and are standard



FIG. 9 11. Battery of redwood tanks used for storage of corrosive sour-oil crudes. (Courtesy California Redwood Association.)

equipment in every brewery. They are also used by distillers and in wineries for storage of ciders, fruit juices, and raw whiskies. Because of the better thermal-insulating characteristics of wood, there is less danger of water freezing in a wooden tank, one of the reasons for the erection of wood tanks for boiler-water storage along railroad right of ways. In tanneries may be found batteries of wooden extractor tanks and vats for tanning hides, while tanks of wood used for dyeing fabric are general in the textile industry. Many other uses of the wood tank also might be cited, space permitting.

There are many authentic records attesting to the service life of wooden tanks, but perhaps the oldest is that of a battery of redwood wine tanks, reputed to have been in continuous service for a period of 87 years.

## II. BOXES AND CRATES

The volume of wood consumed annually in the manufacture of boxes and crates is exceeded only by that used in general construction. Currently about 15 per cent of the nation's annual production of lumber, approximately six billion board feet, is needed to meet the industrial and agricultural requirements for box and crating materials of every description. There are nearly 700 box-shook \* factories in the United States regularly engaged in the manufacture of box and crating stocks. The supply of shook is further augmented by many of the more progressive sawmill owners who have installed box-shook departments within their plants to provide an outlet for their low grades of lumber. Slabs, trimmings, and edgings are also commonly worked up into battens, cleats, box boards, and crate stock.

In recent years several types of paper, fiberboard, and metal containers have replaced boxes in the packaging of numerous industrial commodities, but increased demands for boxes from some quarters have about offset losses of markets attributable to the adoption of competitive containers.

Considerable time and large sums of money have been expended in the promulgation of studies leading to improved designs and serviceability of boxes and crates. Severe losses of war matériel by the armed services during the early phases of the Second World War resulted in improved designs of many containers of this sort, while the expansion of truck- and air-freight lines was largely responsible for the development of sturdy but lightweight crates and boxes.

There are no distinct lines of demarcation between some crates and boxes. A crate for light loads, especially agricultural products, is similar to a box, the essential difference being that a box has virtually solid faces, whereas a crate has open spaces on the various surfaces. Crates for heavy loads may consist of an open framework in which the framing members carry the load. Other crates for heavy loads may have a framework that is fully sheathed to protect the contents and to give added rigidity; in this form the crate is box-like in appearance. A box for heavy loads consists virtually of solid ends, sides, top, and bottom fastened together without the benefit of a structural framework that would carry the load independently of the six foregoing box components.

Cleats and battens may be added to a box for reinforcement or to obtain better nailing. Bottom cleats are often attached to facilitate handling, and bolts or interior blocking and bracing may be used to help keep the packaged article from shifting. These additional components, however, are not regarded as frame members since they cannot carry the load independently

\* Trade term applied to the wooden components of knocked-down boxes and crates

of the ends, sides, top, and bottom. Interior blocks and bracing often aid in distributing the load to two or more box surfaces, but the framing is still generally regarded as a box.

#### A. SPECIES USED

Practically all but the very densest and the most valuable of American woods are used for box and crating materials. A preference is generally shown, however, for cheap, readily available woods with good machining characteristics, high strength-weight ratios, resistance to splitting, and an ability to hold nails. Because of better color contrast obtainable with multicolored printed or stenciled trademarks, light-colored woods are also desired.

#### B. CLASSES OF WOOD BOXES

There are currently in use three general classes of wood boxes, (1) the nailed wood box, (2) the cleated plywood box, and (3) the wire-bound box.

**1. Nailed Wood Boxes.** Boxes in this category are available in hundreds of sizes and capacities, but each one of them is an adaptation of one of seven standardized styles. They offer maximum resistance to puncturing, crushing, and corner mashing but are usually considerably heavier, size for size, than either cleated plywood or wire-bound boxes.

The thickness of boards used in nailed boxes is largely determined by the nail-holding capacity of the wood employed in fabrication rather than by the bending or crushing strength of the wood itself. End-grain nailing is only about half as efficient as side-grain nailing, hence corners of boxes may be weak unless they are designed for a maximum of side-grain nailing.

Sinker, cooler, and corker nails with diamond points have been found very suitable for box construction. Many other nails with triangular or square cross sections or those with barbs or spiral grooves have excellent holding power, but their added costs are often unwarranted. The holding power of common round box nails may be measurably increased by dipping them in a slurry of Portland cement and then drying them thoroughly before they are driven. The cement increases the friction between nail and wood, and as a consequence nail-withdrawal resistance may be increased by as much as 50 per cent.

Even better tenacity of common box nails may be procured by etching them. The U.S. Forest Products Laboratory reports that nails immersed in a 10 per cent aqueous solution of monoammonium sulfate can be suitably etched in 7 hours. Cadmium-plated and galvanized nails show little or no increased efficiency over plain untreated nails.

a. *Style 1 Box.* This box (Fig. 9-12) consists of plain sides, ends, top, and bottom and is made without cleats or other reinforcements. Structurally it is the weakest of the six standard styles, yet it is a satisfactory

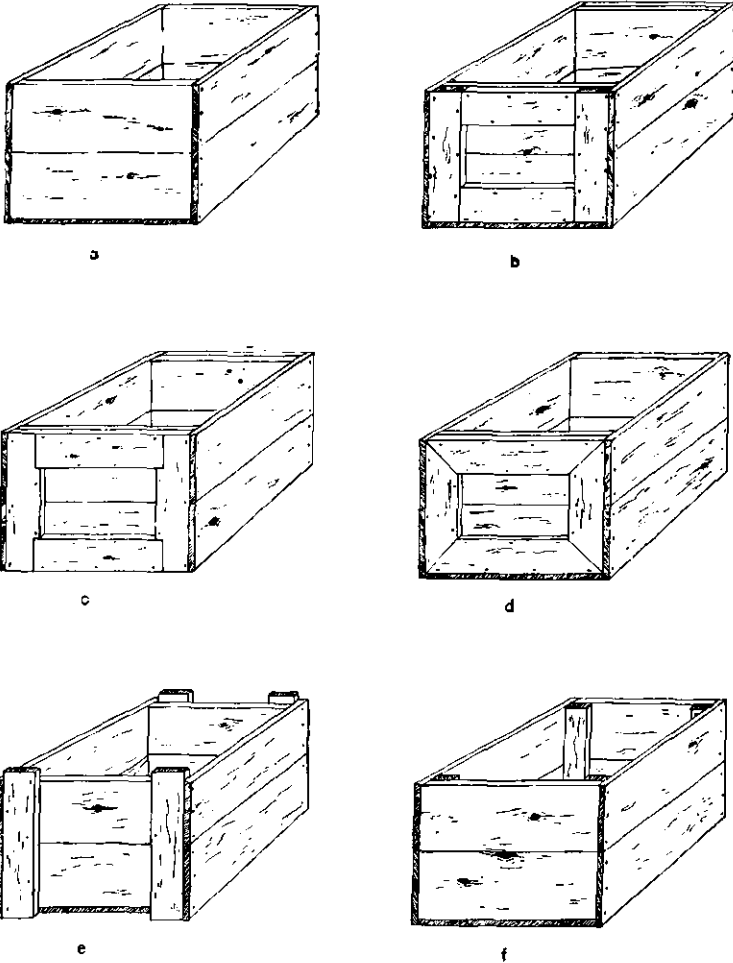


FIG. 9-12. Standard box styles: (a) style 1 box; (b) style 2 box; (c) style 2½ box; (d) style 3 box; (e) style 4 box; (f) style 5 box.

container for many kinds of merchandise. It is exceedingly easy to construct and requires less storage space than other boxes of similar configuration, owing to the absence of cleats. Its principal disadvantages are that (1) the sides, top, and bottom cannot be stagger-nailed to the ends; (2)

nailing of the sides into end grain of the ends is unavoidable; (3) end splitting is common because the grain of sides and ends is essentially parallel.

*b. Style 2 Box.* This box differs from the one above in that four cleats are securely fastened to the ends, and the sides and top and bottom boards are nailed flush with the outer faces of the cleats. The vertical cleats of this box are called *through* cleats, the horizontal pair are *fillers*. The advantages of this box are (1) end cleats permit stagger-nailing of sides, top, and bottom; (2) side-grain nailing is effectively increased, thus stronger end joints are realized; (3) the cleats make for sturdy reinforcement of the ends and provide a recess for shipping tickets, as well as handholds for lifting. Properly constructed Style 2 boxes can be used for merchandise weighing 800 to 1,000 lb.

*c. Style 2½ Box.* This box is very similar to the Style 2 box except that the filler cleats are fitted into notches in the through cleats. This design is commonly used with dense woods, since the through cleats help carry the load when tops and bottoms are attached.

*d. Style 3 Box.* In this box the filler and through cleats are miter-jointed.

Both the Style 2½ and Style 3 boxes have the same advantages as the Style 2 boxes, and they are commonly used for the same purposes.

*e. Style 4 Box.* This box is constructed with but two through cleats at each end. In its manufacture the nails used are longer than the combined thickness of end and cleat and when driven are clinched on the inside. The box is of somewhat simpler construction than the three just described but should never be used for gross weights in excess of 500 lb. The two cleats provide protection for shipping tickets and may be used as handholds when the box is placed upon its side.

*f. Style 5 Box.* This construction differs from the one above in that the cleats are nailed at the inside corners. Sometimes cleats with triangular cross sections are used. By placing cleats on the inside there is little likelihood of their being knocked off in transit. Like the Style 1 box, it requires less storage space, but it is more difficult to handle.

*g. Style 6 Box.* This box is similar to a Style 1 box except that the sides and ends are made with locked corners. The bottom and top are nailed to the sides and ends in the usual manner.

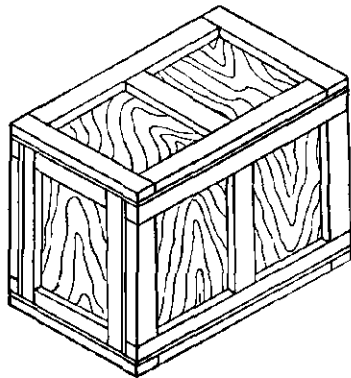


FIG. 9-13. Diagrammatic sketch of a cleated plywood box.



**2. Cleated Plywood Boxes.** Figure 9-13 is a diagrammatic sketch of a typical cleated plywood box. Note that the ends, sides, top, and bottom are made with one-piece plywood panels reinforced with through and filler cleats and that the package, when ready for shipment, is bound with stapled steel straps. Boxes of this sort are light in weight and offer excellent resistance to mashing at the corners, diagonal distortion, and puncturing. They are essentially dustproof, easy to handle, difficult to open in transit; they are suitable for air-borne shipping. Boxes of this type can be made to

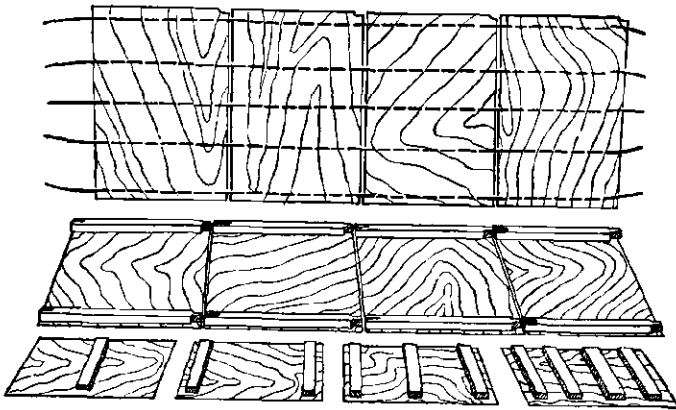


FIG. 9-14. Diagrammatic sketch showing knocked-down wire-bound box. Note four types of ends used.

carry gross loads of 1,000 lb., but usually they are used for much lighter loads. This box may be constructed with the interlocking three-way corner.

**3. Wire-bound Wood Boxes.** These boxes (Fig. 9-14) are lightweight, prefabricated shipping containers made of veneer (or thin boards) with reinforcing cleats and bound together with wire. The two sides, top, and bottom, with the cleats attached, are made into a four-piece mat held together with two or more strands of binding wire. The ends are single pieces of veneer reinforced with from one to four battens as required. In the assembly of these mats, the cleats, which are made with mortised joints, lock into place. Before the top is brought into position the two ends are inserted and nailed to the cleats from the inside. Closure of the box is then accomplished by bringing the top into position and twisting the ends of the binding wires together. Some boxes are made with loops at the end of the binding wires. One of these loops is passed through the other and bent backward to close the box.

This container is very light in weight but usually sturdy and may be made for commodity shipments not exceeding 500 lb.

### C. WOOD CRATES

There are no general standardized designs for crates such as there are for boxes, although many styles of crates have been standardized by shippers of durable goods and by fruit packers' associations and cooperatives. The open, three-way-corner, diagonally braced crate (Fig. 9-15) is used in

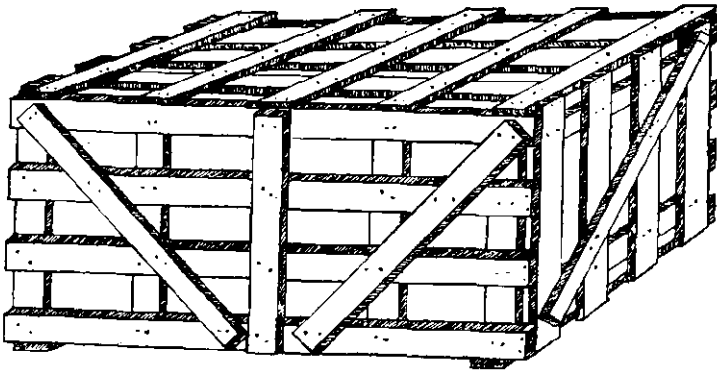


FIG. 9-15. Open three-way corner, diagonally braced crate.

shipping such products as stoves, glass, refrigerators, furniture, bicycles, plumbing fixtures, and a host of other moderately heavy durable goods.

Box-type crates are used when supplementary sheathing is necessary to protect the merchandise against weathering, salt spray, dust, and other destructive agencies. They are commonly used in shipment of aircraft parts, including engines, heavy machinery, and similar products.

### D. WOOD BOX AND CRATE IN AGRICULTURE

Boxes and crates have become nearly universal shipping containers for a variety of agricultural products. In some instances they have replaced the sack barrel, while in a few others they themselves have been replaced by sacks, baskets, and other types of containers.

More than 70 million two-compartment nailed boxes are required annually to package the nation's orange crop, and another 12 million are consumed in the packaging of other citrus fruits.

The apple producers of the Pacific Northwest were the first to use wood boxes in the shipment of apples. The box, which is now standardized at

2,173.5 cu. in., has since been adopted by producers in several apple-growing centers in the United States. Pear boxes similar to the standard apple box are used by Washington, California, and Oregon growers, while many styles of wooden boxes are used by Eastern producers.

Cherries, peaches, plums, prunes, grapes, and other soft fruits are packaged in shallow boxes known to the trade as lugs. Open-slat crates are preferred for lettuce, cauliflower, melons, celery, and tomatoes.

Cheese, butter, and egg producers are other large consumers of wood boxes and crates.

#### E. INDUSTRIAL BOXES AND CRATES

Approximately 60 per cent of all boxes and crates manufactured are used in shipping industrial commodities. Such containers are made in accordance with thousands of customer specifications and range from large, heavy, box-like crates for use in packaging industrial machinery often weighing several tons to small, sturdy, compact cases required for delicate and sensitive scientific instruments not infrequently weighing but a few ounces.

Wood boxes built to certain specifications are acceptable to the Interstate Commerce Commission for the movement of explosives and dangerous chemicals. Because they afford maximum protection in transit against pilferage, contamination, breakage, spoilage, or corrosion of their contents, wood boxes and crates are used in vast numbers for overseas commodity shipments. Millions of board feet of crating are required annually in the transportation of farm and industrial machinery, aircraft and automotive parts, and heavy electrical equipment such as motors, generators, transformers, and massive insulators.

The American fishing industries ice-pack much of their catch in wood boxes for quick delivery to inland consumers. Some meat packers are again using boxes for bulk shipments of pork and lard, while several canneries that had discarded the box in favor of fiberboard shipping containers are now showing a preference for some of the new lightweight boxes because of the added protection afforded their commodities while in transit.

Large volumes of low-grade lumber are also used each year in the manufacture of a number of moderately light but sturdy containers that are collectively known as returnable boxes. In this class are such familiar items as the bottled-milk crate, carrying and shipping cases for bottled carbonated and mineral waters and malt beverages such as beer and ale, and banana and bread boxes. Some of these containers are doing yeoman service, and the records of one brewery reveal that many of their cases are still serviceable after 1,200 round trips.

### F. STATUS OF THE INDUSTRY

Statistics relating to the nominal yearly consumption of wood in boxes and crating for the past 10 years indicate the unprecedented demand for these items during the Second World War. Current trends, however, suggest that the demand for such containers will not diminish appreciably in the near future. It is true that competitive containers have forced the box out of some fields, yet its increased use in others, coupled with its introduction in still others, has essentially offset such losses. The popularity of the box and crate today is due in large measure to the activities of the National Wood Box Association and its numerous regional organizations. These agencies, working closely with state and Federal groups, have rendered many invaluable services to shippers, carriers, and consumers in coordinating specifications, improving designs, and promoting the general use of boxes and crates through educational and trade-promotion programs.

### III. VENEER BASKETS

The use of veneers in the manufacture of baskets had its beginning in 1866 when James Kirby, of Benton Harbor, Michigan, made a  $\frac{1}{3}$ -bu. basket for the peach growers of southern Michigan. About this time A. W. Wells & Co., of St. Joseph, Michigan, also introduced a basket made of sliced veneers for use by orchardists in his area. These two products were immediate successes, others were soon introduced, and all of them became serious competitors of the hand-woven splint baskets then in common use. Today veneer baskets and hampers of many kinds and capacities are used throughout the nation by agriculturalists and orchardists in transporting their products from farm to consumer. While the veneer-basket industry had its beginning in Michigan, it has long since expanded to other parts of the country, and basket plants are now in operation in the vicinity of nearly every major vegetable- and fruit-producing area in the United States.

The first veneer baskets were fashioned by hand, and their production in any one plant was limited to a few hundred per day. The inventive genius of some of the first manufacturers, however, soon led to the development of numerous mechanical devices that did away with slow, laborious hand operations. Today basket factories are highly mechanized, and some of the largest have capacities of more than 2,000 dozen units daily.

### A. SPECIES USED

The bulk of all of the veneer used in the manufacture of baskets is rotary-cut. A preference is shown for those woods that are flexible but tough,

moderately heavy, odorless, light in color, and able to retain nails, staples, and wire stitching. The principal species used in basket manufacture are beech, elm, hard and soft maples, black and yellow birches, red gum, black and tupelo gums, basswood, northern black cottonwood, yellow poplar, and some of the ashes. Quantities of spruce and white pine are also used in some areas.

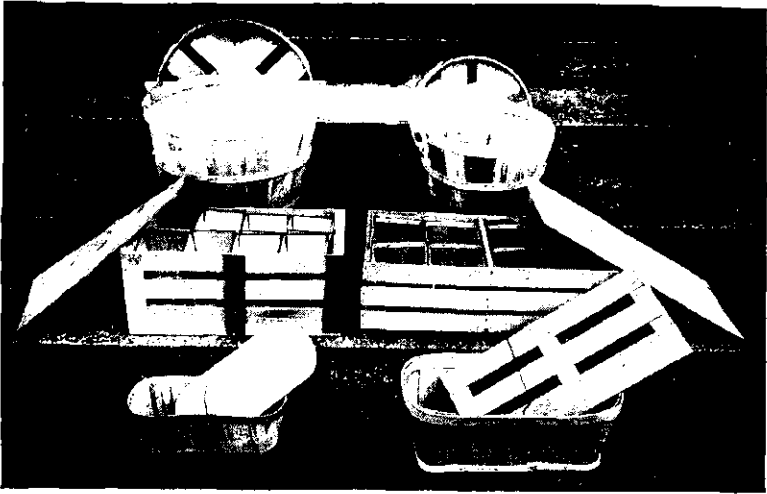


FIG. 9 16. Types of wooden baskets: top row, tub baskets; second row, berry boxes; third row, Climax baskets. (U.S. Forest Service.)

#### B. CLASSES OF VENEER BASKETS

Six kinds or classes of veneer baskets are currently manufactured, *viz.*, (1) berry boxes, (2) till baskets, (3) hampers, (4) round-stave baskets, (5) splint or market baskets, and (6) Climax or grape baskets.

1. **Berry Boxes.** These are the familiar containers used in the distribution and marketing of strawberries, raspberries, currants, and similar fruits. Several types are in common use, including the American, the metal-rim, the Hallock, and the stitched tray. A berry box of heavy paper is commonly used in California. The American type is used in greater quantities than any of the others. The metal-rim box is made in both Eastern and Western United States, and its popularity is exceeded only by the American. The Hallock, which features a raised bottom, is most commonly employed

in the Pacific Northwest and in the Lake states regions. The stitched tray is largely restricted to Missouri and Utah. Berry boxes are manufactured only in dry-measure capacities of  $\frac{1}{2}$  pt., 1 pt., and 1 qt.

**2. Till Baskets.** Till baskets are square or rectangular containers shaped like an inverted frustum of a pyramid. They are principally used for such soft fruits as apricots, peaches, plums, and prunes. In their manufacture, which today is done largely with fully automatic machines, precut veneers are fed into a device that folds them over a form or anvil and staples wooden hoops or crips on metal rims in a single operation. Till baskets are made in 1-, 2-, 3-, and 4-qt. (dry-measure) capacity.

**3. Hampers.** Hampers are flat-bottomed baskets shaped like an inverted frustum of a cone. They are made with a one- or two-piece wooden bottom and tapered staves securely stapled together with two to four hoops, depending upon their size. Hampers are available in nine standard sizes, viz.,  $\frac{1}{8}$ ,  $\frac{1}{4}$ ,  $\frac{1}{2}$ ,  $\frac{5}{8}$ ,  $\frac{3}{4}$ , 1,  $1\frac{1}{4}$ ,  $1\frac{1}{2}$ , and 2 bu.

**4. Round-stave Baskets.** Baskets in this category are divided into two general classes, depending on their construction. Both types may be furnished with wire handles and, when required, a cover. "Round-bottom" baskets are those in which the sides and bottoms are formed from continuous staves, while baskets which are made with noncontinuous staves attached to bottoms of solid wood or built-up members are called *tubs*. When only top and middle hoops are used on round-bottom baskets, the bottoms are definitely rounded; however, when a third basal hoop is attached so that the sides are straighter, and the bottoms are relatively flat, such baskets are often referred to as bent bottoms. Round-stave baskets are supplied in nine sizes corresponding in capacities to the nine hamper sizes indicated above and are used for packaging a wide variety of agricultural products from many sections of the United States. Figures 9-17 and 9-18 illustrate two phases in the manufacture of these containers.

**5. Splint or Market Baskets.** These are rectilinear structures woven into shape with veneer splints and furnished with a rigid handle. In the past this basket, made with a diamond weave, was used extensively for



FIG. 9 17. Basket assembly positioned to receive basket-forming die. (Courtesy Courtney Product Advancement Corp., Benton Harbor, Michigan.)

many agricultural products. Today it has been largely replaced by baskets with square-braid weaves and its use is largely limited to the agricultural areas of the Central States. Splint baskets are made in six standard sizes, dry measure, of 4-, 8-, 12-, 16-, 24-, and 32-qt. capacity.

**6. Climax or Grape Baskets.** Climax baskets superficially resemble oblong tills but are readily distinguishable from the latter by their rounded ends, continuous walls, and solid-wood bottoms. The 1-qt. Climax is restricted by Federal statute to the use of mushrooms. Three other sizes, 2-, 4-, and 12-qt. Climaxes, are used for grapes and many other fruits and vegetables.

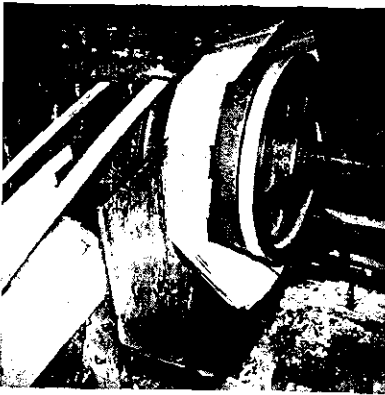


FIG. 9-18. Basket being shaped. Note hoops to left which will be stapled in place at the finish of the forward travel of the basket die. (Courtesy Product Advancement Corp., Benton Harbor, Michigan.)

### C. BASKET STANDARDIZATION

Prior to the Standard Container Acts of 1916 and 1928, baskets were manufactured in many styles, shapes, and alleged capacities. These acts not only established the number of cubic inches capacity for each but also reduced the number of containers in each category that could be marketed. Thus, while there were originally 44 berry boxes of various styles and capacities on the market prior to the passage of the acts, today such boxes are limited to three capacities. Similarly, the number of till baskets dropped from 44 to 4 standard capacities, round-stave baskets from 36 to 6, hampers from 75 to 9, and Climax baskets from 30 to 4.

The acts are administered by the Bureau of Agricultural Economics. This bureau has been responsible for the elimination of many odd-sized packages and others of deceptive size.

Basket standardization has resulted in many benefits to all concerned. A consumer now is assured that he is paying for only what he buys. The grower benefits from price reductions occasioned by standard manufacturing procedures and products, while the problems of the manufacturer are simplified to the extent that he can standardize his production equipment and concentrate upon the production of the few standard items he is required to stock.

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## CHAPTER 10

### SHINGLES AND SHAKES

The origin of shingles is obscured in the beginnings of history. There is little doubt that handmade shingles, comparable to present-day shakes, were among the first wood products manufactured by man. It has been surmised that primitive man probably learned early that certain straight-grained woods could be split with sharp stones, long before steel implements were in use. The earliest European writings mention shingles and shakes. One definition from an old English dictionary, which is comprehensible in modern English, is as follows: "Shyngles, wyche be tyles of woode such as churches and steples be covered with. (Huloet.)" \* In terms of modern usage, a shingle is a small, thin piece of wood with parallel edges, thinner at one end than the other, commonly used for covering the sides and roofs of buildings. Present-day shingles are sawed. Shakes are split or rived boards that are the same thickness at both ends, although they may be tapered in splitting by reversing the block each time a shake is split off. Modern shakes are sometimes sawed with a taper on one side or machined on the top side to simulate a split surface. In early times shingles were shaved, rived, or split with a broadax or froe after the logs had been cut into bolts of the proper length. Sometimes they were tapered at one end with a drawknife so they would lie flat like modern shingles. Thus early shingles were more like modern shakes. Early American settlers brought the art to this country, and they found species that were well suited to shingle making. Shingles were easy to make compared to the laborious methods of manufacturing lumber then in use, and they soon became a standard building material.

The beginnings of the western red cedar shingle industry in the Pacific Northwest followed closely after trapping, which was the first industry in the region. It has been reported that Hudson's Bay Company trappers cut shingles for a living after they became too old for the rigors of the trapline. These shingles were shipped to California or around Cape Horn to the Eastern states. The following extract quotes an interesting record of an early shipment of shingles:

That shingles were a staple article of commerce along the North Pacific coast over a hundred years ago is well established by a reference to the logs of Hudson's Bay

\* Quoted in *The Century Dictionary and Cyclopedia*. The Century Company, 1911.

trading schooners, one example of which will suffice. The schooner "Columbia," the first vessel launched on the Columbia River, at Vancouver, Washington, was dispatched to the Fraser River in 1830, under command of William Ryan. Leaving Fort Vancouver on July 9 she arrived at Fort Langley on the Fraser on August 15. The captain's entry for August 17 reads: "Received on board 16 casks salmon, 12 bds. shingles, 13 bales beaver, 16 bales salmon."<sup>7</sup>

By 1845, shaved shingles were being produced in commercial quantities in the Pacific Northwest, but full-scale production did not develop until the introduction of the block shingle machine from Canada and the arrival of the Great Northern Railroad at Seattle.

#### A. SPECIES USED FOR SHINGLES

The variety of species that have been used for shingles in the United States parallels closely the depletion of supplies of suitable timbers as lumbering moved westward. The Pilgrims found the heartwood of virgin white pine highly durable and of excellent properties for shingles, far better than the heartwood of second- and third-growth trees of today. The John Howard Payne house, immortalized in the song "Home, Sweet Home," is a favorite example of the durability of shingles. Built in 1660, the siding of white pine shingles is still intact and the roof was only recently re-covered with red cedar shingles. Later, northern and southern white cedars were used, and in the development of the Middle Western states, durable white oak and chestnut shingles and shakes were common. Northern white cedar, from the Northeastern and Lake states and from Canada, is still the source of small quantities of shingles. In the Gulf states it was early discovered that cypress possessed the qualities desired for shingles, and this species is still used to a limited extent. As population moved westward and the large stands of western red cedar and redwood were discovered, the national source of shingles moved to the West Coast and red cedar soon dominated the shingle market. Redwood, partly because the wood is more valuable for other uses, has never been developed as a major source of shingles, although limited quantities are sold in California and occasionally shipped to other states.

Locally, numerous species have been and are still being used to a very limited extent. Southern pine in the South, sugar pine in the Sierra regions of California, hemlock and spruce in the East, and occasionally Douglas fir in the West are among many that could be mentioned. Port Orford cedar possesses ideal properties, but short supplies and more profitable uses have limited this species to local consumption. Alaska yellow cedar falls in a somewhat similar category. In some parts of the country, small operators are still manufacturing shingles from hardwoods for local use.

1. **Western Red Cedar.** At the present time western red cedar accounts for approximately 95 per cent of all shingles produced in the United States. The principal commercial stands are located west of the Cascade Mountains in Washington and Oregon, but the species is also found in commercial quantities in some parts of Idaho and Montana and east of the Cascades in Washington. Extensive stands are also found in British Columbia, Canada. In 1945, total production in the United States was 3,156,613 squares\*, of which all but 182,057 squares were manufactured from western red cedar. This latter amount represented the total production of redwood, southern cypress, northern and southern white cedar, and small quantities of other species cut for local use. According to the Bureau of the Census,<sup>9</sup> total shingle production by United States mills in 1947 was 3,803,286 squares, but this report was not broken down by species. Western red cedar dominates the field so completely that this chapter will deal primarily with the shingle industry of the Pacific Northwest.

The prewar demand for western red cedar for lumber and shingles was between 500 and 650 million board feet of logs per year, which was augmented by the importation of about 20 to 45 million board feet of logs from British Columbia. Of the total logs consumed, approximately 80 per cent were used for shingles and the remainder for cedar lumber, from which bevel and rustic siding, finish, dimension, and boards were manufactured. In a recent estimate, the U.S. Forest Service<sup>11</sup> indicates an annual postwar requirement for shingles alone of between 400 and 500 million board feet. This represents little change from prewar production, and the shingle output can be expected to approximate prewar levels. At present, production is limited by lack of log supplies rather than by lack of demand.

#### B. QUALITIES DESIRED IN WOOD USED FOR SHINGLES

Wood for use in the manufacture of shingles should have the following properties: (1) durability, (2) freedom from splitting in nailing, (3) dimensional stability, *i.e.*, low ratio of tangential to radial shrinkage and minimum shrinkage in all planes, (4) light weight, (5) good insulating properties, (6) adequate strength, (7) straight, even grain for ease of manufacture, (8) ability to take stains and paint, (9) ability to resist abrasion, and (10) pleasing appearance. Availability of sufficient supplies of logs or bolts, at a reasonable cost, is also an important factor.

Western red cedar, redwood, cypress, and northern and southern white cedar all possess the desired properties to a high degree when compared

\* For the definition of this term see page 221.

to other species commonly used for lumber and other purposes. Western red cedar is somewhat superior to the other shingle species on most counts, which is one of the reasons for its dominance of the shingle field. The availability of larger stands of red cedar has also played an important part. As matters now stand, suitable supplies of logs of all shingle species, including red cedar, are in short supply. Unless research can develop treatments for shingles made from other woods that will make them equal or superior to red cedar, this species will continue to be the predominant source of wood shingles.

### C. THE MANUFACTURE OF SHINGLES

Most cedar logs are purchased on a specialized cedar-log market. The cost of logs is a dominant factor in the production costs of shingles, but prices so fluctuate that specific figures will not be given. Some of the reasons for this are differences in log grades and scaling practices in the United States and Canada, differences in logging costs, fluctuations in Douglas fir production (upon which cedar-log supplies depend to a large extent), log inventories at various times in the year, and government price and quota controls.

A small percentage of logs destined for small shingle mills located away from water transportation are bolted by hand in the woods. Shingle bolts are split segments of a log, ranging from 48 to 54 in. in length, depending on the length of the shingles to be manufactured. By far the greatest number of logs are cut to standard log lengths in the woods and handled with conventional logging equipment prior to delivery to water transportation. After arrival at the shingle mill, the logs are usually dumped in a log pond for ease of sorting. They are then cut to convenient lengths for elevation into the mill, which is usually accomplished by means of a conventional log haul. Most shingle mills are of two-story construction with the shingle machines on the second level. Steam-driven drag saws were formerly used to cut the logs in the pond, but power-driven chain saws are becoming popular because of their greater speed and efficiency. On reaching the log deck the logs are cut into 16-, 18-, or 24-in. lengths, depending on the length of the shingles to be manufactured. Deck saws are up to 10 ft. in diameter and are operated at a rate of speed that will ensure a smooth, accurate cut. These blocks are then quartered, either by sawing or splitting, and reduced still further, if necessary, to make them of suitable size for the shingle machines. Sawing is more common than splitting, probably because of the lower cost of sawing equipment. Splitting is more desirable because of the saving in saw kerf, and since the splits tend to follow the plane of the rays, more true radial

surfaces are obtained. This results in a higher proportion of vertical-grain shingles. Splitters, operated by either steam or pneumatic power, may be either vertical or horizontal and may have three or more knives. Some mills use a one-knife splitter and resplit as many times as necessary to obtain the desired size of blocks. Multiple-knife splitter heads are more common. Some prefer three-knife to four-knife splitters because of the larger proportion of wider shingles that can be cut from larger blocks. Sawyers working on a piece-work basis prefer large blocks because fewer need be placed in the machine and it is, therefore, cutting shingles a greater percentage of the time. The blunt, wedge-shaped knives usually enter the blocks only about 1 in. The blocks are brought to the splitter by some form of mechanical conveyer. Some mills use a plunger with a ball-bearing head to elevate the block above the conveyer chains in preparation for splitting. This device permits the operator to turn the block to whatever position will provide the maximum yield of high-grade material. Shadow guides are commonly used to indicate the exact positions that the knives will strike when the splitter head is lowered.

After quartering, in most Canadian and a few American mills, the blocks are passed to a specialized saw table, equipped with a vertically oriented circular saw called a *knee bolter*. Here the bark and sapwood and certain surface defects are removed. Most American mills dispense with this operation because the bark and sapwood are removed from each shingle at the time it is edged in the normal process of manufacture. The blocks are then moved by conveyer from the splitter or the knee bolter to the shingle machines (Fig. 10-1), where sufficient quantities are stock-piled within convenient reach of the sawyer. Virtually all machines now in use in the red cedar shingle industry are of the vertical type, although a few of the older horizontal machines are still in use in other regions. The vertical design makes it possible for one operator to edge and grade the shingles as they are cut from the block. In this way the sawyer is constantly aware of the quality of the shingles being produced, which permits him to adjust the block when necessary to stay within specification limits for edge-grain shingles. It may be necessary to adjust the block several times to keep the cutting face as closely as possible in the plane of the wood rays, or at right angles to the growth rings. Each such adjustment results in the loss of some material, called a *spall*, which is the slice of wood that must be removed to reorient the block.

Shingle machines are equipped with clamping jaws that hold the blocks rigidly in place on a reciprocating power-driven carriage (Fig. 10-1). The blocks are placed in the machine in the vertical position and are oriented in such a manner that the shingles are cut from the radial surface that was exposed by splitting. The carriage, which is actuated by an

eccentric crank from a geared drive, passes the block back and forth through the saw at the rate of about 35 strokes per minute. On each return stroke of the carriage, pawls engage the carriage feed rolls, tilting the carriage, so that a tapered shingle is cut on each forward stroke. The butt, or thick end, of the shingles is cut from the top of the block on one stroke and from the bottom on the next stroke. Machines called *double-butting machines*



FIG. 10-1. Shingle machine, showing carriage and setworks. (Courtesy Sumner Iron Works, Everett, Washington.)

make two strokes before the carriage is tilted. This gives two butts at the top, then two at the bottom, instead of alternating as with single-butting machines. The saws used are approximately 40 in. in diameter, from 8 to 10 gauge at the center, tapering to 16 to 19 gauge at the rims, and have about 80 teeth.

As each shingle comes off the saw the sawyer picks it up and places it on a *springboard* (sometimes called *shingle jointer*, or *knot saw*) for edging, or jointing (Fig. 10-2). The springboard is a small hinged table having a guide for the butt of the shingle that is at a true right angle with the edging saw. After the shingle has been placed in the proper position on the springboard, the latter is pushed down, bringing the edge of the shingle into contact with a circular saw. This trims away any bark or sapwood that may be present or merely joints the edge at right angles to the butt. The shingle is then turned over and the process repeated in order to make

both edges parallel and to remove any defects that may be present on the second edge. Defects in the center as well as the edge can be removed with this saw, making one or two acceptable narrower shingles from a larger shingle that would be rejected or reduced to a lower grade. While the edging is in process the sawyer grades the shingle, then tosses it into



FIG. 10-2. Shingle sawyer trimming edge of a shingle with his right hand as he takes the next shingle from the saw with his left hand. (Courtesy Red Cedar Shingle Bureau.)

the proper grade chute where it passes to the shingle packer, usually located on a lower level. Rejected shingles are kept separate.

Packers are stationed beside bins fed by the sawyer with a packing frame near at hand (Fig. 10-3). The shingles are regraded by the weaver as they are packed as extra assurance that no mistakes are made. Enough of each grade is placed in the packing frame to produce a standard-size bundle. One half of the butts are at one end of the bundle and the other half at the other, with the thin tips overlapping in the center. The bundle is bound by *band sticks*, one each at the center of the bundle above and below, the ends being bound under pressure with metal straps or bands. This method of packaging assures flat shingles, even during the drying process. The packer then places the bundles on a conveyer that takes them either to storage or to the dry kilns. At this stage the shingles are

in the green condition, with the wood usually well above the fiber saturation point. Unless cargo shipment is contemplated, the shingles must be dried. Reprising, accomplished in a horizontal-press frame, is necessary after kiln drying to take up the slack caused by shrinkage.

1. **Manufacturing Methods in Canada.** Operating techniques in Canadian mills are similar to those in the United States, with some minor ex-



FIG. 10-3. Shingle packer binding off a bundle of shingles in a parking frame. The various grades of shingles come from the sawyer, at the upper level, through the chutes at the rear. (Courtesy Red Cedar Shingle Bureau.)

ceptions. Machine speeds are limited by law to 34 strokes per minute, whereas there is no limit in this country. It has been found, however, that 36 strokes per minute is about the maximum that is consistent with satisfactory grade recovery and minimum waste. The output per machine in the United States is approximately  $4\frac{1}{2}$  squares per hour; in Canada it is  $3\frac{1}{2}$  squares per hour. Several other factors besides carriage speeds are involved. Chinese sawyers, commonly employed in Canadian mills, work less rapidly than American workers. Also, Canadian mills concentrate on the production of the high grades. This reduces output because the blocks must be turned more often and the machines are idle a greater part of the time. The lower rate of production has tended to offset lower wage rates in Canada. Returns to the owners are, however, greater because of the larger proportion of higher grade shingles produced. The average yield



of shingles per M bd. ft. log scale is approximately 25 per cent higher in the Pacific Northwest than in British Columbia, or  $12\frac{1}{2}$  and 10 squares, respectively.

#### D. SEASONING AND STORAGE

Green shingles are usually shipped by water or by truck, since freight rates on these carriers are based on volume and not on weight. Cargo, or water, shipments declined sharply during the Second World War, amounting to less than 10 per cent of total shipments in 1944, and this form of transportation has still recovered only a small part of its original volume.<sup>13</sup> Truck shipments of green shingles between Oregon and California have increased since then, but it is doubted if they have offset losses in cargo movements. This means that approximately 90 per cent of all red cedar shingles are dried before shipment in order to reduce transportation charges. Small quantities of shingles are still air-seasoned, but the major portion is kiln-dried. Western red cedar requires mild drying schedules because the wood is subject to collapse and honeycombing. Overdrying of shingles to reduce shipping costs was one of the practices that created prejudices against wood shingles prior to the establishment of minimum standards. Satisfactory drying schedules have been developed through research, and most operators now recognize the importance of proper seasoning. Savings in freight costs are not the only advantages of drying. Properly kiln-dried shingles assure uniform moisture content at the time of laying, which equalizes shrinkage and virtually eliminates cupping and warping after the shingles are laid. To preserve these advantages it is desirable that shingles be stored under conditions which provide sufficient circulation of air and which avoid exposure of outer layers to rain or the direct rays of the sun.

#### E. STAINING AND THE APPLICATION OF WOOD PRESERVATIVES

The heartwood of red cedar is highly durable, and neither stains nor preservatives are required to obtain long, satisfactory service from a roof covered with untreated, all-heartwood shingles. Evidence of this is found in the fact that by far the largest proportion of shingles is not stained or otherwise treated. Color, however, is sometimes desired, and the life of shingles containing sapwood can be prolonged by the use of appropriate wood preservatives. Shingles may be stained by dipping or by pressure methods in commercial plants or by hand on the job. They may also be stained in place, on roofs or side walls, but the results are less effective. Painting, although satisfactory for shingles on sidewalls, is not generally recommended for shingled roofs.

The advantages of stained shingles are (1) they provide a choice of colors or combinations of colors; (2) stains of good quality contain linseed oil, which reduces shrinking and swelling during wet and dry periods; (3) preservative treatments can be combined with staining to prolong the life of shingles that contain sapwood; and (4) stains reduce the rate of mechanical wear of the surface of shingles. Mechanical wear is obvious only after long periods of time, but shingles eventually become thinner as a result of attrition by sand and dust particles and of leaching and mild hydrolysis of the surface layers of the wood from exposure to rain. Proper prestaining, followed by restaining of the exposed butts, will help to prevent deterioration. The additional cost of stained shingles is small compared to the cost of laying the roof. It is highly desirable, therefore, that they be bought from a reliable dealer or, in the case of on-the-job applications, that only the best ingredients be purchased. Additional information on this subject can be obtained in selected references 3 and 12.

The preservation of shingles is not practiced extensively but will, no doubt, become more common now that substitute species that are less durable are coming under consideration for use as shingles. For years, creosote was the standard preservative for shingles, some companies developing "decolorized" fractions of creosote for use with light-colored stains. Some of the newer preservatives, such as pentachlorophenol and copper naphthanate, may well find a place in this field. The disadvantage of the standard grade of creosote has been the impossibility of using it in combination with light colors.

Preservatives are best applied by pressure methods, but reasonably effective results can be obtained either by dipping or by the use of the conventional hot-and-cold-bath method of applying wood preservatives. Preservatives applied to a roof or sidewall after it has been laid cannot be expected to be effective in the prevention of decay; the preservative will not reach inaccessible areas under and between the shingles where decay is most likely to become established. A more complete discussion of the subject of preserving shingles can be found in selected reference 12.

#### F. CLASSIFICATION OF SHINGLES

The establishment in 1931 of quality standards for the manufacture of wood shingles by the Bureau of Standards of the Department of Commerce marked a turning-point in the elimination of earlier practices that had been detrimental to the future of wood shingles. The Red Cedar Shingle Bureau and many shingle manufacturers gave full support to the project, and between 85 and 90 per cent of the shingles now manufactured conform to these standards. The standard, as revised, is known as Commercial Stand-

ard 31-38 and covers the No. 1 grades of redwood and cypress shingles, as well as those manufactured from red cedar. The grade marks of accepted association inspection agencies assure *conformance* to this standard. This applies, as well, to shingles manufactured in Canada for the American market.

**1. Length and Width of Shingles.** Most shingles are packed and sold in random widths, ranging from 3 to 14 in. This leaves only length and thickness as the criteria for classification. Standard lengths are 16, 18, and 24 in. Ten per cent of the shingles in any one shipment may be 1 in. either over or under the specified length. *Dimension* shingles are an exception to the general rule, since they are jointed to definite widths.

**2. Thickness of Shingles.** The thickness of shingles is measured at the butt when green and designated by the number of butts required to make up a specified dimension. For example, 4/2 in. means that four butts are required to equal 2 in. When length and thickness are combined there are three standard sizes of shingles: 16 in.—5/2 in.; 18 in.—5/2¼ in.; and 24 in.—4/2 in. Nonstandard specialty items, either thicker or thinner than the above, are produced in small quantities.

**3. Grades.** Specifications for shingles are given in *Commercial Standard 31-38* \* and in the grade rule books of the various shingle associations.<sup>3</sup> These should be studied with care by all prospective purchasers and users of shingles. The grades for the several lengths of shingles are somewhat similar. The following summary of the grades of 16-in. shingles is presented as an example:

*No. 1 Shingles.* No. 1 red cedar shingles represent the best grade that is manufactured. These shingles are intended primarily for roof construction, where the shingles should lie flat and tight and where there must be complete protection from rain water driven by high winds.

No. 1 shingles must be 100 per cent edge or vertical grain, 100 per cent clear, and 100 per cent heartwood. None of these shingles should be wider than 14 in. and none narrower than 3 in. There should be 20 courses of shingles at each end of the bundle. Not more than 10 per cent of the combined width of the shingles laid side by side (running inches) in any shipment may be less than 4 in. in width.

*No. 2 Shingles.* Shingles of No. 2 grade must be clear or free from blemishes for three-fourths of their length as measured from the butts. A maximum width of only 1 in. of sapwood is permissible in the first 10 in. Mixed vertical and flat grains are allowed. No shingles shall be wider than 14 in. and none narrower than 3 in. Not more than 20 per cent of the running inches in any shipment may be less than 4 in.

\* U.S. Department of Commerce, Bureau of Standards. Wood Shingles (Red Cedar, Tidewater Red Cypress, California Redwood). *Commercial Standard*, pp. 31-37, 4th ed.

*No. 3 Shingles.* No. 3 shingles must be 8 in. clear or better and may contain sapwood. No shingle shall be wider than 14 in. and none narrower than  $2\frac{1}{2}$  in., and not more than 30 per cent of the running inches in any shipment may be less than 4 in. wide. Knotholes up to 3 in. in diameter are permitted in the upper half.\*<sup>a</sup>

*Undercoursing grade.* A fourth grade of shingle, known unofficially as No. 4 but properly designated Undercoursing grade, is produced by many mills and is recognized by the industry through the Red Cedar Shingle Bureau. As the name implies, it is intended solely for the undercourse of double-coursed shingle sidewalls. Since the undercourse is always completely covered, the grade permits certain defects throughout the area of the shingle. Many mills mix their No. 3 grade shingles with their Undercoursing grade, producing a grade known as Special Undercoursing. The Undercoursing grades were produced as a result of the increased popularity of double-coursed sidewall construction.

The following commercial designations are generally recognized in the American shingle market:

16 in.— $5\frac{1}{2}$ in.	Perfects, or XXXXX
18 in.— $5\frac{1}{2}$ in.	Eurekas <sup>c</sup>
18 in.— $5\frac{1}{4}$ in.	Perfections
24 in. $4\frac{1}{2}$ in.	Royals

<sup>a</sup> Manufactured to a limited extent in Canada and marketed in small quantities in the United States.

No. 2 and No. 3 shingles are sometimes designated as 8-, 10-, or 16-in. clears, based on the number of inches of wood, measured from the butt, that is clear of defects.

**4. Unit of Measure.** The unit of measure used in marketing shingles is the *square*, or *square pack*, which is defined by the Bureau of Standards as "A unit providing sufficient shingles for the coverage of an area of 100 sq. ft. when the shingles are laid at any specified exposure to the weather." For roofing, the specified exposures for the 16-, 18-, and 24-in. lengths are 5,  $5\frac{1}{2}$ , and  $7\frac{1}{2}$  in., respectively, and four bundles are required to equal one square. For sidewalls, exposures may be greater,  $6\frac{3}{4}$ ,  $7\frac{1}{2}$ ,  $8\frac{1}{2}$ , and  $11\frac{1}{2}$  in. being specified; consequently, three bundles equal one square. Because of the increased popularity of double-coursed applications, the three-bundle square is being used less frequently. Bundle sizes are determined by the number of courses of shingle butts at each end of the bundle. When a bundle is designated as 20/20, it means that there are 40 layers, or courses, of shingles overlapping under the band stick, with 20 courses of

\* Effective Sept. 1, 1947, No. 3 16-in. shingles were changed from 8 in. clear to 6 in. clear. In view of this, the wording of the last part of the last sentence should read "the upper portion" instead of "the upper half."

butts on each side of the sticks. Dimension shingles are sold by the piece, or net count, but one square, when laid according to specified exposures, will cover 100 sq. ft.

### G. APPLICATION OF SHINGLES

The application of shingles, although based on a good deal of research as well as practical experience, is an industrial art rather than a technical subject. Authoritative handbooks are available that give detailed instructions and information on the proper methods of laying shingles on roofs and sidewalls, recommended exposures, special adaptations for hips, ridges, valleys and flashings, types and sizes of nails to use, overroofing, double-coursing, staining and painting, and numerous other techniques essential to the building trades.<sup>2,3</sup> Such information is beyond the scope of this text, but it is recommended that everyone who is interested in wood utilization obtain a good handbook for ready reference. Some general remarks may, however, be of interest.

No. 1 shingles should always be used for the roofs of primary buildings, where maximum protection from the weather and long life are essential. The lower grades can be used for the roofs of secondary structures, such as home garages and numerous farm buildings, but anything less than the best grade of shingle is an unwise investment for the roof of a primary structure. The properties of the No. 1 grade—all-vertical grain to provide greater strength and minimum shrinking and swelling, 100 per cent heartwood to provide maximum durability, and freedom from defects—assure minimum maintenance costs and maximum life. No. 2 shingles are standard for sidewalls and well suited for roofs of secondary buildings, for overroofing over old shingles, and for double-coursing under No. 1 shingles. No. 3, the economy grade, gives good service when used in proper locations, such as undercoursing, overroofing of farm buildings, or sidewalls of garages, summer cabins, and farm buildings.

Strict adherence to the recommendations of the accepted trade associations with respect to exposures and spacing, types and sizes of nails, and other details, cannot be overemphasized. They are designed to assure the user of maximum service. Digressions from these accepted standards usually result in false economies. Users of shingles should follow the instructions proposed by the Red Cedar Shingle Bureau,<sup>3</sup> or other reliable sources.

Overroofing, a relatively recent development, has numerous advantages over reroofing when a roof is in need of replacement. Among these are the following: (1) it provides double insulation, with consequent savings in fuel and greater comfort in summer; (2) it can be done at any time, in

the rainy season as well as during dry periods; (3) it is less costly, as it eliminates the labor cost of removing the old shingles; (4) it adds strength to the roof without appreciably increasing the dead load (shingles weigh less than 2 lb. per sq. ft.); and (5) the litter of old shingles, always a nuisance to remove, is eliminated. In reroofing barns and feed sheds it excludes the possibility of nails and other dangerous debris falling into haymows or feed bins.

Shingles should not be wetted or soaked prior to installation. It was long believed that wetting and consequent swelling would ensure that the shingles would not be laid too close together. Proper lateral spacing of dry shingles will accomplish the same purpose more efficiently, and the laying of wet shingles is detrimental to the construction of a good roof. Shrinkage stresses between nails often cause splits and checks as a shingle dries. The equilibrium moisture content attained in the dealer's storage shed in the area in which the shingles are to be used is usually the most suitable for laying the shingles. It should be remembered that the spacing recommendations of the appropriate trade associations make the proper allowance for shrinking and swelling.

**1. The Life of Shingles.** No. 1 shingles, if properly applied, can be expected to have a life of 35 years under average climatic conditions on steep roofs; 25 years on roofs with a one-fourth pitch; and a life in excess of the life of the average structure when used as sidewalls. The above expectancies can be considered as averages; there are numerous records of roofs that have lasted in excess of 75 years. An example is quoted as follows: "Lowland, the magnificent mansion of the late George Abbot James, at Nahant, Massachusetts, was built and roofed with red cedar shingles in 1872 and is found to be in perfect state of preservation." \* The life expectancies of No. 2 and No. 3 shingles depend to a large extent on the proper selection of the uses to which these lower grades are to be put. No. 2 shingles, when used on sidewalls, will match or even exceed the life of No. 1 shingles used on the roof of the same building. No. 3 shingles will give service commensurate with their cost if used where exposure conditions are not too severe. Even flat-grained shingles have been known to last as long as 25 years on roofs.

**2. Advantages of Wood Shingles.** Among the more important advantages of wood shingles are (1) superior insulating properties, (2) long life, (3) resistance to wind, snow, and hail damage, (4) suitability in nearly all climates, and (5) attractive appearance. Wood in general has far better insulating qualities than most other building materials, and western red cedar is high in efficiency in this respect when compared to other woods used for construction purposes. The thermal conductivity of shingles as

\* The Encyclopedia Americana. Americana Corporation, New York. 1947.

normally laid up is only about one-third that of asphalt roofing. In other words, wood shingles, on an average, provide three times as much insulation as asphalt shingles. The life of wood shingles compares favorably to, and usually exceeds, that of composition roofings. Wood shingles are less subject to damage by hail and high winds, and their performance is little affected by climatic conditions; they serve equally well in both hot and cold climates. To most people, wood shingles are more attractive in appearance than most competitive materials. Weathering and slight variations in the natural color of the heartwood of red cedar and the soft texture that results from the broken lines of shingles laid in random widths gives a harmonious effect not found in the stereotyped patterns of most composition roofings. The colors of stained shingles, since the stains are absorbed by the wood, are more soft and natural than the harsh colors of many composition materials.

The outstanding advantage of red cedar shingles is their long life. In a questionnaire distributed by the Bureau of Standards to 148 field offices of the Home Owner's Loan Association and Federal Housing Administration in 48 states and the District of Columbia<sup>15</sup>, information was requested on the length of life of wood and asphalt shingles. The results showed that the average life of wood shingles in all states was approximately 20 years, as compared to about 14 for asphalt shingles. It was further shown that climate had a marked effect on the life of the asphalt product, whereas it made much less difference in the case of wood shingles. In 21 states south of a line corresponding roughly to the 40th parallel of latitude, the average life of asphalt shingles was only 12 years. North of this line the average was 16 years. This was not a scientifically planned experiment, but the results are indicative of the relative lives of the two roofing materials.

Among lesser advantages, it is claimed that damages to shrubbery and the dangers attending snow and ice avalanches from roofs is reduced on all but the steepest roofs when wood shingles are used, that condensation is not a serious problem under shingle coverings, and that noise transmission is far less than with most other roofing and sidewall substitutes. The disadvantages of wood shingles are higher initial cost and their inability to meet building-code restrictions that have become established throughout the country.

#### H. CHARACTER OF THE RED CEDAR SHINGLE INDUSTRY

Shingle mills are of two types: "straight" shingle mills and "combination" mills. The former produce shingles exclusively; the latter, both shingles and cedar lumber. Not many sawmills in the Pacific Northwest combine the manufacture of cedar with other species such as Douglas

fir and hemlock. Most companies prefer to sell their cedar logs on the open market. A few large, integrated operations retain their cedar logs in order to obtain the added profits that can be derived by converting the logs in their own shingle mill or sawmill. By and large, however, the cedar industry is one of intensive specialization.

Shingle mills vary in size from 1- to 25-machine installations. In the United States there has been a marked increase in the number of small mills in recent years; in British Columbia the trend has been in the opposite direction. The Second World War interrupted this trend in the United States. Large numbers of one- and two-machine mills were shut down for the duration, but it appears likely, as can be seen from Table 10-1, that the trend will be resumed. This table is a tabulation of the number of mills and machines in the United States for selected years from 1936 to 1947.

TABLE 10-1. TOTAL NUMBER OF SHINGLE MILLS AND SHINGLE MACHINES IN THE UNITED STATES FOR SELECTED YEARS, 1936 TO 1947, INCLUSIVE <sup>a</sup>

	1936 (June)	1941 (Sept.)	1944 (Jan.)	1946 (Sept.)	1947 (Jan.)
Total number of mills.....	288	325	122	236	288
Total number machines.....	861	804	588	557	584
Average number machines per mill.....	3.0	2.5	2.8	2.4	2.0

<sup>a</sup> Sources: U.S. Department of Commerce, Bureau of Census. Facts for Industry, Forest Products: 1945 Lumber, Lath and Shingle Production. 1945. U.S. Tariff Commission. Red Cedar Shingles. War Changes in Industry Series. Report 8. 1945.

It should be noted that an increase in the number of mills is not accompanied by a corresponding increase in the number of machines. In fact, the trend toward increased numbers of small mills has been accompanied by a decrease in the total number of machines. Often, when a large mill is abandoned because of lack of timber supplies, employees purchase some of the machines and establish small units. Small units, scattered over a large area, have a better chance of survival in terms of timber supply than a single large mill. They require less raw material and can be moved more easily to new sources of timber. Ownership of shingle mills is, for the most part, in the hands of small individual operators. Corporate ownership is relatively rare in the United States; the largest organization in existence in 1945 owned four mills having 44 machines. Shingle brokers and wholesalers finance a small number of plants, and about half a dozen are owned and operated on a cooperative basis by groups of workers.



The shingle industry is characterized by instability and intermittency of operation. Many of the small operations are insecurely financed, and an average of 20 to 30 per cent of all mills are shut down most of the time. Idle mills are most numerous from December to March, but a rather large number is closed in all months of the year. Unfavorable weather conditions in the logging areas cause most of the winter shutdowns. Other factors contributing to the unevenness of production are local log shortages, insufficient railroad cars, scarcity of labor, competition for labor from more stable industries, labor disputes, plant breakdowns, mill fires, slack orders, and insolvency caused by inadequate financing. At no time is production up to full capacity even when the demand for shingles is high. The same conditions exist in Canada.

### I. MARKETING OF SHINGLES

The history of marketing shingles is an excellent example of the damage to a product that can result from a lack of specifications and inspection standards and a strong trade association to enforce them. In the early 1930's, the quality of shingles in the United States was at a very low level. A high proportion of the output consisted of improperly dried, thin, flat-grained shingles. It is generally believed that this condition influenced materially the establishment of the asphalt-roofing industry on a competitive basis. It may also have had an influence in the establishment of fire ordinances and underwriters' codes that are inimical to the interests of the wood-shingle industry. Loose, cupped, and warped shingles are known to contribute to the ignitibility of roofs and to the spread of fires. The first impact of competition from other types of roofing materials caused reductions in the prices of shingles; the second result was a marked improvement in the quality of shingles. During the same period, Canadian shingles commanded a premium on the American market because of the more rigid inspection to which they were subjected.

**1. Markets.** Shingles are used in all parts of the United States, but restrictive legislation has played an important part in the pattern of distribution. Consumption is limited to a large extent to rural and urban areas where discriminatory legislation has been less severe than in many large cities. Consumption is not proportional to density of population, largely because of the building-code restrictions just mentioned. In 1940, the distribution of red cedar shingles consumed in the United States was as indicated in Table 10-2. The unfavorable position in which shingles had been placed was eventually overcome through the establishment of specifications and the strengthening of inspection procedures. The trade associations of the industry were instrumental in these reforms.

Information presented in Table 10-2 shows that the bulk of shingles manufactured in the United States is used in the northern half of the country, while most Canadian imports are consumed in the Middle West and Eastern States. At least this was the situation prior to the Second World War and it is expected that distribution will revert to previous

TABLE 10-2. RED CEDAR SHINGLES: DISTRIBUTION OF UNITED STATES AND CANADIAN SHIPMENTS BY REGIONS, 1940 <sup>a</sup>

Region	Percentage		
	United States shipments	Canadian shipments	Total shipments
West and East North Central, New England, and Middle Atlantic.....	38.6	72.3	48.7
South Atlantic, East and West South Central.....	16.9	22.6	18.6
Rocky Mountain and Pacific Coast.....	43.4	5.1	32.0
Hawaii and Alaska.....	1.1	.....	0.7
Total.....	100.0	100.0	100.0

<sup>a</sup> U.S. Tariff Commission. Report to the United States Senate on Red Cedar Shingles. Report 149, 2d ser. 1942.

pattern once war-born irregularities have subsided. Consumption of shingles should increase on the West Coast in the near future because of the coincidence of large increases in population and proximity to the source of supplies.

The status of tariff agreements between the United States and Canada, the position of Canada with respect to United Kingdom preferential agreements, and the number of shingles reserved for Canadian consumption, all have a bearing on the shingle market in the United States. The question of tariffs and trade agreements is too lengthy to discuss here, but it cannot be ignored in any analysis of shingle markets.<sup>13,14</sup>

**2. Competitive Factors.** In spite of their many advantages, wood shingles have lost ground steadily to asphalt shingles and roll roofing since shortly after the First World War. The principal reasons are quoted as follows: "Among the factors operating against wood shingles and in favor of other roofings are (1) the location of the respective industries in relation to markets, and differences in the distribution systems; (2) building regula-

tions; (3) the relative costs of the several roofings; (4) fire-insurance rates; and (5) trade promotion and salesmanship. All these play an important part in the ultimate choice of the consumer and tend to create an expanding market, particularly for asphalt roofings, and a contracting market for wood shingles." <sup>13</sup>

*Competition from other types of roofing materials*, such as asbestos shingles, some of the older metal roofings, tile, and slate is not a serious threat to wood shingles because these products occupy a higher price level or their weight results in shipping-cost penalties. Aluminum siding and roofings are being sold at competitive prices and are being used rather extensively for barns and other farm buildings at the time this is written. Whether or not this material will remain in the competitive market when low-cost war surplus supplies of aluminum are exhausted is not known. Thin aluminum sheeting has certain obvious shortcomings for use as roofing and sidewalls but, if sold at a low enough price, it could offer serious competition to wood shingles. More serious from the standpoint of competition is a recently announced aluminum shingle that provides for a five-inch exposure and carries a guarantee of sixty years. It is claimed that these will be available in unlimited quantities at a lower cost than wood shingles. Aluminum bevel siding, prime-coated for any color of house paint, has also been announced. Plastic shingles of all colors, that are fused to each other and to the roof boards or shingles, are to be marketed by a large company in the near future. They have an expected life of forty years.

**3. Building Codes.** Restrictive building regulations date to the period prior to the acceptance of commercial standards and specifications for wood shingles. Before and just after 1930, a large part of the domestic shingle production consisted of flat-grained shingles that cupped, warped and split, thus contributing to fire hazard. Many of these restrictions remain in force, even though conformance to Commercial Standard 31-38 and its revisions has resulted in a " . . . vastly improved shingle which practically eliminates all danger from brands and sparks on roofs." <sup>13</sup> In spite of determined efforts, and some success, by the Red Cedar Shingle Bureau to combat restrictive codes, the sentiment against wood shingles continues to grow in some parts of the country. Even when restrictions are not exclusively prohibitive, increased fire-insurance rates are a further handicap to wood shingles. Actually, though wood shingles have a lower ignition point than mineral-coated asphalt shingles, they do not contribute as much fuel to a fire as do asphalt materials when once ignited. Evidence tends to show that many restrictive building codes are predicated on prejudices of previous years and that many of these objections are not valid in the case of wood shingles manufactured in accordance with present-day specifications.

**4. Future Trends.** In discussing the competition of composition shingles with wood shingles it should be remembered that this conflict concerns only one of the many wood-using industries of the country.\* As a matter of fact, the composition-roofing industries utilize large quantities of wood fiber, either in the form of paper or matted fiber, as a base that is impregnated with asphalt. Snoke<sup>6</sup> reports that both groundwood fiber and chemical-wood fibers are used in the manufacture of felts for asphalt-prepared roofing. Usually the two are used together, the former in amounts up to nearly 19 per cent, the latter up to 14 per cent, depending on the formulation. In some formulations the felts may contain as much as 32 per cent of wood fibers. The other components, depending on the type of roofing being made, consist of rags, up to 75 per cent; jute, up to about 15 per cent; and wool, rayon, silk, hair, and kapok in lesser quantities. Recent research has shown the way to the use of mechanically fiberized wood residue for this purpose, in even larger proportions; a process that can play an important part in better and more complete wood utilization. Neither must it be forgotten that domestic wood shingles must face the competition of Canadian importations. The exact extent and form of this competition are unpredictable because of quotas, tariff restrictions, and trade agreements that may change rather rapidly in the years to come. At present, the Canadian government is reserving a large part of the output of red cedar shingles for home use. Canada has its own postwar building problem, and exports may not assume large proportions in the immediate future unless the demand for Canadian shingles in the United States increases materially or the price becomes especially attractive and present Canadian export restrictions are lifted. One thing seems fairly certain: the demand for shingles should be quite active for some years to come because of the great need for housing and other construction in the postwar period. In fact, this demand may exceed the available supplies of raw material. Large segments of the industry are idle at the present time, some of them because of log shortages.<sup>8</sup> This may eventually be the limiting factor. Unless substitute species can be developed (and acceptance of new species is always slow), it is possible that wood shingles will lose even more ground to competitive materials as soon as the rush of postwar construction is over.

#### J. THE MANUFACTURE OF SHAKES

Shake making, which was an important business in colonial and pioneer times, is now practiced to only a limited extent. The number of shakes

\* There is, however, a definite parallel between the building-code restrictions governing the use of wood shingles and similar regulations against the use of wood for other purposes.

now manufactured is difficult to determine, because statistics on shakes are combined with those on shingles. Shakes are more costly than shingles and are most commonly used for special effects on resort, hunting and fishing lodges, and types of architecture that derive beauty and authenticity from the duplication of the old-fashioned appearance that shakes provide. Homemade shakes are used to some extent in the construction of cabins by trappers, hunters, and other persons living in isolated places.

Handmade split shakes are usually 25, 31, or 37 in. long and vary in width from 5 to 18 in. They are usually from  $\frac{1}{2}$  to  $1\frac{1}{4}$  in. in thickness. Some are tapered, but if ease of production or a particularly rough effect is desired, they are left the full thickness at both ends. Numerous mechanical methods, including both sawing and special machining, have been devised.<sup>7</sup> Among these are (1) resawing thick split shakes from corner to corner, resulting in two shakes having a rough, split surface and a flat sawed back; (2) running a heavy-sawed shingle through a special machine head that imparts to the surface the rough appearance of a split shake; and (3) passing a heavy shingle under a heated pressure roll that is embossed with the impression of a split shake. Various methods of grooving shingles have also been devised. At the present time, the manufacture of shakes is almost entirely limited to the Pacific Coast states and to certain areas in the northern Rocky Mountains. Tray shakes, used for fruit boxes, once a common commodity in California, have all but disappeared.

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## CHAPTER 11

### WOOD FLOUR

Wood flour is a term applied to finely ground wood, resembling wheat flour in appearance. This product is used extensively in the manufacture of linoleum, nitroglycerine explosives, and a variety of plastic and other molded products.

#### A. WOODS USED

As used today, wood flour must be light in weight and color, fluffy, and highly absorptive. These requirements limit the species used to light-colored types with a low resin content. Any wood that contains excessive pitch, gum, resin, or similar substances that may cause mechanical difficulties in grinding or produce discoloration in the finished product is not suitable for wood-flour manufacture.

It is estimated that at least 75 per cent of the total wood flour produced in this country is made of white pine (eastern, western, and sugar); the other 25 per cent comes largely from spruce, poplar, maple, birch, and hemlock. Probably a number of other light-colored woods could be used, although no actual information on this point is available. Some darker colored woods, such as willow, yellow poplar, and even redwood have been used for special grades of wood flour in which color is not important.

#### B. PREPARATION OF MATERIAL

In the United States wood flour is made largely from sawdust and shavings resulting from the remanufacture of white pine. In addition, considerable quantities of solid wood, largely in the form of slabs, edgings, and trimmings, are used to supplement the sawdust and shavings. When solid wood is used it must be free of bark, dirt, and other foreign matter and then be reduced to small chips by means of a chipper, a hog, or a hammer mill. The greatest difficulty experienced in utilization of ordinary sawmill residue for wood-flour manufacture is connected with the removal of bark and dirt from small pieces of wood such as are usually found in such material. The raw material must be seasoned to 8 to 10 per cent moisture content, as otherwise the particles of wood flour will tend to

pack. The material from the chipper, as well as the sawdust, is passed through vibrating-type screens. That which passes through these screens is fed by an automatic feeder to the pulverizing equipment, while the coarser particles are returned to a hog.

### C. MANUFACTURE

Some wood flour is obtained by reclamation, *i. e.*, by recovery of wood dust from sanders and by screening of sawdust. Sander dust is generally screened to size, and if sanding abrasive is objectionable this can be eliminated by air separation. The screening of sawdust yields small amounts of a granular type of wood flour (about 4 per cent of 80 mesh or finer), suitable for such unexacting uses as fur cleaning.

The bulk of wood flour, however, is produced by pulverizing wood in one of the several types of pulverizing mills. In the United States there are three principal types of wood-flour mills in use, which, on the basis of the method of pulverization, can be classed as *attrition mills*, *impact* or *hammer mills*, and *roller mills*.<sup>5, 12</sup>

The oldest type of attrition mill is the *stone mill*, an adaptation of the old type burrstone mill used for grinding grain. This mill consists of two superimposed millstones, 40 to 60 in. in diameter. The top stone is stationary, but the lower one is power-driven. The stones are enclosed in a wooden structure, except for an opening on the top through which an intake feed pipe delivers the material into an opening in the upper stone. The inner surface of the top stone is somewhat concave in the center and shallowly grooved to allow the coarser particles of wood to penetrate between the grinding surfaces; the opposing surface of the lower stone is perfectly flat. The pulverized material gradually works its way out toward the periphery of the stones and drops into the casing which surrounds them. The fineness of the finished product is controlled by the spacing of the stones. In this type of mill the initial size of the raw material must first be reduced to that of sawdust. To prevent overheating, which may result in charring or even combustion, small amounts of water or steam are introduced between the stones. Very fine wood flour can be produced by this method. Stone mills are common abroad, especially in Scandinavia,<sup>16</sup> but are seldom used in this country because of their relatively high power consumption.

American attrition mills have many improvements over the old stone mills and are of two general types, *double* and *single attrition mills*. The double attrition mills consist of two metal grinding disks, revolving in opposite directions, enclosed in an iron housing. The lower disk is solid



and is covered with grinding plates of hard steel provided with numerous V-shaped depressions with sharp cutting edges. The upper disk is made of spokes to which grinding plates, similar to those on the lower disk, are attached. These plates, however, do not extend all the way to the center of the upper disk, leaving an opening in the center. Wood fed into the upper disk gradually finds its way through the spokes to the grinding surface, and the wood flour is forced out at the periphery of the disks and is deposited at the bottom of the enclosing case.

Single attrition mills are equipped with a single revolving disk similar to the upper spoke disk of the double attrition mills, and the wood material is pulverized by a rubbing action of this disk against the sides of the housing, which is provided with a suitable grinding surface. Attrition mills are generally equipped with a pneumatic collecting system consisting of a manifold connected to the suction side of a fan, which blows material to the sifting room.

A *hammer mill* consists of either an upright or a horizontal metal chamber with a revolving steel shaft to which staggered beaters or hammers are attached. The interior wall of the cylinder is provided with a grinding surface. The wood substance is pulverized by the impact of the rapidly swinging hammers against the grinding surface of the cylinder.

Hammer mills are somewhat lower in first cost but are considerably higher in maintenance charges than attrition mills of a corresponding capacity. Hammer mills are also objectionable because of their tendency to permit slivers of comparatively small diameter but of considerable length to escape through their screens. The attrition mills will produce a larger tonnage of wood flour with less horsepower. The capacity of different grinding equipment varies greatly with the type, size of the grinding surface, power used, fineness of the product desired, and the type of wood.

Some wood flour is also produced by crushing in *roller mills*. This is accomplished by passing the material between either (1) a moving roller and a stationary metal surface; in this case the pulverization occurs at the line of contact between the roller and the stationary surface; or (2) two or more steel rollers, made with teeth of varying degree of fineness. In the latter instance several pairs of rollers are used, one over the other, the material being fed to the top pair and dropped from one pair to the next.\*

Wood flour as it comes from the grinding equipment is of different

\* A patent has recently been issued to Kassay, A. W., Balz, E. H., and W. D. Williams (U.S. Pat. 2,364,721, Dec. 12, 1944) for a process of embrittlement of wood by impregnation with urea, as an aid to pulverization.

degrees of fineness.\* The coarser grades of wood flour are separated by means of screen separators, called sifters. However, if stock finer than 60 mesh is desired, the grading is frequently accomplished by means of an air separator on the principle that for any given air velocity, a point is reached at which the air resistance of a particle of a given size is balanced by its weight and all larger particles settle. The speed with which the air passes through the separator therefore determines the fineness of the

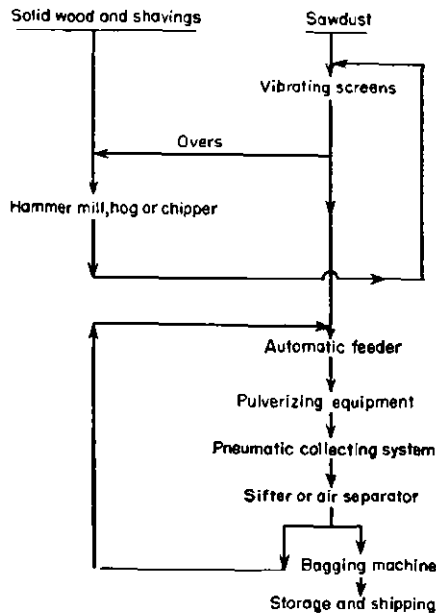


FIG. 11-1. Flowsheet showing wood flour manufacture. (Adapted from an article by J. A. Emmett, *Machines and Methods for Making Wood Flour*. *Wood-Worker*, 56:26-28, Feb. 1938.)

product. Fast currents will carry larger particles, while the slower ones will pick up only fine dust. Thus, by regulating the speed of the air, the grade of the resulting product can also be regulated without the use of screen. The big advantage of an air separator is that even the finest flour collects in the enclosing cyclone dust collector, with hardly any loss.

Finely ground wood flour will absorb considerable moisture (4 to 6 per cent) from the atmosphere. It is usually not redried at the processing plants, however, but by consumers in accordance with their particular

\* The sizes of wood flour most commonly used are 40, 60, and 80 mesh. The finest commercial grade of wood is about 150 mesh, although meshes as fine as 350 to 400 have been attained with pulverizing equipment.

requirements. Wood flour is usually packed in 100-lb. jute sacks, using screw-compression-type packers.

The presence of air-borne wood dust in wood-flour manufacturing plants creates a constant fire hazard. Under certain conditions the presence of such dust in the air may create conditions favoring explosive combustion.<sup>10</sup> Such conditions exist when concentration of wood dust is such that each particle is surrounded by enough air to allow complete combustion and when spacing of the particles is close enough to allow propagation of flame from one particle to another. Either greater or lesser concentration of particles will not cause explosion. The fire hazard in wood-flour plants can be considerably minimized by the observance of the following points:<sup>12</sup> (1) installation of an efficient dust-collecting and air-conditioning system, (2) elimination of dust accumulations on rafters, open shelves, corners, and other poorly accessible parts of the building, (3) use of completely enclosed nonsparking motors and switches and elimination of all sources of static by proper grounding, (4) installation of sprinkling systems and nonsparking floors, and (5) enforcement of nonsmoking rules and all other general safety rules.

#### D. TYPES OF WOOD FLOUR

There are three principal types of commercial wood flour.<sup>14</sup> These vary in accordance with intended use, fineness, color, and resin content.

**1. Technical Wood Flour.** This grade is made principally of white pine shavings and sawdust; it must be very fine (at least 60 mesh), light-colored, and free from staining ingredients. If species other than white pine are used, the wood flour from each species must be kept separately. It is used largely as a filler in resinoid plastics.

**2. Nontechnical Wood Flour.** This grade is made according to less rigid specifications as to color, fineness, resin content, and species of wood used; frequently a mixture of softwood and hardwood flour is accepted. This grade is used in such molded products as moldings, artificial-wood carvings, and commoner grades of linoleum and similar compositions.

**3. Granulated Wood Flour.** This is a special grade of technical wood flour in which the wood particles must conform to a specific weight as well as size. This is the most expensive grade of wood flour.

#### E. USES OF WOOD FLOUR

The principal uses of wood flour fall into the following categories: (1) fillers, either as an extender to reduce the amount of more expensive ingre-

dients or as a modifier of physical properties, (2) absorbents, and (3) mild abrasives.

As a filler, wood flour finds its greatest application in the manufacture of linoleum, particularly of the inlaid type, and to a lesser degree in the battleship and printed grades. The linoleum industry normally consumes more than 50 per cent of the wood flour used in this country. In addition to acting as an extender, wood flour in linoleum also functions as a carrier for colors throughout the thickness of the sheet.

Large quantities of wood flour are utilized as a filler in the manufacture of plastics, composition flooring, artificial wood, moldings, insulating brick, and similar products. Although the use of wood flour in the plastics industry may be motivated by considerations of economy, the principal reason for its use lies in the ability of this material to modify favorably the physical properties of plastic materials by increasing impact strength, reducing brittleness and shrinkage, and providing opacity to transparent or translucent plastics. Wood flour is also utilized as an extender in glues used in woodworking and plywood plants, especially with the synthetic types of adhesives.

Other examples of the use of wood flour involving modification of physical properties include its utilization in foundries as an antibind agent, in ceramics to effect porosity in burned-out materials, in electrical equipment to increase insulation, and in special types of paint to obtain sound deadening properties.<sup>12</sup> Wood flour is used decoratively in "oatmeal" and "velvet" wallpapers, where colored grains of wood flour sprinkled over the surface provide desired design and texture.

The most important use of wood flour as an absorbent is in the manufacture of dynamite. Wood flour is added to nitroglycerine together with oxidizing agents, such as sodium nitrate and ammonium nitrate, primarily to reduce its sensitivity to shock. Wood flour and other vegetable fiber have largely replaced *Kieselguhr* (a fine earth) as an explosive absorbent, because combustion of organic material during explosion contributes to the force of the blast.

Wood flour is used as a mild abrasive and as an oil absorbent in the cleaning of furs and as an abrasive in certain types of soaps, especially recommended for use by mechanics. Square-cut, relatively coarse hardwood wood flour is extensively used in the jewelry trade for cleaning silverware.\* There are many other minor uses of wood flour; a partial list

\* This type of wood flour can be produced more advantageously with a rotary-knife cutter, since such a cutter takes sawdust and shavings equally well and produces sharp, clear-cut particles. A 30-in. cutter will produce from 750 to 1,000 lb. of wood flour per hour.

of products containing wood flour, compiled by the Department of Commerce, includes more than 100 different items.

#### F. STATUS OF INDUSTRY

New industrial uses for wood flour are being constantly developed. Since, however, it is always used as a secondary material in the manufacture of other products, the future of the wood-flour industry will depend on the general condition of the consuming industries, particularly those engaged in the manufacture of linoleum, nitroglycerine explosives, and plastic and molded products. Because of the relatively low cost and high technical qualities of the product, it is not expected that wood flour will be displaced on a large scale by any other organic material or by mineral fillers.

A more serious threat to the stability of the domestic wood-flour industry may be expected from the renewal of European competition and from the considerably expanded Canadian production. Prior to 1940, imports averaged approximately 20 per cent of the total wood flour used in this country. European wood flour, which in the past has been considered superior in quality to the domestic product, in normal times was able to compete successfully for the United States market, even with an added 25 per cent ad valorem import duty. During the Second World War there were practically no imports, and domestic production was able to meet the demand. In 1930 the consumption of wood flour was approximately 35,000 tons; in 1947 more than 75,000 tons was required to meet industrial needs.

The cost of milling and screening depends on the type of mill and the grade of flour produced. Equipment capable of producing 1 ton of 40-mesh flour per hour costs between \$5,000 and \$10,000. Though the cost of the equipment to produce finer grades of flour is not substantially greater, the output of similar pieces of equipment varies inversely with the mesh for grades up to 100 mesh (*i.e.*, for 80 mesh, the capacity of the same mill is only  $\frac{1}{2}$  ton of flour per hour) and as the square of the ratio of meshes for finer grades (*i.e.*, for 200 mesh, the output is only one-fourth that of a 100-mesh mill).<sup>12</sup> It is generally considered that the manufacturing costs and the overhead comprise about 60 per cent and the raw-material costs 40 per cent of the total cost of manufacture of wood flour.

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## CHAPTER 12

### SAWDUST AND SHAVINGS \*

Large quantities of sawdust and shavings are marketed every year for a great variety of uses other than fuel. Dealers in the Chicago district alone, for instance, dispose of about 12,000 carloads, or approximately 260,000 tons, of sawdust and shavings annually. Nevertheless, the total volume of these products consumed by industries represents but a fraction of the volume available at sawmills and woodworking plants.†

It is not uncommon, however, to find a shortage of sawdust and shavings of the right kind at the time of greatest consumption of these materials. The main reasons for this are as follows: (1) shaving and sawdust production, as well as their greatest consumption, is seasonal in many localities; (2) users of sawdust and shavings are becoming increasingly more exacting as to the quality and composition of sawdust best suited for their purposes; this makes the average run of sawmill and factory stock of little commercial value; (3) because of the low margin of profit on sawdust and shavings it is seldom found profitable to supplement the local output by shipping such materials from the regions where they are available in large volumes.

#### I. SAWDUST

Between 10 and 13 per cent of the total content of the log is reduced to sawdust in milling operations. Sawdust is commonly classified as softwood, hardwood, mixed softwood, and mixed softwood and hardwood; it may be sold either green, air-dry or kiln-dry. Green softwood sawdust is used mostly as fuel at or near the point of production, and small quantities of green hardwood sawdust are used for curing meats; most of the sawdust sold by dealers for industrial purposes is either air- or kiln-dried.

\* This information is based principally on the United States government publications listed at the end of this chapter.

† The U.S. Forest Service estimates that in 1944, 1.3 billion cubic feet of sawdust, shavings, and other fine material was produced by the primary wood-manufacturing industries and another 500 million cubic feet by the secondary wood-using industries. This represents about 24 per cent of the total amount of wood cut in that year. Nearly 40 per cent of this waste was not used at all, and 60 per cent was utilized, principally as fuel. (Wood Waste in the United States. Report 4 from A Reappraisal of the Forest Situation. U.S. Forest Service, 1947.)

Demand for sawdust for industrial uses is becoming so exacting that it is usually graded for size. Frequently sawdust is also separated by species, since for some uses any woods that may discolor the product with which they come in contact must be carefully excluded. For this reason the sawdust of one species is usually worth more than that of a mixture from several woods. Hardwood sawdust is either sifted or is sold in various approximate size grades, designated by the types of machinery from which it results, such as sander dust, resaw dust, etc. Sifted hardwood sawdust is designated by mesh sizes, from 8 to 40 mesh. The sifting may be done either at the plant or by the dealers in their storage places. Softwood sawdust is seldom sifted.

The sawdust business is so competitive and the margin of profit so small that excepting for a few of the most progressive concerns, sawmills and woodworking plants find it unprofitable to sell direct to consumers. The sawdust, therefore, is usually handled by dealers who contract with the producers for the output of a mill or factory. Small city woodworking plants are frequently willing to give their sawdust gratis to reduce the fire hazard and to save the space that it would otherwise occupy. In the case of larger plants, the dealers usually contract for a definite number of cars for a stated period of time. Dealers in the large cities usually maintain storage sheds and screening plants. The sawdust is taken directly from the cars to mechanical screens, bagged automatically, and stored by species and grades.

#### A. LIMITATIONS IN UTILIZATION OF SAWDUST

The profitable handling of sawdust is limited to a large extent by several factors:

1. **Handling Charges.** The margin of profit on sawdust is so small that all handling must be reduced to a minimum; this factor prevents many sawmill operators from engaging in the sifting and grading of sawdust necessary for its direct disposal to the consumer.

2. **Cost of Transportation.** This is the chief limiting factor in the marketing of sawdust. With the low prices which sawdust brings on the market, freight rates control the distance from which this product can be profitably shipped; ordinarily shipping of sawdust by rail is limited to a radius of about 100 miles.

3. **Lack of Uniformity of Product.** This factor turns many present and prospective consumers of sawdust to other materials. Many industrial uses require sawdust of uniform quality in regard to species, grade, moisture content, and freedom from foreign substances; all these requirements can seldom be guaranteed either by the producers or by the distributors.



4. **Quantity of Sawdust Available.** The demand for sawdust is seasonal, more of it being required in the fall and the winter, *i.e.*, at the time of least activity of sawmills. On the other hand, the use of sawdust for wood flour, alcohol, wood briquettes, and other products requires installation of specialized equipment which must be kept busy throughout the year. Unless large and dependable supplies of sawdust of a given quality can be guaranteed, the installation of such equipment is not justified.

5. **Physical State of Sawdust.** The small size of sawdust particles and its bulkiness in large quantities place definite restrictions on its chemical and mechanical utilization.

#### B. USES OF SAWDUST

For convenience of discussion the uses of sawdust may be grouped as follows: (1) sawdust as fuel, (2) sawdust in its natural condition, (3) sawdust in the manufacture of other products, and (4) sawdust in the manufacture of chemical products.

1. **Sawdust as Fuel.** The utilization of sawdust as fuel is discussed in the chapter on Wood Fuel (see Chap. 13).

2. **Sawdust in Its Natural Condition.** The uses of sawdust in its natural state are so numerous that only a few major ones can be enumerated. Many of these uses depend on its high absorptivity.

*a. Stable and Kennel Bedding.* Sawdust as well as shavings is extensively used as bedding for animals, especially for cattle at large dairy farms. For this purpose white pine and spruce are considered the most desirable and bring the highest price. In kennels eastern red cedar sawdust and shavings are preferred because of their reputed effect as an insect repellent.

*b. Absorbent.* Sawdust is widely used in butcher shops, fish markets, machine shops, garages, factories, and warehouses as floor covering. Any kind of sawdust may be used for this purpose, though clean, light-colored material is preferred.

*c. Leather Manufacture.* Sawdust is used in the leather industry to the extent of more than 1,000 tons annually. Its greatest use at tanneries is in the manufacture of patent leathers and uppers, for moistening the hides for stretching. The requirements of tanners vary greatly in regard to the species and the fineness of sawdust desired. In all cases, however, the requirements are very exacting as to freedom of the sawdust from splinters, grease, and any foreign material that may impart color to the leather. The difficulties experienced in obtaining sawdust of uniform quality and free from discoloring substances have caused many leather manufacturers to turn from sawdust to other methods of moistening hides.

*d. Conditioning of Furs.* Sawdust is used extensively for moistening the skins when they come to the dressing plant, and also in cleaning the pelts to

remove all grease and dirt, to give the hair a light, fluffy appearance, and to restore luster. The operation is carried on in drums in which the pelts are tumbled about with sawdust. Carefully screened, fine hard maple sawdust is generally used by furriers, though limited quantities of other hardwoods are also used by some fur dressers, who by experience have found that a certain kind of sawdust is especially suited for a given type of fur. The sawdust used for removing grease and dirt is mixed with some cleaning ingredient which cuts the grease, while the sawdust absorbs it.

*e. Cleaning, Drying, and Polishing Metals.* Several hundred tons of sawdust are used annually for removing oil and grease from metal and metal products such as cutlery, metal objects turned in lathes, and aluminum wares. The finished products are first dipped into kerosene or other solvent, and the solvent is then dried with sawdust. Sawdust is also used in the plating industry for drying and polishing finished products removed from the plating solution. Likewise, dry sawdust is frequently used to clean heavy machinery from grease and oil.

*f. Packing.* Sawdust is frequently used as a packing medium, especially in the shipment of grapes and other fruit, as well as in packing fragile articles and canned goods. In packing fruit only coarse, granular sawdust is utilized; spruce sawdust is preferred because it is light-colored, odorless, and tasteless, though redwood, white fir, and even Douglas fir are also used. About 4,000 tons of sifted sawdust are consumed annually by the grape packers of California alone.

Other uses of sawdust in the natural state include *insulation* (see Chap. 16); *curing of freshly poured cement*, 1 to 2 in. of wet sawdust from a non-staining species is spread for a period of 10 days to 2 weeks, to allow a slow curing of the cement; *in ice houses*, though this use is falling off sharply owing to electric refrigeration and the manufacture of artificial ice; *for stuffed toys and pin cushions*; *in nursery practice* for "healing" the stock for a short time prior to shipment; *as a soil conditioner* (sometimes in a partly charred state) because of its ability to absorb and spread fertilizing materials and to increase the porosity of the soil; *in insect bait*, as a carrier for arsenic and other poisons to combat chewing insects, such as cutworms; *in meat and salt smoking*, for which purposes green hickory sawdust is preferred, although maple, oak, walnut, and mahogany are also extensively used.

**3. Sawdust in the Manufacture of Other Products.** Large quantities of sawdust and shavings, principally white pine, are utilized in the manufacture of *wood flour* (see Chap. 11); sawdust is also an important ingredient of a number of composition products, some of which are described below.

*a. Composition Flooring.* This is made usually of caustic magnesia cement, with various amounts of sawdust as a filler. Though different kinds of sawdust are used for this purpose, medium fine (20 to 40 mesh) maple

sawdust is generally preferred. The dry ingredients, consisting of sawdust and pigment, are thoroughly mixed and a solution of magnesium chloride is added. The mixture is then spread like cement. Usually two coats are used, the top layer containing a larger percentage of fine material, such as wood flour.

*b. Stucco and Plasters.* Sawdust is added to bind the mass together, producing at the same time a lighter and more porous product which can be nailed without damage and which has better insulating qualities.

*c. Gypsum Compositions.* Sawdust is used in a number of gypsum products, such as interior partitions, insulation products, and roofing materials. Sawdust makes gypsum products more porous, decreasing their weight and increasing their insulating qualities; it also softens the finished product to the extent that it can be nailed and sawed; finally, it lessens the cost of the finished product.

*d. Clay Products.* The use of sawdust in clay products today is practically limited to the manufacture of porous hollow building tiles. Sawdust is added to make the tiles lighter in weight, more resistant to heat, and capable of holding nails. When the clay is fired the sawdust is burned out of the tile, leaving it in a porous condition. Sawdust is not used in the manufacture of common bricks, flue linings, or clay pipes, because it tends to increase the absorptive capacity of these products.

*e. Concrete Products and Artificial Stones.* Sawdust is used in the preparation of the so-called "lightweight concretes," which contain as much as one-third to one-half sawdust. The advantages of such concrete are that the product can be sawed, fastened with nails and screws, and polished. This product is said to be very fire-resistant and nonconductive of sound. This type of concrete is used for floors where it is desired to attach wooden members to concrete by means of nails or screws; it has also been suggested for construction of floors in cattle barns.

A number of products called *artificial stones* are made of different binders with sawdust as a filler. They can be colored and when polished resemble marble or stone. Such products are widely used for building purposes in the form of roof, floor, and panel tiles and building stones.

*f. Artificial Wood.* This is a product made of sawdust, paper waste, casein glue, and limestone or chalk. The ingredients are ground together, moistened with water, and molded. The finished product is said to possess many of the properties of natural wood.

*g. Abrasives.* Wet sawdust is mixed with coke, salt, and sand in the manufacture of silicon carbide abrasives. When these are fused in an electric furnace, the sawdust burns out first, leaving the rest of the mass in a porous condition, thus providing outlets for escaping gases generated during the fusion; if no such provision were made these escaping gases would

rupture the fusing mass. Any kind of sawdust, dry or wet, can be used.

*h. Floor-sweeping Compounds.* In the manufacture of sweeping compounds, sawdust is mixed with an antiseptic and cleaning ingredients, such as clean, fine sand, to which essential oils, such as oil of eucalyptus or oil of sassafras, are added to impart a pleasant odor and to absorb the fine particles of dust. Ordinary damp sawdust is probably just as satisfactory, and on concrete floors it is preferred, since it prevents excessive dust.

*i. Molded Articles and Plastics.* Finely ground sawdust and shavings combined with a suitable binder, such as starch, gluc, or aluminum sulfate, are used in making molded ornaments, dolls, novelties, insulators, and similar items.

A relatively low-cost plastic mix, in which a large percentage of the material consists of hydrolyzed dry sawdust, has recently been developed by the U.S. Forest Products Laboratory. A number of other similar products have also been announced by other research organizations (see *Plastics*, page 486). None of them has as yet reached commercial development on an extensive scale.

*j. Wallboard.* A number of processes have recently been announced for the manufacture of wallboard made entirely of pressed sawdust and other granulated wood waste with the addition of a suitable binder; other types of wallboard are made by combining sawdust with the wood-pulp or other type of vegetable fiber.

It has been estimated that as much as 2,000 sq. ft. of board may be obtained from a ton of sawdust. Extreme simplicity of operation, dispensing with the service of skilled technicians, is claimed for one process. In addition to wallboards a variety of other pressed items, such as containers, disposable dishes, and moldings can be made of any suitable sawdust-resin mixture. Commercial development of an inexpensive molding process for sawdust and similar wood residue will go a long way in solving the major wood-waste problems now confronting the wood-conversion industries of this country.

**4. Sawdust in the Manufacture of Chemical Products.** The possibilities of sawdust utilization in the manufacture of chemical products include (1) destructive distillation, (2) steam extraction, (3) production of ethyl alcohol and cattle food, and (4) production of oxalic acid, dyes, and similar products.

*a. Destructive Distillation of Hardwood Sawdust.* Although a possibility, this technique has not achieved commercial success, largely because of the bulkiness of the material, which necessitates large quantities of it for uninterrupted production, and the difficulties encountered in carbonization of sawdust (see page 384).

*b. Steam Extraction.* Steam extraction of turpentine and pine oil from the sawdust of resinous woods in a manner similar to that employed with chipped southern pine stumps is technically quite feasible. It is, however, questionable if at present the yield obtained and the supply of raw material would justify the cost of operation.

*c. Ethyl Alcohol and Yeast from Wood.* The production of ethyl alcohol and yeast from sawdust and other wood waste is discussed in the section on saccharification of wood (see p. 403).

*d. Oxalic Acid.* In the past, considerable quantities of oxalic acid were produced by fusion of sawdust with a caustic. Though at present oxalic acid is made by other processes, opportunities for more efficient fusion of sawdust have recently been demonstrated by Othmer and his co-workers.<sup>4,5</sup> This new method yields up to 75 per cent of oxalic acid on the basis of dry weight of wood; in addition, considerable quantities of acetic and formic acids and methanol are obtained. The approximate yield of chemicals in the experimental runs were as follows:

<i>Material used, lb.</i>	<i>Product formed, lb.</i>
100 dry sawdust	45.5 oxalic acid
9 sodium hydroxide	11.7 acetic acid
34.7 lime	2.48 formic acid
61.1 100% sulfuric acid	5.5 methanol
	85.0 calcium sulfate (waste)
	3.0 wood oil

By carrying out fusions on several different species of wood, it has been shown that a constant ratio exists between the yields obtained and the amount of cellulose in wood. Since, however, the yields were somewhat higher than could be expected from the cellulose alone, it appears that other constituents of the wood also entered into the reaction. Commercial success of this treatment depends largely on the efficiency of recovery of caustic soda and success in separating the materials resulting from the fusion.

Oxalic acid is an important organic acid, of which some 10 million pounds is used annually in the United States. It is used in large quantities by laundries as an acid rinse; also in the production of celluloid and rayon, in the manufacture of explosives, leather manufacture and dressing, purification of glycerol and stearin, bleaching straw, and in the preparation of certain dyes.

## II. SHAVINGS

On the basis of volume, the most important use of shavings is for fuel, either as such or in the form of wood briquettes. Other important uses for shavings include packing of such products as canned goods, paint, and

building-stone blocks, clean shavings of nonstaining species being preferred; stable and kennel bedding; lime burning; wood flour; insulation; wood pulp; and in wallboards made of shavings and resins. White pine shavings are in greatest demand; the use of other light-colored woods such as spruce, cottonwood, aspen, and basswood is also quite extensive.

The chief difficulty encountered in the profitable utilization of shavings is their bulkiness, which makes long shipping economically prohibitive. According to the Department of Commerce, 12 to 15 cents per 100 lb. is usually the maximum freight rate that can be absorbed by the product. The shavings are either shipped in carload lots or, to decrease their bulk and for convenience of handling, they may be pressed into bales weighing 80 to 240 lb. each.

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## CHAPTER 13

### WOOD FUEL

At one time wood was extensively used throughout the country for domestic heating and cooking purposes, as well as for generating steam and later electricity in industrial establishments.\* Coal and other types of fuel have, however, gradually displaced wood in most industrial plants, with the exception of many woodworking industries. The use of wood fuel for domestic purposes in cities has also sharply declined, largely because of the introduction of central and automatic heating systems which require types of fuel better adapted to thermal control. Today, except for certain sections of the West and South, the use of wood for domestic fuel is confined largely to rural communities, where lack of ready cash outweighs considerations of convenience. Even in rural districts, however, the use of fuels other than wood is steadily increasing. That the consumption of wood for fuel in rural communities is greatly influenced by financial considerations has been shown by the considerable increase in the use of wood fuel through the Eastern and Central United States during depression years. For instance, the Minnesota Forest Survey disclosed the production of 1,744,000 cords of fuel wood in that state in 1934 as compared with 1,163,000 in 1929, or an increase of 50 per cent.

In cities the use of wood as a fuel today is limited mostly to fireplaces. However, in the sawmilling districts of Oregon and Washington, following improvements in sawdust-burning equipment, there has been a considerable increase in the use of sawdust and hogged wood for domestic heating. The diversion of solid wood residue to other more profitable uses (*e.g.*, wood saccharification, Chap. 19) may curtail further expansion in the use of sawdust for domestic heating.

Wood fuel in industrial establishments is at present confined largely to the utilization of mill residue for generating power in sawmills and wood-

\* R. V. Reynolds and A. H. Pierson<sup>11</sup> report that on the basis of timber consumed in the 300 years of American history, fuel has accounted for more than half (estimated at 1,000 billion cubic feet of standing timber) of the total volume cut from our forests and for more than twice as much as lumber; even in 1940 the quantity of timber cut for fuel was second only to lumber. They estimate further that about 75 per cent of this total was hardwoods, 40 to 50 per cent of which was oak. More than 60 per cent of all the wood taken for fuel came from saw-timber trees. At the peak of consumption (1870 to 1880) the saw-timber component was 64 per cent, decreasing to 46 per cent in the period between 1920 and 1929.

working plants. In certain sections of the West Coast and in the South, where large quantities of such material are available above the requirements of the producing plants, there is frequently an outlet for such fuel in other local industries and municipal establishments.

In spite of a sharp decline in the use of wood as domestic and industrial fuel, wood is consumed in larger quantities for fuel than for any other use except lumber. Per capita consumption of wood fuel reached its peak in the United States about 1860 with an average of 4.5 cords. The peak of volume consumption, however, did not occur until the period just before 1880. In the United States census of 1880 the total wood fuel consumed in this country was placed at about 146 million cords. The consumption of coal for the same year is given at about 71.5 million short tons. In 1908 the U.S. Forest Service estimated the annual consumption of wood fuel at 86 million cords. The consumption of coal meanwhile increased to about 416 million short tons. Today the consumption of wood fuel is placed at between 40 and 50 million cords, while total consumption of coal ranges between 400 and 600 million short tons annually. The above figures do not take into consideration mill residue used for fuel. No figures are available to indicate the total volume of such material available or utilized for the whole country, but some idea of the enormous quantity available may be gained from the U.S. Forest Service survey conducted in 1945 for the states of Oregon and Washington. According to this survey,<sup>18</sup> solid-wood by-products resulting from the manufacture of 1,000 bd. ft. of lumber averaged 64 cu. ft. in the primary sawmilling operations, or a total of about 680 million cubic feet of solid-wood residues for these two states. In addition, an estimated 209 million cubic feet of bark was also produced. Of the total amount of solid-wood residues developed in Oregon and Washington, 79 per cent was used or sold by the sawmills for fuel, 2.5 per cent was sold for pulp and other uses, and 18.5 per cent was destroyed.

In Canada, the Dominion Bureau of Statistics estimates the annual consumption of fuel wood at about 10 million cords of cordwood, plus some 400,000 cords of wood residue. This may be compared to the annual consumption of some 32 million short tons of coal.

## I. WOOD COMBUSTION

### A. ADVANTAGES AND DISADVANTAGES OF WOOD AS A FUEL

One of the advantages of wood as a fuel is that dry wood ignites readily and gives a quick, hot flame; \* this makes wood desirable when quick heat

\* Ignition temperatures vary widely, however, depending on duration of heat application. While wood may be ignited by prolonged contact with steam pipes, it can also withstand intense heat for short time intervals without igniting.



for a short time is wanted. Wood fuel is clean and leaves a small amount of ash (about 1 per cent of the oven-dry weight of wood), which has some value as a fertilizer. More important, however, are the economic advantages of using wood fuel. Where locally available and burned in properly designed furnaces and stoves, wood should be just as economical as, or more so than, other types of fuel. In rural communities, when wood is obtained from woodlots owned by the farmer, its use for domestic heating does away with the necessity of cash outlay for fuel. In addition, its sale in the outlying communities provides an additional and fairly dependable income from the farm woodlands.

Some of the disadvantages of wood as a fuel are (1) wood must be seasoned, requiring large storage space; (2) because of its bulkiness and relatively low margin of profit, wood can be transported only short distances; \* (3) wood burns rapidly, necessitating frequent refueling; (4) wood fuel gives a low efficiency, if burned in an ordinary furnace; (5) it is difficult to obtain wood fuel of uniform quality, especially in so far as its moisture content is concerned.

Some of the above disadvantages, *viz.*, the inefficiency of burning and the necessity for frequent refueling, can be largely eliminated by the use of equipment expressly designed for burning wood.† Examples of such improved equipment are the slow-combustion stoves and furnaces now in wide use in European countries; improved wood stoves and furnaces of American design are now also available. These improved stoves are designed to utilize all the combustible elements, which in the ordinary wood furnace are allowed to escape up the chimney. To accomplish this the wood is burned very slowly, with just enough air admitted to allow a slow distillation of wood gases, which are then mixed with an air current of high temperature and burned under the most favorable conditions by being passed through a zone of high temperature. Such stoves and furnaces are

\* Cordwood can be transported profitably usually a distance of not more than 5 miles if a team is used and not more than 20 to 30 miles by truck. Markets for sawmill refuse as fuel are likewise determined largely by the cost of transportation. In a study made in Oregon,<sup>16</sup> it was shown that transportation in some instances may amount to 75 per cent or more of the total cost of the wood delivered. Of the three principal methods of transportation used in that region, barge transportation, when available, is the most economical means for hauling large quantities of wood fuel; rail transportation is more economical than truck on hauls exceeding 40 to 45 miles; the large trucks with trailers give a lower per-unit hauling cost than small-size (1½- to 2½-ton) trucks and consequently can go out farther from a given center of supply.

† The most inefficient way of burning wood in dwellings is in fireplaces. "An experiment conducted in Georgia is said to have shown that in order to maintain a prescribed temperature in a certain room it was necessary to burn 10 times as much wood in a fireplace as the amount required when using a good wood stove." R. V. Reynolds and A. H. Pierson.<sup>13</sup>

said to have much greater efficiency <sup>3, 15</sup> than ordinary burners; \* the slow-combustion stoves and furnaces require attention only every 8 to 24 hours.

The efficiency of an ordinary coal-burning furnace also can be greatly increased by substituting special wood grates for conventional coal grates or by removing the grate bars entirely and laying firebrick on the floor of the ashpit.<sup>12</sup> In the latter case the fire is built on the firebrick; the ashpit door is kept tightly closed and the ventilator in the fuel door open. In this way a wood fire can be made to burn very slowly, with considerable increase in the efficiency of wood as a fuel. If it is undesirable to remove the coal grates, more efficiency can be obtained from wood by placing sheet iron or firebrick on the grates. Likewise, greater effectiveness can be secured from burning wood in the ordinary furnace by combining it with coal. The firebox should be filled with wood to about the level of the fire door, and small-sized coal, such as buckwheat or nut, added on top. Some precaution must be taken not to cover the entire surface of wood too heavily, to avoid the possibility of gas explosions.

#### B. COMBUSTION OF WOOD

The processes of wood combustion can be divided into three stages: (1) drying, (2) distillation of volatile material, and (3) burning of solid, non-volatile, carbonized material (charcoal), with formation of an ash residue. The distillation of volatile products begins when the internal temperature of wood rises to about 275°C. and the wood begins to decompose with the evolution of combustible and noncombustible gases. The former consist of carbon monoxide, hydrogen, and methane; and the latter include nitrogen, oxygen, and carbon dioxide. If there is an adequate supply of air, ignition of combustible gases takes place. Once started, combustion is continued exothermically as long as there is a sufficient supply of air and as long as the heat of combustion is great enough to raise the temperature in new portions of the wood to the ignition point. The residual substance, after all gases are distilled, is charcoal.

This stage of combustion is followed by the second, or endothermic, stage, during which combustion is maintained in part by the heat from residual charcoal. If at this stage of burning the outside heat is withdrawn and the heat supplied by the charred portion of the stick is not sufficient to raise the temperature of new portions of the wood to the ignition point, combustion

\* Hale \* found that when hard maple was burned in the ordinary furnace, its heat efficiency at 20 per cent moisture was 50 to 60 per cent of the gross calorific value of hard maple at that moisture content; white pine had an efficiency of only 50 per cent; and anthracite coal burned in the same furnace gave an efficiency of 73 per cent.

ceases. This explains why it is difficult to maintain combustion in a single large stick without other combustible material. When the kindling burns out, heat from the layer of charcoal formed on the outside of a large stick usually is not sufficient to raise the temperature in the inner portion to the point where more combustible gases can evolve, and the fire becomes extinguished.

### C. AVAILABLE HEAT FROM WOOD

The heat value of a substance is determined by the amount of heat (expressed in British thermal units) produced in burning it to total ash. Since different woods are fundamentally alike in the chemical composition of the wood substance, *at the same moisture content*, the heat value obtained from unit weights of all woods, regardless of the species, is about the same. Exceptions to this are woods containing such combustible materials as resins, oils, and gums; these substances have a high calorific value (approximately 17,500 Btu \* per lb.), and therefore woods containing appreciable amounts of them will have correspondingly high heat values. Tests conducted at the Forest Products Laboratories of Canada indicate that the average *higher* calorific value of hardwoods is about 8500 Btu per lb. of oven-dry wood, † while that of white pine is 9000, Douglas fir 9200, and western red cedar 9700 Btu per lb. of oven-dry wood.<sup>6</sup> By way of comparison, anthracite coal yields 12,900 Btu per lb., bituminous coal 13,200, and crude oil 19,500 per lb.

The higher calorific value represents the total amount of heat given off by wood burned in a calorimeter, or it represents the calculated heat value based on a chemical analysis of the wood. In any fuel containing hydrogen, the calorific value, as determined in a calorimeter, is higher than that obtainable under most working conditions because of the latent heat of the volatilized water formed in the combustion of the hydrogen. This heat is released when the vapor is condensed, but in practice the vapor usually passes off uncondensed. In estimating the higher calorific value of wood on the basis of a chemical analysis, to secure a reasonable degree of accuracy the calculations should be based on an ultimate analysis that reduces the fuel to its elementary constituents, such as carbon, hydrogen, oxygen, nitrogen, ash, and moisture. An ultimate analysis does not reveal how these constituents are combined in the fuel. Fuels of almost identical ultimate analyses produce different heating values when tested in a calorimeter. Although methods other than these two have been used to de-

\* Btu—British thermal unit: the quantity of heat required to raise one pound of water one degree Fahrenheit, at or near its maximum density.

† The U.S. Forest Products Laboratory uses a figure of 8600 Btu as the average higher calorific value for hardwoods.

termine calorific values, the heat values determined in a calorimeter are regarded as the most reliable.

The lower calorific value, the available heat from the combustion of wood, is greatly affected by several factors, such as (1) the amount of moisture in the wood, (2) moisture formed in the burning of hydrogen, (3) the amount of air admitted for combustion, (4) heat carried away in dry chimney gases, (5) heat loss because of unconsumed gaseous combustible matter discharged with flue gases, (6) losses due to unconsumed solid combustible matter, and (7) radiation losses from the combustion chamber. Minor losses, usually ignored, include (1) heating of water vapor in the air admitted for combustion, (2) heating of wood substance to the ignition temperature, and (3) the heat required to separate bound water from wood substance.\* Table 13-1, prepared on the basis of certain assumptions, shows the effect of moisture on the lower calorific value of wood.

TABLE 13-1. HEAT AVAILABLE FROM 1 LB. OF MOIST WOOD

Moisture content of wood		Available heat, Btu <sup>a</sup>
Ovendry basis, %	Moist basis, %	
0	0.00	7098
5	4.76	6701
10	9.09	6341
15	13.04	6011
20	16.67	5710
25	20.00	5432
30	23.08	5176
40	28.57	4718
50	33.33	4322
75	42.86	3529
100	50.00	2934
150	60.00	2101
200	66.67	1546
250	71.43	1149

<sup>a</sup> Based on a higher calorific value of 8600 Btu, an initial wood temperature of 62°F., a flue-gas temperature of 450°F., an initial air temperature of 62°F., and 50 per cent excess air.

\* For 1 lb. of owendry wood, the loss due to atmospheric moisture (assuming an initial temperature of 62°F., a relative humidity of 80 per cent, 50 per cent excess air, and a flue-gas temperature of 450°F.) is about 15 Btu, the loss due to heating the wood to the ignition temperature (assuming that the initial temperature of the wood is 62°F. and that the ignition temperature is 472°F.) is about 134 Btu, and the loss due to the heat required to separate water and wood substance is about 34 Btu in drying from the fiber-saturation point (30 per cent moisture content, owendry basis) to the owendry condition.

Neglecting all losses other than those due to the moisture content of the wood, the burning of hydrogen, the air required for combustion, and certain flue-gas losses, the following formula may be used to determine approximately the available heat from one pound of moist wood:

$$h = \frac{H - [(m + 0.54)(1085 - t_w + 0.46t_g) + 0.24(t_g - t_a)a]}{1 + m}$$

where  $h$  = heat available from 1 lb. of moist wood, Btu

$H$  = higher calorific value of 1 lb. of wood, Btu

$m$  = moisture content (ovendry basis) of wood, expressed decimally

$t_w$  = initial temperature of wood and its included water, degrees Fahrenheit

$t_g$  = temperature of flue gases, degrees Fahrenheit

$a$  = air required for combustion, pounds. (Theoretically, about 6 lb. of dry air is required to burn 1 lb. of ovendry wood.)

$t_a$  = initial temperature of air, degrees Fahrenheit

#### Sample Calculations

1. Assume a higher calorific value of 8600 Btu, a wood-moisture content (ovendry basis) of 20 per cent, an initial wood temperature of 62°F., a flue-gas temperature of 450°F., an initial air temperature of 62°F., and 50 per cent excess air. The approximate available heat is:

$$\begin{aligned} h &= \frac{8600 - \{(0.20 + 0.54)[1085 - 62 + (0.46 \times 450)] + 0.24(450 - 62)9\}}{1 + 0.20} \\ &= \frac{8600 - [(0.74)(1230) + 0.24(388)9]}{1.20} \\ &= \frac{8600 - (910.20 + 838.08)}{1.20} = \frac{6851.72}{1.20} = 5710 \text{ Btu} \end{aligned}$$

2. Assume that the wood has a moisture content of 150 per cent (ovendry basis) and that all other conditions of the above example prevail. The approximate heat available is

$$\begin{aligned} h &= \frac{8600 - \{(1.50 + 0.54)(1230) + 838.08\}}{1 + 1.50} \\ &= \frac{8600 - (2509.20 + 838.08)}{2.50} = \frac{5252.72}{2.50} = 2101 \text{ Btu} \end{aligned}$$

Wood fuel is generally used in the air-dry condition. A comparison of the available heat in green and air-dry wood and their equivalents in coal is given in Table 13-2.

TABLE 13-2. APPROXIMATE WEIGHT AND HEATING VALUE PER CORD (80 CU. FT.) OF DIFFERENT WOODS, GREEN AND AIR-DRY (20 PER CENT MOISTURE) <sup>a</sup>

Woods	Weight, pounds		Available heat, million Btu		Equivalent in coal tons	
	Green	Air-dry	Green	Air-dry	Green	Air-dry
Ash.....	3,840	3,440	16.5	20.0	0.75	0.91
Aspen.....	3,440	2,160	10.3	12.5	0.47	0.57
Beech, American.....	4,320	3,760	17.3	21.8	0.79	0.99
Birch, yellow.....	4,560	3,680	17.3	21.3	0.79	0.97
Douglas fir.....	3,200	2,400	13.0	18.0	0.59	0.82
Elm, American.....	4,320	2,900	14.3	17.2	0.65	0.78
Hickory, shagbark.....	5,040	4,240	20.7	24.6	0.94	1.12
Maple, red.....	4,000	3,200	15.0	18.6	0.68	0.85
Maple, sugar.....	4,480	3,680	18.4	21.3	0.84	0.97
Oak, red.....	5,120	3,680	17.9	21.3	0.81	0.97
Oak, white.....	5,040	3,920	19.2	22.7	0.87	1.04
Pine, eastern white.....	2,880	2,080	12.1	13.3	0.55	0.60
Pine, southern yellow.....	4,000	2,600	14.2	20.5	0.64	0.93

<sup>a</sup> Data from the U.S. Forest Products Laboratory, except for Douglas fir and southern pine. Heat value of coal, under similar conditions of combustion, is considered to be 11,000 Btu.<sup>7</sup>

## II. TYPES OF WOOD FUEL

Besides cordwood cut expressly for use as a fuel, other types of wood fuel include mill residues, such as edgings, trimmings, slabs and short lengths; sawdust and shavings; wood briquettes; wood charcoal; and wood gas.

### A. CORDWOOD

Wood fuel is usually sold by the cord. The standard cord is a pile of wood 8 ft. long, 4 ft. wide, and 4 ft. high. Wood fuel, however, is usually sold by the *short cord*, also called *face cord*, *rick*, or *rank*, which is a pile of wood 8 ft. long and 4 ft. high, the width varying with the length of pieces, usually 12, 14, 16, 18, 24, or 36 in. It is customary to pile green wood 2 or 3 in. higher than 4 ft. to allow for settling and shrinkage.

Although the space occupied by a standard cord equals 128 cu. ft., the solid volume of wood is considerably smaller because of the voids between the sticks. It is customary to assume that a well-piled standard cord will contain 90 cu. ft. of solid wood. Actually, the volume of wood in the cord varies greatly, depending on (1) the care exercised in piling; (2) the size of the sticks (the smaller the diameter of the sticks, the smaller the solid-wood content of the cord); (3) whether the sticks are round or split (split sticks 10 in. in diameter and over reduce the solid-wood volume by as much as 5 cu. ft. or more per cord; however, a cord of split wood generally has a greater solid content than a cord of *small*—less than 10 in. in diameter—round wood); (4) the number of crooked and limby sticks in the cord; and (5) bark thickness.

Measurements made at the Lake States Forest Experiment Station on hard maple and yellow birch cordwood 4 ft. 3 in. long, cut for a hardwood distillation plant and piled 4 ft. 4 in. high, gave the figures shown in Table 13-3.

TABLE 13-3. AMOUNT OF SOLID WOOD PER CORD OF STICKS OF DIFFERENT DIAMETERS <sup>a</sup>

Middle diameter of sticks, outside bark, in.	Number of sticks	Cu. ft. content with bark
5	93	50
6	75	59
7	61	66
8	50	70
9	42	74
10	35	77
11	30	80
12	26	82
14	20	84
16	15	86
18	12	87
20	10	88

<sup>a</sup> Lake States Forest Experiment Station, *Tech. Note 8*. October, 1928.

The same study showed that if sticks 10 in. in diameter and larger were split, the solid content of the cord would be reduced by about 5 cu. ft.; if sticks more than 16 in. in diameter were split, the solid content of the cord would be reduced by 7 cu. ft.

Since moisture in wood reduces its heat value, fuel wood should be

thoroughly air-seasoned, which in the Northeastern United States requires 9 to 12 months; in the South the time of seasoning is usually about 6 months.

The bulk of cordwood comes from woodlots, although considerable quantities are also cut, in connection with logging, from trees that will not yield other products or from slash remaining after logging. Since, under ordinary conditions, firewood is probably one of the least profitable forms of disposal of timber from woodlots, only those trees that have no other commercial value should be cut for fuel wood. These include species of little commercial value for other wood products, thinnings cut in improvement work, and dead and defective trees that will not yield logs or other forest products. In Minnesota, according to the U.S. Forest Survey of 1934, out of 1,744,000 cords of fuel wood, 60 per cent were cut from cull and dead trees, 5 per cent from logging and mill residue, 10 per cent from trees suited for low-grade lumber, and 25 per cent from sound trees 6 to 8 in. in diameter.

Since cutting wood fuel is largely a farm activity, it may be carried on at any time when labor is available; therefore most firewood is cut during the slack months of late fall and winter. Unless a saw rig can be located right in the woods, the trunks, called poles, are skidded or hauled to a roadside where they can be reached by wagon or truck. In some sections of the country it is customary to cut fuel wood into 4-ft. lengths (usually 4 ft. 3 in. to 4 ft. 6 in. to allow for crosscutting into three sticks) and stack it in standard cords for seasoning.

On the basis of a comprehensive study made in New York State, Hoyle<sup>8</sup> reports that one experienced man can cut from  $1\frac{1}{3}$  to 7 cords of 14-in. wood per 9-hour day, 2 cords a day per man being a representative figure under average conditions. This includes all woods operations such as felling, skidding, sawing, and splitting when necessary.

The cutting of fuel wood into shorter lengths is usually done by means of a portable buzzsaw run by a gasoline engine or a farm tractor (Fig. 13-1). If the saw is kept busy all the time, two men can cut about 2 cords of stove wood per hour.

The relative importance of wood fuel to producers in some states, when compared to other forest products, is frequently underestimated, as shown by the analysis made by Hoyle<sup>8</sup> for New York State. In that state the estimated annual cut of fuel wood during the depression years of 1932 to 1936 was approximately four million standard cords. At 50 cents a cord stumpage, this equals two million dollars, a sum approximating the annual value of the stumpage for all other forest products, including lumber and pulpwood, cut in the state during the same years. Even in normal times fuel wood in New York State represents nearly one-third of the total stump-



age value and two-thirds of the delivered value of all other forest products cut in the state.

### B. SAWDUST AND SHAVINGS AND OTHER MILL RESIDUE

The greatest use of sawdust and shavings is for fuel. Because of their bulkiness they are consumed largely either at the points of production or by industrial plants nearby. The use of sawdust for fuel requires specially

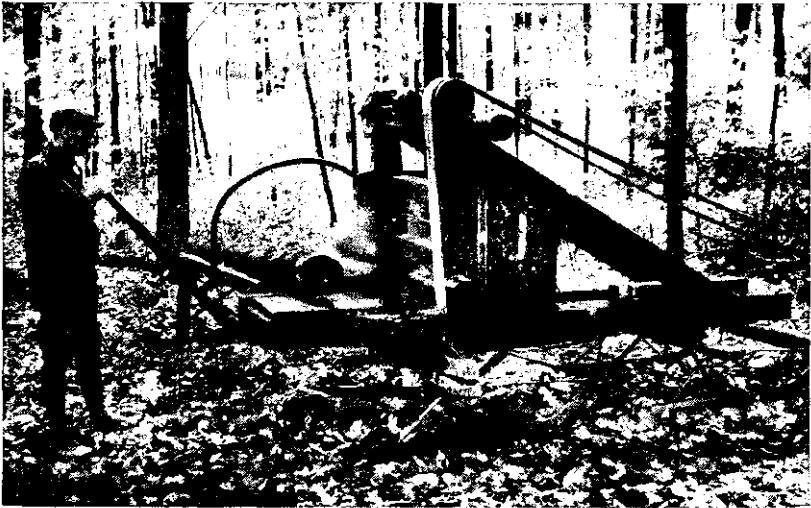
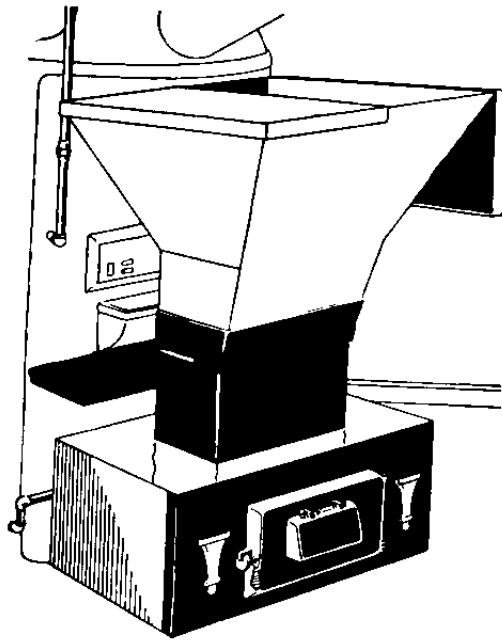


FIG. 13-1. A portable buzzsaw run by a tractor in a Michigan State College woodlot. (Courtesy P. W. Robbins.)

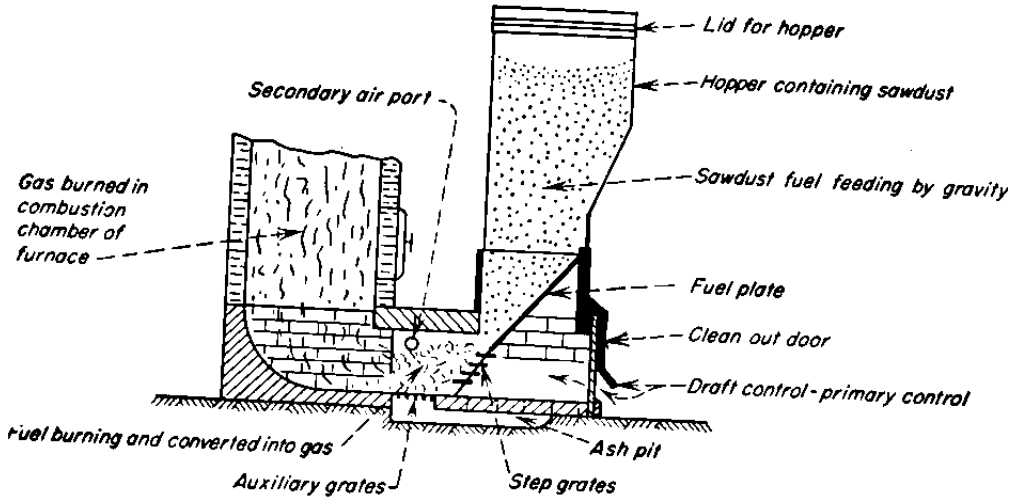
constructed grates and a proper mixture of sawdust with larger pieces of wood residue. For better results green sawdust and shavings are frequently combined with about 50 per cent of hogged mill residue.<sup>9</sup>

The heat value of green sawdust depends largely on its moisture and bark content. Since most of it contains 40 to 70 per cent of moisture, the heat value of green sawdust when burned is only about half or less that of oven-dry wood. The advantages of sawdust as a fuel for generating power are its cheapness, cleanliness, and steadiness of combustion. The principal drawback to its use as a fuel is its bulkiness, which necessitates considerable handling and a large storage space, the latter being necessary to ensure against a shortage of fuel. It is estimated that about 1 cu. ft. of hogged wood and sawdust is required to develop one horsepower.

In the Pacific Northwest, sawdust is also extensively used for domestic heating and in hotels. Most of the sawdust used for this purpose is un-



a



b

FIG. 13-2. A typical sawdust burner: a, typical attachment to the front of a heating plant for burning sawdust; b, section of sawdust burner attached to furnace. (Reproduced by permission from *The Utilization of Sawmill Waste and Sawdust for Fuel*, by J. H. Jenkins and F. W. Guernsey, Forest Service Circular 48, Department of Mines and Resources, Ottawa, Canada, 1937.)

seasoned Douglas fir, just as it comes from the saw. It is sold by the *unit*, which equals 200 cu. ft. of space and contains about 80 cu. ft. of solid wood. The use of sawdust in the home requires a special attachment which can be installed in any make of coal-burning furnace. A typical attachment contains a hopper from which the sawdust is fed by gravity to the grate (Fig. 13-2). An important feature of such an installation is light feeding of sawdust and control of the volume of air admitted, the two ensuring complete and continued combustion.

Jenkins and Guernsey<sup>9</sup> report that on the Pacific Coast the normal winter consumption of sawdust ranges from  $1\frac{1}{2}$  to 2 units per room. On this basis, in Vancouver and vicinity it will cost about \$35 to heat a five-room house for the winter, if sawdust is bought when the summer rates are in effect. It is estimated that approximately 50,000 sawdust-burning furnaces have been installed in Portland, Seattle, Tacoma, and other cities of Oregon, Washington, and Idaho.

### C. WOOD BRIQUETTES

The name *wood briquette* is applied to sawdust, shavings, and hogged wood residue compressed together with or without the aid of a binder for use as a fuel. The manufacturing of wood briquettes for fuel has been successful in European countries, especially in Germany and France, for many years; in the United States, however, briquetting has attained a degree of success only in the last 10 or 15 years when equipment was perfected for compressing dry sawdust and shavings without artificial binders.

The major deterrent factors for successful development of the wood-waste briquetting industry in this country are as follows: (1) a large and continuous supply of suitable raw material is required to make operation profitable; (2) production costs must be kept very low in order to compete with other forms of cheap fuel; (3) because of the bulkiness and low margin of profit, the product must be sold largely in the vicinity of producing plants and therefore requires a dependable local market; (4) with the methods now in use, successful briquetting requires dry material, which necessitates special equipment for drying wood waste. All these conditions can be met in only very few localities, *viz.*, the Pacific Coast region, the Inland Empire, and the South. At the present time, however, large-scale production of wood briquettes is confined to the Pacific Coast states, Idaho, and northwestern Montana, where about 200,000 tons of briquettes are produced annually.

There are a number of systems in use for briquetting wood residues; all of them, however, depend on its compression in a press. In some systems binders such as coal-tar pitch, petroleum refuse, and waste sulfite liquor

are added to the wood before pressing. A few systems resort to mechanical binding such as encircling the briquettes with wire or the use of a central core made of wire or rope.

Considerably more promising is the improved briquetting machine which makes the briquettes of dry wood residues without binder, under a

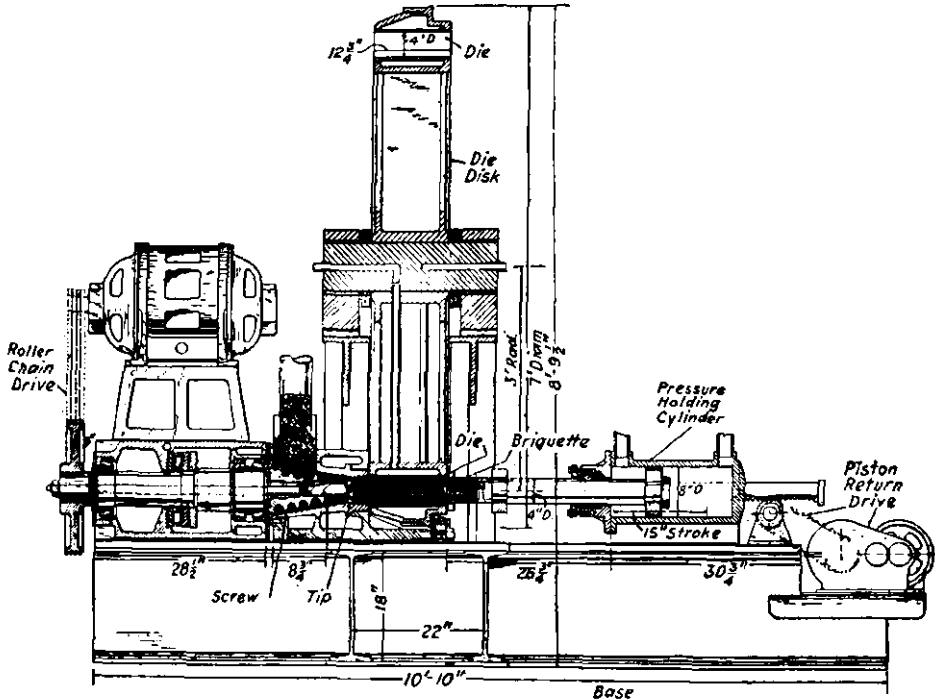


FIG. 13-3. Sectional drawing showing complete details of wood-briquetting machine. (By permission, Wood Briquettes, Inc., Lewiston, Idaho.)

pressure sufficient to destroy the natural elasticity of the wood. The product sold under the trade name *Pres-to-log* is in the form of a cylinder  $4\frac{1}{8}$  in. in diameter and  $123\frac{3}{4}$  in. long, each briquette weighing about 8 lb. The wood material used in the manufacture of *Pres-to-logs* must be dry and of uniform size. The wood residue, if green, is first dried with flue gases to a moisture content of 6 per cent or less and then ground before it is blown through a conveyer pipe to the machine.

The pressing machine consists of three principal parts: <sup>4</sup> the pressing mechanism consisting of a tapering screw auger and a cam-actuated pressing head; a large revolving disk, containing a series of dies; and the hydraulic pressure-holding cylinder (Figs. 13-3 and 13-4). The raw material is

blown into a tapering spiral compressing screw, and as it moves forward it is compressed into a constantly decreasing space against the rear end of the pressing head. The head is equipped with a cutting edge and a slot. As the head revolves, the material compressed against it is cut in the form of a continuous spiral, which passes through the slot to the front of the head and is compressed to its final density in the cylindrical opening in the die wheel by the forward movement of the head. The pressure exerted by the

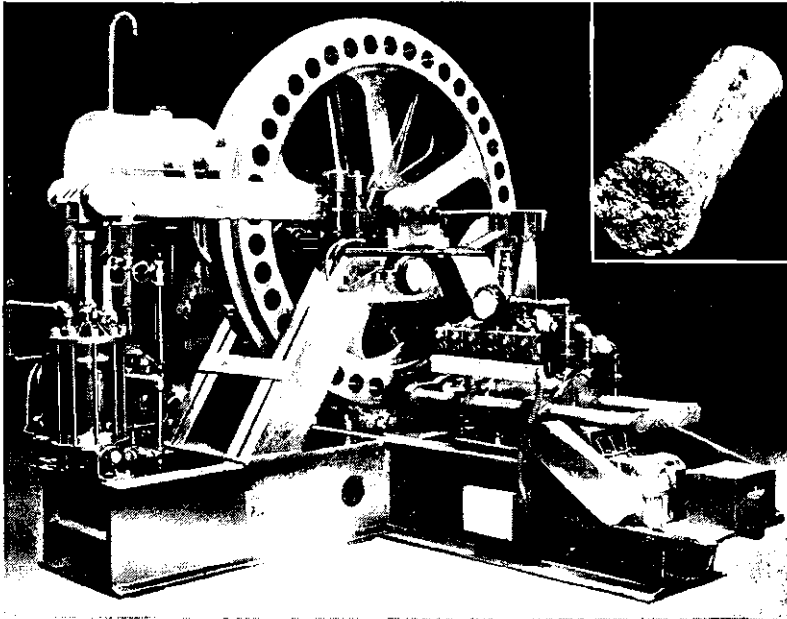


FIG. 13 4. Pres-to-log briquetting machine, back view. Pres-to-log briquette is shown in the upper right corner. (Courtesy Wood Briquettes, Inc., Lewiston, Idaho.)

screw-auger extension head ranges from 15,000 to 25,000 p.s.i. The material is pressed against the rod of the pressure-holding cylinder which closes the die opening on the side opposite to the pressure head. When one die opening is filled, the die wheel is rotated so that the next opening comes against the pressing screw. Since intense heat, ranging from 350 to 450°F., is developed during the pressing, the die wheel is cooled by means of an internally circulating water system.

It takes about 21 minutes for the disk to be filled. When the first filled die returns to starting position, the briquette is sufficiently cool to be forced out of the die. This is accomplished by forcing into the die holding a cooled briquette the raw material for a new briquette. The pressure on the rod of

the pressure-holding cylinder, held against the cool end of the briquette, is so adjusted that the rod gradually recedes, allowing the cool briquette to unload and at the same time exerting sufficient pressure to compress the raw material into a briquette. When the entire briquette is out, the pressure on the rod is released, the briquette is allowed to drop, and the die wheel moves forward to the next position. The pressure cylinder forces the piston rod against the next opening and the operation is repeated. Such a machine has a capacity of 10 to 11 tons of briquettes in 24 hours of operation. A smaller machine capable of producing briquettes of any size from  $\frac{1}{4}$  to  $1\frac{1}{2}$  in. in diameter has recently been developed.\*

Wood briquettes are used for domestic heating in furnaces and fireplaces and in heating and cooking stoves. They are also well adapted for use in diners and lounge cars, automobile trailers, and similar places. The advantages claimed for wood briquettes are their cleanliness, ease of handling and igniting, small volume of smoke, low ash content, and compactness. Pound for pound the heat value of wood briquettes equals that of wood at the same moisture and resin contents. If resins are used for binding, the heat value of briquettes will be correspondingly higher. Since, however, wood briquettes are usually drier than firewood, they will generate more heat per pound of material than firewood, and therefore when used for domestic heating in place of cordwood, a proportionally higher price can justifiably be paid for them.

Wood briquettes treated with chemicals to produce colored flames simulating old driftwood have been developed for use in fireplaces and are generally found on the market as a novelty during the Christmas season. Other special types of wood briquettes include fire lighters and briquettes for automobile tourists' use. Such briquettes are impregnated with inflammable substances to facilitate combustion. Still another type of briquette is made of one part of dry sawdust and two parts of coal dust.

#### D. CHARCOAL

Charcoal is used for fuel (1) for domestic and institutional purposes, (2) in blast furnaces in manufacture of charcoal iron, (3) for metallurgical work other than in blast furnaces, and (4) for generation of producer gas. A decade ago the largest industrial use for charcoal was as a fuel in connection with the manufacture of charcoal iron, when the iron industry consumed half the charcoal production. Since 1930 the largest outlet for charcoal has been for domestic fuel.

Charcoal is light in weight and easy to handle, produces a quick and hot

\* Bowling, R. T. Small wood-briquetting machine. Forest Products Research Society Preprint. 1948.

fire, and gives off little smoke or odor. The glowing charcoal is especially suitable for broiling and roasting foods in cafes, restaurants, trains, and homes. Because of its efficiency as a fuel it is adapted for use by people of moderate-to-low incomes, as is shown by the annual consumption of some three million bushels (2,000 carloads) of charcoal fuel in the metropolitan area of New York City. Another promising field for charcoal fuel is for auto campers and recreationists, since glowing charcoal does not blacken utensils placed over it, as does a wood fire.

#### E. CHARCOAL BRIQUETTES

For most uses charcoal in the form in which it is produced is quite satisfactory. However, for heating and for use in producer-gas plants in vehicles, charcoal in the form of briquettes is *more desirable*.

Charcoal may be briquetted by means of pressure alone; however, a more stable briquette is formed when a binder, such as wood tar, pitch, natural gums, *sulfite liquor*, or *cassava meal*, is added. Of these, tar and pitch are unsuitable as binders of briquettes to be used in producer-gas plants. The advantage of charcoal briquettes over ordinary charcoal as a fuel is that the briquettes are more compact, containing approximately four times as much fuel as there is in the same volume of charcoal; other advantages are freedom from dust and ease of handling.

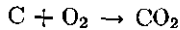
#### F. PRODUCER GAS

The term *producer gas* is applied to a mixture of combustible and non-combustible gases generated by slow combustion of a fuel in specially designed units called producer-gas units. Different types of fuel have been successfully used in the manufacture of producer gas, among them wood and charcoal. Wood can be used either in the form of small pieces or as a mixture of sawdust with hogged fuel. Sawdust is used green and can be added to the extent of about 50 per cent of the mixture.

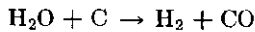
The principle of the producer-gas plant involves the conversion of fuel into gas by means of retarded combustion. The fuel is burned in a thick layer in a specially designed chamber called a *generator*,\* into which just enough air is admitted to allow complete combustion only in the portion of the fuel bed nearest to the air supply. The oxygen of the air combines with the fuel gases at the source of air supply, forming carbon dioxide gas. This gas passes through the glowing fuel in the rest of the fuel bed, absorb-

\* Some writers call the generator a *producer* while others confine the term *producer* to the entire producer-gas unit, including in addition to the generator the cleaning and the cooling units.

ing carbon and forming carbon monoxide. These reactions can be represented as follows:<sup>11</sup>



These reactions are exothermic and liberate a certain amount of heat in excess of that necessary to maintain the working temperatures of the generator. This excess heat can be utilized for production of more carbon monoxide by admitting water into the generator either in the form of steam or as a fine jet of water. When steam comes in contact with glowing carbon at temperatures above 1000°C., hydrogen and carbon monoxide are formed, thus:



Since this reaction is endothermic, the amount of water admitted into the generator must be carefully regulated so as not to lower the effective temperature within the generator.

Carbon monoxide is allowed to mix with air in the mixing valve, forming a combustible gas. The heating value of wood gas is estimated at 130 to 150 Btu per cu. ft. of gas. The gas can either be burned directly beneath steam boilers or can be utilized in internal-combustion engines in place of gasoline. If used as a fuel for steam boilers, the gas can be burned without further cleaning; if used in internal-combustion engines, it must be passed through filters to remove tarry and carbonaceous products. The filtered gas is then directed to a mixing valve where it is mixed with air, and the mixture is then passed into the manifold.

Producer gas from wood as well as from other fuels has been used extensively in Europe since 1918, when gasoline shortage did much to promote the use of wood gas as a substitute. In Great Britain the use of producer gas is largely limited to stationary engines, while in the continental countries, including the U.S.S.R., and in Australia, wood gas is also used for trucks, busses, and passenger automobiles.

A portable producer-gas plant, suitable for use with internal-combustion engines, consists of a generator, a cleaning and cooling apparatus, and a mixing valve. The fuel, small pieces of hardwood or charcoal, is fed from the hopper into the combustion chamber of the generator.\* The gas which emerges from the generator is passed through a cleaner, where impurities, such as dust, soot, and tarry substances, are removed, and then through a cooler to increase its density.

\* Four classes of generators are recognized on the basis of the directions of the draft: updraft, downdraft, cross draft, and combination, in which two systems of draft are in operation.



The producer-gas plants are mounted on running boards or on specially built platforms in the rear of cars, busses, or trucks; in models designed for producer-gas operation, the plants are built in the body of the vehicle. The improved models of the producer-gas plants weigh 450 to 700 lb., or 7 to 15 lb. per horsepower. Depending on the type of producer plant, the engine may be started either on the generated gas or with gasoline. When starting is done with producer gas, 2 to 5 minutes must elapse from the time the fuel is ignited before enough combustible gas is generated to start the engine.

Either small pieces of dry wood or wood charcoal can be used. The use of charcoal as a producer-gas fuel has the advantage over the use of wood in that it practically eliminates the necessity for cleaning equipment for removing tar and other impurities from the gas. On this account many European designers of producer-gas equipment for vehicles prefer charcoal as a fuel.

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## CHAPTER 14

### MINOR WOOD PRODUCTS

The scope of this text will not allow detailed discussion of many less important wood products. The few items described in this chapter will serve to illustrate the nature of such industries.

#### I. WOOD-CASED LEAD PENCILS

##### A. PENCIL MATERIALS

The essential materials in the manufacture of pencils are graphite, clay, wood, and glue. Czechoslovakia, Ceylon, Italy, Germany, Korea, Madagascar, the United States, Mexico, and Canada produce the world's supply of graphite. Ceylon and Mexican graphites are considered best suited to pencil manufacture. Graphite comes in the form of tiny silvery flakes and also as amorphous graphite, and the two kinds frequently are blended in making leads. While graphite formerly was used exclusively for pencils, at the present time, in this country, only about 7 per cent finds its way into pencil factories. Suitable clay for the manufacture of pencils is found in New Jersey, Austria, and Czechoslovakia; that coming from Czechoslovakia is reputed to be the best in the world.

The ideal woods for lead pencils are eastern red cedar and southern red cedar, but because of the scarcity of these species, incense cedar now accounts for almost 98 per cent of the total amount of wood used in this country for pencil making. In Europe, alder is used extensively and is supplemented by imports of African pencil cedar (*Juniperus procera* Hochst.). The growth of the American industry has had a noticeable effect on the supply of the two red cedars. Where these cedars were once plentiful, they were used for fence rails, but these, as well as old stumps, are rapidly disappearing under the constant demands of pencil factories. The use of mechanical sharpeners is, however, widening the range of species that may be used for pencils. Redwood and possibly some cedars of the genus *Thuja* are potential pencil woods that have not come into general use.

The preferred woods for pencil manufacture are pleasantly scented, reddish in color, rather brittle, easy to cut with a knife (free from annual

rings having hard bands of summerwood), and capable of taking a smooth finish. When alder and the sapwood of the preferred species are used, the wood is often dyed and perfumed so that the final product resembles red cedar in color and scent. Brittleness is an undesirable quality in wood for most uses, but in pencil manufacture it is a desirable property. By placing the lead, which is rather brittle, in a brittle wood, a flexure of the pencil sufficient to break the lead will usually break the case.

In the United States, in 1940, a total of 29,815,000 bd. ft. of lumber was used in the manufacture of pencils and penholders, distributed as follows: incense cedar, 29,100,000 bd. ft.; red cedars, 715,000 bd. ft.

### B. PENCIL-SLAT MANUFACTURE

It was once the custom to place eastern and southern red cedar logs in moist and muddy places, and in ponds, in order to decay the sapwood. Sapwood was considered unsuitable for pencil cases and this was an easy way to dispose of it. Three or four years sufficed to do this, and the heartwood was said to become "mellow and brittle—exactly what the pencil maker desired." Virtually no rotting is done now; the sapwood is made into cheap pencils and penholders. Rejects from pencil stock, such as pieces containing flinty streaks, are suitable for penholders; birch, basswood, pine, yellow poplar, and other woods also have been used for this purpose.

Logs for pencil stock are either cut into bolts that are sawed into slats  $\frac{3}{16}$  in. thick, wide enough to make two to seven pencils (usually five to seven), and  $7\frac{1}{4}$  in. long; or they are cut into planks about  $2\frac{5}{8}$  in. thick, the planks being cut up into squares from which pencil-slat blocks are sawed. These squares are cut from the plank by ripping off strips having widths equal to the thickness of the plank. The square strips are then crosscut to eliminate cross-grained and defective portions and to produce pieces 8 in., or multiples of 8 in., in length for the slat saw.

The grade of each plank for pencil stock is determined by the percentage of slat blocks 8 in. in length that it will yield. Three grades of pencil plank (No. 1, No. 2, and No. 3) are recognized in incense cedar. No. 1 pencil stock must contain 50 per cent or more of blocks; No. 2, 25 to 50 per cent; and No. 3,  $12\frac{1}{2}$  per cent of blocks.

Pencil plank is often seasoned before being cut into slats, because the slats must be very carefully dried to a moisture content of about 6 per cent. Slats are planed to half the thickness of a pencil and are grooved for the leads. The planing and grooving are done in one operation, and the grooves are just deep enough to cover one-half the diameter of the lead. The slats are then ready for shipment to the factories for pencil assembly.

The American pencil-slat industry has been shifting factories from the Eastern United States to the Pacific Coast states because of the depletion of the red cedars and the increased use of incense cedar.

### C. PENCIL ASSEMBLY AND FINISHING

Leads are placed into the grooves of one slat that has been brushed with an adhesive, and a similar slat is placed on top to form a block. A quantity of these built-up blocks is placed in a frame, pressed carefully under hydraulic pressure, locked in the frame, and put aside to allow the adhesive to set.

After the glued blocks have set sufficiently, they are ready to be made into separate pencils. This is done in either of two ways. In the first method, the blocks are run through a one-spindle molder that half-shapes the block into pencils; then the blocks are turned over and put through the machine again. This method allows the block to be turned end for end in order to get smooth planing, in case there is a slightly cross-grained slat on the second side. The other method forms the completely shaped pencil (whether it is round, oval, hexagonal, or of other shapes) in one passage through a two-spindle molder. Figure 14-1 shows a two-spindle pencil molder.

The shaped pencils are then sandpapered. Higher grade pencils are painted, varnished, and burnished. The trimming of the ends is accomplished by two large, rapidly revolving, sandpaper-covered drums set opposite each other a pencil length apart. An endless belt carries the pencils between the two drums. This process removes all varnish on the ends and at the same time reduces the pencils to exactly the same length, usually 7 in.

Fine drawing pencils are made without erasers. A cheap pencil is drilled at one end and an eraser glued into the resultant hole. The better pencil furnished with an eraser formerly had a metal ferrule to hold the rubber, but the use of plastic ferrules is now common. To attach an eraser with a ferrule, several steps are necessary. First a shoulder is cut or pressed on one end of the pencil, usually by an automatic machine; the ferrule is fitted on and prick-punched to secure it to the wood, and the rubber plug is inserted, sometimes by an automatic machine and often partly by hand. The eraser is a compound of rubber and an abrasive. To give maximum elasticity and length of life, the rubber erasive material is vulcanized with sulfur.

The last step in the manufacture of a pencil is stamping. Gold leaf, sheet aluminum, and bronze powder are usually used to stamp on the pencil the manufacturer's name and trade mark and the degree of hardness

of the lead. The steel stamping die is generally electrically heated, and it is applied with some pressure, thereby pressing the material into the painted surface. Branded pencils, after careful inspection, are now ready to be boxed for shipment.

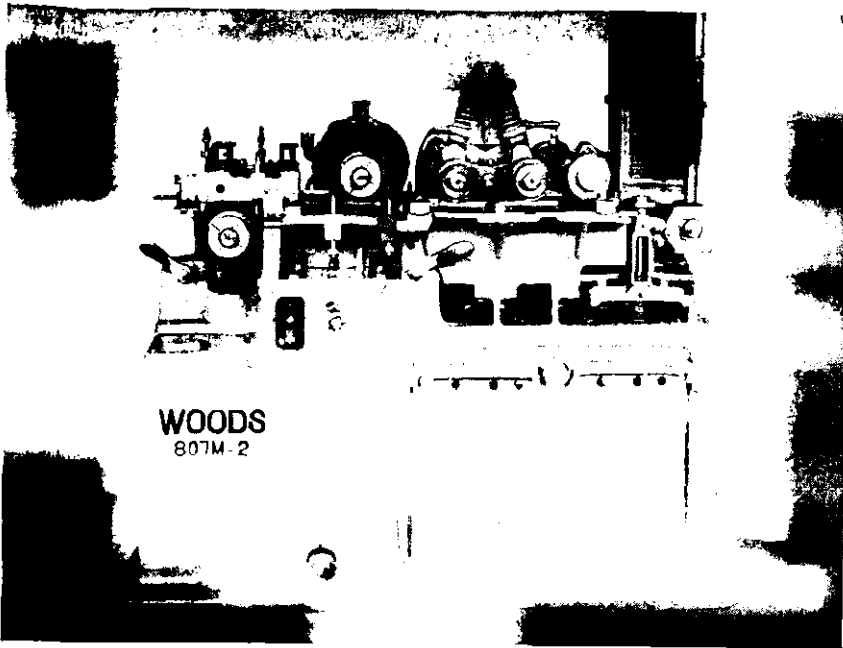


FIG. 14-1. Two-spindle pencil molder. (Courtesy S. A. Woods Machine Company.)

Pencil manufacture proper is essentially an assembling process, but a few of the larger companies produce their own leads, ferrules, erasers, and slats.

## II. MATCHES

A modern match may be defined as a piece of inflammable material, such as wood, cardboard, or waxed thread,\* provided with a tip consisting of a mixture of chemicals and other substances that may be ignited by friction. Some matches may be ignited on almost any dry surface, but others require a specially prepared surface.

\* American matches are generally provided with wood or cardboard splints, but small foreign matches called *vestas* are made with a splint consisting of a cotton thread coated with stearine and paraffin. These splints are smoothed and rounded by being drawn through holes in a metal plate, are cut to length, and are then tipped with ordinary igniting composition.

Present-day matches manufactured in the United States may be classified in two groups: (1) the wood-splint, double-dip, strike-anywhere match, and (2) the safety match having either a wood or cardboard splint. The head of the former consists of two parts: the larger part, the *bulb*, and the smaller *tip*. The bulb is made of a slow-burning mixture that is difficult to ignite by friction, and the tip is made to ignite easily by the heat of friction. These double-dip strike-anywhere matches have been manufactured in the United States since about 1905.

The safety, or strike-on-the-box, wood-splint match and paper matches have heads that contain large quantities of chlorate of potash with some slow combustible. Ignition is accomplished by striking the match on the side of the box or folder, which is coated with a composition containing red phosphorus and some abrasive material.

In order to reduce the fire hazard from discarded matches, splints are now impregnated with a weak solution of ammonium phosphate to prevent them from becoming glowing embers after the flames are extinguished. An impregnated splint turns black immediately after the flame is snuffed out.

Manufacture of matches has been developed to the point where it is a continuous mechanical operation requiring comparatively little labor; from the time the wood is put into the splint-making machine, the product is not touched by human hands until the consumer receives it.

Two types of wooden match splints are used in this country: the square splint and the round, grooved splint. The latter type is more popular than the former, and about 97½ per cent of American wood match splints are of this kind. The principal species used for the round, *grooved splints* are the white pines, while aspen is the favored wood for square match splints.

Because most American match factories are located in the eastern half of the United States, many plants using the pine match splint obtain their wood in the form of match blocks from mills located principally in Washington and Idaho. Aspen for square splint matches can usually be obtained from points much closer to the match factory.

#### A. PINE MATCH-BLOCK MANUFACTURE

Sawmills usually produce match plank in two thicknesses, each sufficiently heavy so that when air-seasoned or kiln-dried, the lumber will surface to thicknesses of 2 and 2½ in., respectively. The bulk of match plank is air-seasoned from 1 to 2 years, and the balance is carefully kiln-dried. Some prejudice to the use of kiln-dried match blocks exists, based on the charge that they produce darker colored and weaker splints. If the

kiln-drying operation is performed properly, these objections should be eliminated.

Match plank must be sawed parallel to the bark of the log in order to obtain straight-grained stock. Match plank is selected on the basis of straightness of grain, softness, uniformity of texture, white color, freedom from decay, and high yields of match blocks between knots. Most match-block companies require at least a 60 per cent yield of match blocks from each plank.

After the stock is dried to the proper moisture content, the planks are taken into the match-block factory, where they are crosscut into lengths of  $1\frac{7}{8}$ ,  $2\frac{1}{8}$ , and  $2\frac{3}{8}$  in.\* The resulting blocks are then carefully inspected for cross-grained areas and other defects. Blocks not requiring removal of defect are known as *picker blocks*. Defective blocks are sent to a *chopper* who removes the defects with a hatchet. Acceptable blocks from the chopper must be at least 2 in. wide and are known as *chopped blocks*. After a final inspection, the blocks are stored in bins for shipment to match factories.

It is estimated that 20 to 25 per cent of the annual production of western white pine lumber is used for match plank.

#### B. MANUFACTURE OF ROUND, GROOVED-SPLINT MATCHES

Both strike-anywhere and safety matches are now being made with the "round," grooved pine splint. The match blocks are placed, with the end grain of the wood up, on a ratchet-driven conveyer that carries them to cutting dies. The feed mechanism for the cutting dies is illustrated in Fig. 14-2. The dies are of a tubular type, descending vertically into the blocks. There are usually 42 or 57 of these dies in one cutting head so that, at each descent, this number of match splints can be cut simultaneously. The head makes about 300 strokes per minute.† On the downward stroke, the dies cut the splints; on the upward stroke, the splints are implanted into holes in an iron plate that is one of a series hinged together to form a continuous belt consisting of 1,600 to 2,400 plates. The perforated area of each plate is about 4 by 16 in., containing up to 600 or more holes. This belt and the cutting head are geared together in such a fashion that the belt moves forward as the head descends, and as the head rises another set of holes is in position to receive the new

\* In the Second World War, as a wood-conservation measure, manufacture of  $2\frac{3}{8}$ -in. matches was discontinued.

† To increase match production in the Second World War, cutting heads were speeded up to 420 strokes per minute.



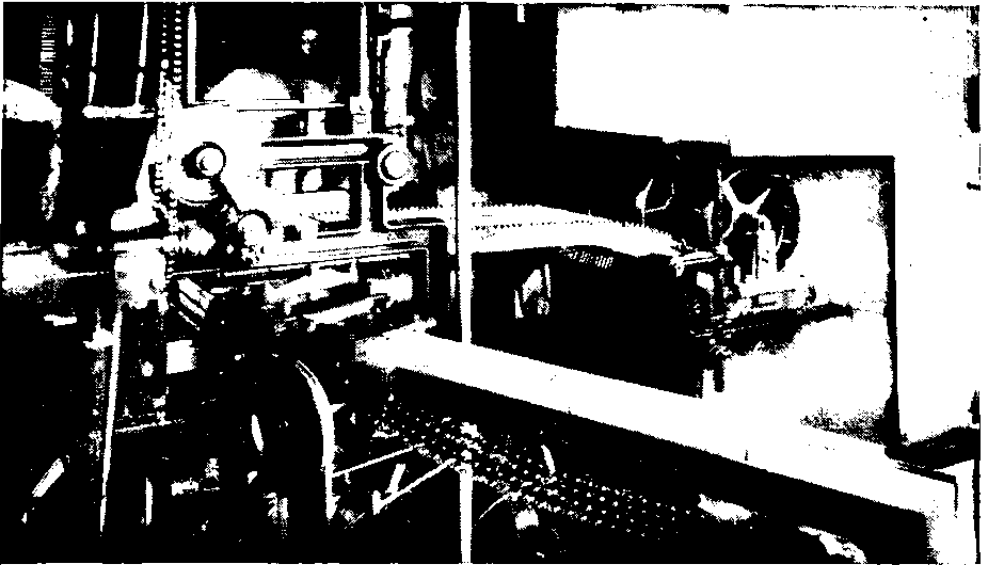


FIG. 14-2. Splint-cutting section of match machine. (Courtesy Palmer Match Company.)

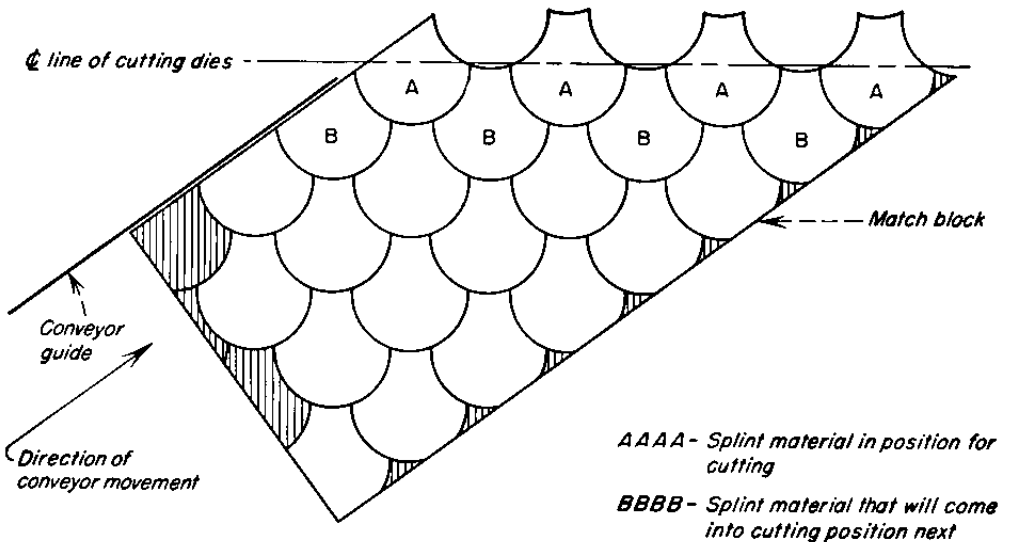


FIG. 14-3. Sketch showing method of cutting round, grooved match splints and utilization of match blocks. Shaded areas are not used.

splints. The belt travels over large carrier wheels mounted in a suitable framework set on the floor of the factory.

By having the conveyer feeding the match blocks to the cutting dies set at an angle with the line of dies, the *face* of the block to be cut moves in a combined forward and lateral manner *with respect to the dies*; the block actually moves in only the one direction determined by the conveyer.

With each intermittent movement of the conveyer belt, the cutting face of the block moves, in a direction at right angles to the line of dies, one-half the diameter of a match splint. This is sufficient to cause the face of the block to move laterally, with respect to the dies, so that another row of match-splint material is centered under the dies. By using tubular cutting dies, the resulting match splints are not cylindrical, but they have one large convex face and three smaller concave faces. Occasional splints will have a flat face because of insufficient wood on those cut from the edges of the match block. Figure 14-3 presents a sketch showing this method of cutting and the utilization of wood in a match block. This method of cutting



FIG. 14-4. Charge end of match machine. (Courtesy Palmer Match Company.)

converts about 90 per cent of the wood in a shipment of match blocks into splints, and it also provides thin ridges that facilitate igniting of the wood.

At some plants, two lines of match blocks, separated by a partition above the conveyer, are fed into the splint-cutting machine. This procedure fills the ends of the plates in the match machine belt, leaving an unfilled area in the middle of each plate.

After the splints have been implanted in the belt, the next operation performed, as the belt moves forward, is that of brushing. Here a revolving brush strikes the splints and removes broken or weak ones and, in addition, removes tiny splinters from the remaining sticks.

Following the brushing operation, the belt is depressed so that the splints are dipped into a vat containing ammonium phosphate to impreg-

nate them for the prevention of afterglow. The splints are then subjected to a blast of warm air for drying.

When the splints have been dried, the belt again carries them through a vat of melted paraffin to provide a flame carrier, the splints being dipped about one-fourth to one-third their length.

The next operation of the process consists of passing the splints over a composition roller that carries material for the bulb of the head of the strike-anywhere match or, in the case of the safety match, material for the complete head.

The splints are then subjected to a current of properly conditioned air for the purpose of setting the composition. In order to give sufficient time for drying, the belt is made to travel up and down through a series of huge carrier wheels.

To complete the heads of strike-anywhere matches, the partially dried bulbs pass over a second roller that carries the sensitive composition that will form the tips; final drying in a properly conditioned atmosphere follows. For making matches in a 60-minute cycle, the factory must maintain a temperature of about 72°F. and a relative humidity of 50 per cent. At the termination of the cycle, the completed matches are pushed out of the belt plates into a conveyer, to be delivered to automatic packing equipment. The time required to make a completed match varies from 40 to 60 minutes, depending on the individual factory, and the daily output per machine is usually between seven and nine million matches, based on wartime production rates.

### C. MANUFACTURE OF SQUARE-SPLINT MATCHES

In the manufacture of square-splint matches, short aspen bolts are placed in a small lathe and cut into veneer  $\frac{1}{10}$  in. thick. By means of spurs set in a pressure bar, the bolt is scored ahead of the lathe knife and the veneer comes off in several strips, each strip being equal in width to the length of the matches to be produced. These strips are taken to a splint machine that automatically impregnates, dries, cuts the veneer into splints, and assembles the splints in trays for the dipping machine. At the dipping machine, a joggling mechanism and plunger insert the splints into the plates of the belt that carries them forward for the impregnation and tipping operations. Square matches are of the safety type.

### D. MANUFACTURE OF PAPER MATCHES

Paper matches are made into books or folders usually containing 20 matches each. Book matches are of the safety type and are made auto-

matically by a machine that slits and dips the cardboard, puts the composition on the cover, binds, and cuts the books apart.

#### E. MATCH PACKAGING

When wood-splint matches are ejected from the plates of the match-making machine, all heads point in one direction. Matches that are sold in small boxes containing about 40 matches are packed with the heads all in one direction, but strike-anywhere matches in the larger household sizes of boxes are packaged so that the match heads in one layer, containing approximately half of the matches, point in one direction, while the heads in the second layer point in the opposite direction. This is done as a safety measure. Should the box be thrown on a hard surface, accidentally igniting the matches, only half the contents would be likely to light.

Small amounts of wood-splint matches of the safety type are encased in paper folders with the heads and friction paper concealed. These matches are ignited when withdrawn from the folder, and they are particularly adapted for use in windy situations.

#### F. MATCHBOX MANUFACTURE

The making of matchboxes is incidental to match manufacture. Equipment for this purpose consists of printing presses and box-making machines. Machines for producing household-size boxes make strips, boxes, and slides (the outer cases). A slitter takes large rolls of cardboard and cuts strips of proper width for the various box parts. Protection strips are folded at the proper points; boxes are folded and glued, and the slide machine takes the printed box covers and folds, glues, and sands them automatically.

Small boxes, having a capacity of about 40 matches each, are made in several ways. Some are made entirely of cardboard, similar to the household-size box, and still others are made with paper-covered wood slides and boxes. These two types are popular in the United States. A paper box may be perforated so that it can be torn in two for easy attachment to smokers' stands and ash trays. In the manufacture of boxes with wood parts,  $\frac{1}{30}$ -in. veneer is used and the veneer is scored in the proper places for subsequent folding before it leaves the lathe. Three pieces of veneer are required for each box: one for the bottom of the inside box, one for the rim of this box, and one for the slide or outer case. Very thin paper applied with an adhesive holds the parts together. Birch and maple are commonly used in the United States for these wood box parts.

### G. WOOD USED BY THE MATCH INDUSTRY

It was estimated in 1940 that the match industry used about 81,648,000 bd. ft. of wood in the manufacture of matches and matchboxes. The principal species in order of importance in 1940 were western white pine, aspen, birch, spruce, and maple. Western white pine supplied 90.6 per cent, aspen 6.9 per cent, birch 2.4 per cent, and spruce and maple 0.1 per cent of the wood used in that year.

### III. FLAT, ROUND-END WOOD TOOTHPICKS

It is claimed that one Charles Forster of Strong, Maine, was the first American to manufacture wood toothpicks. He learned this art from natives of South America, and his first product was whittled by hand. The article had become so popular by 1860 that he began producing it with machinery.

This simple article now sustains a prosperous industry that used the equivalent of 3,585,000 bd. ft. of white birch in 1940. White birch is the favored species for this purpose because of its strength, white color, and lack of taste. Toothpicks have been made of birch, maple, gum, and aspen. The stock used for white birch toothpicks must be free from knots and red heartwood; it also must be straight and at least 8 in. in diameter. In other words, only high-grade material is used. Maine, the center of the industry, has the largest toothpick mills in the world.

In modern machine manufacture of flat toothpicks, logs are cut into bolts from 10½ to 24 in. long. These bolts may be peeled and worked in the green state, but usually they are placed in hot water or are steamed to soften the wood and to loosen the bark before insertion in a veneer lathe. The typical lathe, taking bolts up to 24 in. in length and up to 20 in. in diameter, is used for cutting veneer strips that are about 2 ⅙ in. wide and ⅓ in. thick. The width of these strips is accurately controlled by spurs that are set in milled recesses in a pressure bar; they score the rotating bolt just ahead of the cutting knife. Good bolts may be used to a 3-in. core.

Each ribbon of veneer so produced is then fed into a pointing machine that bevels or skives the edges to produce the thin ends required in a toothpick; the veneer is pulled over two knives by means of feed rolls. These knives may be adjusted to appropriate angles.

After passing through the pointing machine, the skived strip is rolled on a winding spool. When the spool is filled, the roll of veneer is slipped off and is taken to the cutting machine.

The toothpick-cutting machine is an automatic device of the punch-press type that cuts and forms the toothpicks. It is operated at a speed

of about 2,000 strokes per minute, each stroke forcing two toothpicks through dies in the bedplate of the machine. The dies are so arranged that there is little loss of material, and approximately 154 toothpicks are obtained from each lineal foot of veneer.

The formed toothpicks are dried in trays in a steam-heated box-type oven having a recirculating air system or in more modern automatic conveyer driers. In the box-type oven, the drying time is about 2 hours.

When thoroughly dried, the toothpicks are placed in a tumbling barrel or polishing drum with a small amount of powdered chalk or shaved paraffin. The tumbling action wears off the sharp corners, and the chalk or paraffin gives the toothpicks a glaze.

Polished toothpicks are placed in an automatic straightening and box-filling machine. This machine assembles the toothpicks in an orderly manner and places them in small boxes ready for closing. A standard packing case holds 1,152 of these small boxes, each of which contains 750 toothpicks.

A complete unit of toothpick machines consists of one veneer lathe, one pointing machine, one veneer-winding spool, six toothpick-cutting machines, one drying oven, and one straightening and box-filling machine. Such a unit requires only about 15 horsepower for its operation, and its hourly output is about 1,440,000 toothpicks. One standard cord of sound white birch wood will yield from six million to nine million flat toothpicks.

A second type of toothpick that is circular in cross section and tapered from the middle toward both ends is also made, but producing plants have refused, on the grounds that its manufacture is a trade secret, to divulge the method used.

#### IV. WOOD EXCELSIOR

Excelsior is a name formerly applied only to thin strands of wood produced by the excelsior-shredding machine but now also extended to the product made by shredding newspapers and other waste paper. Wood excelsior is said to be an American invention which was placed on the market about 1860 under the name of *wood fiber*. The name "excelsior" first appeared in the advertisement of an upholstering firm, which used shredded wood in place of hair in cushions and mattresses; it was adapted, so the story goes, from Longfellow's poem "Excelsior."

##### A. MANUFACTURE OF EXCELSIOR

The principal qualities desired in excelsior wood are freedom from objectionable odor and staining materials, lightness of weight and color, and the ability to produce soft but strong and resilient strands. The excelsior stock must be free from bowing or twisting, straight-grained, and free

from decay, knots, and similar defects. The principal species used for excelsior are cottonwood, aspen, yellow pines, basswood and yellow poplar.

**1. Preparation of Material.** Excelsior wood comes in 36- to 56-in. lengths. These bolts are peeled and piled in racks 8 ft. long by 4½ ft. high for seasoning, since before the wood can be satisfactorily converted into excelsior it must be dried to about 16 to 18 per cent moisture content; this takes 12 to 24 months in the North and 6 to 9 months in the South. When dry, the bolts

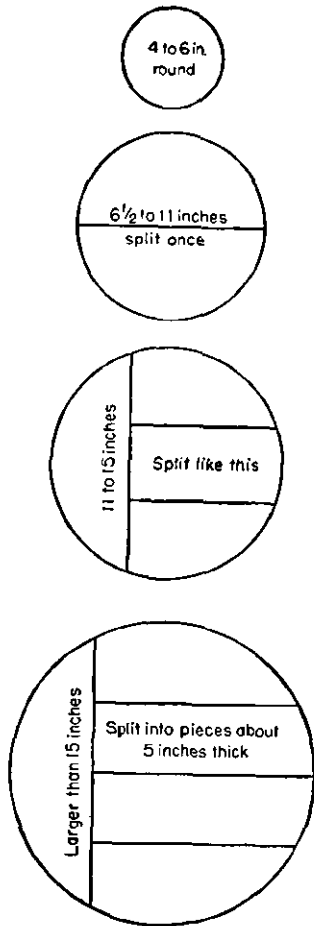


FIG. 14-5. The recommended method of splitting wood blocks for excelsior machine.

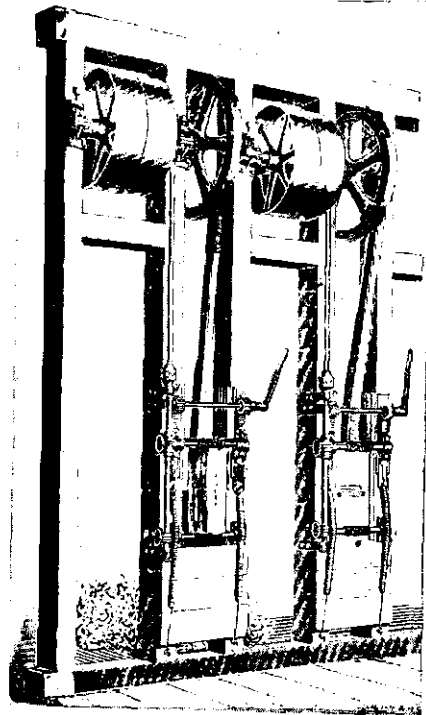


FIG. 14-6. Two upright excelsior machines framed together. (Courtesy Indianapolis Excelsior Machinery Co., Indianapolis, Indiana.)

are cut into 16-in. lengths, and those more than 9 in. (6 in some mills) in diameter are split (Fig. 14-5).

**2. Manufacture.** The actual manufacture of excelsior is a relatively simple process; it consists of shredding the wood in an excelsior-shredding machine, of which there are two types—the upright and the horizontal.

In the upright machine (Fig. 14-6) the stick of wood is placed between two corrugated feed rolls, by means of which it is firmly held in position.

The wood comes into contact with a moving slide, equipped with steel spurs and a knife, the cutting edge of which is generally toothed. The spurs score the wood and the resulting strands are then cut off by the knife that follows the spurs. No spurs are used in cutting coarse and ribbon-fine grades of excelsior. The excelsior drops into a conveyor that delivers it to the baling press, similar to that used in hay baling, where the excelsior is put into bales weighing 60 to 200 lb. each. Several upright shredding machines are usually framed together. A typical installation consists of several frames, each frame containing six to eight machines in a battery, a number that one operator can conveniently attend.



FIG. 14 7. Eight-block horizontal excelsior machine. (Courtesy Lewis T. Kline, Alpena, Michigan.)

The horizontal machines (Fig. 14-7) work on the same principle as the upright, except that each machine can handle eight blocks of wood at the same time. The blocks are fastened directly above the slides equipped with oscillating knives or with spurs and knives. The shreds of excelsior drop on a conveyer belt and are carried to the baler. The capacity of an upright machine is 800 to 1,000 lb. of the common grade of excelsior in 10 hours, while the horizontal machine can produce 8,000 to 10,000 lb. of excelsior in the same length of time.

All residues, including the sawdust produced in crosscutting of the bolts and also the spalts (the small pieces of bolts that cannot be entirely utilized in the excelsior machine), are burned as fuel in generating steam for the plant.

The equipment of a typical excelsior-manufacturing plant consists of a barker, cutoff saw, wood splitter, battery of shredding machines, knife and spur grinder, baling device, and scales.

## B. GRADES OF EXCELSIOR AND YIELD

Excelsior is manufactured in several grades, determined by the thickness and width of strands. These grades are ordinarily classified as follows:



(1) *coarse excelsior*— $\frac{1}{20}$  to  $\frac{1}{80}$  in. in thickness and  $\frac{1}{4}$  to  $\frac{1}{16}$  in. in width; (2) *standard or common excelsior*— $\frac{1}{30}$  to  $\frac{1}{100}$  in. in thickness, generally subdivided into several width classes, *viz.*, *fine*,  $\frac{1}{26}$  in. wide, *medium*,  $\frac{1}{8}$  in. wide, and *coarse*,  $\frac{7}{32}$  in. wide; (3) *wood wool*— $\frac{1}{100}$  to  $\frac{1}{500}$  in. in thickness and  $\frac{1}{32}$  to  $\frac{1}{500}$  in. in width. The bulk of production, perhaps 80 to 90 per cent of the total output of excelsior, is of coarse and standard grades.

The average yield of excelsior equals about 1 ton for each cord of 56-in. wood used. The yield varies somewhat with the grade of excelsior and the quality of raw material.

### C. USES OF EXCELSIOR

Formerly the two principal uses for excelsior were as mattress stuffing and as a packing medium. Since 1920, however, the use of excelsior in the mattress industry has been largely discontinued in favor of cotton linters. Today the common and the coarse excelsior are used principally for protective packing, and to some extent in kennel and stable bedding, and for stuffing toys; the fine grade or wood wool is used largely in cheaper grades of upholstered furniture and in automobile seats and cushions. Recently an insulating material consisting of excelsior and gypsum has been put on the market; excelsior is also used for reinforcing gypsum-fiber concrete, in a certain type of building boards. Such boards are low in density, which makes them excellent for heat and sound insulation. At the same time they are *strong* enough to carry part of the load in structural design. Their rough surface provides a good base for stucco, plaster, or cement. The material may be nailed and sawed and may also be impregnated with fire-resistant chemicals.\* These uses are, however, of little importance compared to the total production of excelsior. Considerable quantities of excelsior are made into paper-covered pads and wrappers used in packing. Finer grades of excelsior are used to a limited extent in gas and liquid filtering, and the extra fine grades are suitable as absorbent material.

### D. LOCATION AND STATUS OF THE INDUSTRY

There were 53 excelsior plants in the United States in 1939, as compared to 66 in 1929 and 95 in 1919. Virginia leads with 18 plants; in the South, in addition to Virginia, excelsior plants are also found in North Carolina, Georgia, Florida, Arkansas, Alabama, and Mississippi. In the North, excelsior plants are located principally in New Hampshire, New

\* Garland, Hereford. Aspen for Excelsior. Lake States Aspen Report No. 16. Lake States Forest Exp. Sta., St. Paul, Minnesota. 1949.

York, Minnesota, Wisconsin, and Michigan. The Northern plants use largely aspen and cottonwood, while in the South excelsior is produced chiefly from southern pine.

The industry as a whole is on the decline. The beginning of the decline in the use of wood excelsior can be traced back to 1920, when large quantities of cotton linters, stored for war purposes, were put on the market at salvage prices. These linters were purchased largely by the mattress industry to replace excelsior as a filler; since that time the use of excelsior for mattresses, formerly one of its most important uses, has been almost entirely discontinued. Two other factors which caused a still further decline in the use of wood excelsior were (1) the advent of corrugated and fiber boxes offered in a variety of sizes made to fit the products—this has eliminated in many cases the necessity for a filling medium essential in the standard-sized wooden boxes; (2) substitution for wood excelsior of a product made by shredding newspapers and other wastepaper, which can be produced at a considerably lower cost, since it requires very simple equipment, does away with the necessity for carrying in storage a large supply of wood, and has the added advantage that it can be manufactured in cities, *i.e.*, near existing markets or by the consumers as needed. Unless new users for wood excelsior are found in the near future, it is fully expected that the decline in the use of excelsior will continue still further.

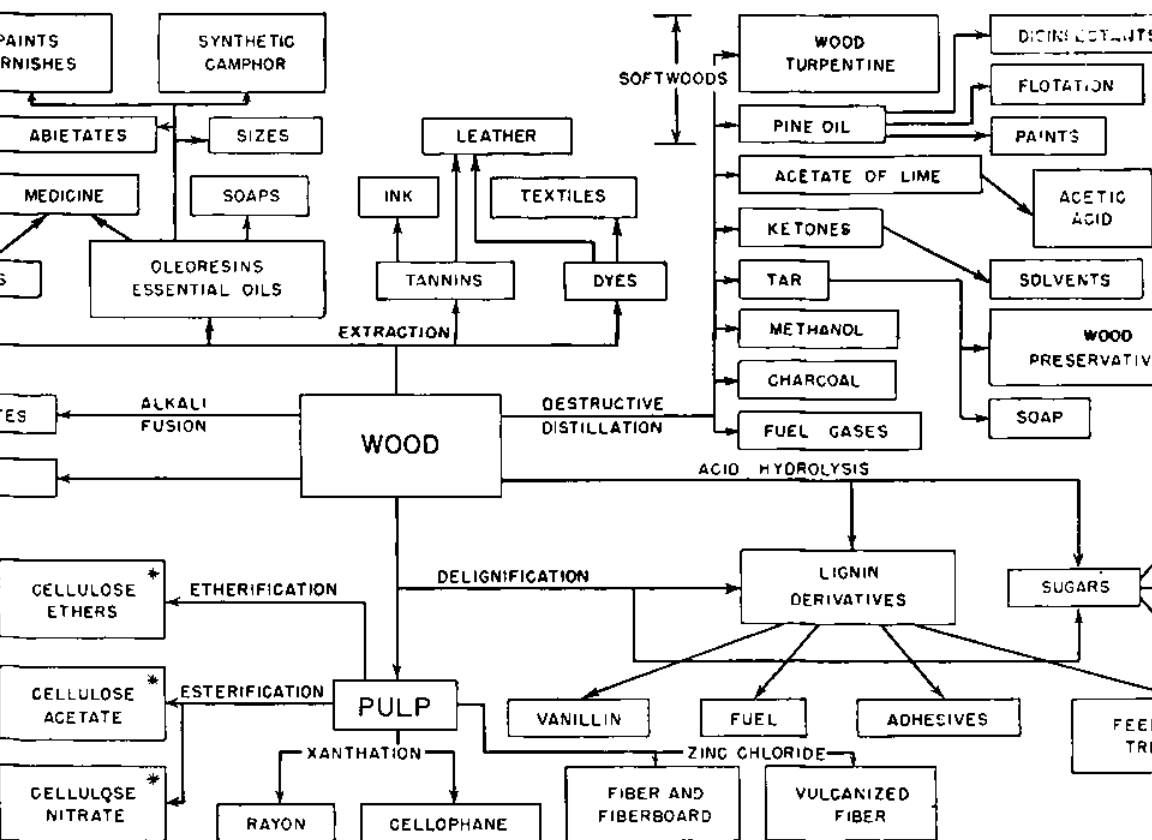
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**Part III**

**CHEMICALLY DERIVED PRODUCTS FROM WOOD**



INDUSTRIAL SIGNIFICANCE  
OF  
CHEMICAL WOOD PRODUCTS

FROM COTTON STATES

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## CHAPTER 15

### PULP AND PAPER

The pulp and paper industry \* of the United States ranks today among the first 10 industries of this country in the value of its products; it employs more than a quarter of a million people, and its capitalization is estimated at more than one and one-half billion dollars.

The real beginning of the paper industry of the United States may be dated from 1827, when Henry Barclay of Saugerties, New York, imported from England the first papermaking machine. By 1850 all but two paper mills in the United States were equipped with paper machines. Further expansion of the industry, however, was severely hampered by a scarcity of rags, the only source of raw fibrous material at that time. It was only with the introduction of wood pulp about 1860 that the American pulp and paper industry began its rapid development, more than doubling the value of its products in the following 20 years. That expansion of the pulp and paper industry will continue for some time is indicated by the still growing demand for pulp and pulp products.†

Although the United States is the largest producer of wood pulp and products made of it, in the prewar years the domestic production of pulp represented less than 50 per cent of the country's total annual requirements. The deficiency in normal times was supplied by imports from Canada, Sweden, Finland, and Norway, largely in the form of pulpwood, wood pulp, and newsprint paper. Since 1942 the imports of paper, pulp, and pulpwood have declined and the domestic production of pulpwood has increased, reaching a record figure of approximately 25 million cords in 1951. This figure represents an increase in domestic production of pulpwood of almost 150 per cent over 1939. The study of trends in paper and paperboard consumption in the United States indicates that the nation's requirements for pulpwood in the immediate years ahead will continue to increase.

\* The term *paper industry* is used here to designate the industries engaged in the production not only of paper, but also of various types of board and other items made of wood pulp.

† Within recent years the per-capita consumption of pulp products in the United States has ranged from 250 to 380 lb. a year; it is expected that the development of many new wood-pulp products will lead to further increases in pulp consumption.

According to the U.S. Forest Service estimates,<sup>2</sup> under proper forest management, these requirements can be easily met from domestic sources without impairing the forest resources of the country.

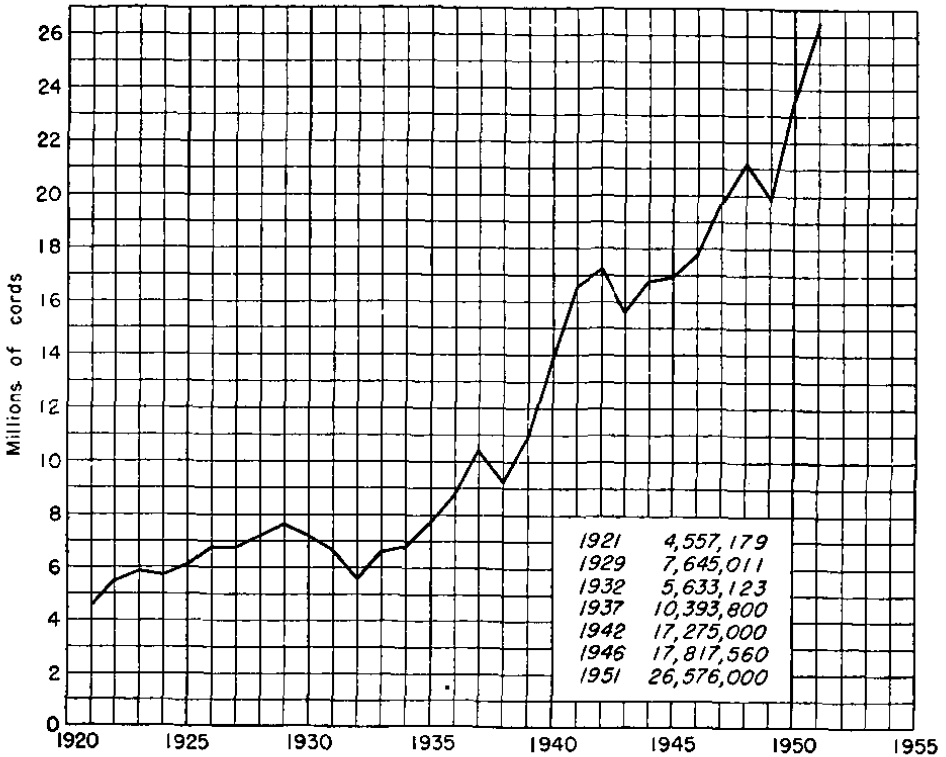


FIG. 15-1. Pulpwood consumption—domestic production and imported. (Courtesy United States Pulp Producers Association.)

## I. PULP MANUFACTURE

### A. PAPERMAKING MATERIALS

Pulp and paper can be made from the fiber † of many different kinds of plants. The principal factors which determine the commercial utility of a given plant for papermaking are (1) suitability of fibers for conversion

\* For statistics on pulp and paper production, see current issues of Industry Report, Pulp and Paper, Bureau of Foreign and Domestic Commerce, Department of Commerce, and Wood Pulp Statistics, United States Pulp Producers Association, Inc., New York.

† The term *fiber* as used in this chapter refers to any vegetable cell found in paper, regardless of its exact technical designation.

into pulp, (2) fiber yield per unit volume of raw material, (3) quality of the resulting pulp for papermaking purposes, (4) dependability of supply, (5) cost of collection, transportation, and conversion, and (6) degree of deterioration in storage.

The three principal materials used in papermaking in the United States are wood, old paper stock, and cotton and linen rags. Other papermaking materials used in this country are jute, hemp, straw, cornstalks, and sugar cane, or bagasse. Of these, wood is by far the most important source of pulp on the basis of the quantity produced. Both conifers and hardwoods are used; the former, however, are utilized to a much greater extent, because of the greater average length of their fibers and the larger percentage of long fibers per given volume of wood. The average length of fibers in a coniferous wood is about 3 mm., that of hardwoods only about 1 mm. (Fig. 15-2). The most important coniferous pulpwood species in this country are southern yellow pines, spruces, western and eastern hemlocks, jack pine, and several of the balsam firs. The most important hardwood species are cottonwoods and aspen, beech, birch, maple, red and black gums, and yellow poplar.

Spruces, which until recently were the leading pulpwood on the basis of quantity used, were superseded in 1939 by southern yellow pines. The consumption of spruce and fir has dropped from a high of 76 per cent of the total in 1899 to about 20 per cent in 1947, while that of southern yellow pine has increased from less than 5 per cent in 1919 to more than 42 per cent in 1947 and that of hemlock from less than 13 per cent to 15 per cent. The increased use of some species and introduction of new ones can be attributed to two main factors: (1) advancement in technical knowledge permitting broader utilization, and (2) economic pressure requiring the use of readily available material. It may be expected that the relative importance of spruce will continue to decline, while that of southern pines, hemlock, and hardwoods will continue to advance.

Printed wastepaper, commonly called *old-paper stock*, is used in this country to the extent that in certain grades of paper and board it surpasses new pulp in quantity used. The largest tonnage of wastepaper is remade into boards, liners, and newsprint, although the best grades of old paper, properly freed from ink and color, are used extensively in book paper and even in the manufacture of the finest writing papers.

Of other papermaking materials, cotton and linen reach the pulp mills in the form of rags. Jute, manila, and sisal hemp come in the form of old rope, sacking, and burlap. Hemp goes largely into special strong papers used in flour, cement, and other heavy-duty paper sacks. Jute is used in the manufacture of wrapping, buff drawing, and similar strong papers. Numerous attempts made to utilize cornstalks and sugar cane for paper-



making have met with scant success in this country, owing primarily to the high cost of baling and delivery. Considerable quantities of bagasse and a limited quantity of cornstalks are, however, converted into certain types of building board and heat-insulating materials.

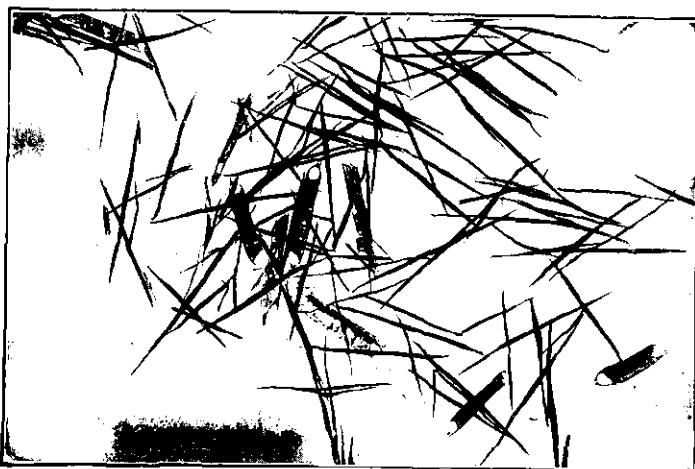
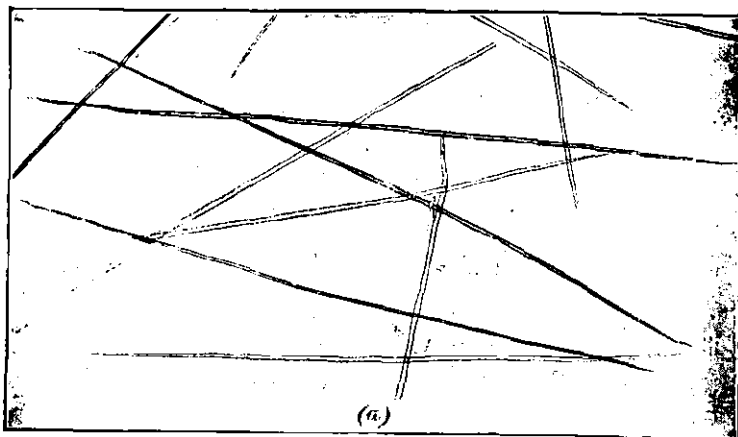


FIG. 15-2. Wood fibers: *a*, spruce fibers,  $\times 20$ ; *b*, poplar fibers,  $\times 20$ . (From *The Manufacture of Pulp and Paper*, McGraw-Hill Book Company, Inc.)

Another important source of paper fiber deserving special mention, although not used in the United States, is esparto, a grass common in Spain and North Africa and used in considerable quantities in Europe for high-grade book and printing papers. Various grain straws are important

as a source of papermaking fibers in some countries, especially Argentina and Hungary, where the scarcity of other materials makes them an important source of pulp. In the United States the use of cereal straws is limited largely to the manufacture of corrugated board, boxboard, and insulating board, while flax straw is used in the manufacture of cigarette papers.

**1. Methods of Obtaining Pulpwood.** Pulp mills in the United States procure pulpwood (1) from loggers chiefly concerned with cutting saw timber, (2) from the lands which they own or control and log specifically for pulpwood, (3) from pulpwood dealers,\* (4) from small operators and farmers, or (5) from importers. Of the total pulpwood consumed in American pulp mills, about one-fourth comes from timberlands owned or controlled by the pulp-producing concerns. In the Northeastern, Lake, and Central states and in the South, the trend in recent years has been toward an increase in the proportion of pulp obtained from the properties so owned or controlled, while in the Pacific Coast region greater reliance has been placed on purchases.

United States pulp producers own or control more than 14 million acres of timberland, of which 3 million are in Canada. Two-thirds of the uncut land held by the pulp producers is in the Northeast, one-sixth is in the South, and the rest is principally in the Lake and Central states. The acreage of uncut timberlands owned by the pulp mills in the Pacific Coast region is small, but the stand per acre is about 15 times as large as in any other region. The average stand of recoverable pulpwood in the Northeastern, Lake, Central, and Southern regions is about  $3\frac{1}{2}$  cords per acre and in the Pacific Coast region more than 77 cords. The large acreage of uncut forest lands owned or controlled by active pulp concerns in the Northeastern, Lake, and Central regions is, to a considerable extent, held as a reserve for future use when more urgently needed. This is likely to remain so as long as pulp and paper companies can acquire their supply of pulpwood from outside sources at a figure lower or not appreciably higher than the cost of getting out wood from their own holdings.

**2. Delivery of Wood to the Mill.** The method of delivery of pulpwood depends largely on the location of the mill. The most commonly used methods of delivery are (1) water transportation, including driving, towing in booms, rafting, and delivery in barges and vessels; and (2) land transportation, including rail, trucks, and sleighs.

Whenever feasible, water transportation is preferred, since it is usually the cheapest method of delivery. Rail transportation is the most expensive and is restricted to hauls not in excess of 600 miles and usually much

\* See p. 341.

shorter. In recent years trucking has become an increasingly important method of pulpwood delivery; it is usually confined to a radius of about 30 miles and is frequently limited to dry seasons of the year. Pulpwood, depending on the method of transportation, is delivered either in cordwood lengths of 4 to 8 ft., in log lengths of 12 to 16 ft. or in tree lengths.

**3. Condition of Delivered Pulpwood.** Pulpwood which is floated is usually delivered to the mill unbarked. Except in the South, pulpwood delivered by rail, truck, or barge, as well as imported pulpwood, is frequently barked by the pulpwood dealers. In recent years a little more than half of the total pulpwood consumed in the United States was purchased by the mills either in a peeled or rossed condition. The advantages of barking pulpwood in the woods are as follows: (1) barked wood dries more rapidly and is less subject to decay and insect attack, (2) when pulpwood is to be shipped long distances, the shipping charges can be reduced, and (3) if pulpwood is cut during the growing seasons, i.e., in the spring or early summer, the bark can be pried loose more easily by hand.

**4. Storage of Pulpwood.** Whether pulpwood is used immediately upon its arrival at the mill or held in storage, and the extent of storage in the latter case, depends largely on the method of delivery, climatic conditions, and capacity of the mill.

When the wood is transported by rail, trucks, or ships, it must be unloaded immediately to avoid tying up equipment. If pulpwood is delivered faster than it can be used by the mill, the excess is stored in log ponds or, if none is available, in storage piles. The mills depending on water transportation usually have holding areas or storage ponds for impounding pulpwood. In a cold climate or where water driving is confined to certain seasons, the mills accumulate their winter supplies of pulpwood during the spring and summer months. Pulpwood in that case is ordinarily placed in land storage piles. It is recommended that wood be barked before it is piled, to reduce deterioration. Such piles may attain 80 ft. or more in height, their size limited chiefly by the fire risk and the type of equipment available for handling pulpwood.

**5. Measurements of Pulpwood.** Pulpwood is measured either by volume or by weight. The units of volume measurements are: (1) *The cord*, containing 128 cu. ft. of space, or 75 to 100 cu. ft. of solid pulpwood, depending on diameter, crook and knottiness of the sticks, bark thickness, and closeness of piling. (2) *The cunit*, or *C-unit*,\* consisting of 100 cu. ft. of solid, unbarked wood. The cunit approximates the actual cubic content

\* Not to be confused with "the unit," a measure commonly employed in the South to designate a stack of pulpwood 8 ft. long and 4 ft. high but consisting of bolts greater than 4 ft. in length. The units may contain from 128 to 160 cu. ft. of stacked wood. The term *unit* is also applied to designate 200 cu. ft. of sawdust and hogged fuel.

of solid wood in the cord and can therefore be taken as the equivalent of a well-stacked cord. (3) *The cubic foot*. When the latter measure is used, pulpwood is scaled in cubic feet and then converted into cunits or cords. (4) *The board foot*. It is customary to consider 500 bd. ft. as a cord of wood.

The unit of weight commonly employed is the *ton*, equivalent to 2,000 lb. of either air-dry or oven-dry wood. The use of this unit necessitates moisture-content determinations to allow adjustments in weight to be made for the water content of pulpwood. Several Southern pulp mills are buying their pulpwood from farmers on the weight basis, without taking into account the moisture content.

### B. PREPARATION AND TREATMENT OF WOOD PULP

When pulpwood is delivered to the mill in log length, it is first reduced to shorter lengths in the *breakdown mill* (also called *cutoff mill*), which generally consists of a log haul-up or a jack ladder, a slasher or swing-saw system, and a series of conveyers to carry the blocks and refuse from the mill.

A slasher is designed to cut logs into bolts of the desired length. It is made up of endless chains, equipped approximately every 20 in. with castings or spurs similar to those used on haul-up chains; a table with an inclined plane; and a series of circular saws. The chains carry the logs up the inclined plane against the saws, which cut them into the desired lengths. The pieces, called *bolts* or *blocks*, usually 2 to 4 ft. long, are then conveyed to the barking drums or to storage piles. Where logs of varying lengths and diameters have to be reduced to short blocks of uniform length, a swing-saw system is generally used in place of a slasher. On the West Coast, the large western hemlock logs are reduced into cants in a band sawmill. In a number of Western mills this method is giving way to hydraulic barking, followed by log-size chipping.

**1. Barking or Rossing the Pulpwood.** Before the blocks are reduced to chips all the bark must be removed, if this has not already been done in the woods.\* The machines for removing bark are called *barkers*, and the process of removing bark is referred to as *rossing*. The reasons for removing bark before pulping are (1) the fiber content of bark is very low, (2) if left on the wood the bark would consume the chemicals and steam and occupy space without bringing any return, (3) bark produces dirty pulp and paper, (4) bark of some species contains too much resin.

\* A new method of bark removal designed to prolong the "sap-peeling" season (i.e., the period in the spring and early summer when bark peels off readily with a "spud" or an axe) was introduced in this country in 1949. This method, generally known as "chemical debarking," consists of applying sodium arsenite (other chemicals are being investigated) to girdled trees. This treatment kills the trees quickly and renders the bark in a satisfactory peeling condition.

There are three principal types of barkers: *knife barkers*, *barking drums*, and *stationary barkers*; a fourth type, the *high-pressure hydraulic barker*, though of recent origin, is rapidly gaining in favor.\* The knife barker is the oldest type of barking equipment. It consists of a heavy cast-iron disk mounted on a shaft and equipped with four to seven knives. Usually only short blocks are barked by means of knife barkers. The blocks are held against a rapidly revolving disk and are rotated either by hand or



FIG. 15-3. Barking drums. (Courtesy The Newsprint Service Bureau, New York.)

by means of an attachment until all bark is removed. The knife barkers are very wasteful, since they remove a considerable amount of wood with the bark; as much as 25 per cent of the wood is sometimes lost. For this reason, and also because knife barkers are very dangerous to operate, they have been largely replaced by drum and stationary barkers, except for removal of pieces of bark still adhering to the barked blocks and in mills where exceptionally clean wood is desired.

There are several types of barking drums, but all of them work on the same general principle (Fig. 15-3). The drums consist of a large, slightly inclined shell up to 12 ft. in diameter and 45 ft. in length, with an inner surface made of boiler plate, channel iron, or specially designed corrugated bars. The blocks of wood are fed automatically into one end of the drum,

\* For a more complete discussion of bark-removing devices, see: Forbes, E. W. *Bark-Peeling Machines and Methods*. U.S. Forest Products Laboratory, Report No. D 1730, Madison, Wisconsin. Jan. 1949.

within which they are tumbled against one another by a rotational motion of the barrel. This action, assisted by the streams of water played constantly on the blocks, removes the bark; clean blocks gradually work their way toward the opposite end of the drum where they are discharged on the conveyers.

A variation of the barking drum is the stationary barker. It consists of several trough-shaped pockets equipped along the bottom with several

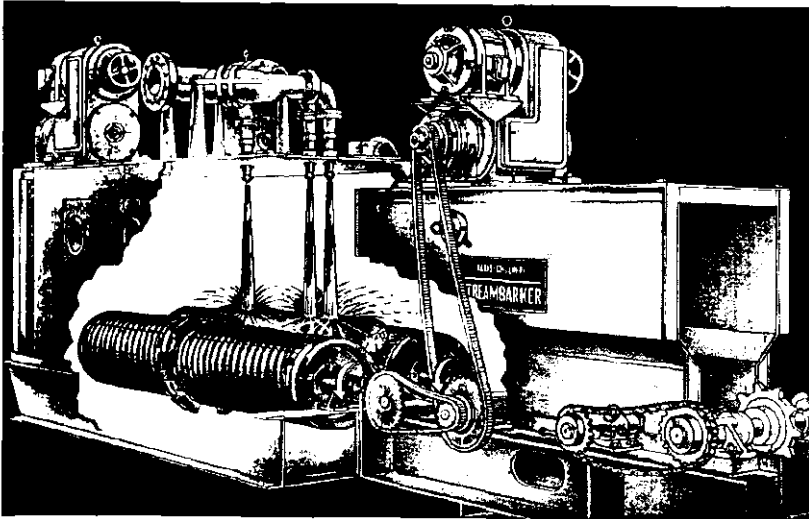


FIG. 15-4. Isometric drawing of Allis-Chalmers Streambarker. (Courtesy Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin.)

revolving double-ended cams. The cams give a rolling and tilting motion to the logs, resulting in removal of the bark. The bark removal is further facilitated by a water spray, which keeps the bark wet. The logs travel gradually from the first pocket into the last, from which they are discharged on a conveyer.

One commercial model of hydraulic barker consists of a chamber equipped with two bed rollers, one of which is fluted and the other spirally threaded (Fig. 15-4). Both rollers revolve in the same direction but at different speeds, so that the log is revolved and moved forward at the same time. The barking is accomplished by water streams under a pressure of 650 p.s.i., issuing from three nozzles located parallel with, and directly over, the axis of the logs moving through the machine. The first two nozzles, placed close together at the entering end of the barker, loosen the bark, which is then removed by a steel-wire brush placed in the center of

the spiral roll. The third jet washes the log clean. Barking is facilitated by the sharp threads of the rolls which score the bark, thus providing a number of points where the water stream can start bark erosion. The logs are brought to and carried away from the barker by a conveyer system. This barker averages about 10 cords of coniferous wood and 6 cords of hardwood an hour. The advantages claimed for this machine are (1) reduction in loss due to "brooming" of ends and chipping—this amounts to a saving of as much as 10 to 20 per cent of the total quantity of pulpwood handled; (2) considerable reduction in the man-hours required to handle the same quantity of pulpwood; (3) cleaner pulpwood and fewer rejects due to imperfectly removed bark; and (4) equal or greater production per same power consumption and lower capital investment in equipment.

A company-built jet debarker installed at the Everett, Washington, mill of the Weyerhaeuser Timber Company is an example of successful application of hydraulic principles to barking large logs. An increase of 18 to 20 per cent in the yield of pulp chips and appreciable savings in labor costs and steam consumption are claimed for this equipment over the previously used method of debarking.

In West Coast mills, in which large logs are reduced to cants in the breakdown mill, the bark is removed by means of a planer equipped with revolving curved knives, which plane the bark away. The barked cants are then conveyed to a woodworking room where all knots and other undesirable defects are removed by means of knot-boring machines. Each of these machines consists of a table equipped with mechanical arms for holding the cants rigid and a power drill (Fig. 15-5).

The bark removed in rossing wood is conveyed with other wood refuse to the boilerhouse. If water has been used in barking, it is customary to put the bark through a press to squeeze out some of the water. Since pressed bark may still contain upward to 40 per cent of water, some plants put it also through specially designed bark driers.

Before the rossed wood is converted into pulp it is usually washed in a tumbler type of washing drum and inspected for bark patches, which are removed with a knife barker. Larger blocks may be split into smaller pieces. Further treatment of the wood depends on whether a *mechanical* or *chemical* pulp is to be produced.

### C. MECHANICAL PULP

Mechanical pulp, otherwise called *groundwood* pulp, is produced by forcing rossed wood laterally against a revolving grindstone. By this means the wood is reduced to a fibrous mass which, after screening and subsequent thickening, is converted into pulp products. The process was perfected in

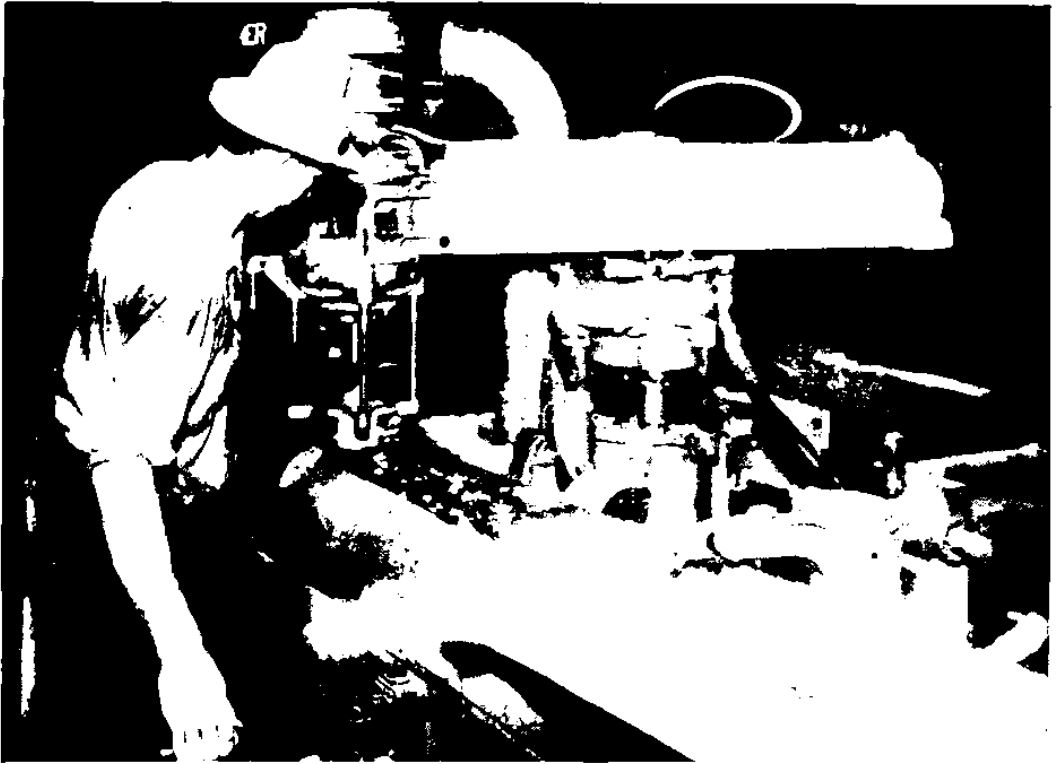


Fig. 15-5. Knot-boring machine. In pulping western hemlock, knots and other defects are removed by means of a knot-boring machine before the wood is chipped. (Courtesy Weyerhaeuser Timber Company.)

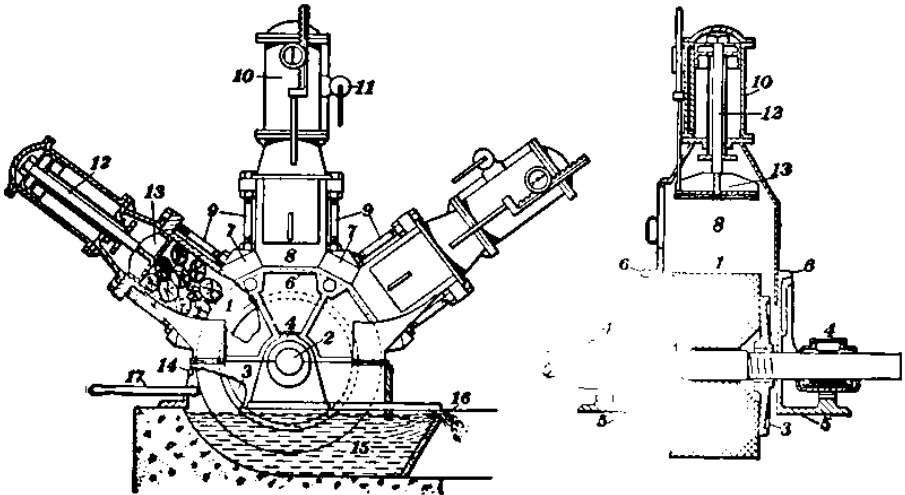


Fig. 15-6. A three-pocket hand-fed pulpwood grinder. The grindstone 1 is mounted on a shaft 2, clamped between flanges 3 and supported by bearings 4, fixed to bar-plates 5. The stone is covered by steel plates 6, connected by cross braces 7. Wood is placed in the pocket 8, supported over the stone by steel bolts 9. A piston, in a hydraulic cylinder 10, mounted over each pocket is actuated by the flow of water under pressure from the valve 11. The piston rod 12 transmits the pressure through the pressure-foot 13 on the sticks of wood. The stone is cooled by the white water flowing through pipe 14. The pulp collects in the pit 15, falls over the dam 16 into the stock sewers. The stone is sharpened with a burr mounted on a lathe 17. (From the *Manufacture of Pulp and Paper*, McGraw-Hill Book Company, Inc.)



Germany by Keller, who built the first successful wood grinder in 1840.

1. **Woods Used.** The principal woods used in the manufacture of mechanical pulp are spruces and balsam fir. Among other woods used are hemlocks, jack pine, southern yellow pines, and a small amount of hardwoods. Hardwoods, however, are not well suited for mechanical pulp, since they have very short fibers and produce a very weak ground-wood pulp.

2. **Grinders.** Machines designed for reducing wood into mechanical pulp are called pulp grinders. Depending on the method of loading, pulp grinders may be divided into two major types: *hand-fed grinders* and *magazine grinders*.

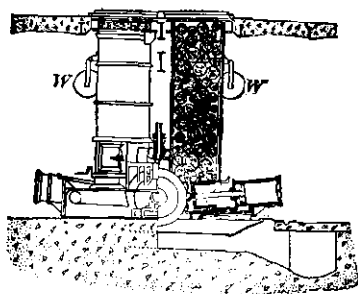


FIG. 15-7. Two-compartment magazine grinder. The wheel *W*, which turns as the wood drops into the magazine, is so calibrated that the number of turns records the number of cords used. (From *The Manufacture of Pulp and Paper*, McGraw-Hill Book Company, Inc.)

The *hand-fed grinder* consists of a grindstone mounted on a steel shaft (Fig. 15-6). The wood is placed into pockets, of which there may be three or four, and pressed against a revolving grindstone by means of hydraulic cylinders. These grinders use 24- to 48-in. sticks of wood and are capable of producing 5 to 7 tons of air-dry pulp in 24 hours. The resulting ground mass is washed off the stone by a continuous stream of water, and the

wet pulp, termed *slush*, collects in the pit below the grindstone, whence it is conducted to screens.

The main feature of the *magazine grinder* (Fig. 15-7), of which there are many makes, is a grindstone mounted on a shaft, with a magazine holding a quantity of wood placed over it. The sticks of wood are forced against the stone by means of hydraulic cylinders. The ground pulp is washed into the pit by water, as with the *hand-fed grinders*. The main advantage of the magazine grinder over the *hand-fed grinders* is the lower cost of grinding achieved by (1) increased holding capacity of the magazines, requiring less attention, and (2) increased production per foot of face of stone. The size of sticks used in the magazine grinders is usually 48 in., and their capacity is 16 to 25 tons of air-dry pulp in 24 hours.

A continuous grinder, eliminating hydraulic-pressure-operated pockets, is also available. This machine, known as the *Roberts grinder*, consists of a box-like cast-iron chamber, in which a massive ring revolves in a non-concentric circle around a standard grindstone. The pulpwood is drawn

into the space between the ring and the stone and is forced against the face of the stone at a predetermined pressure.

*Grindstones* used in the grinders are either (1) *natural sandstones* quarried in Virginia and Ohio or imported from England, Canada, and Japan or (2) *artificial grindstones* made of artificial abrasives bound together with ceramic bonds. Before a new stone can be put into operation, its surface must be scarred by a burr. The burr is rotated against the surface of the stone, forming grooves of a definite design on the face of the stone. During the grinding of pulpwood the ground fibers collect in these grooves and are protected there from regrinding until washed from the surface of the stone into the pit. The quality of pulp produced by a grindstone is greatly affected by the type of burr used.

When the stone becomes dulled it must be *reburred*, or *sharpened*. The frequency of sharpening depends on the hardness of the stone and the quality of pulp desired. The life of a stone varies from a few months to about 2 years, depending on the quality of the stone and the frequency of sharpening.

**3. Properties and Uses of Mechanical Pulp.** The yield of mechanical pulp is usually about 90 per cent of the dry weight of wood, as compared to 40 to 50 per cent in chemical processes. Mechanical pulp is characterized in general by lack of strength and rapid deterioration and is therefore used only in cheaper grades of paper and in boards. To add strength, mechanical pulp is usually mixed with some chemical pulp. The principal items made of varying amounts of mechanical pulp are newsprint, magazine and book paper, towels, cheap box paper and low grades of tissue and wrapping papers, wallpaper, box boards, wallboards, and other items which do not require strength or are intended to be used for only a short time. Mechanical pulp is also used as an absorbent for explosives in the manufacture of dynamite.

Mechanical pulp possessing a greater strength than groundwood pulp produced by the ordinary method may be obtained by steaming or boiling the logs in retorts at a moderate pressure prior to grinding. This treatment causes discoloration in the pulp, with the result that pulp produced from the steamed wood is brown in color, the product being known as *brown pulp*. Steamed groundwood pulp is somewhat more expensive to produce, and its dark color limits its use to container boards and wrapping papers simulating kraft paper. The compensation factor, as has been noted before, is its greater strength.

**4. Miscellaneous Mechanical and Semimechanical Pulping Processes.** Several other types of equipment are available for production of mechanical pulp. An example of such equipment is Allis Chalmers' Defiberizer, a machine built to accommodate bolts 3 to 12 in. in diameter and 24 to

30 in. in length. The bolts are placed in a hopper which reciprocates over a high-speed head equipped with steel needles. The carding action of these needles reduces the bolts to fiber. To assure quality of fiber, the wood must have a minimum of 35 per cent of moisture. The resulting fiber drops into a suction discharge, from which it passes through an expansion chamber to remove slivers. The sliver-free fiber is blown into a collector system from which it drops into a bailer.

The Asplund Defibrator uses wood chips about  $1\frac{1}{2}$  by  $\frac{3}{4}$  in. in size. The chips, fed from a hopper, are first compressed into cylindrical plugs and are then subjected to the action of high-pressure steam (140 to 170 lb.) for 45 to 60 seconds. The action of the steam renders the chips soft for the grinding operation that follows. From the preheater the chips fall through to a screw-type conveyer which delivers them to metal grinding disks, one stationary and the other rotating. The chips are delivered by a screw-type conveyer to the center of the rotating disk and are then thrown into the grinding zone by centrifugal force. The fiber thus produced is blown into a discharge chamber from which it is discharged into a cyclone separator. In the separator a water shower forms a fiber-water suspension. Asplund Defibrators are rated to produce 12 to 14 tons of oven-dry fiber per 24 hours of operation.

The Asplund Defibrator can be combined with a reaction chamber for cooking the pulp. The resulting equipment is called the Chemipulper and provides for a combination of continuous cooking under controlled conditions of time, pressure, and temperature and controlled refining under pressure. The chemical treatment can be either alkali, acid, or neutral. The reaction chamber, which is interposed between the feed end and the Defibrator, is made up in sections; the number of sections provided is varied according to the degree of treatment required.

Fiber produced by these types of equipment is suitable as fill insulation for refrigerators and, in admixture with standard chemical pulps, for the manufacture of insulating board and roofing felts.

#### D. CHEMICAL PULP

The object of chemical pulping is to separate wood fibers from each other with minimum mechanical damage; this is accomplished by suitable chemical action which removes the more soluble cementing materials, largely lignin and hemicelluloses, leaving behind a fibrous mass (pulp), consisting of more or less pure cellulose. Chemical pulp is made commercially either by the *acid sulfite process*, or by one of the two alkaline methods known as the *soda process* and the *sulfate process*, respectively.

1. **Chipping.** In the manufacture of chemical pulp, bolts are reduced to small chips about  $\frac{1}{2}$  to 1 in. in length and  $\frac{1}{8}$  to  $\frac{1}{16}$  in. in thickness. Chipping is accomplished by machines called *chippers* (Fig. 15-8). They consist of a revolving disk equipped with several heavy knives. The blocks of wood are fed into a chipper through an inclined chute making a 45-degree angle with the horizontal. As a result the chips are sliced on an angle presenting a maximum of open fiber ends to the action of chemicals. Chippers of commercial size will reduce 5 to 30 cords of wood per hour.

The chips as they come out of a chipper are not uniform in size and contain 2 to 5 per cent of wood dust and up to 3 per cent of coarse material. In order to separate the fine material and obtain chips of a fairly uniform size, the chips are put through a screen of either rotary or shaker type (Fig. 15-9). The dust is blown to the boilerhouse, and the large slivers remaining on the screen are put through chip crushers or rechippers, where they are either crushed or cut into smaller sized chips.

2. **Sulfite Pulp.** The first man to suggest the use of sulfur dioxide with the addition of a base for cooking wood was an American chemist, Benjamin Chew Tilghmann, who in 1866 and 1867 was granted English patents on a process of cooking wood with a solution of sulfur dioxide with or without the addition of the bisulfite of alkali, such as calcium or magnesium bisulfite. Extensive experiments were carried on by him and his brother at the mills of W. W. Harding & Sons, in Manayunk, Pennsylvania, but his process, because of inferior equipment, was never a commercial success, and the experiments were finally discontinued. It was the Swedish chemist C. D. Ekman who apparently quite independently developed a commercially successful sulfite process and established the first sulfite mill at Bergvik, Sweden, in 1874. In 1880 a German, A. Mitscherlich, patented a sulfite process which, though it differed little from the original Tilghman process, was commercially successful. At about the same time Eugene Ritter and Carl Kellner of Austria also patented a sulfite process. It was not until about 1887 that the sulfite process was reintroduced in the United States.

*a. Woods Used.* Since wood resins are only partially eliminated by the sulfite cook, highly resinous woods are not very suitable for pulping by this process. The principal species used are spruces, hemlocks, and balsam fir, though small amounts of western firs, tamarack, yellow pines, and cottonwood are also utilized; the use of hardwoods is limited by their short fibers and the low strength of the resulting pulp. Dr. C. F. Herty and others have reported that in southern pine trees under 25 years of age there is little or no heartwood formed and their wood does not contain appreciably more resin than spruce; they can, therefore, be successfully pulped by the

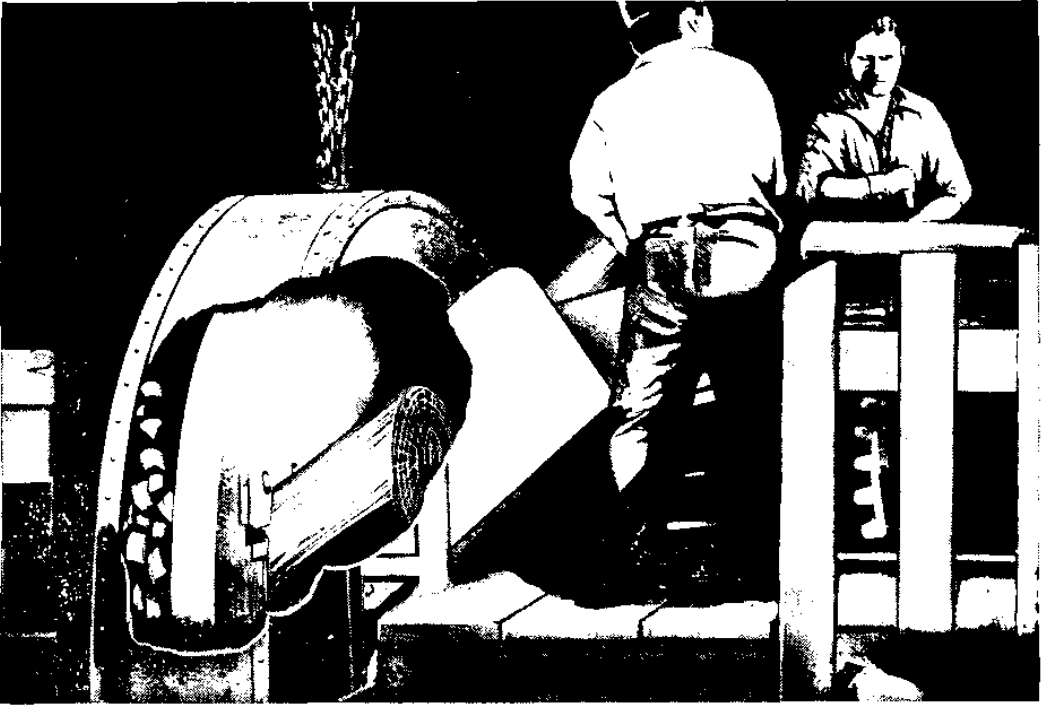


FIG. 15-8. Chipper. The barked pulpwood is reduced to chips as it is fed against a 7-ft. disk, fitted with four knives, revolving 300 times per minute. (Courtesy Hammermill Paper Company, Erie, Pennsylvania.)

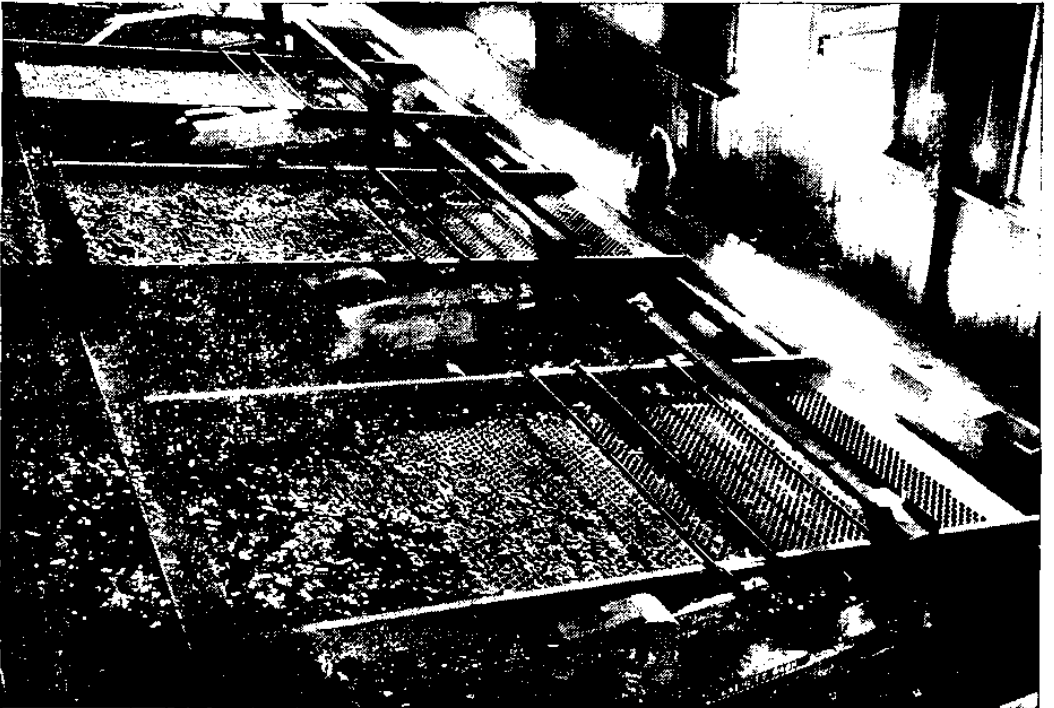


FIG. 15-9. Oscillating screens. These screens allow acceptable chips to drop to a conveyer below that carries them to the storage building. The larger pieces are returned to a crusher. (Courtesy Weyerhaeuser Timber Company.)

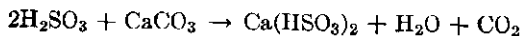
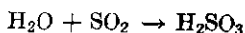
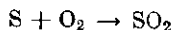
sulfite method. Sulfite pulp from southern yellow pine is now produced on a commercial scale in at least one pulp mill; such pulpwood is said to produce a high percentage of screenings and requires special treatments for removal of pitch.

*b. Liquor Preparation.* The sulfite process is an acid process, in which the active reagents which reduce wood into pulp are an aqueous solution of sulfurous acid ( $\text{H}_2\text{SO}_3$ ) and calcium bisulfite [ $\text{Ca}(\text{HSO}_3)_2$ ], although sometimes sodium and magnesium bisulfites are also used. The *cooking liquor*, as it is called, is produced at the mill by burning sulfur (S) or pyrites ( $\text{FeS}_2$ ) in a burner or a furnace to form sulfur dioxide ( $\text{SO}_2$ ) gas. This gas is cooled by passing through a series of lead pipes and then forced into the bottom of a tower, some 10 ft. in diameter and about 100 ft. high, filled with limestone ( $\text{CaCO}_3$ ); water is introduced at the top of the tower to make the solution. Milk of lime [ $\text{Ca}(\text{OH})_2$ ], made by slaking burned lime with water, is sometimes used instead of limestone. In this case sulfur dioxide is passed through the milk of lime in an absorption tank which is much smaller than the limestone tower.

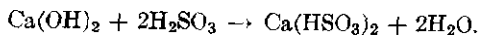
When a tower system is used, two or more interchangeable towers are employed. The ascending  $\text{SO}_2$  gas passes into the first tower where it forms a *strong acid liquor*. Between 75 and 95 per cent of  $\text{SO}_2$  gas is absorbed in this tower, and the remainder passes into the second tower, where water is sprayed on the limestone. The water combines with  $\text{SO}_2$  gas, forming sulfurous acid ( $\text{H}_2\text{SO}_3$ ), which reacts with limestone to form a weak solution of calcium bisulfite. This solution is pumped to the top of the first, or strong, tower. The resulting liquor, consisting of calcium bisulfite with excess sulfurous acid, is conducted into a third, or reclaiming, tower, where it combines with the unabsorbed portion of  $\text{SO}_2$  gas, liberated from the digesters during the cooking operation. The resulting *fortified, or cooking acid* is then stored in tanks until needed for use in the digesters.

In a typical milk of lime absorption system, sulfur dioxide is passed through the milk of lime in a high tank divided into several compartments by horizontal perforated partitions. The milk of lime is pumped into the top compartment in a continuous flow and reacts with the sulfur dioxide gas that bubbles up through the perforated false bottom. The weak liquor that forms as a result of this reaction passes through an overflow pipe to the compartments below, where it is successively fortified by absorbing more gas. From the bottom of the fourth tank it is pumped to the top of a recovery system. Milk of lime systems, though still used to some extent in the United States, are being rapidly replaced by the tower systems, which are considered simpler to operate, require less power, and cost less for upkeep.

The chemical reactions which accompany acid formation may be expressed in a simplified form as follows:



The carbon dioxide gas ( $\text{CO}_2$ ) that forms during this reaction escapes through the top of the tower. If, instead of limestone, milk of lime,  $\text{Ca}(\text{OH})_2$ , is used, the reaction may be represented as follows:



*c. Cooking.* Cooking subjects the wood chips to the action of acid liquor at elevated temperature and pressure long enough to produce pulp, *i.e.*, to free the cellulose fiber from the cementing and encrusting substances. During the cooking process lignin combines with  $\text{SO}_2$  or  $-\text{HSO}_3$ , forming a calcium derivative (or other salt derivative if other bisulfites are used) of lignosulfonic acid which splits off from the cellulose-lignin complex and passes in that form into the waste liquor. Since the sulfite process presents conditions favorable for acid hydrolysis, the hemicelluloses which are also removed from the wood during cooking are hydrolyzed to simple sugars, such as mannose, xylose, and glucose. Other by-products of sulfite cooking are acetic and formic acids and methanol. Acetic acid apparently results from a partial hydrolysis of the noncellulosic cell-wall constituents, while the origin of formic acid is unknown. Methanol arises mostly from lignin and to some extent also from the hemicelluloses. Since cellulose is relatively stable under conditions prevailing during sulfite cooking, the major portion of it remains behind in a more or less unaltered state.

Sulfite cooking is carried on in large steel vessels, or *digesters* (Fig. 15-10). A digester consists of a cylindrical shell 10 to 17 ft. in diameter and 40 to 70 ft. in height, with cone-shaped ends. The shell is lined on the inside with acid-resistant brick, laid in an acid-resistant mortar. The upper end of the shell is equipped with a detachable head, which is removed every time the digester is charged. The head is secured to the rim of the digester shell proper with clamps or bolts that hold it firmly against internal pressures which develop in the digester during cooking. At the bottom of the digester is a large pipe, opened by means of a blow valve, through which the contents are forced or blown into a pit at the completion of a cook. Some digesters used in the Mitscherlich process have a large manhole through which the pulp is washed out or removed with rakes. The digester is also fitted with connections to a relief line (usually in the head), coup-

lings for steam and acid lines, and temperature- and pressure-recording and -controlling instruments.

The usual capacity of the digester is from 12 to 18 tons of fiber, equivalent to 20 to 35 cords of wood, although digesters with a capacity as high as 40 tons are in use. Chips are loaded into the digester by gravity from a chip bin placed above or, in some of the newer mills, by belt conveyers

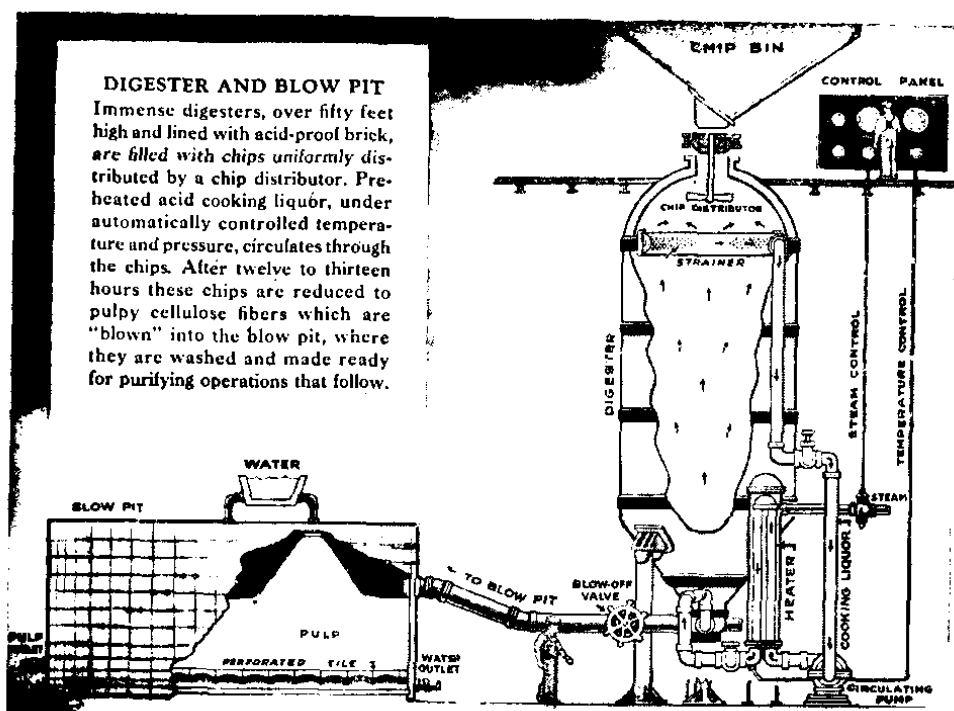


FIG. 15-10. Digester and blow pit. (Courtesy Hammmill Paper Company, Erie, Pennsylvania.)

which carry the chips to the top of the digester from chip bins or silos located on the ground floor. Cooking liquor, approximately 2,000 gal. for each ton of pulp produced, is added. Then the digester is closed and the temperature gradually raised until the pressure builds up to 70 to 110 lb.

The methods of cooking now in use may be classified as (1) the slow-cook process, commonly called the indirect, or Mitscherlich, process, and (2) the quick-cook processes. The quick-cook processes may be further subdivided as (1) the direct-cook, sometimes also called the Ritter-Kellner process, and (2) modified quick-cook systems.

(1) **THE MITSCHERLICH PROCESS.** In the indirect, or Mitscherlich, process, the chips are steamed in the charged digester for several hours at temperatures not exceeding 100°C. The brownish water condensate is



discharged as waste. The object of this initial steaming is to obtain better penetration of the cooking liquor into the chips. At the end of the steaming period the steam valve is turned off and the liquor line is opened. The partial vacuum that results from cooling the digester facilitates rapid filling of the vessel with cold liquor.

Heat for cooking in this process is supplied by copper, lead, or stainless-steel coils placed in the digester. Since steam does not come into direct contact with the liquor, more dilute acid is used than is customary with a direct cook. The temperature is gradually raised to 110°C., which may take 10 to 12 hours. When this temperature is reached, the pressure is relieved by opening a valve to get rid of the air. The temperature is then gradually raised to 125°C., and then held at that level until cooking is completed. The pressure in the digester is maintained at not more than 80 lb. At the end of the cooking period the steam is shut off and the pressure gradually reduced by relieving the gas, which is allowed to return to the reclamation tower. The waste liquor is drained, and the digester is filled with water and drained again. The pulp is not blown out as in the direct process but washed out or removed with rakes through the manhole at the bottom of the digester.

In American mills the actual cooking time consumed in this process varies from 20 to 30 hours, depending on the temperature used. The complete cooking cycle generally requires from 30 to 40 hours.

The advantages of the Mitscherlich process are in the high quality and superior strength of the resulting pulp, coupled with a somewhat higher yield, when compared to the quality and yield of pulp obtained by the quick-cook processes. These advantages result from the use of weaker acid and the lower temperatures and pressures employed. The drawbacks of the Mitscherlich process are the length of time required to complete the cooking and the high cost of maintaining the steam coils (250 to 500 ft. in the average digester) in repair. The frequently occurring leaks allow cooking acids to get into the steam condensate, making it impossible to use it in the boiler plant; this increases the consumption of coal.

This process is in general use in Europe; in America it has been supplanted to a considerable degree by the quick-cook processes.

(2) THE DIRECT-COOK PROCESS. In the direct-cook process steam is introduced directly into the digester; this allows rapid building up of temperature with resulting reduction in time of cooking. The digesters are filled with chips by allowing them to drop loosely into the digester; to ensure closer packing, some mills employ mechanical distributors consisting of rotating paddles, or blow steam or compressed air. The acid is pumped into the bottom of the digester or run into the top before the head is secured. Since the steam condenses in the digester and dilutes the cook-

ing liquor, more concentrated acid must be used in this process than in the Mitscherlich.

The actual cooking procedures vary considerably from mill to mill. Under average conditions it takes 12 hours or less to complete a cook. The temperatures are gradually raised to a maximum of 300°F. (149°C.), the rate of temperature rise being controlled largely by the time necessary to obtain full penetration of the chips by the liquor. If temperatures are allowed to rise too rapidly before the chips are completely saturated with liquor, the chip centers may become hard and turn reddish or brownish in color. The pressure which accompanies the cooking temperatures reaches a maximum of 75 lb. Since pressure in direct-cooking procedures may be due to a large extent to the pressure of the gas liberated during cooking, it cannot be used as a reliable indicator of temperature conditions in the digester. Direct temperature readings, therefore, are indispensable in this process for the maintenance of proper cooking conditions in the digester. Temperatures and pressures are generally controlled automatically by operating the relief or the steam valves. In either case, gases formed during cooking are blown off (relieved) intermittently or continuously. This is done to ensure a safe working pressure in the digester, to aid circulation of liquor, and to increase the efficiency of the SO<sub>2</sub> recovery.

(3) THE MODIFIED QUICK-COOK SYSTEMS. In an attempt to improve the uniformity of cooking conditions and to reduce steam consumption, a number of modifications in the standard cooking systems have been introduced in the sulfite mills.

In the Decker process the hot relief vapors from one digester are conducted into the bottom of another digester being started, thus reducing the amount of steam required for cooking.

In the direct-heating and liquor-circulating system, sometimes called the Morterud process, the liquor is continuously circulated through the digester and an outside heater. Since heating in this process, as in the Mitscherlich method, is accomplished indirectly, the liquor is not diluted and hence less acid (and in a less concentrated form) is employed. In addition, more uniform temperature conditions prevail in the digester and a considerable reduction in steam consumption is effected. Although widely used in Europe, this method of cooking in the United States so far has been used more extensively with the alkaline processes than with the sulfite.

Another frequently used modification of the direct-cook process is the Chemipulp hot-acid recovery system. This system requires the use of an accumulator, a spherical shell provided with standard digester lining. The accumulator has a capacity of from one and one-third to three times the volume of acid required to fill the digester. When the digester is filled with chips and the head is firmly secured, the acid from the accumulator

is pumped into the digester. The air from the digester is allowed to escape into the atmosphere. The air vent is closed and the relief lines leading to the accumulator are opened just as soon as the digester is filled with the acid. The hot relief gases from the digester are mixed with the acid in the accumulator. The excess of gases not absorbed in the accumulator is conducted to the absorption tank. After the first few hours of cooking, the connecting lines between the digester and the accumulator are closed and relief gases are conducted directly to the absorption tanks. The Chemipulp system results in a material saving in steam consumption, reduction in cooking time, higher acid strength, and more efficient recovery of sulfur dioxide.

Cooking is continued until the  $\text{SO}_2$  content in the digester, as determined by acid test samplings, reaches a certain point or until the desired quality of pulp, determined from samples blown from the digester, is obtained. When cooking is completed, the digester is emptied under pressure of about 50 lb. through the blow valve at the bottom of the cylinder. The contents are forced into a large acid-resistant tank called the *blow pit*. This operation is referred to as *blowing the digester*. The blow pit is equipped with a perforated wood or chrome-nickel-stainless-steel bottom, through which the cooking liquor, containing dissolved lignin and other noncellulosic wood components, is drained into a sewer or is conducted to a plant for recovery of by-products. The pulp is then washed until the water shows no traces of the cooking liquor, leaving a clean, light-colored fibrous pulp which is transferred to a storage tank. This operation generally requires several hours.

(4) MAGNESIUM OXIDE-SULFITE PROCESS. In this new process, as announced by the Weyerhaeuser Timber Company,\* magnesium oxide ( $\text{MgO}$ ) replaces calcium bisulfite [ $\text{Ca}(\text{HSO}_3)_2$ ]. The features of this process are the recovery of magnesium oxide dust and sulfur dioxide ( $\text{SO}_2$ ) gas, and the production of heat that supplies a part of the power for operation of the mill. A 100 per cent re-use of the waste cooking liquor is claimed.

At the Weyerhaeuser mill the digesters are not blown, but instead are dumped into large receptacles. When the digesters are ready for dumping, they are back-filled with waste liquor. Additional waste liquor is used continuously during dumping to dilute the pulp. The diluted pulp is carried to the agitated tanks where it is held at approximately 3 per cent consistency.

The pulp is separated from the liquor by washing in steel boxes with acid-proof lining. The waste liquor, containing 12 to 14 per cent solids, is then carried to the evaporators. Before entering these, it is neutralized

\* Morgan, H. W., and R. E. Baker. A new sulfite liquor cycle. The first  $\text{MgO}$  plant *Pulp and Paper*. Nov. 1948.

with magnesium oxide to prevent loss of sulfur dioxide ( $\text{SO}_2$ ) gas during the evaporation.

The concentrated liquor is passed to the burners. The sulfur dioxide gas which is released is carried off by flues to the Stebbins tile-lined absorption towers, built in series of three. The burned magnesium oxide is collected in cyclones, redissolved in water, and is fed down from the top of the absorption towers in the form of water suspension. The sulfur dioxide gas rises in the tower countercurrently to the magnesium oxide slurry.

The weak acid from the absorption towers is fortified with more sulfur dioxide in separate (Jensen) towers. This produces a strong acid, consisting of a mixture of magnesium bisulfite and free sulfurous acid, with about 3 per cent of free sulfur dioxide gas. The strong acid is pumped back to the digester building, where it is further fortified with the digester relief and stored in tanks before being fed back into the digesters.

*d. Recovery of Gas.* The efficiency of recovery of sulfur dioxide in the form of gas is very important from the standpoint of reduction in the consumption of sulfur per ton of pulp. In commercial practice it takes 200 to 300 lb. of sulfur to produce a ton of pulp, depending on the efficiency of the recovery system, the quality of pulp, and the species of wood used.

In the sulfite process the first part of the cooking cycle consists of penetration of chips and combination with lignin by the active chemical reagent ( $\text{SO}_2$ ), without appreciable solution of any cell-wall constituents of the wood. This stage is followed by acid hydrolysis and dissolution of sulfonated lignin. To obtain a reasonable rate of chemical reaction, two to four times the amount of  $\text{SO}_2$  actually consumed is added to the cook. This excess of  $\text{SO}_2$  is gradually drawn off as a gas from the top or the side of the digester and returned to the acid-making plant to be reused in preparation of fresh sulfite liquor.

The relief gases frequently contain considerable quantities of liquor. These are separated by passing the relief through separators and coolers. The gas is piped to the acid storage tanks for absorption, while the separated liquor is either discarded or that portion of it which was obtained at digester temperatures below  $135^\circ\text{C}$ . is mixed with the acid, before it is strengthened with relief gases. The relief liquor obtained above  $135^\circ\text{C}$ . is not used because it contains considerable amounts of decomposed bisulfite. In the plants employing the Chemipulp system, appreciable quantities of relief are recovered in the pressure accumulator. The so-called "sulfite turpentine" is sometimes recovered from the condensed relief gases in amounts of from 0.36 to 1.0 gal. per ton of pulp.

*e. Utilization of Sulfite Liquor.* Sulfite waste liquor is one of today's greatest industrial wastes. It has been estimated that for every ton of pulp, about 2,000 gal. of the liquor is produced, which presents a disposal

problem. Based on the 1946 production of sulfite pulp in the United States, the total quantity of sulfite liquor for disposal was more than 5,800,000,000 gal. Though several hundred patents dealing with utilization of sulfite liquor have been issued in this country, commercial utilization of the liquor has not yet been developed on an extensive scale. The total consumption of sulfite liquor at the present time represents only an insignificant amount of the total waste liquor produced.

There are two main reasons why greater utilization of sulfite liquor is essential. (1) For every ton of pulp produced by the sulfite method,

TABLE 15-1. CHEMICAL ANALYSIS OF COMMERCIAL UNBLEACHED SULFITE PULPS  
(U.S. Forest Products Laboratory)

Pulps	Cellulose		Lignin, %	Total pentosans, %
	Total, %	Alpha, %		
Spruce.....	94.6-97.0	81.2-86.13	1.0-2.2	5.1
80 per cent spruce, 20 per cent balsam.....	97.2	85.4	0.8	5.2
Hemlock.....	92.4-98.3	72.7-83.8	0.8-3.5	

roughly an equal amount of wood substance, containing many valuable wood constituents which could be utilized if recovered, is discarded with the waste liquor. (2) Even more important are the problems arising from the common practice of discharging the liquor into streams. The trouble arises largely from the action of certain microorganisms on the organic matter present, causing a decrease in the dissolved oxygen content of the water and an appreciable increase in the carbon dioxide content, a condition which is highly unfavorable to aquatic organisms. The presence of sulfite waste liquor in water also interferes with coagulation processes in municipal water-purification plants. Therefore, although sulfite spent liquor is not taken into consideration in calculating the price of sulfite pulp, Federal and state regulations prohibiting pollution of streams make the economical disposal of the waste sulfite liquor one of the most urgent problems facing sulfite mills.

The liquor as it comes from the digesters contains 10 to 12 per cent solids. Before it can be processed it is usually necessary to concentrate it to 50 per cent total solids or more. This is accomplished either by precipitation with calcium hydroxide or by evaporation.

When the lime precipitation method is used (Howard process), most of the lignin is separated from the waste sulfite liquor together with the carbohydrates; the latter are filtered out and discarded. The carbohydrate-free precipitate is then further processed for the production of tanning extract, cement hardener, and other uses. Since, however, the outlet for these materials is limited, the bulk of the precipitated lignin is mixed with wood waste or coal and utilized as a boiler fuel. Spent liquor from 1 ton of pulp yields up to 1,250 lb. of ligneous residue with a heating value of 8500 Btu per lb. In addition, 50 to 75 lb. of sulfur and 80 to 130 lb. of calcium oxide per ton of pulp are also recovered. In Sweden, attempts are made to evaporate the waste liquor and to burn the evaporated product either as a concentrated solution or as a powdered dried fuel for generation of steam.

Sulfite-liquor extracts can be used for tanning leather; these extracts are prepared by neutralization of the liquor with lime, concentration, and separation of the organic and inorganic materials. Sulfite liquor has been used for the manufacture of sulfur indathrene and similar dyes. The concentrated liquor possesses high adhesive properties, which suggest its use as a binding agent. As such it has been widely used in Sweden as a dust binder on unpaved roads. In this country it has been used in New Jersey for more than 20 years for maintaining dirt roads; it is also reported that in eastern Washington more than 2,000 miles of highways and streets are treated with sulfite liquor direct from the digester. The adhesive properties of the waste sulfite liquor also recommend it for the manufacture of plastics, building boards, molded articles, silica bricks, fuel briquettes from wood or coal, lacquers and varnishes, and as a linoleum cement; for the last purpose the concentrated liquor is mixed with a clay base and a preservative.

In Europe, fermentable sugars resulting from the hydrolysis of hemicelluloses are converted to ethyl alcohol by neutralization and subsequent fermentation of the spent liquor; the yield of alcohol usually amounts to about 1 per cent by volume of the waste liquor. Successful recovery of ethyl alcohol from sulfite liquor has also been reported from Everett, Washington. The production of alcohol from the waste liquor does not solve, however, the problem of liquor disposal, since the fermentation residue may be as objectionable as the original waste.

A commercially successful process has been developed for utilization of sulfite waste liquor in preparation of baker's yeast. A method employed at Liverpool, Nova Scotia, involves treating of the hot sulfite spent liquor with limestone and soda. The resulting liquor is then inoculated with the yeast at suitable fermentation temperatures, and filtered air is circulated to protect the yeast from the effects of gases formed. The yield of

yeast varies from 350 to 450 lb. per 2,000 gal. of sulfite waste liquor. This plant reports an output of about 20,000 lb. of yeast per week; equipment to double this production is being installed.

Vanillin, a product exactly like that obtained from the vanilla bean, is another interesting by-product of sulfite pulping. The sulfite liquor from coniferous woods is first freed of lime by precipitation with sodium carbonate, and the resulting soda liquor is heated under pressure with caustic soda, which breaks down the lignin compounds partially into vanillin and partially into desulfonated lignin. The vanillin may be separated by extraction with butyl alcohol, or the desulfonated lignin may be precipitated with acid and the crude vanillin extracted from the filtrate with a suitable solvent. The white pure vanillin crystals are then obtained by conventional methods of separation and purification.\*

In Norway and Finland, sulfite liquor is used as a source of printing ink for newspapers and of laundry soap. The organic residue of waste sulfite liquor has been found to give beneficial results as a fertilizer. A lime sulfur spray, prepared by passing hydrogen sulfide gas into sulfite waste liquor, has been suggested for use as an insecticide and fungicide.

*f. Yield, Quality, and Uses of Sulfite Pulp.* The yield of pulp in the sulfite process depends on the species of wood used and on the severity of treatment. The average yield is about 50 per cent of the dry weight of wood. The sulfite process requires an average of 1.8 cords of rough wood for each ton of pulp produced.

The chemical composition of sulfite pulp is influenced by the extent of delignification, the species of wood, and to a lesser degree by variations in the quality of wood of a given species. Cooking procedures leading to a more complete removal of lignin from the pulp result in a reduction in the total yield of pulp and an increase in its alpha-cellulose content. Consumption of bleach is also reduced with the reduction in lignin content of the pulp.

If strong, unbleached sulfite pulp is required, it is cooked for a shorter time than the grades of pulp intended for further purification and bleaching. Unbleached sulfite pulp is fairly light in color and can be used for many grades of paper without bleaching; it is extensively used with groundwood pulp in newsprint and other inexpensive papers. The bleached sulfite pulp is used in the higher grades of writing and printing paper and, when further purified with an alkali, in the manufacture of rayon and other chemical cellulose products.

**3. Alkaline Pulps.** The two principal alkaline processes for the manufacture of pulp are (1) the *soda process*, developed by Watt and Burgess

\* The authors are indebted to R. S. Hatch, Weyerhaeuser Timber Company, for the description of this process.

in England in 1853, and (2) the *sulfate process*, proposed by C. F. Dahl of Germany in 1879.

In both processes caustic soda ( $\text{NaOH}$ ) is the active pulping agent responsible for dissolving the noncellulosic components of the wood, and in both soda is reclaimed, to be used again. However, since only about 85 per cent of the soda can be thus recovered, the loss is made up by addition of soda ash ( $\text{Na}_2\text{CO}_3$ ) in the soda process and salt cake ( $\text{Na}_2\text{SO}_4$ ) in the sulfate process.

The chemical reactions involving dissolution of the noncellulosic components of the wood by an alkali pulping agent are still poorly understood. Alkaline delignification apparently involves three consecutive stages:

1. Absorption of alkali by the wood, probably by acidic-phenolic groups in the lignin complex.
2. Chemical combination between the lignin and the absorbed alkali.
3. Chemical hydrolysis which causes the alkali-lignin complex to disperse in the liquid.

The alkaline liquors remove the intercellular lignin rapidly and before any action on the lignin in the secondary wall takes place. This is in direct contrast with the sulfite liquor, which removes both types of lignin at about the same rate but more slowly than the alkaline pulping agents. This difference in selective action may be responsible for less degradation and hence stronger fiber resulting from the alkaline cooking, especially by the sulfate process. Alkaline cooking also results in removal of a much greater per cent of the noncellulosic carbohydrates, which are severely degraded and appear in the "black liquor" in the form of sodium salts.

a. *The Sulfate Process.* The sulfate process differs from the soda process in that, in addition to caustic soda ( $\text{NaOH}$ ), the cooking (*white*) liquor also contains some sodium sulfide ( $\text{Na}_2\text{S}$ ), as well as small amounts of other, relatively inactive, compounds, such as sodium carbonate, sodium sulfate, and others. The process is called the sulfate process, because sodium sulfide is obtained from sodium sulfate [*salt cake* ( $\text{Na}_2\text{SO}_4$ )].

(1) **WOODS USED.** Any kind of wood can be pulped by this process. It is, however, especially adapted to pulping resinous woods. In this country, southern yellow pines provide the bulk of the wood pulped by the sulfate process, tamarack, spruce, and hemlock contributing 12 to 15 per cent each. Of late, jack pine and Douglas fir have also been used in increasingly large quantities.

(2) **COOKING.** Cooking in the sulfate process is carried on in unlined steel digesters. In the older mills, horizontal and vertical rotary digesters were frequently used. Rotary digesters, however, are expensive to maintain and produce inferior pulp, and their capacity is limited to not more



than 1,500 cu. ft. In the newer mills stationary digesters, from 2,500 to 4,300 cu. ft. in capacity, are used exclusively.

Either direct or indirect methods of cooking are employed. In both methods the liquor is generally recirculated to obtain more uniform cooking conditions. Directly heated digesters are less expensive to install but consume more steam. The most commonly used system for circulating liquor in the indirect cooking is the already described Morterud system or one of its numerous modifications.

The cooking cycle in the sulfate process may be divided into three stages: the initial, or liquor-penetration phase, the full-pressure period, and the gassing-down period. In the first stage steam pressure is built up to about 60 or 70 lb. This stage lasts about 30 minutes, and during this time the air and all noncondensable gases must be removed from the digester as fast as they form; failure to do so results in false pressure that interferes with steam penetration and results in incomplete delignification (undercooking) of the pulp. During this period turpentine (when highly resinous woods are used) begins to distill with the steam. Toward the close of this period, when pressure reaches 40 to 60 lb., the rate of delignification is noticeably increased.

Following the initial stage the pressure is brought up quickly to 100 lb. or more (340°F. or above).\* No relieving is necessary during this stage of cooking, because generation of gases is small, and therefore the temperature and pressure will correspond quite closely. The full-pressure period is associated with the removal of more resistant secondary-wall lignin.

When the cook is completed, which in some mills takes from 2½ to 6 hours, the pressure is gradually reduced to about 60 lb.; this is called *gassing down*. The digester is then blown by opening a blow valve at the bottom. Rotary digesters are emptied by opening the manhole and revolving the digester.

In the more modern mills, to conserve as much steam as possible, the digesters are blown into a blow tank, a large steel shell elevated above the digester. The blow tank is connected to the blowpipe of the digester. The sudden release of pressure when stock enters the blow tank through a blowpipe causes violent evolution of steam and helps in disintegration of the cooked chips into a fibrous state. The steam is passed through a separator to remove the turpentine and then is used for heating the water

\* Experiments at the U.S. Forest Products Laboratory, Madison, Wisconsin, have indicated that in the range of 320 to 366°F. there is no critical temperature which is more beneficial than others from the standpoint of yield of pulp. Higher temperatures speed the reaction and hence decrease the time of cooking; at the same time they decrease somewhat the strength of the resulting pulp.

employed in washing the pulp. The stock, which at this stage contains the fiber, the organic matter dissolved during the cooking, all the alkali added to the cook, and considerable quantities of water, is allowed to drop from the blow tank to the washing equipment. In mills which are not equipped with blow tanks the stock is discharged into a blow pit.

(3) WASHING. A thorough washing of pulp is very essential in the alkaline processes, because the efficiency of the washing system determines not only the purity of the resulting pulp but also the completeness of chemical recovery. Since all the waste liquor goes to a recovery system, the minimum dilution of the waste liquor commensurate with good recovery of chemicals is aimed at in an efficient washing process. The system is considered to be efficient when the total washing loss of salt cake per ton of fiber is less than 50 lb. and the amount of water used in the removal of chemicals does not exceed 2 lb. of water per pound of pulp.

The washing of pulp is carried on in *wash pans*, in *diffusers*, or in *vacuum washers*. The *wash pans* are open steel tanks with false bottoms in which washing takes place by gravity displacement of water flooded on the top of the pulp. The *diffusers* are large steel vessels, equal or larger in volume than the digesters, provided with perforated false bottoms through which the liquor drains. The washing is carried on with hot water under pressure. The washed stock is transferred into a storage chest, where the stock is kept agitated and further amounts of soda are removed by soaking. The *vacuum washer* consists of a wire-wound cylinder rotating in a vat of pulp. The suction draws a layer of pulp to the wire and filters out most of the black liquor. The mat of fibers formed on the wire is drenched with hot-water showers, and the wash water is likewise drawn through the wire. The pulp is then washed off the cylinder with a shower of *white water* into a stock chest, where it is diluted for further washing in the secondary vacuum washer. The filtrate from the first cylinder is conducted to the black-liquor storage to be treated for the recovery of chemicals; the filtrate from the second washer is usually discarded.

(4) THE RECOVERY SYSTEM. The success of operations in a sulfate mill depends to a large extent on the efficiency of the recovery system. The *black liquor* separated from the fiber during washing contains most of the chemicals originally used in cooking, as well as more than one-half of the total dry weight of the original wood.

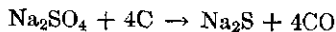
The recovery of chemicals in the sulfate process involves the following series of steps: (1) concentration of liquor to a consistency at which the organic material it contains is in a combustible condition; (2) burning of the concentrate with maximum recovery of heat and sodium salts, and reduction of sodium sulfate ( $\text{Na}_2\text{SO}_4$ ) into sodium sulfide ( $\text{Na}_2\text{S}$ ); (3) conversion of sodium sulfide and sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) into caustic

soda (NaOH); and (4) separation of impurities (mud) from the sodium salts to form the clear white liquor used in cooking.

When highly resinous conifers such as southern pines are pulped, the black liquor contains appreciable amounts of resins and fats. In some plants these products, known as *sulfate soap*, or *skimmings*, are allowed to rise to the surface of the black liquor in storage tanks. The soap is skimmed and when treated with an acid or sulfur dioxide yields *tall oil*, a dark oily liquid containing resin and fatty acids, from which rosin and pine oil may be recovered (see Chap. 20, Naval Stores, page 449, for details). Whether tall oil is recovered depends on the operational conditions in a given plant.

In modern plants black liquor is passed into a battery of multiple-effect evaporators. As the liquor progresses from one cell (called "effect") to another, its boiling point is lowered by reducing the pressure (with a vacuum pump). With this system the only heat from outside sources needed is that required to raise the liquor to the boiling point in the first effect. Steam evaporating from that cell is sufficient to boil the liquor in the second, since this is kept under reduced pressure. Additional effects are similarly operated. After the system is placed in operation it is customary to have the most concentrated liquor in the first effect and the fresh liquor in the last; this is because more concentrated liquor is more viscous and requires more heat to continue further evaporation of water. The concentrated liquor as it is discharged from the evaporators contains 50 to 60 per cent of solids. In some mills it is further concentrated with high-pressure steam in a single-cell concentrator to 70 or 80 per cent of solids.

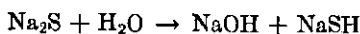
The concentrated liquor is pumped into a recovery furnace, of which there are several different types. In the older, rotary-type furnace, the material works gradually from the back of the furnace, which is about 20 ft. long, to the front end. Some heat is supplied to the end of the furnace by means of a firebox. However, as the concentrate moves along the furnace, the organic material becomes concentrated enough to support its own combustion. The burned ash, called *black ash*, is discharged from the front end of the furnace; it consists of a mixture of compounds, principally sodium carbonate ( $\text{Na}_2\text{CO}_3$ ), sodium sulfide ( $\text{Na}_2\text{S}$ ), and sodium sulfate ( $\text{Na}_2\text{SO}_4$ ). The black ash is mixed with a sufficient amount of fresh salt cake ( $\text{Na}_2\text{SO}_4$ ) to replace losses incurred in cooking and washing. The fortified black ash is shoveled into the smelters, where some of the sodium sulfate is reduced at high temperature to sodium sulfide, thus:



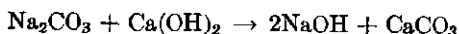
In modern mills the rotary furnaces and the smelters are replaced by single furnace chambers, in which all the recovery burning is performed.

Several such systems are in operation. In all these the black liquor is first fortified by addition of fresh salt cake and then sprayed into a furnace, where the organic matter is burned and a smelt, consisting of sodium salts, is formed.

Regardless of the method of smelting employed, the red-hot smelt from the furnace is allowed to flow into a tank containing water. The resulting solution is called *green liquor*, because it is usually tinted green by ferrous hydroxide. Green liquor consists mostly of sodium carbonate and sodium sulfide. Some sodium sulfide is converted into caustic soda, thus:



Green liquor is treated with lime [ $\text{Ca}(\text{OH})_2$ ], which converts sodium carbonate in the green liquor into caustic soda.



This step is known as *causticizing of soda ash*. In the older mills it is carried on as a batch process by agitating green liquor and quicklime in a tank. When the reaction is completed the agitation is stopped and the sludge, called *mud*, is allowed to settle out. The clear solution on the top of the tank is decanted, forming the white, or cooking, liquor. The precipitate (*mud*) is then washed out and filtered in order to recover the residual chemicals contained in it.

In more modern mills the batch method of causticizing has been replaced with one of the several continuous systems. In these systems all the steps of causticizing and clarification of white liquor and washing of mud are carried on as a continuous process. The most widely used continuous system is the Dorr process.

The clear white liquor, consisting principally of caustic soda and sodium sulfide, is pumped into a storage tank until needed. In some mills the lime left behind in the mud is reburned and used again with fresh lime in causticizing further quantities of green liquor.

At the outbreak of the Second World War, when the supply of imported salt cake was threatened, synthetic salt cake was introduced as a substitute. This product consists of an intimate fusion of soda ash and sulfur. Synthetic salt cake is added directly to the green liquor, thus making smelting unnecessary. The new method, if completely successful, promises considerable reduction in costs, brought about by savings in fuel consumed in smelting, higher yield of sulfides, and elimination of some of the equipment now required in the sulfate process. Improved control over pulping operations, resulting in more uniform quality of pulp, is also claimed to be an advantage of using the synthetic product in place of the natural salt cake.

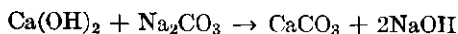
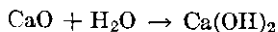
The sulfate process is accompanied by a very disagreeable odor, largely due to formation of methyl mercaptan ( $\text{CH}_3\text{SH}$ ). This odor is a sufficiently serious nuisance to result in prohibiting use of this process in heavily populated regions. The most practical way to reduce odors in the sulfate process is to pass the relief gases through a spray condenser and to collect and burn all the noncondensable gases in the recovery furnace.

(5) PROPERTIES AND USES OF SULFATE PULP. Sulfate pulp is a very strong pulp, since it is made of coniferous woods with long fibers and since the chemicals used in this process do not reduce the strength of fibers as much as those used in the acid and soda processes. The yield of pulp is about 45 to 48 per cent of the dry weight of wood.

Sulfate pulp is sometimes called "kraft" pulp (from the German, meaning "strength"); the use of this term, however, should be limited to that subdivision of the sulfate process in which the pulp is intentionally undercooked to produce very strong fiber. The chief drawback of sulfate kraft pulp is its brownish color, which restricts its use to the manufacture of wrapping paper, bags, and various other containers, board, and other products where strength is more important than color. Although kraft pulp can be bleached, the prolonged bleaching results in a reduction of fiber strength and is also rather expensive. There are several mills now in operation in the South producing bleached sulfate pulp which in some respects competes with bleached sulfite pulp from other regions. This pulp is cooked slightly softer than ordinary sulfate and is then bleached by the multistage bleaching process (see section on bleaching). Bleached sulfate pulps of exceptionally high strength are also made from spruce, jack pine, and hemlock in the Northern states and from spruce in Scandinavia.

*a. Soda Process.* The soda process is much older than the sulfate process and is also simpler. As in the latter, the success of operations depends on the efficiency with which the chemicals are recovered. The principle of this process is based on the ability of caustic soda to dissolve lignin and to hydrolyze the noncellulosic carbohydrate components (hemicelluloses) of the wood.

The active reagent in the soda process is caustic soda ( $\text{NaOH}$ ). The chemical reactions that take place in the formation of cooking liquor may be indicated thus:



The white liquor in the soda process contains also small amounts of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ). The presence of this chemical is considered

undesirable, but its occurrence in white liquor is considered unavoidable because of the incomplete reaction between lime and soda during causticizing.

(1) WOODS USED. The soda process is practically restricted to pulping of hardwoods, principally aspen, cottonwood, beech, birch, maple, red gum, and yellow poplar, although almost any other available hardwood may be used. Sometimes, to produce long-fibered stock, conifers such as spruce, hemlock, pine, and balsam fir are also used. The conifers require more alkali and longer cooking and yield less pulp than do the hardwoods.

(2) COOKING. The stationary digesters used in the soda process are similar in design to those used in the sulfite process, except that, as in the sulfate process, they are not lined with brick. In the older soda mills, rotary digesters, either horizontal or spherical, were extensively used.

In the soda process, cooking is generally carried on by the direct-heating method and liquor system. Maximum pressures of from 125 to 130 lb. and temperatures of from 165 to 174°C. are reached as quickly as possible and are maintained until cooking is completed. To do away with the effects of false pressure due to accumulation of air and gases, the digester is relieved several times in the course of cooking. Cooking is continued for 2 to 6 hours.

When cooking is completed the pulp is blown into a blow pit or a blow tank, where the expended cooking liquor is allowed to drain off. Washing of soda pulp is generally carried on in open wash pans, rather than in diffusers, as is the case in the sulfate process. It is customary to wash the pulp first with the weak liquor from the previous wash; the resulting liquor is conducted to the recovery plant. The first washing is followed by a hot-water rinse which forms the weak-liquor wash used for the following cook. The final wash, also with hot water, is discarded.

(3) RECOVERY SYSTEM. The black liquor obtained from the blow pits and the first wash of the pulp contain all the organic matter dissolved in pulping wood, as well as most of the alkali used in cooking. This liquor is conducted into a recovery plant, where it is put through multiple-effect evaporators similar in design and operation to those employed in the sulfate mills.

The concentrated black liquor, containing about 60 per cent of solids, is put through a furnace, where all organic material is burned. The resulting black ash, largely a crude form of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ), is combined with fresh sodium carbonate to make up the loss. Unlike the sulfate process, no smelting is required in the soda recovery system. The ash is dissolved in water and treated with quicklime (causticized) by a batch or a continuous process similar to that employed in the sulfate mills. The

solution, clarified by settling, forms the white or cooking liquor; it contains about 10 per cent caustic soda. The precipitate (mud) is washed to recover residual chemicals.

The loss of chemicals in a modern plant equals about 60 lb. of soda and in the older plants two to three times that amount, per ton of fiber.

(4) YIELDS, CHARACTERISTICS, AND USES OF SODA PULP. The yield of soda pulp is about 45 per cent or less of the dry weight of wood. The resulting pulp is quite dark in color but is readily bleached to good white.

Since hardwood fibers are short, the soda pulp produced from hardwoods is usually mixed in varying proportions with sulfite pulp made of coniferous woods. The short hardwood fibers act as a filler, with the result that paper containing soda pulp is more opaque and bulky. Soda pulp is used largely in the manufacture of book and magazine stock and in writing and absorbent papers.

#### E. SEMICHEMICAL PULP

The standard commercial processes of pulping wood result in yields of less than 50 per cent of the original wood by weight. In order to increase yield, the cooking procedure, *i.e.*, temperature, concentration of chemicals, and time of cooking, can be modified so as to prevent the solution of the less resistant beta- and gamma-cellulose and of a certain amount of lignin. Following a mild cooking, the wood chips can be broken into pulp by mechanical means in a rod mill, disk fiberizer, or some other attritional device. Pulps resulting from such two-stage pulping treatment are called semichemical.

Although neutral sulfite (sodium sulfite + sodium bicarbonate) is the most frequently used pulping agent in the production of semichemical pulp, other agents such as acid sulfite and modified soda and sulfate liquors are also used. Therefore, the general term *semichemical pulp* must be prefixed with the name of the particular agent used (*e.g.*, neutral sulfite semichemical pulp). The principal difficulties in semichemical pulping involve adequate control of cooking and satisfactory fiberizing of the semi-cooked chips. When the cooking is properly controlled, yields of 60 to 80 per cent, or even higher, of the oven-dry weight of the wood can be secured. Acid semichemical pulps are dark-colored, resembling kraft, while neutral types vary with the color of the wood from light brown to dirty white. In spite of its color, occasioned by a high lignin content, semichemical pulp is seldom bleached because of cost factors. Its principal use is found in the production of corrugated board.

All woods can be reduced to semichemical pulps. The hardwoods, however, are considered more suitable than softwoods, because the former produce semichemical pulps with higher strength characteristics than would

be expected from their fiber lengths, while the reverse is true in the case of softwoods. Most of the domestic semichemical pulp is at present produced from chestnut wood in connection with the extraction of tannin. Other hardwoods, particularly red and black gums in the South and birch and aspen in the Lake states, are also gaining in importance. The greatest potential value of the semichemical processes lies in the opportunities they offer for expansion in the utilization of the low-grade hardwoods.

#### F. TREATMENT OF PULP

Before either mechanical or chemical pulp can be converted into paper or shipped as such, it must undergo a series of treatments, first of which is *screening*.

**1. Screening.** Screening is necessary to remove dirt, foreign material, knots, and other uncooked or unbroken pieces of wood from the pulp and to separate fibers into different grades, based upon their size. This operation is accomplished by means of a series of screens and can be divided into two stages: *coarse screening* and *fine screening*.

The object of coarse screening in the case of mechanical pulp is to remove unground slabs and slivers of wood. This is accomplished by flowing the pulp over a grating made of iron bars set on edge, about 1 in. apart. The coarse material that fails to pass through the grate is removed and usually returned to the grinders. The pulp is then passed over sliver screens consisting of perforated steel plates with holes from  $\frac{3}{4}$  to  $\frac{5}{32}$  in. in diameter. The screens are either stationary or oscillating. The efficiency of operation depends largely on the size of the holes and thickness of the pulp stock; the smaller the holes and the thinner the stock, the freer of slivers will be the accepted stock. On the other hand, fine screening results in a considerable loss of fibers through clinging of fibers to the slivers.

The object of coarse screening in chemical pulp is to remove uncooked chips and knots without breaking them into a finer fibrous mass. The reason for this is that the uncooked portions of the pulp are of poor quality and color and if allowed to break into fibers will adversely affect the quality of the pulp. The chemical pulp from the storage tanks is first thinned with water until the content of the solid matter is about 0.75 per cent or less. This stock is then passed through a rotating screen having  $\frac{3}{16}$ - to  $\frac{1}{2}$ -in. perforations, thus removing unbroken pieces.

After coarse screening, the pulp, in some mills, is passed through a *riffler*, an apparatus where sand, pieces of mineral, particles from the lining of the digesters, and other impurities are allowed to settle. This is accomplished by passing the diluted pulp through a long trough, containing pockets of a rough felt fabric at the bottom, into which the impurities



settle. The riffler is placed level, the current being produced by a pump that draws the stock from the riffler. The velocity of flow is regulated so that the fibers will not settle to the bottom with the heavier impurities.

Different grades of paper require different qualities of pulp. The purpose of fine screening, therefore, is to separate the fibers into several grades according to their length and diameter. This is brought about by controlling (1) the size of the perforations in the screen, (2) the force used in passing the fibers through the screen, and (3) the consistency of the stock.

Fine screens are of either the centrifugal or the diaphragm type. Centrifugal screens consist of a steel-plate shell containing an impeller (agitator), surrounded by a cylindrical screen plate. The rapidly rotating impeller throws the pulp stock, which enters at the top or the side of the machine, against the screen. The centrifugal force developed by the impeller causes the good stock to pass through the perforations in the screen. The accepted stock falls by gravity through the space between the plates and the casing and is carried out through a discharge spout. Stock too coarse to pass through the screen is thrown off the agitator and discharged at the bottom of the screen.

Diaphragm screens, also called *flat screens*, consist of flat metal plates, perforated with slits, which form the top of a shallow box, the bottom of which is made of rubber diaphragms. These diaphragms are vibrated by a cam mechanism which causes the diaphragms to rise and fall, thus creating a partial vacuum in the space under the screen plates. The operation of a diaphragm screen, therefore, depends on a combination of gravity and suction. Enough stock is admitted at one end of the screen to keep the upper surface of the screen plates completely flooded. The accepted stock, or the fiber that passes through the screen openings, is discharged from the flow box under the screen, while the coarse fiber is removed at the tail end of the screen or battery of screens.

**2. Thickening the Stock.** The consistency of the stock after fine screening is from 0.25 to 0.6 per cent solid. The process of thickening the stock to 3 to 6 per cent is called *slushing, deckering, dewatering, or concentrating*. Thickening is accomplished by means of a decker. There are many designs of deckers, but a common type consists of a cylinder covered with a fine-mesh wire screen, revolving in a vat into which the thin stock from fine screens is delivered. The pulp accumulates on the wire mesh, while the water runs through it inside the cylinder. The water thus removed is called *white water* and usually is reused in thinning the stock for screening.

**3. Bleaching.** Pulp as it appears after screening and slushing is off-color. The color of pulp, at this stage of manufacture, is due to the presence

of small amounts of noncellulosic substances (lignin, hemicelluloses, and various extractives, such as tannins and resins) that remain in pulp after cooking. These impurities are chemically combined with the cellulose fiber and can be removed from the pulp only by chemical treatments that will first dissociate them from the cellulose. The operation that accomplishes this end is called *bleaching*. Bleaching not only whitens the pulp but also purifies it by removing some of the colorless noncellulosic impurities which, if left in the pulp, would interfere with the subsequent manufacturing operations.

Although a number of bleaching agents can be employed, only a few are commercially important. In bleaching of chemical pulp the most important agent is *chlorine*. Until 1919 it was supplied almost exclusively in the form of *calcium hypochlorite* ( $\text{CaOCl}_2$ ). Formerly, calcium hypochlorite bleach was made by agitating bleaching powder with water in an iron tank; the lime and other impurities were allowed to settle and the clear bleach liquor containing the hypochlorite drawn off and used in bleaching. Today practically all the hypochlorite used is made by absorbing chlorine in lime and allowing the undissolved lime to settle out. Permanganates produce pulp of good brightness, but the results obtained do not justify the higher cost of these chemicals. More recently, chlorites have been proposed and are now being tried on a commercial scale.

There are in general three systems of bleaching chemical pulp: single-stage, two-stage, and multiple-stage processes. The choice of the system depends to some extent on the process by which the pulp was produced, the degree of whiteness desired, and the size of the output of the mill.

*Single-stage bleaching* consists of adding bleaching liquor to pulp stock in a vat where the stock can be agitated until the desired degree of whiteness is attained; the soluble waste products are then washed from the pulp. In the case of the sulfite and soda pulps the chief drawbacks of the single-stage bleaching are the excessive consumption of bleach required to bring the desired results and the deterioration of the fiber that may result if bleaching is prolonged. Sulfate pulp can be bleached only to a light-brown shade by the single-stage procedure.

The excessive consumption of bleach in the single-stage method can be considerably reduced by employing *two-stage bleaching*. When pulp is bleached, some of the oxidation products dissolve long before the desired whiteness is attained; these dissolved products, however, continue to consume bleach. In the two-stage method the oxidation products are removed by an intermediate washing of the pulp, and therefore less bleach is required. Some improvement in the strength of pulp may also result because of the lower concentration of the bleach used. Although in some plants calcium hypochlorite is employed in both stages, a more common

procedure calls for chlorine-hypochlorite bleaching. In this method, in the first stage, chlorine gas is injected into the pulp suspension and is allowed to act until exhausted. The pulp is then neutralized with caustic soda and washed; this treatment removes nearly all residual lignin and most of the color. It is then subjected to the second stage of bleaching, consisting of treatment with a weak solution of calcium hypochlorite. It has been found by experience that up to a certain point more color can be removed per pound of chlorine used if chlorine gas is employed in place of bleaching powder. However, to obtain satisfactory whiteness the pulp must be subjected to a final treatment with the calcium hypochlorite. In the case of sulfate pulp, when whiteness comparable to the bleached sulfite pulp is required, caustic extraction is substituted for neutralization with lime, following the first-stage chlorination. This treatment serves to extract tannin-base dyes which are not affected by chlorination.

The multiple-stage procedure was devised to replace the single-stage technique, using calcium hypochlorite as the active bleaching agent. Multiple-stage bleaching did not bring about any marked improvement in the properties of pulp, but it did result in considerable economy in the consumption of bleaching agent. In this country this process has been largely abandoned in favor of the two-stage method.

The bleaching of groundwood presents considerable difficulty because groundwood contains nearly all the original cell-wall constituents. In the past a considerable tonnage of groundwood was brightened with calcium and sodium bisulfite, sulfur dioxide, and similar reducing agents. The color of mechanical pulp so bleached gradually darkens, due to atmospheric oxidation. More recently a more satisfactory bleach of groundwood has been obtained with sodium peroxide. Bleached groundwood is used chiefly in lightweight paper to increase opacity without appreciably decreasing the tensile strength of the paper.

**4. Lapping.** If the pulp is not used immediately at the mill but prepared for shipment or storage, it is necessary to extract most of the water from the screened stock and make the pulp into sheets which can be placed in bundles, or laps. This further extraction of water is called *lapping*. The machine by means of which pulp is lapped is called the *wet press*. It consists of a cylinder and a vat similar to that used in a decker. The pulp formed on the cylinder is picked up by an endless felt belt and is passed through a series of squeeze rolls. A smooth roll atop the felt collects pulp from the felt. When sufficient pulp thickness is built up upon the roll, the pulp is cut so that it comes off the roll as a rectangular sheet. This sheet is placed on a table in front of the press roll and folded to make a sheet of pulp about 18 by 24 in. The folded sheets of pulp are called *laps*; they contain 55 to 70 per cent water by weight, based on the air-dry weight of the pulp.

If further reduction in the water content of the lap is desired, the wet pulp is piled on a truck and run through a hydraulic press, where it is subjected to a pressure up to 3,000 p.s.i. The pressed lap contains 40 to 50 per cent water by weight. When pulp with less than 40 per cent is desired it is put through a drier, of which there are two types in general use: (1) the cylinder type and (2) the Fourdrinier. These machines are similar to those used in papermaking and are described in the section dealing with paper manufacture.

### G. USE OF OLD PAPER IN PAPERMAKING

Several million tons of old paper (about nine million in 1951) are used annually in the manufacture of pulp and paper in this country. The reasons for the extensive use of old-paper stock are (1) the immense supply available, (2) the low cost of material, (3) the low cost of converting the stock into pulp, and (4) the high quality of the resulting product.

The largest tonnage of old-paper material is remade into board, such as container box and wallboard, also into roofing, wrapping, and bag papers and newsprint. The old-paper stock used for these products consists chiefly of paper containing mechanical pulp such as newsprint, old box boards, also wrapping paper and other grades of paper unsuited for conversion into better grades of paper. The best grades of old paper, free from mechanical pulp, are carefully sorted out and are used in the manufacture of book, printing, and writing paper. The percentage of old stock paper in these papers may range from 10 to 80 per cent of the total pulp content.

In converting old paper into boards and roofing material, the stock is fiberized by beating it with *white water*\* in a breaker-beater system consisting of a large concrete tub containing a revolving roll equipped with bars. In another system old papers are cooked with white water in a rotary boiler for 2 to 3 hours at 30- to 40-lb. steam pressure. Often no attempt is made to remove ink from old papers, since the color of the pulp is of secondary importance in these products.

Old paper stock used in the manufacture of better grades of papers is converted into pulp either by chemical methods or more frequently by a combination of chemical and mechanical methods; only papers made of chemical pulp are used for this purpose. In the chemical method old paper is shredded and cooked with caustic soda or soda ash solutions, in either open or closed stationary tanks. This treatment breaks up the ink, which is then removed by washing. In the systems employing combined chemical and mechanical actions, shredded old-paper stock is also cooked with

\* Wash water returned from other parts of the mill, after most of the fibers are strained out of it.

caustic soda or soda ash solutions but in closed rotary boilers. It is claimed that this method is more economical, removes ink more completely, and produces a more uniform grade of pulp.

## II. PAPER MANUFACTURE

### A. BEATING

Paper manufacture begins with the operation called *beating*. In this operation the fibrous material (pulp) suspended in water is given a mechanical treatment which results in cutting, splitting, and crushing of the fibers. The beaten stock acquires a characteristic slimy feel and is transformed into a compact and uniform mass of pulp which can be spread into sheets of desired characteristics; its ability to retain water when allowed to drain is considerably increased, and the fibers develop a property of strong adhesion when allowed to dry in contact with each other. Some chemists hold the opinion that in addition to purely physical changes, beating also produces a chemical change which results in the formation of a certain amount of "hydrated" cellulose, a gelatinous mass which acts somewhat as a binding material and tends to increase the tensile and bursting strengths of the paper by cementing the crushed fibers together. This latter view has not been substantiated by any experimental evidence. Clarke,<sup>11</sup> in an attempt to reconcile all the known phenomena resulting from "beating" of the stock, has postulated a composite hypothesis which recognizes (1) loosening of the primary wall and "fuzzing" of the underlying cell-wall structures, thus enabling the wood elements to interlock, (2) deformation of the fiber, allowing better fit among the neighboring fibers, and (3) the creation of smaller bodies which can fit in the spaces between the fibers, thereby further increasing contact between them. The actual adhesion of the modified fibrillar structure of the pulp may be regarded as a chemical bond between the molecules of the water and the fiber surfaces which they contact.

**1. The Beater.** Beating is done in a beater, of which there are many types. The most prevalent is the Hollander or its numerous modifications (also called the *breaker beaters*, or *pulpers*, when used for breaking dried sheets of pulp). A typical beater of the Hollander type (Fig. 15-11) consists of a large open tub, 15 to 25 ft. long or more, 6 to 11 ft. wide, and 2½ to 5 ft. deep, built of wood, concrete, or cast iron. A central partition, called the *mid-feather*, extends to within 2 or 3 ft. of each end of the tub; this partition allows a continuous flow of the pulp around the tub in one direction. On one side of the tub, between the partition and the wall of the tub, is a roll mounted on a shaft. Beneath the roll is a metal bedplate;

both are equipped with metal bars or knives. An integral part of the beater is the *backfall*, shaped on one side to conform to the curve of the beater roll and sloping steeply on the other side. As the roll revolves, the pulp passes between the roll and the plate and is thrown over the backfall, forming a head and causing the *stuff* to travel away from the roll, around the tub, and back to the roll again.

The Hollander beater is criticized on a number of points, chief among which are large power consumption per ton of product, poor and uneven

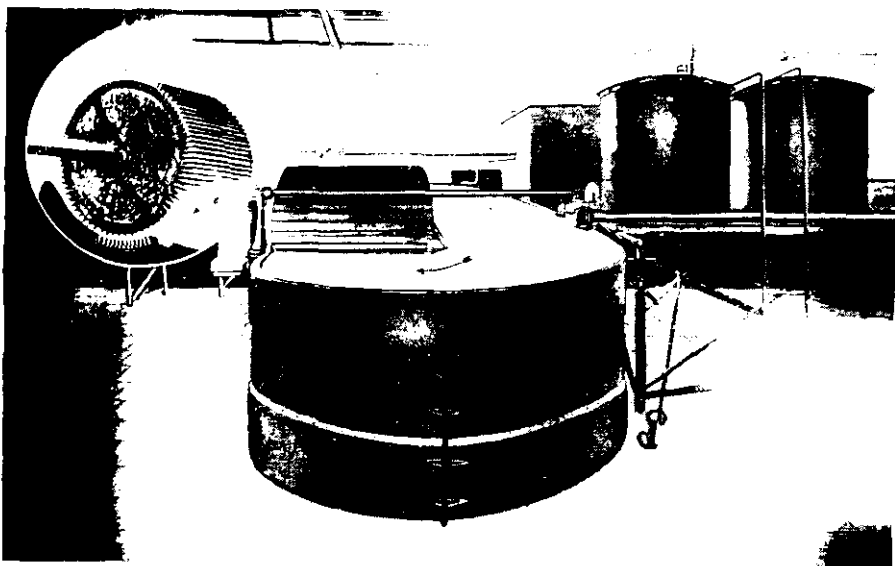


FIG. 15-11. Beater. To reduce the fibers in size so they will form a close, firm sheet, the pulp is mixed with water and beaten for hours between metal bars. Sizing and color are added here. (Courtesy Hammermill Paper Company, Erie, Pennsylvania.)

mixing of stuff, lack of ready control over the beating action, and necessity for large floor space. Attempts to correct these defects have resulted in numerous variations of the Hollander type, as well as in a number of special types of beaters, radically departing in design from that of the breaker beaters. At present, various modifications of the Hollander still constitute the greater number of beaters.

One special type of beater used for beating dried pulp is known as the *kneading pulper*. In this machine, breaking is accomplished by some form of a kneader, adopted from the breadmaking industry. The kneading pulper is sometimes combined with an open tub to provide a soaking period; this model is known as "Tugboat Annie." When combined with a refiner the machine is called "Barnacle Bill" by the manufacturer.

**2. Loading and Sizing.** At this stage of paper manufacture various products are added to the stock in the beater in order to reduce the absorbent qualities of the pulp and to produce a smooth-finished paper surface. Paper made of pure fiber would be so soft and absorbent that it could not be used for writing or printing. An example of such a paper is filter paper. A thin sheet of such paper would also be so transparent that writing or printing could be read from the other side of the sheet. The various materials which are added to pulp stock in the beater are called *fillers* and *sizing*.

*Fillers* are mineral substances, of which the most common are clay, talc, agalite, crown filler, and pearl filler, the last two being proprietary compounds the main constituent of which is calcium sulfate. More expensive fillers include titanium dioxide, zinc sulfide, and similar highly opaque materials. The fine particles of the filler occupy the spaces between the fibers, making the resulting paper smooth and opaque. The addition of a filler to pulp is called *loading*, or *filling*; the latter term is preferred because the former suggests adulteration. Although this was true to some extent in the past, in modern papermaking, fillers are added because they improve the opacity of the paper, prevent "show- and strike-through" and give more "body" to the sheet. Too much filler tends to decrease the strength and to increase the softness of the paper, while too little results in formation of paper with a poor surface and with excessive hardness. If fillers are not properly "anchored" in the paper, they will cause *dusting*.<sup>18, 19</sup>

In addition to filling, most papers are sized, to make them less absorbent to ink and moisture. This is accomplished by adding some water-repellent material which will coat the fibers and fill in the spaces between with a varnish-like substance. An example of paper that has not been sized is blotting paper, which is entirely unsuited for writing. The most common materials used in sizing are rosin and wax. Rosin is first added to a hot soda ash ( $\text{Na}_2\text{CO}_3$ ) solution and the mixture cooked for 4 to 6 hours with constant stirring. This causes the rosin to saponify, the resulting product being a thick fluid called *rosin soap*. The rosin soap is then diluted until an emulsion is formed. This emulsion is introduced into the beater, and a certain amount of *alum* (aluminum sulfate) is added. The chemical reaction which follows produces curdling of the rosin size, which is then deposited on the fibers in the form of very small particles. Of the wax sizes, *paraffin* is the most commonly used; it is introduced into the beater in the form of a water emulsion.

Some types of paper, in place of the internal sizing just described, are given *surface sizing*. The term *surface sizing* includes any treatment given to the *web* after its formation on the wet end of the paper machine;

it is designed to improve the surface characteristics and to reduce the absorptive properties of the paper. A secondary effect of surface sizing is the increase in bursting strength of a paper. The most widely used materials in surface sizing are gelatine glues and starch.

**3. Wet Strength.** One of the most characteristic properties of ordinary paper is loss of strength when a sheet of paper is wetted. Completely wet paper can be disintegrated into pulp by little mechanical action. If wet paper is allowed to dry without being disintegrated, it will regain much of its original strength. The proportion of original strength that a paper retains when completely wet is termed its *wet strength*.

Papers retaining a high per cent of their dry strength when wet are called *wet-strength papers*. A clear distinction should be made between the wet strength and the water repellency of a paper. True wet strength is exemplified by highly absorbent papers which permanently retain much of their dry strength when completely saturated. In contrast, water-repellent sheets may resist initial penetration of water but will retain their strength only for as long a time as is required for moisture to permeate the entire fibrous structure of the sheet. Of course, paper with high wet strength and also good water-repellent characteristics could be produced.

Vegetable parchment is the oldest type of wet-strength paper. Parchments are produced by treating sheets of paper with strong sulfuric acid for a brief period of time. The paper is then washed and the acid neutralized. The resulting sheet is resistant to boiling in water and hot acid and alkali solutions. Other wet-strength processes in use for many years are (1) tub sizing of paper with glue or gelatine, followed by a hardening action with alum or formaldehyde, and (2) the incorporation into a paper of regenerated cellulose made by the viscose method.

The advent of synthetic resins and their introduction into papermaking has resulted in the production of papers with vastly improved wet-strength characteristics. The new processes have to a large extent replaced the older methods and have resulted in the extension of the use of wet-strength papers into a variety of new products.

Of a large number of synthetic resins proposed for use in the manufacture of wet-strength papers, the urea and melamine resins are considered outstanding. As described in U.S. Patent 2,325,302, the mechanism of producing the wet-strength papers consists in introducing

. . . into the cellulose structure resin-forming ingredients either in the unreacted, the unpolymerized, or the partially reacted state, and thereafter the reaction or completion of the reaction between these ingredients is effected to produce the desired result. The materials from which the final resin is formed should enter the cellulose structure in the form of a water solution, and for this condition to be ful-



filled, the materials should be in the form of compounds of relatively low molecular weight. . . . These materials having penetrated the cellulose structure are caused to undergo a condensation or polymerization . . . as a result of the application of heat in the presence of a catalyst, and this reaction results in the formation within the cellulose structure of a water-insoluble resin, the presence of which, particularly in that part of the cellulose structure where two fibers have been dried in contact with each other, has the result of rendering the cellulose bond substantially unaffected by water.

Synthetic resin may be added to pulp either in the beater or in the tub, or the sheets of paper may be impregnated during their passage through

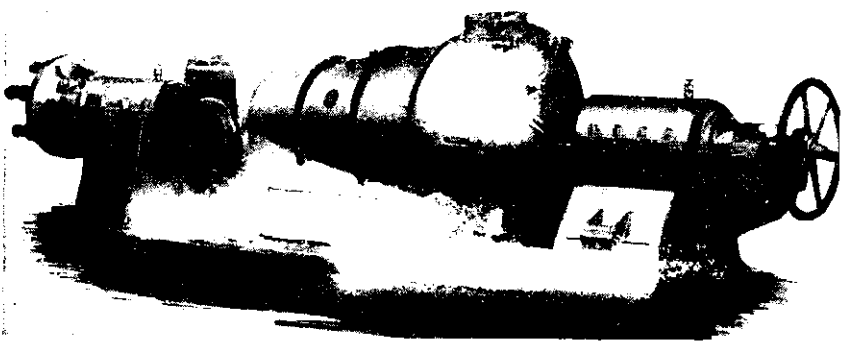


FIG. 15-12. Jordan. (Courtesy Shartle Bros. Machine Co., Middletown, Ohio.)

the paper machine. The resins are added in amounts of less than 5 per cent, since larger quantities do not increase the wet strength any further, and in the case of urea resins, result in appreciable loss in tearing strength and increase in brittleness.

Melamine-treated paper retains its wet strength with age longer than papers treated with urea resins. This is due to the greater resistance of melamine resins to hydrolysis.

**4. Coloring.** Since the natural color of paper produced even from bleached pulp is yellowish, most papers are colored. White paper is produced by adding blue to neutralize the yellow, and other shades are obtained by adding an appropriate dye or pigment to the pulp in the beater or by applying it directly as a coating to paper surfaces.

Pigments include all color materials which are insoluble in water; they are deposited on the surface of the fiber but do not penetrate into the cell wall and are held in the paper by mechanical means with the aid of size and alum. Most of the pigments are mineral colors. Pigments are fast to light but produce a dull surface. The dyes penetrate into the cell-wall

structure of the fiber. Most of the papermaking dyes belong to the aniline group of dyes and are classed as direct dyes, basic dyes, and acid dyes. The direct dyes may be used without the aid of mordants; the basic colors are precipitated from solution by the addition of an alkali; while acid colors require addition of an acid mordant. In general, the direct colors have less tinctorial power, but they are faster to light than either the basic or the acid colors.

Results obtained by coloring are greatly affected by a number of factors, including the type of pulp to be colored, the degree of beating, sizing and

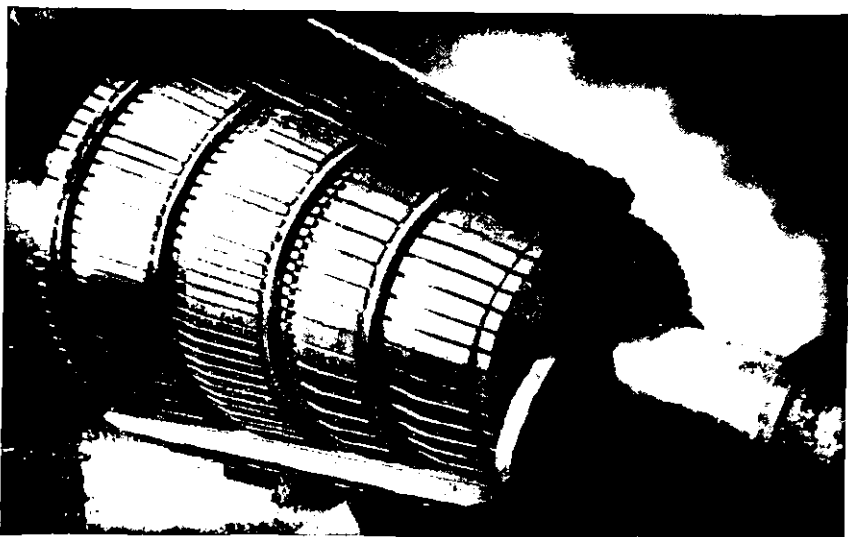


FIG. 15-13. Jordan plug. (Courtesy Shurtle Bros. Machine Co., Middletown, Ohio.)

filling, and the characteristics of the water. Color matching is, therefore, one of the most exacting operations, requiring a thorough understanding of color reactions and considerable ingenuity on the part of the color technician.

**5. Refining.** When pulp has been beaten and all the ingredients that go into the making of paper added, the beater furnish is usually passed to a refining machine called a *Jordan* (Fig. 15-12). This machine consists of a cone-shaped shell bearing bars on the interior surface and a cone-shaped, revolving plug (Fig. 15-13), which fits into the shell and is also equipped with bars. The pulp is fed into the Jordan in the form of a very dilute suspension and, as it passes between the two sets of bars, is given a refining treatment. The stock is then ready for fabrication into paper.

### B. THE FOURDRINIER PAPER MACHINE

The modern papermaking machine (Figs. 15-14 and 15-15), frequently called the Fourdrinier, may be divided into four parts for convenience of description: (1) the Fourdrinier, or wet end, (2) the press section, (3) the drier section, and (4) the calender end.

In the *Fourdrinier end* the prepared pulp stock, consisting of about  $\frac{1}{2}$  to 1 per cent fiber and the rest water, is conducted from a flow box onto an endless fine-mesh wire screen. The moving screen is given a sidewise shaking motion, and as the stock travels along it some water drains through the mesh, leaving on the wire screen a felt of interlocked fibers called the *web*. In order to remove more water from the wet stock, the Fourdrinier end is equipped with suction boxes or rolls, in which a vacuum is created by means of suction pumps. This removes enough water to ensure the paper against being crushed by the press rolls.

When a watermark is desired on the paper, this is usually accomplished in the Fourdrinier part of the paper machine by means of a *dandy roll*. A dandy roll is a skeleton roll 7 to 24 in. in diameter, covered with wire cloth, upon which the design is worked in fine wire or to which brass letters are attached. The dandy roll runs freely on the surface of the wet paper, exerting pressure equal to its own weight. The raised design on the roll makes the wet paper thinner in places where the design comes in contact with it. The outline left on the paper shows clearly when the finished paper is held against the light.

Next the wet sheet of paper is carried on a woolen belt, commonly called *felt*, through the *press section* of the machine. The press consists of a series of rolls through which the paper passes. Before entering the presses the sheet of paper contains about 90 per cent water. The object of the presses is to squeeze out as much water as possible without injury to the wet sheet. As the paper leaves the presses it contains 60 to 70 per cent water.

The wet paper is then carried over the surface of steam-heated, cast-iron cylinders called *driers*. In the course of the passage of the paper over the driers the water content is reduced to from 7 to 10 per cent of moisture based on dry weight. The size and number of driers and their arrangement depend on the speed of the machine and the product manufactured. It is customary to allow one 48-in. drier for every 20 ft. per minute of paper speed for newsprint stock. Better grades of paper require more drying surface.

The remainder of the paper machine is comprised of *calenders*, *slitters*, and *winders*. The calenders consist of a set of very smooth and heavy rolls, between which the paper is passed. The weight and friction of these

rolls imparts to the paper a smooth finish, which varies according to the pressure exerted. As the paper leaves the calenders it is wound on a reel. When one reel is full, the sheet is broken and led to a second empty reel, where winding is continued. The paper from a full reel is then rewound on winders. As it passes from the reel, the original wide sheet of paper is

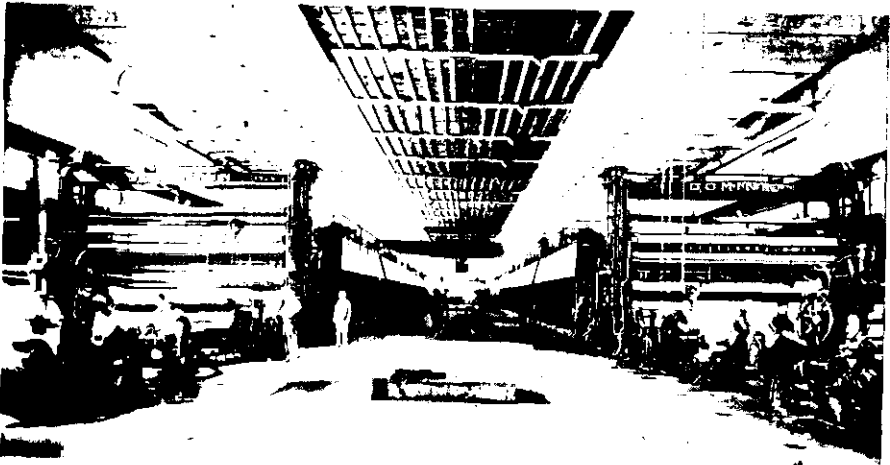


FIG. 15 15. Modern Fourdrinier paper machine. (Courtesy The Newsprint Service Bureau, New York.)

slit into strips of the desired width by means of revolving disks, or slitters. The paper rolls from the winders are then wrapped and ready for shipment.\*

### C. THE CYLINDER PAPER MACHINE

Another standard paper machine is known as the cylinder paper machine. It was invented by John Dickinson of Germantown, Pennsylvania, in 1809. The essential feature of this machine is a perforated, hollow brass cylinder covered with wire mesh. There may be one or several cylinders, depending on the product manufactured. The cylinders are partially submerged in vats which contain diluted paper stock. As they revolve, a thin film of paper stock forms on the wire mesh. The water, draining from the stock through the wire surface, is removed through hollow trun-

\* A modern newsprint paper machine produces a sheet of paper a little more than 300 in. wide at a rate of 1,200 ft. per minute, or about 30,000 sq. ft. of paper a minute. A modern kraft-board machine produces lining board for corrugated cartons at a rate of about 250 sq. ft. a second, or 15,000 sq. ft. a minute and 25 million square feet in 24 hours of operation, an equivalent of about 525 tons of produce a day. At the other end of the scale are the tissue-paper machines, which produce a sheet of paper 72 in. wide at a rate of 100 ft. a minute, or about 2 tons of paper a day.

nions in the axis of the roll. The wet stock is picked off the mesh by the underside of an endless felt which passes over the unimmersed portion of the cylinders. The ability of the felt to pick up the wet pulp is due to the fact that wet stock, when in contact with two surfaces, always sticks to the smoother surface, in this case that of the felt.

If there is more than one cylinder, the felt continues to travel, and passing over the second cylinder picks up another layer of wet pulp, which sticks to the first layer. The number of laminations thus formed is limited only by the number of cylinders used. The first and the last layers formed are called the *liners* and are usually composed of a better grade of paper stock, which may contain coloring matter; the interior layers, or the *fillers*, are usually made of a poorer grade of stock. The paper or board is then passed through a number of pressure rolls and drying cylinders and through a calender, similar to those of the Fourdrinier paper machine.

The one-cylinder machine is exceptionally well adapted to the making of tissue papers and the multicylinder machines to the manufacture of laminated products such as boards and bristols.

#### D. SPECIAL PAPER MACHINES

There are two other papermaking machines used for special purposes. They are the *Harper Fourdrinier* and the *Yankee* machine. The Harper Fourdrinier is used for making lightweight papers, especially tissue, crepe, and cigarette papers. It differs from the standard Fourdrinier machine in that the Fourdrinier, or wet, end of the machine is reversed end for end, so that the flow box is between the Fourdrinier and the press rolls. This arrangement allows a longer run of felts carrying wet paper before the latter enters the presses.

The Yankee machine is designed for making machine-glazed papers, with a glossy finish on one side only. This machine has a wet end of either the cylinder or the Fourdrinier type. It differs from the standard machines in the method of drying. The Yankee machine employs only one large drier, 9 to 15 ft. in diameter, with a highly polished surface. Pressing of the wet paper by means of rolls against the surface of the drier imparts a fine-glazed surface to one side of the paper.

#### E. CLASSIFICATION OF PAPER PRODUCTS

There are many different types of paper and board, but for statistical purposes these are usually combined in several general groups.\*

\* For complete classification and definitions of paper and paper products, see: The Dictionary of Paper. American Paper and Pulp Association. New York. 1940.

**1. Papers.** *Absorbent papers* is a term applied to papers with a high absorbent quality, such as blotting and filter papers and paper toweling. These papers are spongy, loosely fitted, and unsized. Higher grades of absorbent papers are made of soft rags; the lower grades contain mostly wood fiber.

*Book paper* is coated or uncoated printing paper for books, magazines, catalogues, etc. This grade of paper is made of a mixture of bleached sulfite and bleached soda pulp, used in various proportions.

*Building papers* is a general term applied to thick paper made of old stock consisting of rags, wool, old papers, etc., sometimes mixed with asbestos. Building papers include *sheathing papers* used in house construction and *felt papers* used either as such for heat insulation or saturated with tar or asphalt as a roofing material.

*Hanging or wallpaper* is used for papering walls and ceilings. It is made in the same way as newsprint but in heavier sheets. Most grades consist of 75 to 89 per cent groundwood and the remainder unbleached sulfite.

*Newsprint* is a class of paper developed for newspapers and other print purposes where permanency is not required. It is made of 80 to 90 per cent groundwood and 10 to 20 per cent unbleached sulfite.

*Tissue* is a general term used to indicate a class of papers made in weights lighter than 15 lb. per ream, containing 480 sheets, measuring 24 by 36 in.; it includes such papers as carbon (rag and bleached chemical pulp), cigarette (flax), and toilet papers (groundwood and chemical pulp).

*Wrapping papers* is a term applied to strong papers used for wrapping, paper bags, liners, etc. Depending on the grade, they are made of groundwood, semichemical, sulfite, or sulfate pulp, also jute, old rags, and waste-paper. *Kraft paper* is a wrapping paper made wholly or principally of sulfate, or kraft, pulp.

*Writing paper* is a class of papers with a good writing surface; includes bonds, ledgers, envelopes, drawing, and similar types of paper. Depending on the grade, it varies from all rag, or combination of rag, bleached sulfate, and kraft, in the best grades, to sulfite and soda or old paper in the poorer.

**2. Boards.** *Box board* is made largely of old paper and used for the manufacture of paper boxes.

*Bristol board* is paperboard used for drawing purposes, index and playing cards, etc. It is made of a mixture of sulfite and soda pulp, or in the higher grades, of 100 per cent rag.

*Felt* is a group of thick, soft boards possessing high absorbent qualities, made of rags and old paper. Used for insulation, especially in refrigerators and refrigerating cars.

*Fiber building boards* is a term applied to a group of building materials which includes (1) *wallboards* and (2) *insulating boards*. Wallboards are

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used in place of lath and plaster for wall, ceiling, and partition finish in the interior of houses. The primary characteristics of building boards are rigidity, nonwarping with changes in atmospheric moisture, light weight, and good finishing surface, but they may also have high insulating value. Insulating boards are made largely for heat and sound insulation of buildings; however, they may also have a surface suitable for interior finish.

The composition of building boards varies with the type of board but may include groundwood, unbleached sulfite, old-paper stock, lumber residue, straw, cornstalks, bagasse, and other materials. One type of wallboard is made by laminating several plies of heavy paper, using sodium silicate as an adhesive, and waterproofing the outside layers. In addition to wallboard, the trade recognizes *plasterboard*, which is unsized wallboard covered with regular wall plaster, and *gypsum board*, made by rolling plaster of paris between sheets of heavy wrapping paper.

### III. PULP AND PAPER INDUSTRY

The location of a pulp and paper plant is determined mainly by four considerations: availability of raw material, power, water, and the proximity to markets for the finished products. The ideal location would be where all of these factors are favorable. Since this is seldom possible, the tendency is to locate the plant close to the source of the raw material, because it is more profitable to ship a smaller bulk of finished products than to bring in a much larger bulk of raw materials over long distances. This situation exists in Canada, in the South, and to a lesser degree in the Far West. In all these regions, though pulp and paper plants are located close to the vast wood resources, they are far removed from the main consumers of their finished products. On the other hand, there are numerous paper mills in this country, especially in the Central states, that are located far from any source of raw material. The original locations of these plants may have been determined years ago by availability of labor and power, proximity of markets, or personal preferences of the owners. It is important to remember that because of high investment in fixed assets,\* pulp and paper plants cannot be dismantled and moved to another location. This explains why in the older regions, particularly in New England, there are numerous plants originally built close to the local sources of raw material but now operating almost exclusively on pulpwood or pulp imported from other regions of the United States or from abroad.

The selection of a site for a pulp and paper mill is governed to a large extent by consideration of the accessibility to means of transportation

\* A self-containing pulp mill requires an initial investment of more than \$50,000 per ton of daily output, exclusive of forest lands.

and the availability of an adequate water supply of good quality; the latter consideration is particularly important because of the large volume of pure water required in pulp and paper manufacture. The quantity of water used varies with the kind of pulp and paper made, ranging from 20,000 gal. per ton of groundwood to 150,000 gal. per ton of bleached sulfite, and from 15,000 gal. per ton of book paper, where white water is efficiently reused, to as high as 200,000 gal. per ton of paper in mills using large quantities of rags. The average paper mill requires 30,000 to 50,000 gal. of water per ton of finished paper. In the case of the sulfite pulp mills, an added reason for locating plants near a body of water was the universal practice of water disposal of the vast quantities of sulfite waste liquor. With passage of antipollution regulations in many sections of the country, this practice is, however, being gradually discontinued.

#### A. REGIONAL DISTRIBUTION OF PULP AND PAPER INDUSTRIES IN THE UNITED STATES

Pulp and paper industries in the United States are concentrated in four regions: (1) the Northeastern, including New England, New York, Pennsylvania, and New Jersey; (2) the Lake states and Central region; (3) the Southern; (4) the Pacific Coast (Fig. 15-16). These regions vary greatly as to the species of wood used, the supply of pulpwood available, the principal types of pulp manufactured, and the problems of conversion and distribution of pulp and pulp products.

**1. Northeastern Region.** Pulp and paper production in this region is concentrated mainly in New York, Maine, Pennsylvania, Vermont, New Hampshire, and Massachusetts. This region is characterized by large consumption of all grades of paper and other pulp products, due to the concentration of population and large number of printing industries. Even though the original concentration of pulp and paper mills in this region was logical, owing to the considerable areas of original spruce-fir forests, abundance of cheap power, low transportation costs, and nearness of markets, today the situation in regard to local supply of pulpwood is becoming progressively more acute. In the past decade the available supply of pulpwood in the region has shown a steady downward trend, while the demand of industries for pulp is still increasing. The regional deficiency in pulp is being met by importation of large quantities of pulpwood, various types of pulp, newsprint, and other finished pulp products from Canada and the Scandinavian countries, as well as by substantial shipments of sulfite pulp from the Pacific Coast. In recent years the total pulp converted into paper and board within the region was divided as follows: 38 per cent from wood originating in the region, 15 per cent im-

ported wood, and 47 per cent the pulpwood equivalent of pulp brought into the region.

Although the pulp and paper industries of the Northeast will probably never become self-sufficient again, the situation in regard to foreign imports may be somewhat relieved in the future by adoption of a stable policy for management of spruce-fir forests in the region for future pulp

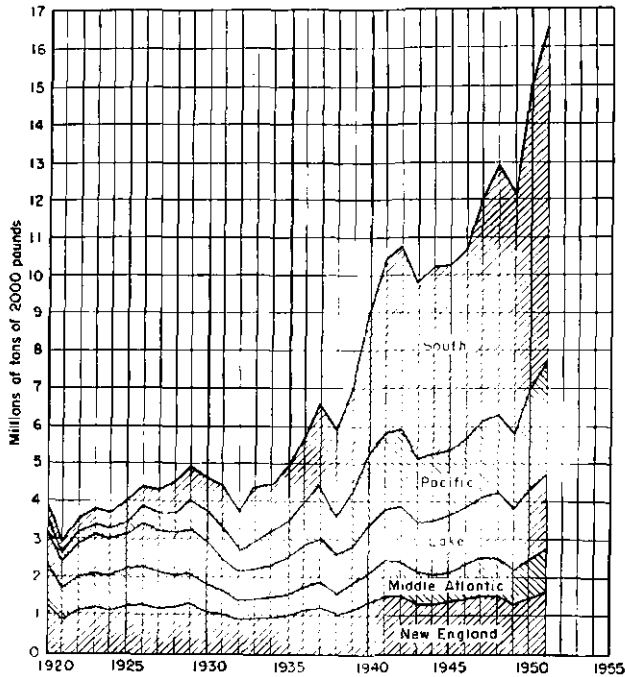


FIG. 15-16. Regional wood-pulp production, 1920 to 1946. (Courtesy United States Pulp Producers Association.)

production, more extensive utilization of hardwoods, and increased shipments of domestic pulp from the Pacific Coast and the South.

The principal pulpwood species in the Northeastern region are eastern spruce and balsam fir, although hardwoods are also being used in increasing amounts. Groundwood pulp constitutes the largest tonnage of the output of this region, with sulfite pulp making up the bulk of the remainder. The greatest part of the pulp produced within this region is converted into paper and board in paper mills integrated with the pulp mills.

**2. The Lake States and Central Region.** Practically all the wood-pulp production of this region is concentrated in Wisconsin, Michigan, and Minnesota, although paper and board are made in all states of the region

from Ohio to Iowa and Kansas. This region shows characteristics similar to those of the Northeastern region in that it exhibits a steady downward trend in the production of domestic pulp, while consuming quantities of pulp in its paper and board industries far in excess of that produced locally. The deficiencies in pulpwood and pulp are supplied by importations from Canada and Europe, and to a much smaller extent by shipments of sulfite pulp from the Pacific Coast. In recent years the pulp consumed in the paper and board production of the region originated as follows: 37 per cent from wood of regional growth, 8 per cent imported wood, and 55 per cent the pulpwood equivalent of pulp brought into the region.

The principal pulpwood species of this region are aspen,\* spruces, balsam fir, hemlock, cottonwood, and jack pine. The most important type of pulp produced locally is sulfite pulp, followed by groundwood and sulfate pulp. The bulk of the pulp produced within this region is converted into paper products at paper mills integrated with the pulp mills.

**3. The Southern Region.** This region comprises the area south of the Ohio and Potomac Rivers and includes also Louisiana, Arkansas, and Texas. The pulp and paper industry of the South is based largely on utilization of second-growth pine stands and to some extent on worked-out naval-stores timber. Considerable quantities of hardwoods are also available for pulp. All pulpwood used in this region is of local origin.

Due to the resinous nature of southern pines, until very recently pulp produced in the South was almost entirely of the sulfate type.† This pulp, known also as kraft pulp, is used in the manufacture of strong brown wrapping and container papers and for paperboards. Very little Southern pulp has so far been shipped from this region, the bulk being converted into paper or board at integrated paper mills. However, when kraft mills now under construction are completed, it is expected that this region will be able to supply much of the demand for kraft pulp in the Northeastern and Lake states and Central regions.

More recently it has been shown that good groundwood and high-grade sulfite pulps can be obtained from young southern pines, if these are protected from injuries and cut before heartwood formation begins. Such pines, according to the late Dr. Herty of the Pulp and Paper Laboratory at Savannah, Georgia, do not contain any more pitch than northern spruce. With the construction of a newsprint mill in Texas,‡ it appears

\* In 1946 aspen accounted for about one-third of the total regional pulpwood production and for the first time on record became the principal pulpwood species of the region.

† The South produces about 80 per cent of the United States requirements for sulfate pulp.

‡ In 1940 two new pulp mills began operation, one producing newsprint and the other purified sulfite pulp for rayon, both using southern pine. In addition, a number of mills produce white paper by mixing hardwood and bleached sulfate pulps.

that production of newsprint from southern pines may become a commercial reality. To eliminate, as far as possible, "pitch" trouble in manufacture of newsprint from southern yellow pine, the U.S. Forest Products Laboratory advocates use of semibleached sulfate pulp in place of sulfite pulp. Under this procedure light-colored wood of low resin content will be necessary only for the groundwood component of newsprint. It is quite likely that with the higher prices currently prevailing for Canadian newsprint and with further improvements in bleaching sulfate pulp, the production of newsprint in the South will be greatly extended. It is also predicted that soon Southern mills will be able to produce highly purified sulfite pulp suitable for rayon manufacture.\* Today the Southern rayon industries consume more than 150,000 tons of high-grade sulfite pulp, purchased outside the South.

Most of the mills in the South are located in the coastal plain from North Carolina to Texas, though progressively more pulp mills are being constructed farther inland. It is expected that these mills will provide employment to about 50,000 men in the mills and in the woods. A great majority of these mills use southern yellow pine as their chief source of pulpwood; one located in Mississippi uses largely cottonwood and willow; a few located in North Carolina and Tennessee at the present time operate mainly on chestnut.

Some of the advantages of the South as an increasingly important center of the pulp and paper industries in this country may be briefly summarized as follows: the South has an abundant supply of relatively cheap pulpwood, which is produced by rapidly growing species, the future supply of which could be assured. This provides the basis for stability, a factor of great importance in the pulp and paper industries, in which capital investments in building and machinery make it prohibitive for the industries to change locations. To this may be added lower construction and operation costs, due to ample supply of cheap labor,† tax exemptions, easy logging, and more favorable climatic conditions, which result in lower carrying charges compared to the Northeastern and Lake states regions. Finally, the multiple-use forestry idea, which looks to a closer coordination between logging for lumber and wood products, including pulpwood, and the naval-stores industries, promises important advantages for the pulp and paper industries of the South.

There is, however, a distinct danger in a too rapid expansion of the pulp and paper industries of the South without careful consideration of the

\* In 1940 two new pulp mills began operation, one producing newsprint and the other purified sulfite pulp for rayon, both using southern pine. In addition, a number of mills produce white paper by mixing hardwood and bleached sulfate pulps.

† There is, however, a tendency to eliminate by legislative acts the wage differential which favors the South.

available pulpwood supply. It is estimated that when in full operation, Southern pulp mills will require six to seven million standard cords of rough wood annually. Although the South, as a whole, can easily meet this requirement, many new mills, as pointed out, are concentrated in a narrow coastal strip 125 to 150 miles wide, where competition for raw materials with established lumber, wood-using, and naval-stores industries is very keen.\*

The pulp mills, which use largely southern pines, own or have cutting rights on approximately five million acres of timberland and are still rapidly increasing their holdings. The company-owned and -controlled lands could supply about one-third of the yearly demand for pine pulpwood. However, the general policy of the pulp and paper companies now operating in the South has been to reserve their own timber and to buy pulpwood in the open market. Most of the pulpwood is now purchased under the contractor system.† Under this system the wood-producing territory from which a mill procures its pulpwood is divided into districts, each of which is assigned to a contractor, generally known as a pulpwood dealer. The mill will buy wood only through its dealer, who is paid an agreed sum per unit or per cord for all wood f.o.b. shipping point. The dealer obtains his wood from producers. A producer may be a farmer cutting his own timber or squads of men cutting on contract from timber owners.

Realizing the danger of further overcutting, the American Pulpwood Association, with the full cooperation of state and Federal forestry agencies, has launched a program pointing toward adoption of sustained yield as a basis for handling of all the pulpwood lands of the South.‡ It is felt that in most regions of the South it is still quite feasible to restock the timberlands and to increase the rate of growth to a point where they will take care of the needs of the existing wood-using industries on a permanent basis. To accomplish this it is necessary (1) to place the Southern forests under intensive management, pointing toward integrated use as an ultimate object, and to restrict pulpwood procurements, whenever feasible, to

\* The forest survey conducted by the Southern Forest Experiment Station indicates that in the naval-stores region, considering both sawmill and pulpwood sizes of southern yellow pine, the drain is 141 per cent, while in the shortleaf-loblolly pine region it is only 84 per cent of the increment.

† Canterbury, N. D. Developments in the Pulpwood Situation in the South. *Jour. Forestry*, 36(6):555-559. 1938.

‡ Interest in conservation of pulpwood in the South is also fostered by the Southern Pulpwood Conservation Association, organized in 1939. The members of this Association represent about three-quarters of the Southern pulp production.

improvement cuttings; (2) to assure an adequate return to the landowners by dealing, whenever possible, directly with the owners, to the exclusion of middlemen.

**4. Pacific Region.** Practically all pulpwood used in this region is of domestic origin. The principal pulpwood species used are western hemlock, western firs, Douglas fir, and Sitka spruce. The present forest growth is estimated at 3,070,000 cords a year, while potential forest growth under intensive forest management with 75 per cent of normal stocking of all forest lands has been estimated by the Northwest Forest Experiment Station at 9,907,000 cords a year, of which one-half should be available for pulpwood.

Of the total quantity of pulp produced in this region, approximately 70 to 75 per cent is manufactured in the state of Washington and the remainder in Oregon. The principal type of pulp produced in the Pacific region is sulfite pulp, followed in importance by groundwood and sulfate types.

Although most of the pulp produced on the West Coast is consumed by the paper and board mills of Washington, Oregon, and California, the Pacific Coast is the only region at the present time which manufactures considerable quantities of pulp, principally sulfite, in excess of the needs of the local paper industries. Some sulfite pulp mills of this region produce pulp largely for sale in other sections of the country, as well as for export. Large quantities of bleached sulfite pulp are shipped from this region by water and rail to rayon-manufacturing regions of the Eastern, Central, and Southern United States.

The present trend on the West Coast is toward expansion of the sulfite-pulp mill capacity, with emphasis on bleached pulp to supply outside market demand. Most of this expansion is taking place in the Puget Sound and Grays Harbor-Olympic Peninsula areas. This expansion will probably continue as long as the demand for bleached sulfite continues to increase in the rayon plants and paper-converting mills of the East. Expansion in kraft and newsprint capacity, on the other hand, depends almost entirely upon increased demand of local consumers in the Western markets, owing to the advantages held by Southern kraft and imported newsprint in ease of reaching the Central and Atlantic Coast markets.

In California more than 90 per cent of the total output of paper mills is paperboard and building papers, the balance being largely fruit wraps and tissue paper. The production of Washington and Oregon mills is, on the other hand, greatly diversified. More than 50 per cent of the paper and

board capacity of Washington, Oregon, California, and British Columbia is owned or controlled by the Crown Zellerbach Corporation.

The outlet for Pacific Coast paper is principally in three Pacific Coast and eight Mountain states, which offer a market for about 1,000,000 to 1,200,000 short tons of all kinds of paper and paperboard yearly.

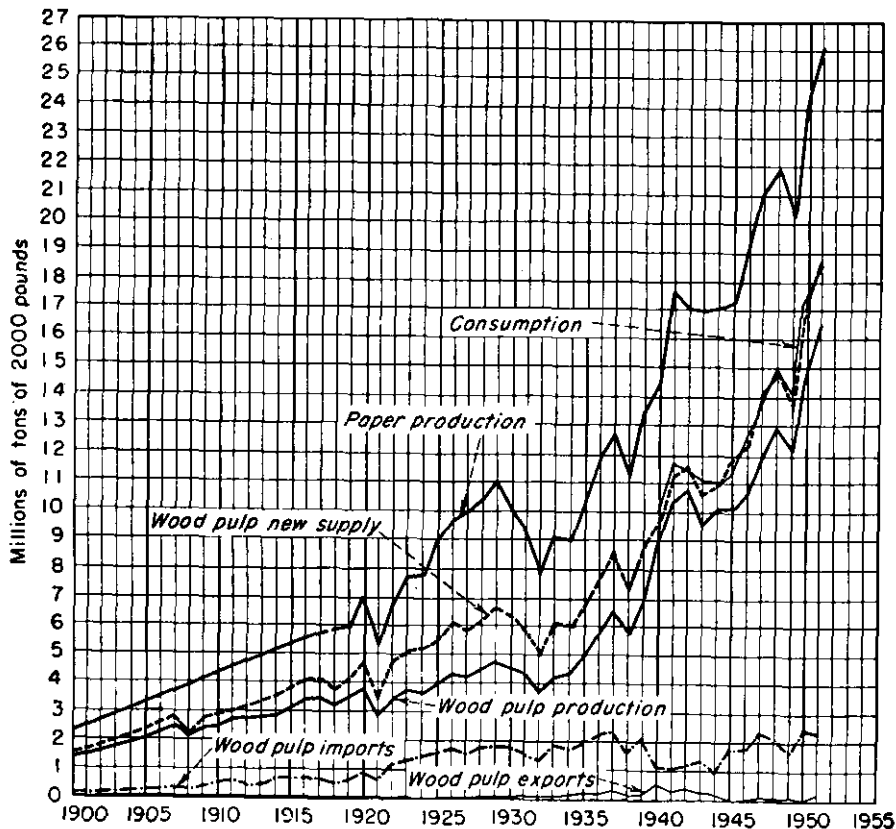


FIG. 15-17. United States production of wood pulp and paper and new supply, consumption, imports, and exports of wood pulp. (Courtesy United States Pulp Producers Association.)

**5. Canada.** Canada is second only to the United States in the quantity of wood pulp produced; \* it leads the world in the production of newsprint and exports more newsprint than all other countries combined. The Canadian wood-pulp industry is of special importance to the United States because Canada is the chief supplier of this country's imports of news-

\* In 1951 Canada produced 15 million cords of pulpwood, of which 2.8 million cords were exported, and more than 9 million tons of pulp, of which 2.3 million tons were exported. About 57 per cent of the total pulp production was groundwood.



print, as well as one of the leading sources of imported pulp. Taking the combined output of wood pulp and newsprint, the United States absorbs 70 to 75 per cent of the total Canadian production. Furthermore, a considerable portion of Canadian pulp and paper capacity is either owned or controlled by United States interests.

The principal pulpwood species in Canada are spruce and balsam, which comprise the bulk of the estimated 100 billion cubic feet of potential pulpwood in that country. The principal types of pulp produced in Canada are groundwood and unbleached sulfite; considerable quantities of bleached sulfite, bleached and unbleached sulfate, and soda are also produced.

The Canadian pulp and paper industry is characterized by large and modern plant facilities. An important recent trend in the Canadian pulp and paper industry is the rapid increase in domestic conversion of pulp into manufactured products; this is particularly true of newsprint manufacture. As a result of restrictive legislation, exports of pulpwood from Canada to the United States have been steadily decreasing.

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## CHAPTER 16

### THERMAL- AND SOUND-INSULATION MATERIALS

The use of various materials for thermal insulation is not new by any means, for man has tried, since time immemorial, to protect himself and his perishable goods from excessive heat or cold. Sound control, also, has long been recognized as a problem in dealing with the acoustics of buildings, particularly theaters and auditoriums. Recent emphasis on sound control is the result of attempts to escape the clatter and din associated with modern living conditions and of the necessity for sound control in radio broadcasting as well as in the production and showing of sound films. Some materials can be used successfully for thermal insulation and sound control, some may serve one purpose better than the other, and some may be suitable for only one type of use. Manufacturers are striving to increase the effectiveness of their products by modifying them for application to thermal insulation or sound-control problems, as the case may be.

#### I. THERMAL-INSULATION MATERIALS AND METHODS

The primary purpose of thermal-insulating materials in house construction, for example, is to retard heat transfer, either from within a building to the outside or from the outside to within a building. Use of thermal-insulating materials reduces fuel consumption, lessens the load on heating systems, and promotes greater comfort for the occupants of a building, not only in winter, but also in summer.

##### A. GENERAL TYPES OF INSULATION

The hundreds of insulating materials on the market may be divided arbitrarily into five principal classes: rigid boards, flexible insulation, fill insulation, reflective insulation, and miscellaneous types. With the exception of reflective insulation, virtually all other classes derive their insulating values from the numerous minute dead-air pockets they contain.

**1. Rigid Boards.** Rigid boards are usually made from plant fibers. Bagasse, cornstalks, wheat straw, wood fiber (including bark in some instances), screenings from paper pulp mills, and old paper are among the materials used in rigid boards. These boards may be more or less homo-

geneous, or they may be laminated. Boards 1 in. or less in thickness are usually homogeneous, but nonlaminated boards of greater thickness are sometimes available. Rigid boards are usually made in widths of 4 ft. and lengths of 6 to 12 ft. Some rigid boards are suitable only for retarding heat transfer, but many are considered to be structural material.

Structural fiber insulating board is divided into five classes: (1) building board, (2) lath (for plaster base), (3) roof insulation board, (4) interior boards (factory finished), and (5) sheathing. Such boards must meet requirements for maximum thermal conductivity, maximum transverse load at rupture, minimum deflection at rupture, maximum tensile strength, maximum deflection at minimum specified transverse strength, maximum water absorption, and maximum linear hygroexpansion.<sup>21</sup>

Nonstructural, homogeneous fiber wallboard requirements include tensile strength, water absorption, bending strength, deflection, and linear hygroexpansion limitations, but no specific requirement for thermal conductivity.<sup>23</sup>

**2. Flexible Insulation.** Flexible insulation is manufactured in two general forms: (1) blankets or quilts and (2) batts. Blanket or quilt insulation consists of loosely felted mats of wood fiber, hair, grass, kapok, cotton, or mineral wool, covered on one or both sides with paper or fabric. It is often made in widths that fit spaces between wall studs and in thicknesses of  $\frac{1}{2}$  to 3 in.; such insulation is usually sold in rolls. Batts, composed of similar materials, are made in widths that will permit insertion between framing members in a building. They are sold in four-foot lengths, most commonly in thicknesses of 2 or  $3\frac{5}{8}$  in., and with or without a covering envelope.

**3. Fill Insulation.** As the name implies, fill insulation includes material in bulk form for filling spaces in wall, floor, ceiling, and roof constructions. Such insulation can be poured or blown into place, or it may be packed into the desired spaces by hand. Products that have been used as fill insulation include granulated cork, shredded vegetable fiber, chemically treated shredded paper, charcoal, bark, sawdust, shavings, hulls of various kinds, vermiculite, mineral wool, diatomaceous earth, and many other materials.

**4. Reflective Insulation.** Reflective insulation consists of materials that have high heat-reflecting properties and low abilities to radiate heat energy. Among the materials having these characteristics are aluminum foil, aluminum-foil-surfaced plasterboard, treated sheet steel, and flexible insulation encased in paper having reflective materials on one or both exposed surfaces. To be effective, the reflective material must be exposed to at least a  $\frac{3}{4}$ -in. air space and preferably a wider one.

**5. Miscellaneous Insulating Materials.** Many types of insulation do not fall into the foregoing groups. Insulating plaster materials, cork and

mineral wool blocks for cold-storage installations, lightweight aggregates that are used in cement and concrete blocks, and fibrous material mixed with an adhesive so that it will adhere to a surface to be insulated when blown against that surface are some examples of materials in this miscellaneous group.

#### B. MANUFACTURE OF WOOD-FIBER INSULATION MATERIALS

Most of the wood-fiber insulating materials on the market at the present time are in the form of boards. The manufacture of fiberboards and flexible insulation rather closely parallels the manufacture of paper. It naturally follows that the species used in paper manufacture are also used in the manufacture of insulation materials. Southern pine, Douglas fir, cottonwood, red gum, spruce, northern white pine, and hemlock are among the woods used for thermal-insulating materials. Improved methods of pulping and refining are extending the list of species to include little-used or heretofore unused southern hardwoods. Chestnut fiber from the spent chips resulting from tannin extraction and southern pine fiber from the spent chips remaining after the extraction of naval stores have been used for the manufacture of insulating boards when sufficient quantities were available.

**1. Pulping Methods.** Virtually every known method of reducing wood to fiber has been used at some time for pulping wood for insulation manufacture, and new methods are constantly being developed. The present trends are toward semichemical pulping and mechanical methods that require a minimum of pretreatment for separation and refining of wood fibers.

*a. Separation of Wood Fibers by Explosion.* In this process no chemicals are employed; the separation of wood fibers depends on the explosive force of steam. This process was developed on a commercial scale by W. H. Mason for the manufacture of fiberboards. Round wood, sawmill edgings, or other mill residue may be used. The wood is reduced to chips, and these are screened to sizes ranging from  $\frac{3}{8}$  to 1 in. in length.

Screened chips are placed in the explosion chamber, or "gun," originally a cylinder about 20 in. in diameter and 5 ft. high with a capacity of about 10 cu. ft. Larger guns are now reported to be in use. The gun is tightly closed, and steam at 350 p.s.i. is introduced. The temperature is raised to about 375°F. and maintained for 30 to 40 seconds. High-pressure steam at 1,000 to 1,200 p.s.i. is then admitted for 5 seconds to raise the temperature to about 540°F.

A quick-acting hydraulic exhaust valve at the bottom of the gun is then opened, and the chips are discharged into the exhaust port and piping at atmospheric pressure; the chips explode immediately because of the high internal pressure. During the exploding operation, full boiler pressure is

kept on the gun to force all the wood through the exhaust port and piping to a cyclone separator where the steam escapes to the atmosphere, and the exploded fibrous mass, consisting of individual and unbroken fibrous bundles, drops into water that is maintained at a temperature of about 160°F. The material is screened, and particles that do not pass through the screen are refined. To the screened pulp, petrolatum or paraffin is next added, and the material is ready for felting into boards on machines similar to the Fourdrinier used in papermaking.

*b. Groundwood Method.* This method uses the same type of pocket grinders as are used in making groundwood paper pulp.

*c. Disk-pulping Methods.* Two disk-pulping principles are employed in reducing wood to fiber. In one method, two motors are mounted on a single base with the rotor shafts aligned. One end of each rotor shaft is equipped with a disk to which segments of corrugated grinding plates are attached; the opposed disks are rotated in opposite directions by their separate motors. Steamed or chemically treated chips are fed into the gap between the two rotating disks that reduce the wood to fibers. The gap between the disks and the corrugations of the grinding plates are varied to produce different grades of pulp. Other disk-pulping processes use one stationary plate and one rotating disk. In each method, the resultant pulpy mass is discharged directly into a stock pit.

*d. Refining of Excelsior-like Material.* This method first reduces the wood to an excelsior-like product by scoring the wood with saws. Wood is placed in a reciprocating frame that rests on a table through which the saws protrude to a given height. This rough fiber is carried away from the table by a blower system to a hammer mill. After passing through the hammer mill, the fibers are put through a refiner similar to the Jordan machine used in refining paper pulp.

**2. Fabrication of Insulating Materials.** Several methods of fabricating insulating materials are interesting enough to merit description.

*a. Board Formation.* Boards may be made of homogeneous or laminated construction. Some of the so-called "homogeneous" boards may be considered semilaminated, especially those of unusual thickness. Early fiberboards were made by cementing several layers of paperboard or pulp together with sodium silicate, asphaltum, tar, gypsum, or other materials. Homogeneous boards may be considered to be structures consisting of interlacing fibers. Most wood-fiber insulating boards are of the homogeneous type.

Homogeneous boards are formed on a cylinder machine, on a Fourdrinier screen, or in a mold. The first two methods permit a continuous flow of material and consequently are the most used. They are adaptations of similar machines used in the manufacture of paper. The cylinder machine consists of a drum covered with wire screen. The drum rotates in a vat

and, by the action of a vacuum drawn through the hollow shaft (trunnion) supporting the drum, picks up a thick layer of pulp that has been furnished with alum, sizing, or other materials. This pulp layer is subjected to pressure by press rolls and a felt belt before it is taken off the drum in a continuous sheet to go through a press that squeezes out some of the water before the sheet goes through the drier. The press also equalizes the thickness of the sheet.

One type of press consists of a series of rolls that gradually increase in size, the smallest first coming in contact with the newly formed sheet. These rolls exert increasing pressure on the sheet as it goes through the press. Another type of press uses the caterpillar-tread principle. The sheet passes between two steel plates that gradually converge from the entering end, and then run parallel for a distance to form the thickness of the board.

After the pressing process has taken place, the sheet is cut into the desired lengths and these are dried, usually in a drier similar to that used in veneer manufacture. The dried boards are then cut to exact lengths and widths, and, depending on the use for which they are intended, they may be beveled on the edges, tongued and grooved, shiplapped, given decorative effects, sanded, or made into tiles.

The Fourdrinier screen, in insulating-board manufacture, operates on the same principle as in paper manufacture except that it is designed to make a much thicker sheet. Semilaminated boards have been made by using two Fourdrinier wires, one above the other, each forming a sheet. The two sheets are then brought into contact with each other before the pressing operation.

Board formation from exploded wood deserves special mention. The wood fibers, after treatment with petrolatum or paraffin,\* are ready for formation into boards. Fourdrinier machines used for this purpose are so designed that they make a wet sheet  $\frac{3}{4}$  in. thick. These wet sheets may be sprayed with dyes, and they are cut by an automatic cutoff knife into lengths of  $12\frac{1}{2}$  ft. while the Fourdrinier wire is in motion. The sheets pass on to movable racks that, when full, are taken to hydraulic hot presses. The amount of pressure applied and the platen surfaces determine the nature of the board produced.\*

\* If the pressure is 200 to 400 p.s.i. and the platens have a highly polished chrome surface, the resulting boards are  $\frac{1}{8}$  to  $\frac{5}{16}$  in. thick, hard and dense, with one surface smooth and the other showing mesh marks. Materials other than petrolatum and paraffin may be incorporated to produce boards with special properties. This type of hard board is not used for insulating purposes, but it finds wide application in concrete forms, automobiles, house trailers, speedboats, and building construction. Many hard boards are now being produced by other methods, by binding the fibrous materials with resins.

The lightest and most porous boards are about  $\frac{1}{2}$  in. thick and are used for thermal insulation and sound control. Complete drying of these boards takes place in the presses, but the boards are subsequently humidified to bring them to the proper moisture content for their intended purposes.

*b. Flexible and Fill Materials.* While most wood-fiber insulating materials are made in the form of boards, there are a few others that deserve consideration. First is a flexible material that consists of northern white pine fibers in the form of a loosely aggregated mat covered on both sides with paper or covered with fabric on one side and paper on the other. Saw-mill refuse is chipped, and the chips are cooked in a solution of sodium sulfite for six hours at 100 p.s.i. steam pressure. After digestion, the cooked chips are washed and reduced to fibers in attrition mills. The fibers are refined, dried, and then blown as a fluffy, woolly product onto a moving apron where sprays coat the fibers with a sizing solution and an adhesive. The thickness of the resulting mat is controlled by regulating the speed of the screen on which the fibers are deposited. The mat is dried and encased in paper or fabric. These mats may be encased with smooth paper, but heavy thicknesses are made flexible by using fabric or crepe paper.

Of the fill insulations, shredded redwood bark is notable. The bark is shredded into a fibrous mass that is sold in bales. Redwood produces a very thick fibrous bark that lends itself well to this treatment. It is not so easy to apply to existing walls as some competing materials that can be blown into openings, but it is excellent when it can be applied during the process of construction.

**3. Production of Insulating Materials and Wallboard.** The first insulating board was produced on a commercial scale in 1912, and since that time, many other types of fiberboard have made their appearance. This has created rather intense competition, and research is being carried on to find new uses and to extend markets. Exports to foreign countries may be expected to increase as the properties of these materials become better known; but on the other hand, American manufacturers have established insulation-board plants utilizing wood as a raw material in Sweden and Finland. These plants are well qualified to supply the European market. As yet, insulating boards have not been used to any great extent in the tropics for protection from excessive heat, probably because of their vulnerability to termite attack. With proper treatment to remedy this, the demand may increase.

Structural fiber wallboard used in building construction is composed of layers of chipboard or pulpboard molded or pasted together and usually sized on the surface or throughout. Nonlaminated wallboard is also made, and some wallboard is manufactured with a solid wood core covered with paper liners.



### C. SOME ELEMENTARY PRINCIPLES OF THERMAL INSULATION

Thermal insulation deals with the problem of reducing heat transfer from one region to another. A few of the principles involved in reducing heat transfer, particularly in buildings, are presented in order that the reader may better understand the factors involved in choosing thermal-insulating materials.

**1. Methods of Heat Transfer.** Transmission of heat is accomplished in three ways: by radiation, by convection, and by conduction, each of which may take place separately or in combination in an ordinary house wall.

*a. Radiation.* Examples of heat transfer by radiation, such as the transfer of heat from the sun to the earth and the radiation of heat from an open fire, are familiar to everyone. While transfer of heat by radiation is generally known to exist at elevated temperatures, it also exists at ordinary temperatures. The usual places in which heat is lost, because of radiation within a wall, are in the air spaces between wall surfaces and their frame members. Here some of the heat conducted through one wall surface is transferred to the other wall surface by direct radiation. Reflective insulation is often used to reduce such heat transfer.

To be effective, reflective insulation must be associated with an air space; reflective insulation is not very effective if applied so that it acts as a heat conductor.

*b. Convection.* Convection, as used here, refers to the transfer of heat by currents in a gas or liquid. Air convection currents within a wall aid in transferring heat from one surface to the other. Some convection probably always exists in the air spaces within walls; the air in contact with a cooler surface sinks and the air in contact with a warmer one rises. This circulation of air carries heat from the warmer surface to the cooler one. Convection currents may be produced by temperature differences, as in the instance cited, or they may be forced by blowing or stirring. Heat loss from the outside surface of a building to the air on a windy day is an example of heat transfer by forced convection.

*c. Conduction.* In solid materials, for example, heat is transferred by means of conduction. This is well illustrated by holding one end of a short metal rod in a flame; heat will soon travel from the end in the flame to the opposite end. The amount of heat transmitted by this method is directly proportional to the temperature difference between two points. Metals, in general, are better heat conductors than nonmetals. The thermal conductivity for a given material increases with density, roughly linearly.

**2. Concepts Basic to Calculation of Heat-transmission Rates.** The most accurate method of determining the rate of heat transfer through a wall

section, for example, is to test it according to the Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate.\* Such testing is not feasible for every possible type of construction, but reasonable accuracy can be attained, in most instances, by calculating heat-transmission rates on the basis of certain properties of the materials used in the structure and a few concepts analogous to those applied to the flow of electricity. Over-all heat-transmission coefficients for a structure can be calculated from the individual thermal conductivities and conductances of the different elements affecting the movement of heat through the structure.

*a. Thermal Conductivity.* Thermal conductivity, the rate of heat transfer through a homogeneous substance under steady flow conditions, is expressed as the amount of heat, in British thermal units (Btu), transmitted in one hour through one square foot of a layer one inch thick when the temperature difference between the two sides is maintained at one degree Fahrenheit. Thermal conductivity is a property of a material, independent of size and shape, and it is an inverse measure of the "insulating value" of the material; the lower the thermal conductivity, the better the insulating value. Thermal-conductivity values determined for a given substance vary with several factors; these values usually increase with increases in density, moisture content, and the average temperatures at which the values are determined.

*b. Internal Resistivity.* To express, as a property, the opposition offered by a homogeneous substance to the transmission of heat, the reciprocal of the thermal-conductivity value can be used. The reciprocal of thermal conductivity may be called *internal resistivity*, and it may be considered to be the temperature difference in degrees Fahrenheit that will have to be maintained between the two sides of a layer of the material one inch thick to cause one Btu of heat to flow through one square foot in one hour. The greater the internal resistivity, the better is the insulating value of the material.

*c. Thermal Conductance.* Thermal conductance, the rate of heat transfer from one surface to another surface through a material or construction under steady flow conditions, is expressed as the amount of heat, in British thermal units, transmitted in one hour from surface to surface through one square foot of a material or construction, whatever its thickness, when the temperature difference between the two surfaces is 1°F. Thermal conductance, per square foot of a flat slab of homogeneous material, is directly proportional to the thermal conductivity and inversely proportional to the thickness of the material. Conductance usually is used to designate the

\* Approved as a tentative code by the American Society of Heating and Ventilating Engineers and the American Society for Testing Materials in 1942.

heat transmission through items such as hollow clay tile, hollow concrete blocks, shingles, and surface films.

*d. Thermal Resistance.* The reciprocal of conductance is known as *thermal resistance*. For a flat slab of homogeneous material, the resistance to heat transmission varies directly as the slab thickness and inversely as the thermal conductivity. The resistance of a flat slab of homogeneous material also can be determined by multiplying its resistivity by its thickness in inches.

*e. Heat Transmission Analogous to Flow of Electricity.* A steady flow of heat through a structure, such as a wall composed of several materials, can be likened to the flow of electricity through several resistances. In an analogous application of Ohm's law in electricity, the heat flow through the wall is directly proportional to the thermal potential (temperature difference between the two sides) and inversely proportional to the total thermal resistance of the wall. Continuing the electrical analogy, when heat flows parallel to the floor and through several individual wall *resistances in series* (plaster and lath, air space, sheathing, building paper, and siding, for example), the sum of the resistances of the individual wall components, including that of the air space, equals the thermal resistance from inside wall surface to outside wall surface. Since conductance \* is the reciprocal of resistance, the surface-to-surface conductance of the wall section under discussion is equal to the reciprocal of the surface-to-surface thermal resistance.

**3. Air Spaces and Surface Films.** Still air is a rather poor conductor of heat, but still air is rarely met in ordinary building construction. Still air is, however, the basis for the efficiency of most insulating materials. In an insulating board, for example, millions of tiny pockets of still air exist between the fibers that were rather loosely aggregated in forming the board.

*a. Enclosed Air Spaces.* In ordinary air spaces within walls, the resistance to heat transmission is greatly reduced by radiation and convection. It has been estimated<sup>28</sup> that from 50 to 80 per cent of the heat transfer across air spaces of ordinary size, bounded by wood, plaster, and similar materials, is the result of radiation. The conductances of enclosed air spaces are affected by several factors, such as the width of the space, the

\* When heat flows through several *resistances in parallel*, then and only then can conductances be added. In most instances involving heat transfer through a structure, the resistances are in series. An appropriate case in which conductances can be added would be met when one is determining the amount of heat transferred through a wall, taking into account the proportion of the wall area in which heat is transmitted through studs. In this instance, separate calculations would be made for conductances between studs and through studs. Adjusting these conductances on the basis of the proportion of the wall area affected by each, the resultant conductances could then be added.

orientation of the space (whether vertical or horizontal), the difference in temperatures of the bounding surfaces, the character of the bounding surfaces with respect to reflectivity, and the direction of heat flow (horizontal, upward, or downward).

Thermal conductances of vertical air spaces of various widths, having horizontal flow of heat, have been found<sup>16</sup> to decrease considerably as widths increase to  $\frac{3}{4}$  in., but conductances for widths greater than  $\frac{3}{4}$  in. do not decrease appreciably. For practical purposes, the conductances of vertical air spaces  $\frac{3}{4}$  in. and wider are assumed to be a constant of 1.10 at a mean air-space temperature of 40°F. in ordinary buildings. Thermal conductances of horizontal air spaces, where the heat flow may be upward or downward depending on outside temperature, are somewhat greater than 1.10 for upward heat flow and somewhat lower than 1.10 for downward heat flow. Air, like other substances, has greater conductances as its mean temperature is increased, and for precise work this factor may be taken into account. Nonreflective surfaces bounding an air space promote the higher conductances, while highly reflective bounding surfaces reduce air-space conductances.

*b. Surface Films.* The thin films of air in immediate contact with the two external surfaces of a wall, for example, contribute some heat-transmission resistance to that of the wall components and any included air spaces. These surface films of air, when disturbed by convection currents, become thinner and less effective in reducing heat flow. Other factors that influence the conductances of surface films include differences in air and wall temperatures, reflectivity of surface, orientation of surface, direction of heat flow, and roughness of surface; the effects of the first four of these five factors on surface-film conductances are very similar to their effects on enclosed air spaces. The relationship between wind velocity and roughness of an outdoor wall surface is such that, for any given wind velocity, surface-film conductances increase with roughness of surface. Increased air velocities, of course, increase outdoor surface-film conductances on all types of surfaces. For a wind velocity of 15 miles per hour and an average outside wall surface, it is common practice to assume a surface-film conductance of 6.00. It is also common practice to assume that rooms contain still air, and on the basis of this assumption, a nonreflective interior wall surface is assigned a surface-film conductance of 1.65.

**4. Application of Principles.** In calculating the total heat loss from within a building, losses from many sources, such as foundations, floors, walls, roofs, doors, windows, and infiltrated air must be taken into account. It is not within the scope of this chapter to discuss this problem, but an interested reader is referred to the latest issue of the "Heating, Ventilating, and Air Conditioning Guide"<sup>17</sup> for authoritative information.

Application of the principles previously discussed can best be illustrated by showing the calculation of an *over-all heat-transmission coefficient*. The over-all heat-transmission coefficient indicates the rate of heat flow from the air on one side of a material or construction to the air on the other side of the material or construction under consideration. It is expressed as the amount of heat, in British thermal units, transmitted in one hour through one square foot of a material or construction for a temperature difference of one degree Fahrenheit. It is the reciprocal of the total resistance of a material or construction.

*a. Heat-transfer Symbols.* The symbols used in the heat-transfer calculations to be presented are:

$a$  = thermal conductance between boundary surfaces of an air space

$C$  = thermal conductance from one surface to another surface through a material or construction

$f_i$  = thermal conductance of the surface film on the inside of a structure

$f_o$  = thermal conductance of the surface film on the outside of a structure

$k$  = thermal conductivity of a homogeneous material

$R$  = thermal resistivity or resistance, which may represent any of the following:

Air space resistance.....	$1/a$
Surface-to-surface resistance of a material.....	$1/C$
Inside surface-film resistance.....	$1/f_i$
Outside surface-film resistance.....	$1/f_o$
Resistivity or resistance per unit thickness.....	$1/k$
Resistance for a given thickness of a material.....	$x/k$
Over-all air-to-air resistance of a material or construction....	$1/U$

$R_t$  = total resistance

$U$  = over-all heat-transmission coefficient

$x$  = thickness, inches

*b. Problem.* Assume still air on the room side and a wind of 15 miles per hour on the outside. Calculate the over-all heat-transmission coefficient for the between-stud section of a wall constructed as follows, starting from the room side.

Wood lath and plaster

Air space 1.56 in. wide

Blanket insulation 0.50 in. thick

Air space 1.56 in. wide

Wood sheathing 25/32 in. thick and building paper

Wood siding 25/32 in. thick and weighing 35 lb. per cu. ft. at 12 per cent moisture content

Table 16-1 showing resistivities and resistances for a few building materials has been prepared in order to avoid the necessity of calculating these values from thermal-conductivity and thermal-conductance data.

TABLE 16-1. THERMAL RESISTIVITIES AND RESISTANCES FOR SOME MATERIALS INVOLVED IN BUILDING CONSTRUCTION

Material	Internal resistivity <sup>a</sup>	Resistance <sup>b</sup>
	$\frac{1}{k}$	$\frac{1}{a}, \frac{1}{C}, \frac{1}{f_i}, \frac{1}{f_o},$ or $\frac{x}{k}$
Air spaces, $\frac{3}{4}$ in. or wider.....	.....	0.91
Air surface films:		
Inside, still air, nonreflective surface, heat flow horizontal.....	.....	0.61
Outside, 15-mile-per-hour wind, average nonreflective surface.....	.....	0.17
Brick, common.....	0.20	
Brick, face.....	0.11	
Concrete, sand and gravel aggregate.....	0.08	
Concrete blocks, 8-in., hollow, sand and gravel aggregate.....	.....	1.00
Concrete blocks, 12-in., hollow, sand and gravel aggregate.....	.....	1.25
Insulation materials:		
Fiberboard, plant fiber.....	3.03	
Flexible, blankets or batts, mineral or plant fiber, covered or uncovered.....	3.70	
Mineral wool of rock, slag, or glass.....	3.70	
Sawdust and shavings.....	2.44	
Lath, metal and plaster.....	.....	0.23
Lath, wood and plaster.....	.....	0.40
Sheathing:		
Insulating fiberboard, $2\frac{5}{32}$ -in.....	.....	2.37
Wood, $2\frac{5}{32}$ -in. plus building paper.....	.....	1.16
Shingles:		
Asbestos.....	.....	0.17
Asphalt.....	.....	0.15
Wood.....	.....	0.78
Tile, 8-in., hollow, clay.....	.....	1.67
Tile, 12-in. hollow, clay.....	.....	2.50
Wood <sup>c</sup> at 12 per cent moisture content, weighing:		
25 lb. per cu. ft.....	1.27	
30 lb. per cu. ft.....	1.10	
35 lb. per cu. ft.....	0.97	
40 lb. per cu. ft.....	0.87	
45 lb. per cu. ft.....	0.78	
50 lb. per cu. ft.....	0.71	

<sup>a</sup> To obtain resistance for any given thickness, multiply internal resistivity by thickness in inches.

<sup>b</sup> Resistances are for materials as used or for dimensions and compositions indicated.

<sup>c</sup> Calculated by U.S. Forest Products Laboratory formula.

*c. Solution to Problem.* Since the construction in question is a wall, the heat flow will be horizontal and through several resistances in series. The total resistance of the wall will be the sum of all individual resistances of the wall components, air spaces, and surface films. Applying data from Table 16-1, we will have the following resistances:

Inside surface film.....	0.61
Wood lath and plaster.....	0.40
Air space.....	0.91
Blanket insulation (0.5 × 3.70).....	1.85
Air space.....	0.91
Wood sheathing and building paper.....	1.16
Wood siding ( $2\frac{3}{4} \times 0.97$ ).....	0.76
Outside surface film.....	0.17
<b>Total resistance, <math>R_t</math>.....</b>	<b>6.77</b>

The over-all heat-transmission coefficient is the reciprocal of the total resistance; therefore,  $U = 1/R_t = 1/6.77 = 0.15$ . Each square foot of this wall, neglecting any difference in heat transfer through studs, will transmit 0.15 Btu of heat per hour for each degree difference in temperature between that of the room and the outside wind.

#### D. SOME CONSIDERATIONS IN CHOOSING INSULATING MATERIALS

The choice of a thermal-insulating material from the hundreds available is difficult for the layman. Claims and counterclaims merely serve to confuse the prospective buyer. A few considerations, such as the type of insulation and method of installation, choice of thickness, condensation within walls, durability, and structural value deserve mention.

**1. Type of Insulation and Method of Installation.** In general, a good measure of the economy of an insulation material is its installed cost per unit of thermal resistance. The effectiveness of flexible and rigid-board insulation depends somewhat on the method of application. Flexible insulation may be packed into wall spaces, it may be nailed to studding before wall surfaces are applied, or it may be stretched between studding and, by the use of nailing strips, fastened to the sides of the studs. The most effective method, perhaps, is the last named, provided the insulation is spaced midway between the two inner surfaces of the wall to gain the added thermal resistance of an extra air space. Care must be taken to have the insulation touch the top and bottom wall plates in order to prevent convection currents around the material.

Rigid-board insulation allows greater freedom in application because of the fact that it can be used as a plaster base, and its effectiveness may also

be increased by placing it midway in an enclosed air space. In order to accomplish this easily and economically, grooved framing members may be used to hold the insulation in place. Both flexible and rigid insulations are largely free from the objection that they may reduce the sound-insulating value of a partition as sometimes happens when fill insulations are used. In fact, flexible and board insulations are sometimes used to provide sound insulation as well as heat insulation.

Fill insulation materials may be packed or blown into wall spaces, or they may be of a hydrated mix in wet condition, the cellular nature of the material being produced by the effervescent process that takes place. Objections to fill insulations have been made on the grounds that (1) they may not fill the spaces entirely because of the difficulty of tamping them so that they reach the bottom plate of the wall, (2) settling takes place, thereby increasing their densities and reducing their thermal resistances in the lower parts of the wall, (3) openings may result at the top of the wall because of settling, and (4) ventilation is lacking for removing moisture condensed within the wall. On the other hand, most of the fill insulations have high efficiencies in retarding heat transmission. When applied above ceilings, the weight of the material should receive consideration.

**2. Choice of Thickness.** Although a given material may have a low thermal conductivity, its effectiveness is also controlled by the thickness applied. Thickness is more important than small variations in thermal conductivity. A higher-thermal-conductivity material of a given thickness may prove to be a better insulator than a slightly thinner low-thermal-conductivity material. For accurate comparisons of materials, the thickness, thermal conductivity, and installed cost must be known for each material.

The thickness of fill insulation is often governed by the width of the space in which it is placed, but other insulations usually may be purchased in several thicknesses. A limiting factor for the latter materials lies in the law of diminishing returns. The first fraction of an inch of the thickness of insulating material gives the greatest effectiveness for the amount of money spent. Each succeeding fraction of an inch of thickness added reduces heat transmission, but it does so at an increasingly higher cost per unit of thermal resistance. For house construction, it is usually most economical to use thicknesses not exceeding  $1\frac{1}{2}$  in.

**3. Condensation.** Well-constructed and well-insulated modern buildings have walls that are much tighter than those in most old houses. These tighter walls and more general use of weather stripping and tight storm sash and doors have reduced air infiltration and ventilation in modern houses. Relative humidities, as a result, are generally higher in such



houses. These high humidities have, in many instances, produced a serious problem of moisture condensation within walls and in attics.

Water vapor from within a building penetrates the inner wall surface and, upon meeting a temperature corresponding to its dew point, is condensed within the wall. Freezing may then take place. This condensation increases the moisture content of the insulating material and may cause its deterioration. The thermal resistance of the insulation, at least, will be lowered, because water is a much better conductor of heat than the insulation. The difficulty does not stop here, but the accumulated moisture or the moisture resulting from melting ice is retained in the wall for protracted periods because of lack of ventilation. This, of course, provides conditions favorable to wood-destroying fungi and often causes damage to plastered inside wall surfaces and to painted outside wall surfaces. The irony of the situation lies in the fact that such conditions result from construction that is intended to lower heating costs by reducing air infiltration and by effectively lessening heat transmission.

Several things may be done, however, to alleviate or dispose of such a problem. These solutions are more easily effected in new construction than in completed houses; but fortunately, the problem can be solved in any house. The satisfactory remedy is the installation of a vapor barrier. In new construction, a 50-lb. asphalt-impregnated building paper with a glazed surface, a foil-covered paper, or a good grade of duplex paper will act as an effective vapor barrier if nailed on the room (warm) side of wall studs and ceiling joists. Papers should be lapped, tightly nailed to framing members, and loosely stretched so that sufficient space is left for the plaster keys that are necessary if the room is to be finished with lath and plaster. Great care should be taken to see that tight joints are secured around windows, doors, and dormers in order to prevent water vapor from entering the walls at these points.

In old houses, effective vapor barriers can be made by painting the inside wall surfaces with two coats of moisture-retardant paint or by using moisture-resistant wallpaper.

Another type of treatment that will help to prevent the disastrous results of condensation on the lower sides of roofs in attics provides ventilation by the installation of louvers in the house gables. The use of small openings, concealed by moldings, at the top and bottom of each stud area to vent off vapor has proved to be less satisfactory than vapor barriers in preventing condensation within walls.

Condensation is likely to occur in any insulated wall; the more efficient the insulation, the more serious may be the problem. Unjust criticism has been leveled at certain types of insulation for "drawing moisture," but

these materials are not in themselves at fault. The fault lies in the failure to prevent water vapor from getting to them.

**4. Durability.** Most rigid boards and many flexible materials used for insulation are of vegetable fiber of one kind or other. These are subject to the action of termites and wood-destroying fungi. An insulation should be as durable as the structure to which it is applied, and some insulation manufacturers are treating their materials with preservatives to prevent destruction by vermin, termites, and decay.

**5. Structural Strength.** Some structural insulation products are being used to replace materials commonly used in construction, particularly wood and steel lath and wood sheathing. It must not be forgotten that materials such as sheathing contribute to the thermal resistance of the wall, and that if they are replaced, the insulation has to be effective enough to overcome this loss in addition to supplying the extra thermal resistance sought.

Strength and stiffness tests have been made on panels of rigid fiberboards, horizontal wood sheathing, and diagonal wood sheathing of equal thicknesses. In general, it has been found that, in regard to strength, the fiberboards occupy an intermediate place between horizontal and diagonal wood sheathing, horizontal wood sheathing giving the lowest values. These results are based on static tests and do not include resistance to puncture. Panels tested for rigidity showed that those sheathed with fiberboard occupied an intermediate position between horizontal and diagonal wood sheathing when no openings were present in the panel, horizontal sheathing giving the least rigidity. Fiberboard sheathing gave somewhat more rigidity than diagonal wood sheathing when panels containing window and door openings were tested. The effectiveness of the fiberboard was found to increase with an increase in the number of nails used, and its effectiveness also depended on the method of applying it around window and door openings.<sup>12</sup>

## II. SOUND-CONTROL MATERIALS AND METHODS

Professor W. C. Sabine of Harvard University, in 1895, undertook the task of improving the acoustics of the auditorium in the Fogg Art Museum that had just been built at that institution. His investigations were the pioneer quantitative scientific work in this field; so fundamental was this work that little has been added to the theoretical basis of the subject. Other workers have added mainly by extending knowledge of the acoustic properties of materials commonly used in building construction, by modifying his formula for calculating reverberation time, and by developing better equipment and methods for the study of sound.

## A. ACOUSTICAL DEFECTS

The usual defects<sup>13</sup> in auditoriums are stated to be: echo, dead spots, sound focuses, and reverberation.

**1. Echo, Dead Spots, and Sound Focuses.** Echo, in the usual sense, means a definite or articulate repetition of a sound after an interval at least equal to the total duration of the sound that is being repeated. Dead spots and sound foci occur as a result of echo-producing conditions. Echo arises by regular reflection of sound from walls, ceilings, or arches without scattering it. Echo and sound foci often are the result of structural features of the room, and their removal may require changes in construction.

**2. Reverberation.** Reverberation means a confused or inarticulate prolongation of a sound, and it is produced by walls and ceilings that have irregular surfaces. In this instance, the reflected sound is diffused in all directions so that its articulate character is destroyed. A sound produced in a room is reflected back and forth from walls, floor, and ceiling, a certain portion being absorbed at each reflection until its intensity is so reduced that the sound becomes inaudible. Because of the speed of sound, there may be many such reflections in the course of a single second in a room of ordinary size. The greater the dimensions of the room, the more prolonged will be the reverberation. By lining the walls and ceiling with sound-absorbent materials, many of which are wood-fiber products, only a few reflections may be required to destroy the sound. Too much of such material can produce an "acoustically dead" room, which is undesirable because it does not satisfy established tastes and auditory habit.

The time in seconds taken for a sound of specified energy to die away to inaudibility is termed *reverberation time*. Excessive reverberation time prolongs each syllable or music note so as to cause it to interfere with the next one. Ideally, each syllable or note should die away before the next arrives, and the sound should always be loud enough to be heard. The first of these two conditions can be obtained by providing enough sound-absorbing material in the room, and the latter can often be secured by increasing the amount of reverberation through a reduction in the amount of sound-absorbing material. To adjust for these two conditions, it is often desirable to have walls with variable sound absorption. Smooth-plastered walls covered with heavy curtains, which can be pulled back to expose more or spread out to expose less wall surface, may effect the necessary compromise between reverberation and loudness of sound.

Acceptable reverberation times<sup>13,14</sup> for speaking and musical performances for rooms of different volumes have been worked out. Rever-

beration time varies directly with the volume of the room and inversely with the total sound absorption of the walls, ceiling, floor, furnishings, and occupants of the rooms. W. C. Sabine \* and others<sup>13</sup> have developed simple formulas for calculating reverberation times. Use of these formulas enables one to estimate the amount of sound-absorption materials necessary to accomplish desired results.

B. SOUND-ABSORPTION COEFFICIENTS

A square foot of material having a sound-absorption coefficient of 1.00 will absorb all incident sound energy; a square foot of a material having a sound-absorption coefficient of 0.30 will absorb three-tenths as much sound as a square foot of material that absorbs all incident sound energy. Sound-absorption coefficients vary, more or less, with the frequency of the incident sound. Although a frequency of 512 cycles per second is considered to be the standard in calculating reverberation time, it is advisable to calculate the reverberation times for other frequencies in order that a room may be made acoustically satisfactory for varying conditions. Although there are some exceptions, sound-absorption coefficients of most materials increase as the frequencies of the incident sound increase. For a frequency of 512 cycles, sound-absorption coefficients may be as low as 0.27 and as high as 0.61 for sound-control materials made of plant fiber.

Materials having the greatest coefficients are not necessarily the most advantageous. When space is not limited, a greater quantity of low-coefficient material will give the same result. From the standpoint of economy, the installed cost per unit of sound absorption may favor a low-coefficient material.

The National Bureau of Standards has measured the total sound absorption of individual objects at a frequency of 512 cycles per second. The numerical value corresponding to each object indicates the number of square feet of a material having a sound-absorption coefficient of 1.00 that would be necessary to absorb the same amount of sound energy as that absorbed by the object.

<i>Object</i>	<i>Sound absorption</i>
Audience, per person . . . . .	4.00
Church pews, per seat . . . . .	0.40
Seats, upholstered, depending on material and lining, per seat . . .	1.00-4.50
Wood seats, for auditoriums, per seat . . . . .	0.25

\* Sabine's formula for reverberation time is  $t = 0.05V/A$ , where  $t$  is the time in seconds,  $V$  is the volume of the room in cubic feet, and  $A$  is the total sound absorption by walls, floors, ceiling, room contents, and audience.

## C. SOUND INSULATION

Sound insulation, as considered here, refers to the reduction of sound transmission through homogeneous substances and walls made up of several materials. While sound-absorbing material within a room that is receiving sound from an outside source may be considered a means of sound insulation, it can be depended on for only a very limited amount of sound reduction. Sound insulation, therefore, must deal primarily with the reduction of sound transmission through a given material or composite of materials. In general, sources of sound can be put into two classes: air-borne and solid-borne.

**1. Transmission of Air-borne Sound.** The principal means for the transmission of air-borne sound are (1) refraction through the wall or insulating medium; (2) through openings, such as unclosed windows, cracks around doors, ventilators, etc.; (3) by means of the diaphragm action of partitions.

When a wave of sound strikes a vibrationless, homogeneous partition, a portion of the incident sound is reflected from the partition, a portion of it is absorbed by the partition, and a third portion of it is refracted through the partition in a manner analogous to the refraction of light through a pane of glass. The greatest percentage of the incident sound is reflected from the partition, and an insignificant part is refracted through to the other side and need not, ordinarily, be considered in buildings.

Openings of any sort that permit a free flow of air transmit sound readily and present a serious problem in sound insulation. Frequently, the best sound-insulated wall may be rendered ineffective because of open windows, cracks around doors, ventilators, heating ducts, or shrinkage cracks developing in wood partitions.

The greatest amount of air-borne sound is transmitted from one room to another by the diaphragm action of the separating wall. Sound waves in air consist of alternate compressions and rarefactions, and if there are no holes or cracks to provide free passage for the waves, the transmission is accomplished by setting the wall in vibration. The wall yields a little to the pressure of each sound wave that strikes it, and it is thrown into a state of vibration. The vibrating wall then sets the air on the opposite side in motion to produce sound waves. The amount of energy transmitted depends largely on the initial energy striking the wall, the mass of the wall, the stiffness of the wall, and the composition of the wall. Occasionally, when the sound is mainly of a single frequency, the wall may be in resonance with the sound frequency; but as a rule the resonance frequencies of building walls are so much lower than the frequencies of ordinary sounds that this condition rarely presents itself.

**2. Reducing Air-borne Sound Transmission.** For homogeneous walls of any type,<sup>7</sup> the weight per unit of area is the most important factor in determining the sound insulation. The sound-insulation factor for homogeneous walls is not directly proportional to the weight per unit of area; it is virtually proportional to the logarithm of the weight per unit of area. As a result, a high degree of sound insulation can be obtained in this way only by making the wall exceedingly heavy. Walls of this type, to obtain efficient sound insulation, may have to be so thick that they are not feasible because of cost and weight of building.

It is usually more economical and practicable to make lighter weight walls of greater stiffness; to break the wall up into two or more layers and to apply, in addition, sound-absorbing blankets or felts between the layers; or to make a wall of a composite of materials. When a wall is broken up in this manner, however, it becomes impossible to predict its sound-insulation value. Panels must be constructed and tested<sup>9,14</sup> before the sound-insulating values of nonhomogeneous walls and floors can be determined.

Some of the methods that have been tried, with more or less success, to obtain sound insulation in wall, ceiling, and floor partitions follow.

*a. Increasing Stiffness of Conventional Walls.* Stiffening of walls whose two surfaces are applied to the same studs may be accomplished through the use of larger or more studding. Each section of wall surface between two adjacent studs acts as a flexible panel held more or less firmly by the studs. When one surface of the panel is thrown into vibration, it sets up corresponding waves in the enclosed air; these air waves throw the opposite between-stud wall surface into vibration, and this surface, in turn, produces sound waves in the air on the farther side of the wall. Air enclosed within a wall acts like an elastic cross-tie between the two surfaces, but it cannot cause the second surface to vibrate so much as the surface receiving the initial sound waves. Such enclosed air has a low transmission and is, in reality, a good insulator. In addition to the vibration of these between-stud panels, the entire first wall surface is thrown into vibration by the initial sound; and, because of physical connection by the same studs, the two entire wall surfaces are obliged to move in unison. This condition is responsible for the greatest amount of air-borne sound transmission from one room to another. A stiffer wall will vibrate less, thereby reducing transmission of sound. Since wall stiffness is controlled largely by the studs, it is possible to increase wall stiffness by increasing the size or the number of studs or both.

*b. Separation of Wall Surfaces.* A wall may be divided into two parts by using two sets of studs staggered from a straight line, each wall surface being applied to half the total number of studs. Occasionally two sets of smaller studs set opposite each other may be used, with or without an in-

insulating material between them. These types of wall construction are designed to utilize the sound-insulation value of a continuous air space by eliminating physical connection of the two opposing wall surfaces. The full effectiveness of the air space is not attained because the studs have common connecting plates at the ceiling and floor.

*c. Use of Composite Materials for Wall Surfaces.* In wall partitions, fiberboard and plaster have been substituted for lath and plaster; sheet-metal lath has been substituted for wood lath; and many combinations of two or more layers (often of different materials on the same wall surface) of fiberboards, felts, etc., have been tried. The problem of sound insulation in partitions that must meet requirements of reduced fire hazard, at a reasonable cost and weight, is not easy to solve, but application of some of these methods has proved to be effective. When furring strips are applied to masonry for the holding of lath and plaster, care must be taken to see that the plaster keys on the reverse side of the lath do not protrude far enough to form a physical bond with the masonry.

*d. Use of Insulation Materials in Air Spaces.* Generally speaking, the introduction of felts, fill-type insulation, sawdust, slag, and other materials into air spaces between wall studs has met with indifferent success. In some instances this procedure has decreased sound transmission; in others, sound transmission actually has been increased. Much depends on the material chosen and the particular wall to which it is applied. If the material packs down, it may act as a tie to transmit sound, but if it does not exert pressure against the surface to aid in damping out vibrations, it is of little value. When the wall surfaces are very thin, proper application of appropriate fillers seems to be definitely beneficial.

**3. Solid-borne Sound Transmission.** Sound that arises from vibration because of impact or contact, when conducted through solid members of a structure, is known as solid-borne sound. Types of impact that produce solid-borne sound include hammering on walls or floors, footfalls, moving of furniture, direct vibration from machinery and musical instruments, and dropping of objects. Solid-borne sound, resulting from contact, is typified by that of water running in pipes that are in contact with solid members of walls.

**4. Reduction of Solid-borne Sound Transmission.** Insulation against air-borne sounds in all kinds of partitions seems not too difficult, but insulation against impact-produced sounds is a much harder task. In fact, it might be said that efficient insulation against impact sound is yet to be discovered. The logical starting point for reduction of impact noises is probably to prevent most of the sound energy from being carried to the structure. This can be accomplished by covering floors with rugs; by putting legs of pianos in easter cups that have rubber or felt bases; by using

flexible or elastic supports for machinery; and by wrapping water pipes, where they touch the building frame, with flexible porous materials.

One of the most effective methods for reducing these noises is to introduce discontinuities in the paths of the conducted sounds comprised of materials as loosely connected as possible. Appropriate materials should differ greatly in density and elasticity from the solid structure of the building. Things that have been done include the building of floating floors on flexible pads such as cork, fiberboard, felts, or other elastic material; the use of ceilings suspended by flexible or elastic ties; and the separation of the entire room surface from the main structure (a room within a room) by the least rigid ties that will suffice.

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## CHAPTER 17

### CELLULOSE FILAMENTS AND FILM

Highly purified cellulose is used extensively as a basic material in the manufacture of a number of derived products such as rayon, transparent films (Cellophane), photographic films, artificial sponges, sausage casings, and lacquers. The two principal sources of cellulose suitable for the manufacture of these products are wood pulp and cotton.\* At the present time utilization of wood pulp in the manufacture of cellulose derivatives is confined principally to the production of rayon by the viscose method.

The principal type of pulp used is a bleached sulfite with a high alpha-cellulose † content, obtained mainly from spruce and western hemlock.‡

The alpha-cellulose content of wood pulp suitable for rayon manufacture ranges from 85 to 96 per cent, depending on the manufacturer's requirements. § The major problem in the purification of wood pulp is the removal of all carbohydrates other than alpha-cellulose (*i.e.*, beta- and gamma-celluloses and hemicelluloses) and the residual noncarbohydrate compounds (traces of lignin, resins, fats, waxes, tannins, etc.) that are left behind after bleaching operations. In the production of purified wood pulp, these products are removed by an alkaline treatment. The two most generally used methods are (1) treatment of pulp with dilute alkali (0.5 to 2 per cent caustic soda at elevated temperatures ranging from 100 to 140°C.) and (2) cold alkali treatment at room temperature and with alkali concentrations ranging from 4 per cent to as high as 20 per cent.

*Rayon, also known as artificial silk, is a trade name adopted in 1924 to designate a class of synthetic filaments and textiles made of them, the principal constituent of which is cellulose. More specifically the term rayon refers to artificial silk made by the viscose process.*

\* In 1951 the rayon industry in the United States consumed 515,500 tons of bleached sulfite pulp, compared to 100,800 tons of cotton-linters pulp. It is expected that the utilization of wood pulp by the industries engaged in the manufacturing of cellulose derivatives will continue to increase.

† Alpha-cellulose is generally defined as the more stable portion of cellulose that fails to dissolve in 17.5 per cent of caustic soda, at 20°C.

‡ Satisfactory pulp for rayon manufacture can also be produced from southern pines and even from hardwoods; in fact, the species used is of secondary importance to the method of isolation and the purity of the pulp.

§ In contrast, cotton linters contain about 98 per cent of alpha-cellulose.

Of the four methods for the manufacture of artificial silk (see Table 17-1) only two, the acetate and the viscose processes, are commercially important today. Cellulose acetate is a cellulose derivative produced by treating cellulose with a mixture of acetic anhydride and glacial acetic

TABLE 17-1. FLOW CHART OF RAYON MANUFACTURE BY FOUR PROCESSES <sup>a</sup>

Viscose	Acetate	Cuprammonium	Nitrocellulose
Wood pulp and cotton linters Caustic steeping	Cotton linters and wood pulp Treated with acetic anhydride, acetic acid, and catalyst	Purified cotton linters Treated with basic copper sulfate and ammonium tartrate	Purified cotton linters Dissolved in nitric acid and sulfuric acid
1. Alkali cellulose: Pressing Grinding Aging Treating with CS <sub>2</sub>	1. Primary cellulose acetate: Hydrolysis Precipitation Washing Extracting Drying	1. Dissolved in cuprammonium solvent: Mixing Diluting Maturing Filtration Deaerating	1. Cellulose nitrate: Precipitation Washing Extracting Dissolving in alcohol-ether Filtration Deaerating
2. Cellulose xanthate: Dissolved in caustic soda Filtering Deaerating Ripening	2. Secondary cellulose acetate: Filtering Deaerating	2. Cuprammonium spinning solution: Wet-spinning into water Stretching	2. Nitrate spinning solution: Dry-spinning into warm air
3. Viscose spinning solution: Wet-spinning through spinnerets into acid bath Spinning Washing	3. Acetate spinning solution: Dry-spinning into warm air Twisting	3. Copper removal: Acid wash Rinsing Drying Twisting	3. Denitrating: Washing Bleaching Scouring Soaping Twisting
4. Desulfuring Washing Bleaching Drying Twisting	4. Acetate yarn	4. Cuprammonium yarn	4. Nitrocellulose yarn
5. Viscose yarn			

<sup>a</sup> Adapted from Rayon and Synthetic Yarn Handbook, 2d ed., The Viscose Company, New York, 1936.

acid, in the presence of a catalyst. The resulting product, cellulose triacetate, when partially hydrolyzed, is soluble in acetone and may be formed into filaments and films. Artificial silk made by the viscose method, on the other hand, is practically pure cellulose. In its production certain chemicals are used to convert the cellulose into a fluid. When in this form cellulose can be precipitated (*regenerated*) under controlled conditions to form solid cellulose filaments or films.

## A. VISCOSE PROCESS

Since in this country the utilization of wood pulp for manufacture of artificial silk is largely confined to the viscose process, a more detailed description of this process is presented.

The viscose method of producing rayon is based on the discovery in 1892 by Cross, Bevan, and Beadle that when cellulose is treated with a strong sodium hydroxide solution an *alkali cellulose* is formed. When this is treated with carbon disulfide, it forms an alkali-soluble *cellulose xanthate* (sodium cellulose salt of dithiocarbonic acid). Cellulose xanthate itself is an intermediate product and is of interest only because it is a practical and inexpensive means of bringing the original raw cellulose into a solution from which it can be reprecipitated (regenerated) in a number of physical forms, such as filaments suitable for spinning, films, or sponge-like masses. The process derives its name from the high viscosity of the cellulose xanthate solution in dilute sodium hydroxide ("viscose").

The steps in the manufacture of viscose rayon include the preparation of alkali cellulose by steeping, pressing, and shredding cellulose material. In steeping, raw cellulose is treated with 17.5 to 18 per cent caustic solution for about an hour at temperatures of 18 to 20°C. The object of this treatment is to remove all the hemicellulose and impurities from the cellulose and to cause it to swell and to absorb sodium hydroxide (*i.e.*, to form alkali cellulose). When wood pulp is used, sheets of pulp approximately 12 by 18 in. are placed on edge in a rectangular tank. Each sheet of pulp is separated by perforated steel plates. The tank is filled with a caustic soda solution and the pulp is allowed to soak in this solution for about an hour at a definite temperature. When this treatment is completed, the caustic solution is drained and the pulp is squeezed by means of a ram until the wet weight of the pulp is about three times that of its original dry weight. Pulp treated with caustic soda in this manner is called alkali cellulose. The wet sheets of alkali cellulose are then reduced to small particles, called *crumbs*, by means of a shredder. This machine consists of a cast-iron trough, equipped with two rotating horizontal steel arms fitted with steel-toothed shoes. The shredder not only breaks up the wet pulp sheets into small particles, but also blends and mixes the crumbs, equalizing the caustic soda content.

The next phase of manufacture consists of aging the crumbs. The crumbs are discharged from the shredder into large cans, which are placed in temperature-controlled rooms. There they remain for about 48 hours, while the alkali cellulose undergoes important physical and chemical changes that alter its molecular structure, decrease its viscosity, and increase its solu-

bility. The aged alkali cellulose is then treated with carbon disulfide ( $\text{CS}_2$ ), which transforms it into an alkali-soluble cellulose derivative known as cellulose xanthate. This operation is carried on in a rotating steel drum called a *churn*. During this reaction the cellulose changes its color from white to orange; at the same time the fluffy crumbs collect into tight balls ranging in size from marbles to baseballs. At the end of the xanthation reaction the excess of carbon disulfide is allowed to drain and the cellulose xanthate is transferred into a mixer equipped with a stirring apparatus, where a known quantity of dilute caustic soda is added. The caustic soda gradually dissolves the cellulose xanthate, the resulting orange-colored viscous solution being the *viscose*, a complex mixture containing cellulose xanthate, caustic, carbon disulfide, and compounds formed by their interaction. The viscose is filtered through several thicknesses of cotton batting and the filtrate allowed to ripen for several days, until all the air bubbles escape, leaving a clear, air-free solution that is now ready for spinning (Fig. 17-1).

Ripening of viscose is accompanied by chemical and physical changes; the former consist of the spontaneous decomposition of the cellulose xanthate, by splitting off of the carbon disulfide and regeneration of the cellulose, and the latter results in improvement in the coagulation properties of the product. This spontaneous decomposition of the cellulose xanthate is too slow for industrial purposes; the regeneration of the cellulose can be made instantaneous, however, by treating the xanthate with mineral acids and acid salts. Such treatment, carried on in the coagulation baths, causes simultaneous regeneration and coagulation of cellulose in the desired physical forms.

More recently several continuous processes have come into use to replace the multiple-stage batch operations just described. In one continuous system, pulp sheets are passed through all the stages of operations on a conveyer, while in another, bulk pulp is treated in vats equipped with agitators and press rolls, or in a centrifuge, for removing the excess of caustic.

**1. Rayon Yarn.** Rayon filaments are produced by forcing the viscose through holes 0.002 to 0.005 in. in diameter in small cups or spinnerets made of precious metal, usually platinum. The spinnerets are immersed in an acid coagulating bath containing warm water, sulfuric acid, sodium sulfate, zinc sulfate, and usually some glucose or magnesium sulfate. This acid bath neutralizes the caustic soda, causing the breakdown of cellulose xanthate and regeneration of solid cellulose in the form of filaments, each hole in the spinneret forming a filament of pure cellulose. These filaments are passed to a spinning box; its rotation causes a group of filaments to be twisted into a thread of the desired twist. In another type of spinning

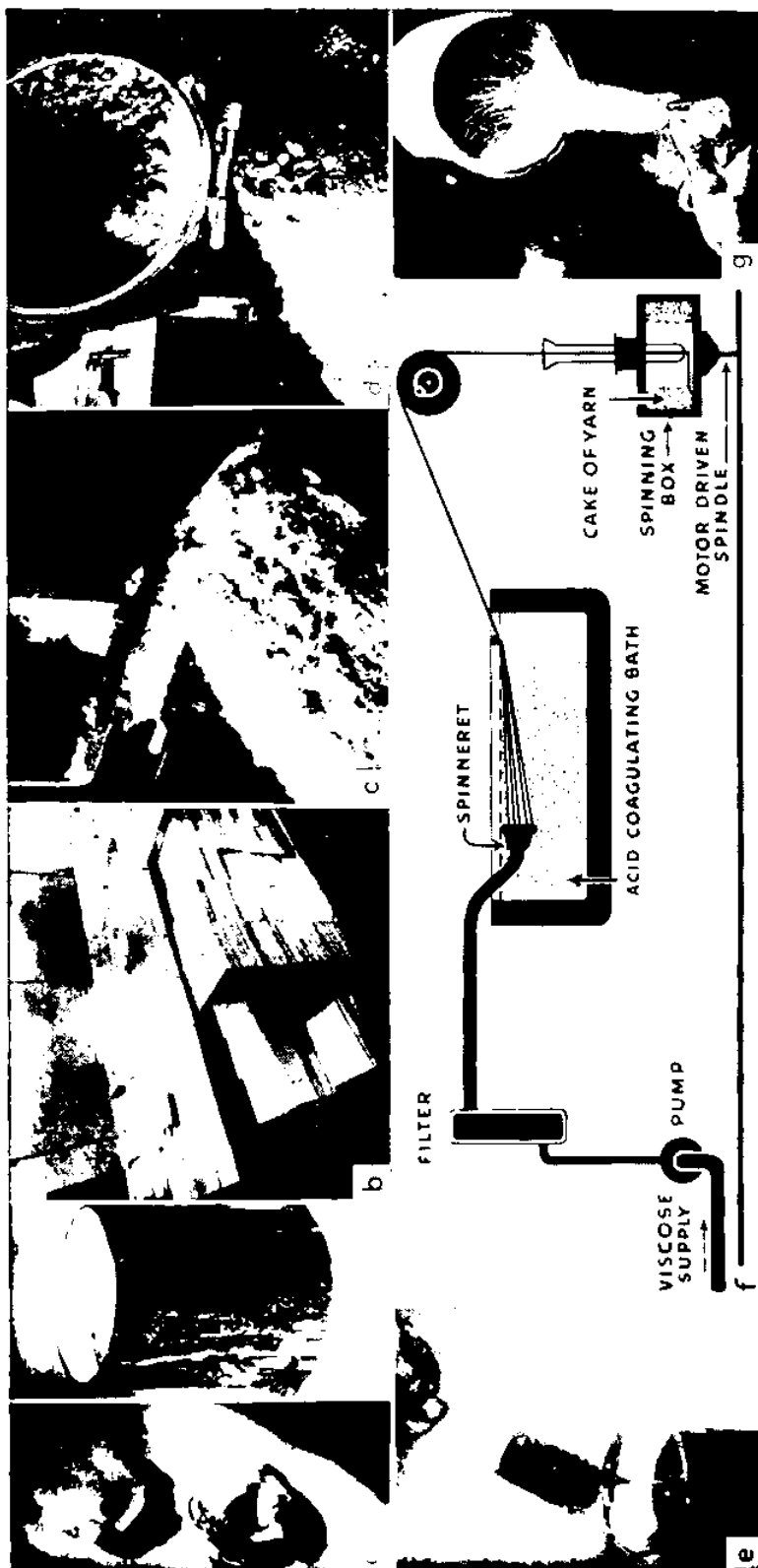


FIG. 17-1. Steps in manufacture of viscose rayon: *a*, cotton and spruce wood; *b*, sheets of pulp; *c*, alkali cellulose; *d*, cellulose xanthate; *e*, viscose spinning solution; *f*, spinning operation; *g*, yarn from spinning machine. (Courtesy American Viscose Corporation.)

machine, the thread as it leaves the hardening bath is wound without a twist, the twisting being done as a separate operation.

The yarn as it comes from the spinning machine still contains more than 70 per cent of bath liquids; these are washed out with water. It is then treated with an alkaline sulfide solution, which dissolves the sulfur deposited on the yarn, and is passed through heated driers. The yarn which is intended for weaving is bleached with a hypochlorite solution and then re-dried. This treatment restores the bright color to rayon which, when it comes from the spinning machine, is a dull yellow. Yarn intended for knitting is bleached after it has been woven into cloth. Rayon yarns have a high luster that is frequently objectionable in a finished product. Today, rayon yarns of normal, semidull, and very dull lusters are offered. Delustering is accomplished by incorporating insoluble pigments into the rayon threads. Colored rayons are produced by spinning a solution of viscose to which a dye has been added. Rayon yarn is used in practically all textile products, either alone or in combination with silk, wool, or cotton.

**2. Staple Fiber.** A far-reaching development in the rayon industry is the invention of the so-called *staple fiber*, made by cutting rayon yarn into short lengths and then spinning it into a fiber; it promises a considerable increase in the amount of wood cellulose converted to textiles. The production of staple fiber in this country in 1935 amounted to only slightly more than 2 per cent of the total rayon fiber made in the United States, but by 1946 it had increased to more than 20 per cent of the total rayon production. The staple fiber is used largely as a substitute for cotton; the goods made of it are said to cost only about one-third as much as cotton materials. The staple fiber is, however, much less water-resistant than cotton and on this account is unsatisfactory when used alone. The advantages claimed for this product over that of rayon filaments are that it mixes well with cotton, silk, or wool, is less subject to crushing, and adds body to fabrics; it is also claimed that dirt does not adhere so much to the staple fiber as to other fabrics. When used in admixture (25 per cent in Germany) with cotton and other natural-fiber materials, the resulting fabrics are said to be of good strength and of fair water-resistant capacity.

## B. TRANSPARENT CELLULOSE FILMS AND CASINGS

Transparent cellulose films, sold under a variety of trade names such as Cellophane, Kodapak, and Protectoid, are produced either by the viscose or cellulose acetate method. The manufacturing process is identical to that employed in yarn manufacture, except that cellulose-containing solutions are forced through long slits instead of spinnerets. The solidified sheets

are then bleached, washed, and dipped into a bath of a softening agent, such as glycerol, and finally passed through a pair of squeeze rolls into a drier, where they are dried under tension. The entire operation is continuous.

To render cellulose films moistureproof, some manufacturers coat them with a thin film of cellulose nitrate lacquer. The cellulose films can be dyed in any desired color or can be embossed by means of pressure rolls. These films find wide application as a wrapping material for food products, textiles, confectionery, and other merchandise. They are also used in the manufacture of artificial flowers, bandages, and similar products.

Sausage casings, bands, and similar items are made by extruding viscose through annular slots into a coagulating bath. The film is coagulated in the form of a tube and then put through the various purification stages in a continuous operation.

### C. DEVELOPMENT OF THE RAYON INDUSTRY IN THE UNITED STATES

The American rights to the viscose process were acquired by the Central Artificial Silk Company of Landsdowne, Pennsylvania, in 1905. These rights were later purchased by S. W. Pettit, under whose direction production reached some 300 lb. of rayon a day. When Pettit died in 1909, his son sold the American rights to a company which, under the name of the Viscose Company of America, established a commercial plant at Marcus Hook, Pennsylvania, in 1910. The next year 365,000 lb. of artificial silk were produced at that plant.

From that time on the American rayon industry began to expand rapidly, reaching production of more than 10 million lb. in the year 1920 and of more than 750 million lb. in 1946. The production of rayon and staple fiber continues to increase at a rate of more than 50 million lb. a year.

Until 1936 the United States led in the production of rayon, with Japan a close second; in 1936 Japan displaced the United States as the world's largest producer of rayon, and in 1937 the United States went into third place, with Germany occupying second place and Italy fourth. The sensationally rapid development of rayon industries in Japan, Germany, and Italy was due in large extent to a rapid increase in consumption of rayon staple fiber. The demand for textiles generated by the Second World War, together with the difficulties of securing adequate supplies of natural fiber, gave impetus to the expansion of rayon production. A first world record of rayon filaments and staple fiber production was established in 1941. From then on however, a growing scarcity of coal and chemicals and a



disorganization of production temporarily reversed the world trend.\*

The American rayon industry is located mainly in the Eastern and Southeastern states, with the largest production concentrated in Pennsylvania, Maryland, West Virginia, Virginia, and Tennessee. About 65 per cent of the domestic rayon is manufactured by the viscose process and 35 per cent by the acetate process. Successful operation of a mill producing rayon involves a large capitalization. A daily capacity of 1 ton is considered the minimum scale of economical operation. The capacity of American plants ranges from 800,000 to about 35 million pounds a year. An average plant will cost about \$2,000,000, including working capital. The production costs are about equally divided among labor, raw material, and depreciation and overhead, although labor may sometimes account for as much as 50 per cent of the total cost.

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\* For instance, the total production of rayon in Germany after the conclusion of the Second World War dropped from a peak of 400,000 tons to less than 49,000, that of Italy from 144,000 tons to 43,000, and that of Japan from 245,000 to about 14,000 tons.

In 1951 the post-war recovery of trade brought production of rayon and acetate up to a new record of 3,957,470 tons. Of these, the United States accounted for about 33 per cent, Germany for 14 per cent, the United Kingdom and Japan for 9 per cent each, and Italy for 7 per cent.

## CHAPTER 18

### CARBONIZATION AND DESTRUCTIVE DISTILLATION OF WOOD

This chapter deals with the manufacture of charcoal in kilns and portable ovens and with the dry or destructive distillation of hardwoods and softwoods. The steam and solvent distillation of pine wood for the production of naval stores is discussed in the chapter on Naval Stores (Chap. 20).

The term *carbonization* is used to denote the production of charcoal irrespective of the method employed, while the term *destructive distillation* implies the recovery of distillates. Thus destructive distillation, as practiced, can be thought of as involving two classes of operations, carbonization and the collection and refining of distillates.

Destructive distillation of wood consists, primarily, of heating wood in a retort or oven in the absence of air (or in the presence of a limited amount of air) to form products of commercial value. The wood is decomposed, and the properties of its components are changed. The chemical changes involve the breaking down, by elevated temperature, of the more complex molecules into simpler ones. Wood has a complex structure, and it is not surprising that its thermal decomposition results in the production of a large number of compounds, some simple in structure and others highly complex. The crude products of destructive distillation may be classed as (1) noncondensable gases; (2) condensable vapors that yield crude pyro-ligneous acid and soluble and insoluble tars; and (3) the residue, charcoal. The manufacture of charcoal in kilns and portable ovens is simply carbonization, with no attempt made to recover the gases and vapors.

There is no record of the beginning of the wood-distillation industry, but there are numerous references to the manufacture of charcoal hundreds of years ago. American progress in developing the modern equipment of today has been gradual and has followed rather definite stages: (1) charcoal heaps or pit kilns without recovery of volatile products, (2) beehive kilns without and with recovery of some of the volatile products, (3) iron or steel retorts with recovery of volatile products, (4) modern steel ovens with emphasis on recovery of volatile products, and (5) retorts that operate continuously on chips and other small wood, with recovery of volatile materials.

Of the crude products of distillation, charcoal is usually the only one that is directly marketable. The gases are often used for fuel at the plant,

and the vapors are condensed. These condensates must be refined to yield salable products. The hardwood distillation industry has been undergoing great changes in refining methods, and much research effort is being spent in the direction of improved refining processes to produce various chemicals. The decline in the use of charcoal for the manufacture of iron and the introduction of synthetic products to compete with those obtainable from wood distillation have been responsible for this activity.

### I. CHARCOAL PRODUCTION WITHOUT RECOVERY OF BY-PRODUCTS

Although most of the charcoal manufactured in the United States comes from the destructive distillation of wood, a small amount is still produced in charcoal pit kilns and portable ovens. A bushel of charcoal as defined by the industry weighs 20 lb.

#### A. CHARCOAL PRODUCTION IN PIT KILNS

The simplest and most commonly used type of charcoal kiln in this country is the pit or dirt kiln. In this method, a central chimney 1 to 2 ft. in diameter is formed by driving several poles into the ground. Wood, in the form of pieces 3 to 4 ft. long, is stacked against the chimney; the sticks in the first layer are placed on end, leaning slightly toward the center. Then another layer of wood is laid flat on top of the first, and the stack is built in the form of a beehive. As the building of the pile progresses, the central chimney is filled with kindling, twigs, and other combustible material.

The entire mound, with the exception of the central opening, is then covered with a layer of twigs, on top of which several inches of sod, turf, or clay are placed. The fire is started by dropping embers down the central chimney or by pouring kerosene on the kindling material and lighting with a torch.

Successful carbonization depends on the admission of air in quantities just sufficient to start combustion. After combustion is proceeding at an even rate, air vents at the bottom of the pile are closed in order that carbonization may take place without allowing the charcoal formed to burn to ashes. When carbonization has been completed, the pile is allowed to cool one to several days, depending on the size of the pile.

The capacities of pit kilns vary from about 2 to 50 cords of wood. The carbonization time depends on the size of kiln, the moisture content of the wood, the species, and weather conditions; it may take from 2 to 5 days for a 2- to 5-cord pile and as much as 2 weeks for a large pile containing 30 to 50 cords. For best results, the wood must be at least partially air-seasoned.

To facilitate cooling, water is poured into the chimney. When the kiln is completely cooled, it is opened and the charcoal is raked from the mound. This operation should not be carried on if there is a strong wind, because there is always danger that the charcoal will ignite.

The yield of charcoal from such woods as maple, beech, and oak is about 30 to 40 bu. per cord of wood. This method is very wasteful when compared to the yields of charcoal obtained from destructive distillation, and, of course, no volatile products are recovered. In some instances, accumulated tar may be salvaged.

### B. THE BEEHIVE KILN

The *beehive kiln* was a special type formerly used to a great extent, especially in Michigan, to produce charcoal for iron manufacture. These kilns, usually built in the shape of a beehive, were constructed of brick or stone, with air holes provided at the base and an iron trap door on the top. The charge was introduced through this top opening, and the operation was started by igniting the wood at the bottom. The charging door was then closed or, in some instances, was left open until part of the moisture in the wood was driven off. The carbonization was accomplished by the heat generated from the combustion of a part of the charge, air being admitted through ports near the base of the kiln. Such kilns had capacities of from 20 to 90 cords of wood.

The beehive kiln gave a somewhat higher yield of charcoal, was easy to operate, and saved the labor involved in the construction of a new kiln for each charge. At first no attempts were made to save the volatile products, but later some were recovered and converted to methyl alcohol and acetate of lime.

Other nonportable types of ovens and kilns for the production of charcoal have been developed in Europe. These have been somewhat on the order of the American beehive kiln but differing fundamentally in one respect: they are equipped with furnaces that supply the heat for carbonization. The gases from the furnaces are led by means of flues through the wood to be carbonized. These European ovens are made of brick or cast iron.

### C. PORTABLE CHARCOAL OVENS

The portable charcoal oven was developed in Europe, and one type is described by Holsoe.<sup>14</sup> This kiln, octagonal in shape and tapered toward the top, is made of 10-gauge sheet metal riveted together and built in three sections: the lower, the upper, and the lid. The lid is provided with an 8-in. hole into which a length of stovepipe is inserted.

Kindling is placed in the center, and the wood, in cordwood lengths, is

stacked in the same manner as in the dirt kiln. When the first layer is completed, the two sections of the kiln are placed over the wood, and the second layer of wood is placed on top of the first. When the kiln is filled, the lid is put in place, and several holes are dug under the sides of the bottom section into which 8-in. stovepipe elbows are inserted to provide air inlets. The charge is ignited by lighting the kindling in the center, and when the fire is well started, the chimney on the top of the lid is closed. The air intake is then controlled by placing extra sections of stovepipe on alternate elbows, causing them to act as chimneys while the other elbows act as intakes. At intervals, these stovepipe sections are changed around to promote equal carbonization. When the carbonization is completed, all holes are closed and the oven is allowed to cool. Then the sections of the kiln are lifted. The capacity of this kiln is about 2 cords of wood.

Advantages claimed for this oven over a pit kiln of the same capacity are (1) much lower unit cost in producing charcoal, (2) greater yield of charcoal per cord, (3) shorter carbonization time, (4) shorter cooling periods, and (5) much less time and labor for the setting-up and dismantling operations.

## II. DESTRUCTIVE DISTILLATION OF HARDWOODS

As stated previously, distillation denotes carbonization plus the recovery of distillates. Many methods of carbonizing the wood in hardwood distillation have been developed, and they may be placed in two arbitrary groups, based on the size of wood used.

### A. CARBONIZATION PROCESSES USING WOOD OF LARGE SIZE

In these processes the wood used ranges from small blocks up to cordwood 63 in. long, in contrast to sawdust, chips, and similar small forms of wood. Development of equipment for handling these larger sized pieces has followed a rather definite pattern.

**1. Cast-iron and Steel Retorts.** While destructive distillation on a rather small scale was carried on in some beehive ovens, the first high yields of volatile products came with the adoption of cast-iron retorts. These retorts were horizontal cylinders about 42 in. in diameter and 8 ft. long, having a capacity of about five-eighths of a cord of wood. Later, steel retorts having a capacity of 2 to 3 cords came into use. These retorts were charged by hand, and they were usually set in pairs, with a firebox beneath for heating. The gases and vapors evolved from the carbonizing wood were led through condensers. The condensed vapors yielded pyroligneous acid

and tar, and the pyroligneous acid was refined to produce methyl alcohol and acetate of lime. The residue, charcoal, was raked out of the retort after it had been allowed to cool for a sufficient length of time to prevent combustion in air. These retorts, especially in hardwood distillation, were superseded by the steel ovens currently in use.

**2. Ovens.** The modern steel oven is rectangular in cross section, approximately 6 ft. wide and 8 ft. high. The ovens vary in length, usually from 26 to 54 ft., and have a capacity of 5 to 10 cords of wood. The steel of the oven is about  $\frac{3}{8}$  to  $\frac{1}{2}$  in. thick. Such ovens are set in brick chambers and, to allow for expansion and contraction, are suspended from steel beams supported by the surrounding brickwork. One firebox is provided under each short oven, but on long ovens a firebox is used under each end to get more uniform heating. Hot gases from the furnace pass along the underside of the oven, around its sides, and over the top. The better ovens are equipped with doors at each end; others have doors only at one end. An oven with doors on both ends permits more rapid charging and discharging; therefore it is more efficient from the standpoint of heat consumption, because it does not cool so much in charging and discharging processes. Virtually gastight inner doors are wedged onto the oven, and, in order to prevent condensation on their inner surfaces, they are protected by outer storm doors.

The bottom of the oven proper is set at the ground level in order to facilitate charging and discharging, and rails are provided for carrying the steel-slat buggies that hold the wood and retain the charcoal after distillation is completed. Each of these buggies has a capacity of 2 to 2½ cords of wood. An oven 54 ft. long holds four of these buggies, giving it a capacity of 8 to 10 cords.

Ovens are provided with one or two outlets to which condensers are attached. The condensers are usually of the upright tubular type, containing numerous copper tubes expanded into brass heads. The heads and tubes are enclosed in a steel shell. Water enters the condenser at the bottom and flows through an outlet at the top. The vapors and gases from the oven pass through the copper tubes, and the vapors are condensed. The condensate is collected in a basin at the bottom of the condenser, the basin being equipped with a trap that permits the condensate to escape but not the noncondensable gases. These gases are generally used for fuel and are led into mains that feed the oven furnaces, or they may be allowed to escape to the atmosphere when they cannot be used as fuel.

The time required to distill a charge of wood varies with the moisture content of the wood, the rate of heating, and other factors. The cycle may be completed in as few as 14 hours, or it may require 30 or more hours

a. *Wood for Oven Distillation.* Methods of handling wood prior to oven carbonization vary. Some large plants operate sawmills to recover salable lumber and utilize the low-grade material, slabs, and edgings for distillation purposes; other plants have mills especially for the purpose of cutting and splitting crooked logs and large limbs into the proper sizes for the ovens; and some plants buy wood in cordwood and slab forms.

It was once universal practice to use wood in cordwood lengths and to air-season this stock for a period of 1 to 2 years. This required a large investment in raw material, and, as competitive conditions became more severe, many plants installed predriers built of ceramic tile or similar material. These predriers are usually heated by the flue gases from the oven furnaces. The flue gases enter the predrier at the end nearer the oven, the end containing the driest wood. When predriers are used, green wood can be dried in 48 hours to a moisture content of about 25 to 30 per cent. Plants operating on an 18-hour carbonization schedule may have enough wood for three oven charges in the predrier at one time. In these instances, the wood may be dried to a moisture content of 20 per cent, or less, in 54 hours. Each oven has its own predrier. In order to facilitate predrying, some plants cut the wood into about 1-ft. lengths. Even at plants with mills and predriers, it is not uncommon to see a storage yard containing cordwood sufficient to keep the plant in operation for 3 to 4 months.

The principal species used in hardwood distillation are sugar maple, beech, birch, oak, hickory, black cherry, ash, and elm. Other species, such as poplar, basswood, hop-hornbeam, sourwood, black walnut, and dogwood are also used in some plants. In general, the lighter weight hardwoods are little used, because of low yields of products, but in some instances the heavier ones are little used because of inadequate supplies. Other species, such as black willow, are sometimes used to make charcoal for special purposes. Bark is not removed from the wood, pieces of greater diameter than 6 or 7 in. are usually split, unsound wood is rejected, and when purchased by the cord, the lengths vary from 48 to 63 in., depending on locality. One plant is now purchasing wood on a weight basis, making adjustments for excessively green stock. Another plant samples each load of wood for moisture content and pays for the calculated amount of dry wood substance.

It is generally believed that heartwood gives greater yields of products than sapwood and that wood from old-growth timber gives higher yields than wood from second-growth trees. Small-scale tests made by Hawley and Palmer<sup>13</sup> gave rather variable results for heartwood, sapwood, slabwood, limbs, and bark.

b. *Treatment of Charcoal.* The distillation of hardwood yields three immediate products: noncondensable gases; an aqueous condensate, pyro-

ligneous acid and tar, commonly called "green liquor," which is collected from the condensers; and charcoal as a residue in the retort.

As soon as the distillation is completed, the charcoal is taken from the oven and placed in almost airtight, uninsulated steel coolers in order to prevent the charcoal from burning to ashes when it strikes the air. When taken from the oven, the charcoal is glowing, and immediately upon contact with air, it blazes with almost explosive violence, although the transfer time from oven to cooler is only a few seconds. The charcoal must remain in these closed coolers for a period of about 48 hours in order that it will be cooled sufficiently to prevent spontaneous combustion when finally exposed to air. Plants operating on a 16- to 18-hour schedule must, therefore, have three of these steel coolers; those operating on longer schedules need fewer.

When the charcoal is taken from these coolers, it must remain out in the open for at least another 48 hours before it can be safely placed in storage bins. In large plants, the several buggies from a complete charge are hauled up an inclined track above the storage bin and placed in a rotary dumper, or *tipple*, that has the appearance of a cylindrical hollow cage with a rectangular opening just slightly larger than the cross section of a buggy. The tipple, mounted on rollers, is then rotated 180 degrees, and the buggies are completely emptied in this one operation. The charcoal remains in the bins for another 48 hours before screening, grading, and bagging in paper for shipment. Freight cars loaded with charcoal are held on a side track for another 24 hours as a precautionary measure, for spontaneous combustion is still to be feared. Fine charcoal screenings are held in storage at one plant for a minimum of 21 days before shipment.

Some plants pulverize all or part of the charcoal produced, mix it with a binder such as starch or wood tar, and compress the mixture into briquettes for domestic and campers' fuel. Others pulverize a part of the charcoal produced and pass steam through it at a temperature of approximately 1000°C. to form *activated carbon* that has a high *adsorptive capacity*. Activated carbon is becoming increasingly important in the treatment of municipal water supplies and sewage sludge beds and for the removal of objectionable odors, tastes, and colors from foods, medicinal products, and other substances.

*c. Utilization of Noncondensable Gases.* These gases are generally used for fuel under the ovens and, on the average, have a calorific value of 300 to 325 Btu per cu. ft. These gases have been used to supply carbon monoxide in the manufacture of benzaldehyde and propiophenone. One cord of hardwood produces about 7,000 cu. ft. of noncondensable gas.

**3. Retorts Heated by Inert Gases.** As early as 1921, a patent for carbonizing green wood by circulating heated inert gases through the wood in a



retort had been granted in this country. Several modifications and improvements on this type of carbonization were made in Germany, Belgium, and France, and commercial operations were established in those countries. The most publicized of these is the Reichert process developed in Germany. No American installations of the Reichert process have materialized, although at least one company gave it consideration about 10 years ago and others have considered it more recently.

Wood, in the form of chunks of 1 cu. ft. or less in volume, is placed in the top of an insulated steel retort, and the retort lid is fastened. Hot gases are then admitted at the top of the retort. These hot gases flow downward, dry the wood, and supply enough heat to cause the exothermic reaction in the dried wood. Gases containing the by-products of distillation leave the bottom of the retort, as does the charcoal residue. A bin at the bottom of the retort provides for the reduction of charcoal temperature by means of cool gases. These retorts may be operated continuously or discontinuously.

The inert, continuously circulating gases entering the top of the retort for drying and heating the wood to the carbonization temperature are the flue gases that are produced when the noncondensable gases from the distillation process are burned in a special furnace. These flue gases are preheated before entering the retort. When a battery of such retorts is operated, it is possible to keep the distillation process going without the use of other fuel. The temperature of these inert circulating gases and the heat generated in the distillation process can be controlled, and it is reported that the yields of charcoal and distillation by-products from the Reichert process exceed those obtainable in the conventional oven.

#### B. CARBONIZATION PROCESSES USING WOOD IN SMALL SIZES

The destructive distillation of wood of small sizes, particularly sawdust, is rather difficult. Solid wood is a poor conductor of heat, and a bulk of sawdust is even poorer in this respect because of the small air spaces between the particles in the mass. It is, therefore, extremely difficult to transfer heat to the center of a stationary mass of sawdust. In distillation, the sawdust must be agitated in one way or another, either by a stirrer or by a rotary retort. The stirrer or the rotary retort must have gastight connections with the stationary parts of the equipment, and if such a process is to be continuous, the sawdust must be introduced and the charcoal must be removed through virtually gastight arrangements. Although many methods of distilling sawdust have been proposed, none is in commercial operation. The distillation of wood chips is not as difficult as the distillation of sawdust. One commercial method for distilling

chips and one noncommercial method for distilling sawdust will be described.\*

1. **The Badger-Stafford Process.** One process, the Badger-Stafford, now in commercial operation at one plant † in the United States, was developed to utilize small pieces of wood, to take full advantage of the exothermic reaction in wood distillation, and to make the operation of carbonization a continuous one. Sawmill scrapwood is reduced to chips that are predried in sloping, rotary steel driers 10 ft. in diameter and 100 ft. long. Flue gases from the sawmill powerhouse enter the driers at about 315°C. and flow countercurrent to the wood.

The wood requires 3 hours to traverse the length of the driers, and the capacity of each drier is about 3 tons of wood delivered at a moisture content of about ½ per cent. The dried wood, while still hot, is then conveyed to stationary, cylindrical-vertical-type retorts 10 ft. in diameter and 40 ft. high, having insulated walls 18 in. thick composed of firebrick, diatomaceous earth, and insulating brick within the steel outside shell.

The dried chips are fed into the tops of these retorts continuously by means of barrel valves that are virtually airtight. The rate of feeding is controlled so that the heat liberated by the exothermic reaction will be sufficient to bring the incoming wood to the distillation point, thereby eliminating the application of external heat, once the process is started. The gases and vapors are led through a condenser on the side of each retort, and a constant pressure, equivalent to 0.1 in. of water, is maintained in each retort to control the rate of removal of noncondensable gases from the condensers. Charcoal passes through grates in the bottom of the retort, is withdrawn through a barrel valve, and is reduced in temperature in continuous coolers that are sprayed on the outside with water. It is then sent through conditioners that are similar to the coolers to remove the heat developed when the charcoal takes up oxygen from the air, in order to prevent combustion in storage. Temperatures in the retort vary from about 255°C. at the walls to 515°C. in the center.

Advantages of the Badger-Stafford process are that (1) fuel costs are saved by elimination of continuous external heating; (2) the operation is

\* A fluidization technique enabling the production of (1) charcoal from sawdust, (2) activated carbon from charcoal, or (3) activated carbon directly from sawdust in one-step operation is under investigation on the West Coast by the Stanford Research Institute and the Oregon Forest Products Laboratory. Carbonization and activation are attained by keeping the sawdust in suspension in an upward flow of a hot, gaseous medium. Advantages of the process include continuous operation, low mechanical energy requirements, simple equipment construction, speed of carbonization, and better control of the resultant carbon and chemical products.

† Ford Motor Company plant located at Kingsford, Michigan.

continuous; (3) the material is handled mechanically; (4) the process utilizes chipped wood; and (5) the distillation takes place under automatically controlled conditions. On the other hand, this process requires (1) that the wood be reduced to small sizes, (2) that the wood be quite dry before entering the retort, so much so that it is considered uneconomical to hog and dry green cordwood, and (3) that there be a market for charcoal in small sizes.

**2. Internally Heated Rotary Retort.** The Oregon Forest Products Laboratory, in 1943, inaugurated a research program to determine the feasibility of producing charcoal from sawdust. The equipment now in use is of a rather large laboratory size, and it is suitable for the carbonization of hardwood or softwood sawdust. The unit consists of an internally heated rotary retort, some by-product-recovery facilities, and milling and pressing machinery for the making of charcoal briquettes. The nearly horizontal retort is 17 in. in diameter and 20 ft. long, and slopes  $\frac{3}{16}$  in. per foot of length. Sawdust of 15 per cent moisture content or less, wet basis, is fed from a hopper into the high end of the retort by a screw conveyor. The retort is heated by a tube 6 in. in diameter, extending lengthwise through the center of the retort shell. A gas burner fires into the low end of the tube, and stack gases are discharged through outlets at the high end of the retort in such a manner that they do not come in contact with the wood gas produced in the carbonization process. The temperature is highest at the discharge (low) end of the retort and becomes progressively lower toward the feed (high) end.

Wood gas from the carbonizing sawdust is exhausted from the feed end of the retort and is passed through a small primary cooler where it is washed with a water spray. Some of the tars are condensed by the water spray. The washed gas then passes into a scrubbing tower 14 in. in diameter and 10 ft. high, where it is further cooled and where virtually all of the tars are removed. This tower contains baffles that provide large cooling surfaces as the gas passes upward countercurrent to the wash liquor. Settled tars are collected from a 50-cu. ft. vat where the wash liquor is accumulated and recirculated. Currently no attempt is made to recover the distillation by-products other than the settled tar. The water-soluble products are allowed to collect and to recirculate as wash liquor. After washing, the gas is conducted to the discharge end of the retort, to be used as fuel for the sawdust-charring process. The retort first is brought up to the required temperature by utility gas; after the charring reaction starts, sufficient wood gas is generated to more than supply the fuel required to maintain operation.

Charcoal is discharged through a double valve arrangement at the low end of the retort. The charcoal is cooled in airtight metal containers for

several days, until it can safely be put into burlap bags. For briquetting, the loose char is pulverized in a pan mill and mixed with a binder, either recovered wood tar or petroleum tar, then briquetted in a press. Green briquettes are then dried or calcined, depending on their proposed use.

### C. STAGES IN THE DISTILLATION PROCESS

In the distillation of wood, several phases are noted. These are best seen in the kind and amount of gas and vapors evolved (the vapors being measured by the distillate produced) and the temperatures of the wood and oven. In the first stage little gas is produced, and the distillate consists of water and very volatile oils. As the temperature of the oven rises to about 280°C., the interior of the wood rises only to about 100°C., the boiling point of water. Even at the end of this stage the amount of gas evolved is still small, but the amount of distillate decreases abruptly, signifying that the wood is becoming dry. In the second stage, the interior of the charge begins to rise rapidly from about 100°C. to about 275°C., and the oven temperature is near 300°C. The yield of distillate, consisting of tar and pyroligneous acid, increases rapidly, and so does the yield of gas. In the third stage, when the interior of the charge has reached about 275 to 280°C., the heat of the reaction is sufficient to carry on the distillation without the application of external heat, and the temperature of the interior of the charge rises above that of the exterior. In other words, the reaction becomes exothermic at a temperature of about 275°C. It is in this stage that the bulk of the pyroligneous acid, gas, and tar is produced. At a temperature of about 350°C., the exothermic reaction is finished and the temperature decreases. In the fourth stage, to complete the distillation, additional external heat is applied to rid the charcoal, as much as possible, of tarry bodies. The heat is usually increased to about 400°C., but very little distillate is produced. It is erroneous to say that charcoal is pure carbon, for analysis shows that charcoal contains only about 82 per cent carbon.

The gases \* evolved in wood carbonization contain a great deal of carbon dioxide, and the percentage of combustible gases (carbon monoxide, meth-

\* The average composition of the total gas evolved in hardwood carbonization, omitting nitrogen (N<sub>2</sub>) and the first 5 per cent and last 5 per cent of the gas, is as follows:

<i>Constituent</i>	<i>Per cent</i>
Carbon dioxide, CO <sub>2</sub> .....	50.74
Carbon monoxide, CO.....	27.88
Methane, CH <sub>4</sub> .....	11.36
Hydrogen, H <sub>2</sub> .....	4.21
Ethane, C <sub>2</sub> H <sub>6</sub> .....	3.09
Unsaturated hydrocarbons, such as ethylene, C <sub>2</sub> H <sub>4</sub> .....	2.72

ane, hydrogen, etc.) exceeds that of carbon dioxide only when the inside temperature of the wood and the temperature of the oven are above 350°C.

#### D. SOME FACTORS AFFECTING PRODUCTS

Klason<sup>15</sup> and his associates contributed much to our knowledge of the exothermic reaction in wood distillation. They distilled wood under vacuum in a short time and also at increased pressures and increased time. In short-time (2- to 3-day) vacuum distillation, it was found that no exothermic reaction occurred, that the amount of tar was materially greater than that obtained under ordinary atmospheric distillation, and that the charcoal yield was materially reduced. In longtime (14-day) distillation under atmospheric pressure, wherein maximum secondary reactions could occur, the amount of tar obtained was very low and the yield of charcoal was high. The tar obtained in vacuum distillation was lighter in color, more transparent, and harder than that obtained in ordinary distillation.

It was therefore concluded that the exothermic reaction of wood distilled at atmospheric pressure occurred not because of the primary reaction, but as the result of a secondary reaction in which the primary tar decomposed into secondary tar, tar coke, and other products. The higher yield of charcoal under atmospheric-pressure distillation is thought to be the result of a combination of primary charcoal and tar coke to form ordinary charcoal.

Klason also found that the yields of methyl alcohol and acetic acid were affected but little by the various methods of distillation. With increasing time, a slight decrease in acetic acid was noted, but the yield of acetone was increased to offset this. Alcohol and acetic acid are considered to be, from these results, primary products, and acetone a secondary product obtained at the expense of the acetic acid.

In commercial operations, the conditions of firing may affect the yield and types of various products. While this behavior is not noted in small-scale laboratory experiments, where the oven is uniformly heated and precise control of temperature is possible, commercial experience indicates that the yields\* of alcohol and acetic acid may be increased by careful firing over a longer period than is customarily used in the distillation cycle. This discrepancy is explained by the fact that the wood may be superheated, causing additional secondary reactions, such as the decomposition of methyl alcohol and acetic acid. Increased speed of distillation can be obtained only by employing higher temperatures, and as a result of higher temperature, secondary reactions are increased.

\* In commercial practice, the yield of acetic acid varies greatly, depending on the amount of control exercised over the conditions governing carbonization; alcohol yield is more constant with varying conditions.

The species of wood used has a pronounced effect on the products recovered and the yields obtained. For example, very little acetic acid and alcohol are carried in the pyroligneous acid from softwood distillation; the yields are so small that little or no attempt is made to recover them. Similarly, pine oil and turpentine are produced in the destructive distillation of southern pine but not in hardwood distillation. Chestnut gives a low yield of alcohol and a high yield of acetic acid; hickory gives a high yield of alcohol, but it is low in acetic acid.

### E. REFINING HARDWOOD PYROLIGNEOUS ACID AND TAR

Formerly it was universal practice to separate tar and oils from the raw pyroligneous acid distillate and to neutralize the tar- and oil-free acid with lime. A few plants still follow this procedure. The acetic acid and lime unite to form calcium acetate. The combination is then distilled in iron stills to free the acetate liquor of alcohol and any oils it contains. The residue is then put in settling tanks. The calcium acetate liquor is drawn off, concentrated, and dried to form a crude calcium acetate that can be shipped in bags. Acetic acid is recovered by the purchaser by mixing the crude calcium acetate with sulfuric acid and distilling, to get an 82 per cent product. Subsequent distillation must be performed to get glacial acetic acid. The weak alcohol from the iron still must be put into a fractionating column \* to yield a 92 to 95 per cent methanol. Some plants merely remove the water to get about an 82 per cent crude methanol, necessitating a subsequent distillation.

**1. Direct Acetic Acid-recovery Methods.** While the acetate of lime method is still used to some extent, increased production of synthetic acetic acid and synthetic methanol has prompted many operators to recover acetic

\* Fractionating columns used in the distillation industry are made of copper and are of the plate and bubble-cap type, with the plates bolted between flanged sections. Short pipes on the upper surface of a plate extend upward far enough into the dome-shaped bubble caps, which are slotted at their bases, so that vapors entering the cap from the compartment below must pass through accumulated condensate on the lower plate of the upper compartment. Vapors of constituents having the highest boiling points are condensed first in the lower compartments.

Part of the hot vapors coming from a lower compartment are cooled and condensed on the lower plate of the next higher compartment, and the vapor with lower-boiling constituents passes upward to repeat the process. Also, the hot vapors coming from a lower compartment cause the condensate in the upper compartment to boil, vaporizing any lower-boiling constituents, so that they go on up to the next compartment. If the condensate is not withdrawn from a compartment, an excess forms and overflows through specially provided pipes called *downcomers* to the next lower compartment to repeat the cycle. The downcomers are long enough to extend from the lower plate of an upper compartment into the condensate on the lower plate of the compartment directly below

acid directly from pyroligneous acid liquor. The conversion of acetic acid to acetate of lime and then back again is too costly to compete with the synthetic product. The competition of synthetic products has been so keen that the hardwood distillation industry has suffered great expense in converting plants from the traditional acetate of lime method to the direct acetic acid-recovery method.

Several methods of producing acetic acid directly are now in use, and others have been devised. Direct acetic acid recovery follows two general methods: (1) the use of a solvent for extracting the acid and (2) the use of an azeotropic mixture and distillation to remove water from the acetic acid. A combination of these two principles might be called a third method. The solvent extraction method may be divided again into two classes: (1) where the extracting solvent rises through the acid-containing liquor, picking up the acetic acid; and (2) where the solvent extracts the acetic acid from the vapors of the liquid containing the acid.

*a. Extraction of Acetic Acid from Liquor.* Examples of solvent extraction processes, using the solvent in contact with the acid-containing liquor in a fractionating column, are (1) the Brewster, using ethyl ether as the solvent, and (2) the modified Brewster, using a mixture of isopropyl ether and ethyl acetate. In these methods, the alcohol, oils, and tars are removed from the raw pyroligneous acid before the acetic acid is removed from the remaining liquor. The solvent is recovered from the acetic acid by distillation.

*b. Extraction of Acetic Acid from Vapor.* The Suida process, using a high-boiling-point wood-tar oil as the solvent, is typical of solvent extraction of acetic acid from pyroligneous acid vapor. Heavy tar is first removed from the raw pyroligneous acid in settling tanks. The raw liquor, free from settled tar, is then evaporated in a primary still above which is a scrubbing column. The vapors from the primary still enter the scrubbing column. The wood-oil solvent enters the top of the scrubbing column and flows downward countercurrent to the vapors, from which it absorbs the acetic acid. The solvent permits alcohol, water, and some of the wood oils present in the raw liquor to pass on to the top of the scrubbing column, but it absorbs virtually all the acetic acid.

The acid-oil combination in the lower part of the scrubbing column is dehydrated by passing over steam coils, and it is then fed directly to the lower part of a vacuum unit, where the acid is flashed off and is rectified in an upper vacuum column. The product, containing 90 to 92 per cent acetic acid, is drawn off and stored in aluminum storage tanks to await shipment. After the last traces of acetic acid are removed from the wood-oil solvent, the solvent is returned to the oil feed tank for reuse.

Evaporation of the pyroligneous acid in the primary stills leaves a residue

of soluble tar that is used as fuel after being steam-distilled to recover any acetic acid it might contain.

The weak alcohol mixture from the top of the scrubbing column is rectified in a continuous still to about a 90 per cent methanol that is then refined by chemical treatment and redistillation.

The fact that the wood-oil solvent in the Suida process is obtained from distillation of wood tar makes such a plant self-contained. Plants using other solvents must go to outside sources or else install special equipment for their production.

*c. Azeotropic Distillation.* Azeotropic distillation methods rely on the fact that many compounds form constant-boiling-point mixtures with water and alcohol and that the boiling points of these mixtures are lower than the boiling point of water alone. The compounds added to produce such mixtures are popularly referred to as "withdrawing agents." Examples of azeotropic distillation processes are the Othmer, using butyl acetate as the withdrawing agent; the Clamecy, originally using a low-boiling-point, light wood oil; and the Piron, using benzene or toluene. These methods are applied to the liquor remaining after tar, alcohol, and oils are removed from the pyroligneous acid. This liquid is placed in a fractionating column with the withdrawing agent and is distilled to remove the water. The water goes to the top of the column, and the water-free acetic acid is collected lower down. The acetic acid is then refined by distillation into glacial acetic acid and a fraction of higher-boiling acids. The withdrawing agent is recovered from the water for reuse.

*d. Solvent Extraction and Azeotropic Distillation.* The Melle process may be cited as one method of recovering acetic acid by using a combination of solvent extraction and azeotropic distillation. Ethyl acetate, which has azeotropic properties, is used as a solvent that has direct contact with the liquor.

*e. Other Solvents and Withdrawing Agents.* Solvents and withdrawing agents other than those cited may be used to extract acetic acid. One plant, for example, uses a mixture of ethyl and methyl acetates as a solvent, and it is possible to use as withdrawing agents benzol, xylol, ethylene dichloride, propyl acetate, and many other compounds.

**2. Steps in the Refining of Pyroligneous Acid and Tar.** The flow sheet in Fig. 18-1 shows the direct recovery of acetic acid by the solvent method, and it gives a general view of the conventional hardwood distillation process. The major products recovered, in addition to charcoal, are methanol and acetic acid. Minor products include allyl alcohol; methyl acetone (a mixture of methanol, methyl acetate, and acetone); wood tar, and alcohol oils; hardwood pitch; and formic, butyric, and propionic acids. Not all



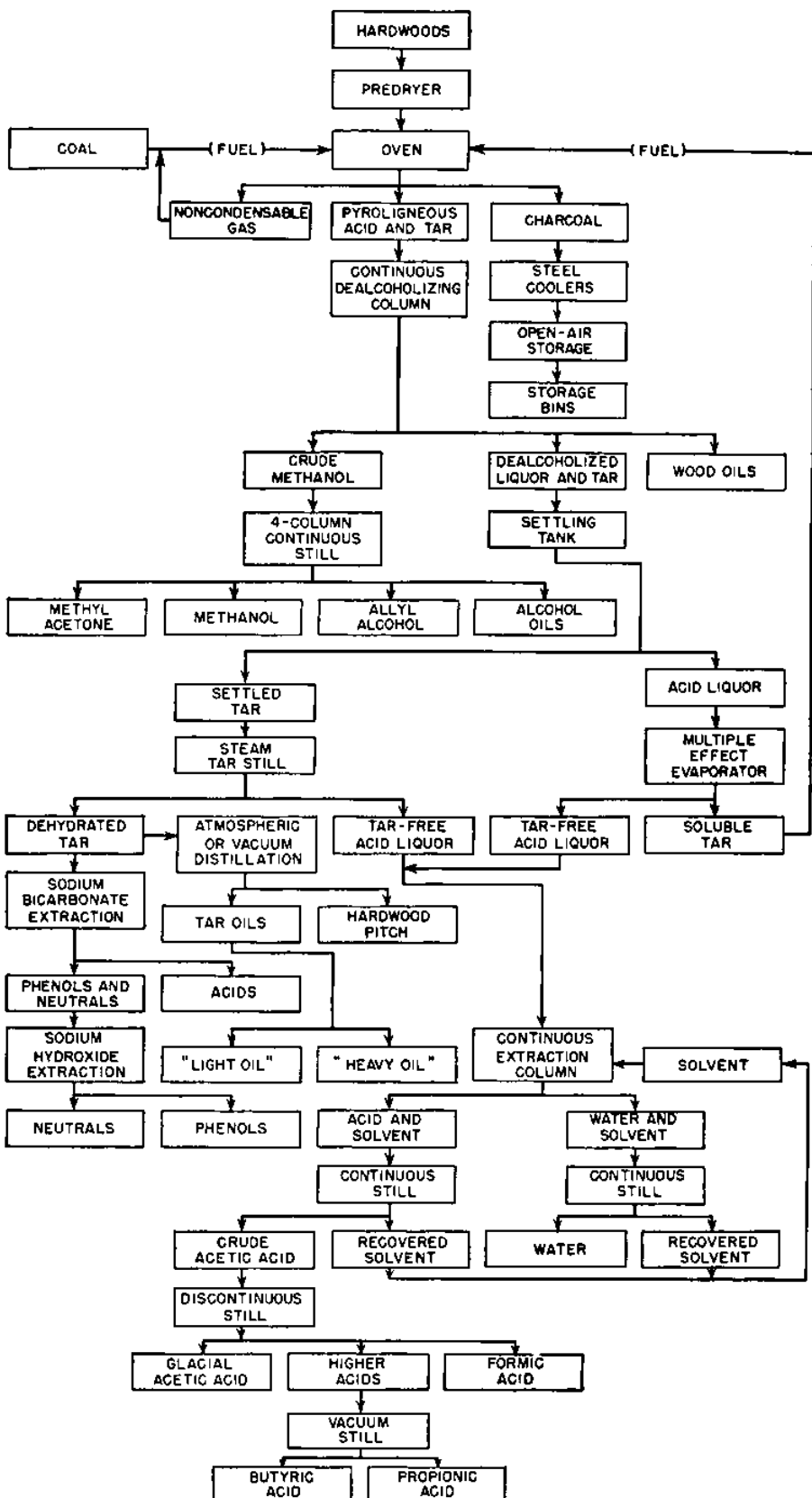


FIG. 18-1. Flow sheet for direct recovery of acetic acid by solvent method from destructive distillation of hardwoods.

distillation plants attempt to recover this list of products; but on the other hand, some recover products not named. The flow sheet, therefore, should not be regarded as directly applicable to every plant; procedures also vary. To cite only one example, many plants send the pyroligneous acid to settling tanks to remove heavy tar before extracting the alcohol.

A brief description of the refining of condensates from the oven, as indicated by the flow sheet, follows. The oven condensate, pyroligneous acid, is fed directly into a continuous dealcoholizing column, consisting of a rectifying and an exhausting section, which separates the pyroligneous vapors into a crude methanol and light oils. The oils are burned as fuel or may be sold when markets are available. The crude alcohol is taken to a four-column continuous still, and, by treatment with caustic and acid, a water-white, pure methanol that can be sold directly is obtained. This column also yields alcohol oils, allyl alcohol, and methyl acetone. Methyl acetone and allyl alcohol undergo further distillation at some plants, although this is not indicated on the flow sheet. The allyl alcohol may be concentrated in a discontinuous still and the methyl acetone may be treated in the same type of still to get various combinations of acetone, methyl acetate, and methanol.

The dealcoholized liquor and tar are discharged from the dealcoholizing column into settling tanks, where heavy tar settles to the bottom. The settled tar is taken to a steam tar still, where acid liquor is removed. The resultant dehydrated tar may be distilled under vacuum or at atmospheric pressure to yield hardwood pitch and tar oils. These tar oils can be further separated into "light" and "heavy" oils. Dehydrated tar also may be subjected to a sodium bicarbonate extraction to separate acids from phenols and neutrals. Separation of phenols and neutrals can be accomplished by a sodium hydroxide extraction.

The acid liquor from the settling tanks is fed into a multiple-effect evaporator to free it of soluble tar. The soluble-tar residue from the evaporator is usually used as fuel under the oven. The tar-free acid liquor from the tar still is combined with the tar-free acid liquor of the evaporator, and the two are fed into the top of a continuous extraction column. The solvent used in this case is injected at the base of the extractor, and the two liquors are countercurrent.

From the extraction column, a water solution containing some solvent is taken to a continuous still, where the solvent is recovered and the water is discharged to the sewer.

From the top of the extraction column, the solvent containing the acetic acid in solution is fed into a continuous still to obtain crude acetic acid and solvent. This solvent and the solvent recovered from the water solution are sent to a tank for reuse in the extraction column.

The crude acid solution goes to a discontinuous still \* and is separated into formic acid, glacial acetic acid, and a residue of higher acids that may be fractionated in a vacuum still with a proper rectifying column to produce butyric and propionic acids.

#### F. YIELDS OF HARDWOOD DISTILLATION PRODUCTS

Data regarding yields of hardwood distillation products are highly variable; yields are usually expressed on the cord basis. It is reasonable to expect these variations because of differences in plant equipment and operation, products recovered, and the fact that the gross volume of the cord, as purchased, varies from 128 to 160 cu. ft., depending on the individual operation. The range of yields quoted on the *cord* basis are:

<i>Product</i>	<i>Quantity</i>	
Noncondensable gas.....	7,000	-11,500 cu. ft
Charcoal.....	900	- 1,080 lb.
Raw pyroligneous acid.....	200	- 276 gal.
Acetate of lime.....	180	- 220 lb.
Acetic acid equivalent for acetate of lime.....	103	- 125 lb.
Crude methanol.....	9.5	- 11 gal.
Refined methanol equivalent for crude methanol.....	7.25-	8.5 gal.
Wood tar and oils.....	22	- 25 gal.

In arriving at the acetic acid equivalent for acetate of lime, it is assumed that 100 lb. of acetate of lime yields 57 lb. of glacial acetic acid; to get the refined methanol equivalent for crude methanol, it is assumed that it takes about 1.3 gal. of crude methanol to produce 1 gal. of refined methanol.

Under present conditions, an average yield of the three principal products, for a standard cord of 128 cu. ft., would be approximately 50 bu. of charcoal, weighing 1,000 lb.; 114 lb. of glacial acetic acid; and 8½ gal. of refined methanol. The high yield of refined methanol is accounted for by improvements in modern plants; one modern plant reports a consistent yield of 10 gal. of refined methanol and 125 lb. of glacial acetic acid.

One report<sup>20</sup> giving yields for the Badger-Stafford process quotes the following on the basis of 1 ton of dry hardwood chips:

Noncondensable gases.....	5,000 cu. ft.
Charcoal.....	600 lb.
Pyroligneous acid.....	111 gal.

\* Because of the high rate of corrosion and other disadvantages of batch systems, much work is now being done to develop methods for refining crude acetic acid in continuous columns.

The pyroligneous acid is reported to yield, in addition to 22 gal. of soluble tar and 66 lb. of pitch, the following:

<i>Product</i>	<i>Gallons</i>
Ethyl acetate.....	14.650
Creosote oil.....	3.250
Chemically pure methanol.....	3.118
Ethyl formate.....	1.270
Methyl acetate.....	0.945
Methyl acetone.....	0.653
Ketones.....	0.226
Allyl alcohol.....	0.048

In this instance acetic acid, as such, was not produced, but it was converted principally into ethyl acetate. The yield of glacial acetic acid per ton of dry wood was reported to be 101.0 lb.

The average cord of wood purchased by northern hardwood distillation plants contains approximately 2,750 lb. of dry wood substance. Therefore, to convert the above yields to an average cord basis, they should be multiplied by 1.375.

### III. DESTRUCTIVE DISTILLATION OF SOFTWOODS

Destructive distillation of softwoods, at the present time, is confined to the resinous wood of southern pines, particularly longleaf pine. Ordinary southern pine wood, including longleaf pine, does not contain enough resin for distillation purposes: only extremely pitchy pieces are suitable. The principal source of material for this industry is the resinous heartwood from fallen trees, logs, and stumps that are so old that the sapwood has rotted away. Such material is called *lightwood* or *fatwood*. Other sources of material are the resinous, conical bases of limbs, known as *pine knots*, from which the stemwood of the tree has rotted entirely away, and slabs from logs cut from trees that have been tapped for naval stores. This branch of the distillation industry is not very large, but it is important because it utilizes material that otherwise has value only as fuel.

The process of softwood destructive distillation is similar in principle to that outlined for hardwoods, but differences exist in the products obtained and in the method of refining distillates. The principal products recovered are charcoal, turpentine, pine oil, dipentene, pine tar, tar oils, and pitch. Softwood pyroligneous acid contains such small amounts of alcohol and acetic acid that no attempt is made to recover them; the oily fractions of the distillate yield the products of value.

There seems to be little standardization in preparing final products from crude oily distillate. Many plants have developed special products for

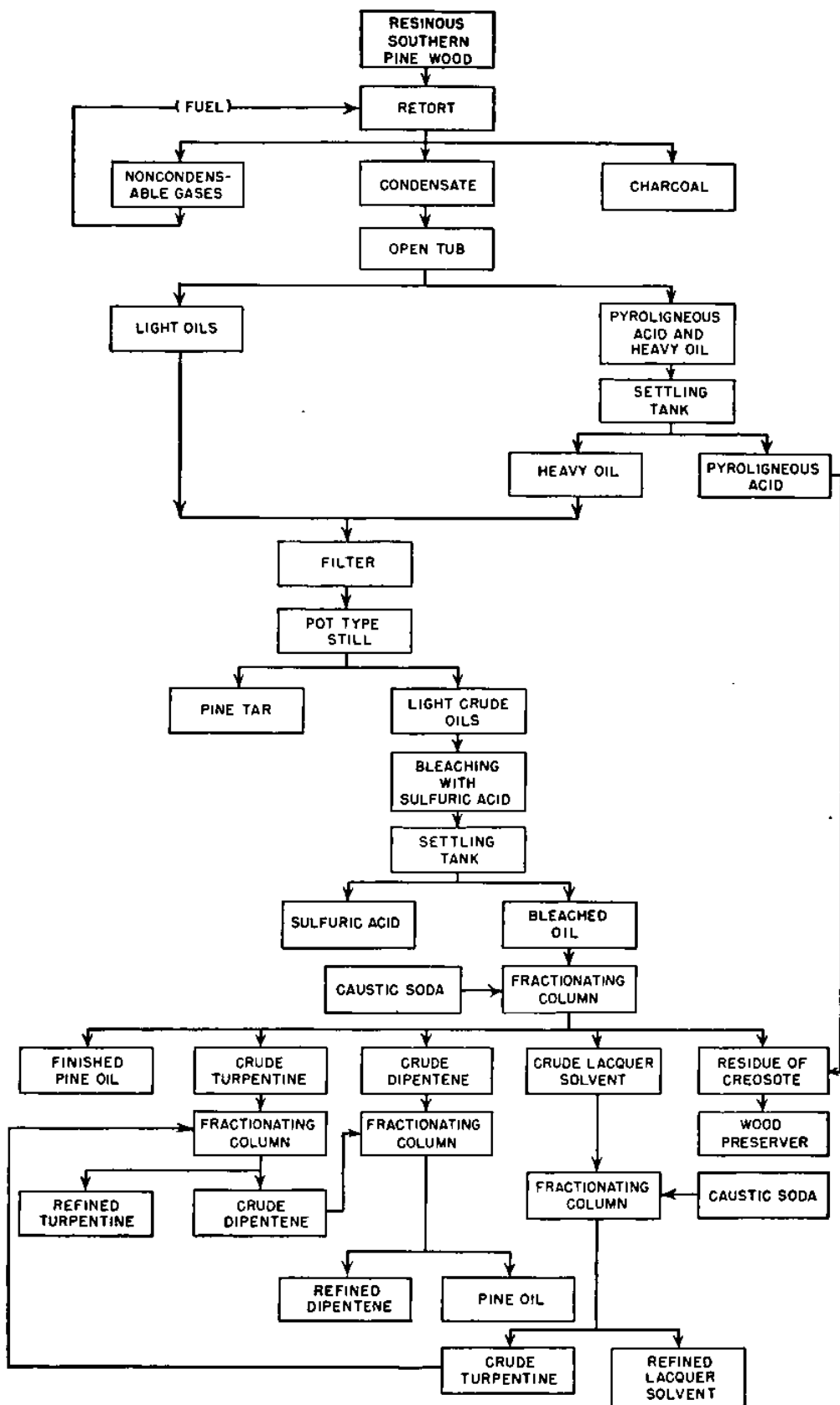


Fig. 18-2. Flow sheet for destructive distillation of southern pine.

particular markets, and some of the products obtained depend on the temperatures to which the wood is subjected. The following description and the flow sheet shown in Fig. 18-2 are based on one method<sup>19</sup> only.

Resinous pine wood is loaded into one-door, cylindrical steel retorts about 5 ft. in diameter and 16 ft. long. Two such retorts are heated by a brick furnace burning natural gas and the noncondensable gases given off during the carbonization period. The oven is heated for 16 hours and is allowed to cool for 8 hours before the charcoal is withdrawn.

The condensate is collected in an open tub, and that of the first half of the run is taken separately from the tub. It consists of the lighter oils. Pyroligneous acid produced in this period settles to the bottom of the tub and is drained off. Heavy oils are produced in the second half of the run, and they, with the pyroligneous acid, are put into settling tanks. Here the heavy oils settle to the bottom and the pyroligneous acid comes to the top.

After settling, the heavy and light oils are filtered and put into a pot still having a capacity of 110 bbl. Light crude oils and a residue of pine tar are obtained in this distillation. The pine tar is pumped into tank cars, to the barreling warehouse, or to storage. The light crude oils are agitated with sulfuric acid for bleaching, and the acid is permitted to settle out.

The oils are then put into a pot still having a fractionating column for another distillation in the presence of caustic soda. The fractionating column yields finished pine oil, crude turpentine, crude dipentene, and a fraction to be redistilled to produce a lacquer solvent. The residue in the still is a creosote, containing caustic soda. The creosote is neutralized by the addition of pyroligneous acid and may be sold as a wood preservative. The crude turpentine, crude dipentene, and crude lacquer solvent are pumped into separate storage tanks. These crudes are redistilled, one at a time, in a pot still with a fractionating column.\* The crude turpentine yields refined turpentine and crude dipentene; crude dipentene yields refined dipentene and pine oil; and the crude lacquer solvent, distilled in the presence of caustic soda, yields refined lacquer solvent and crude turpentine.

Yields from the destructive distillation of southern pine are extremely variable because of the lack of standardized methods and equipment in this branch of the wood-distillation industry. The variation in resin content of the wood also plays a major role in the amount of products recovered. One report gives the following yields for a cord of fatwood: 12 gal. refined turpentine, 1½ gal. pine oil, 50 gal. tar, and 800 to 900 lb. charcoal. Another report shows yields of 4 gal. "wood spirits," 7 gal. turpentine, 4 gal. pine oil, 12 gal. tar oil, 50 gal. tar, and 960 lb. charcoal.

\* In order to show on the flow sheet the complete disposition of products in the refining of the turpentine, dipentene, and lacquer-solvent crudes, three fractionating columns are shown, whereas only one is actually used for each crude in its turn.

## IV. USES OF SOME DESTRUCTIVE-DISTILLATION PRODUCTS

It is not feasible to list all products and the uses for each product derived from the destructive distillation of wood, but it is hoped that the following examples will serve to indicate the wide range and utility of distillation products.

Examples of hardwood distillation products are charcoal, acetic acid, acetone, methanol, tar oils, and hardwood pitch. The list of uses for charcoal is a long one that includes manufacture of charcoal iron in blast furnaces, domestic fuel, charcoal briquettes for domestic and campers' fuels, black-powder explosives, metal casehardening compounds and other metallurgical uses, water filtration, chemical manufacture, producer gas, decolorizing, stock and poultry foods, medicines, and activated carbon for gas adsorption.

Acetic acid, a most important organic compound, is used in making inorganic acetates, such as lead, copper, iron, and sodium acetates; white lead pigments; methyl, ethyl, and amyl acetate solvents; and cellulose acetate for rayon, motion picture and photographic films, lacquers, plastics, and transparent wrapping sheets. It is also used for coagulating plantation-rubber latex, for perfumes, and as a mordant in textile dyeing.

Acetone from wood distillation was formerly used as a solvent for airplane "dopes" (protective coatings for airplane wings), acetylene, and the explosive, cordite. Acetone from synthetic and fermentation processes has now displaced wood-distillation acetone.

Methanol is used in the manufacture of other chemical compounds, shellac, dry-cleaning agents, formaldehyde, pyroxylin products, paints, varnishes, antifreeze, and textile-finishing agents. It is also used as a denaturant for ethyl alcohol.

Tar-oil products may be used for flotation oils, solvent oils, oils for paints and stains, wood creosote preservatives, and inhibitor oils for stabilizing gasoline.

Hardwood pitch is used for insulating purposes in electric transformers and as a filler in rubber.

Some products from the refining of the condensates in the destructive distillation of southern pine are wood turpentine, pine oil, dipentene, lacquer solvent, pine tar, tar oils, and creosote oils, all taken from the oily fractions. The oil-free pyroligneous acid is combined with the creosote oils to produce a wood preservative. Small amounts of pyroligneous acid derivatives have been used to give liquid and salt meat cures a "smoked" flavor, especially in France.

Wood turpentine from destructively distilled pine must be labeled as

such, and it is used by paint and varnish manufacturers. It is also used in the manufacture of synthetic camphor, employed in the making of celluloid.

Pine oil is used for paints, flotation oils, disinfectants, and in the treatment of fabrics before dyeing. Dipentene is used as a solvent in reclaiming old rubber. Pine tar has a large number of uses, the most important of which are in the compounding of rubber and the manufacture of cordage, oakum, soaps, coating and binding materials, medicines, and disinfectants. Tar oils are used in reclaiming rubber and for paints, stains, disinfectants, soaps, and flotation oils.

The uses of southern pine charcoal are about the same as those of hardwood charcoal, but the most important use is for domestic fuel.

#### V. THE WOOD-DISTILLATION INDUSTRY

The wood-distillation industry in the United States is faced with the twin problems of diminishing supplies of available raw material and shrinking markets for its products. Observations of the U.S. Forest Products Laboratory<sup>3</sup> indicate that, despite the utilization of heretofore-unused species, it is becoming increasingly difficult to supply wood-distillation plants with raw material that will permit profitable operation. The fact that the wood-distillation industry, as a whole, can and does utilize wood in the forms of tops, large limbs, low-grade logs, broken and crooked material, stumps, knots, and sawmill leavings makes it an important factor furthering integrated utilization of our forest resources. Most of the larger sizes of wood used by this industry are unsuited for sawlog material. A few plants use wood from thrifty second-growth stands, and many purchase cordwood from nearby farm woodlands. The managements of large distillation companies are keenly aware of the need for future raw material, and the trend in the management of their forest properties is toward sustained yield. Such an industry should be perpetuated and given opportunity for expansion by enlarging the markets for its products.

The supply of raw material has determined the locations of plants and also the types of products recovered. The industry, therefore, may be divided into two branches: hardwood distillation and softwood distillation.

#### A. THE HARDWOOD-DISTILLATION BRANCH

Plants for the destructive distillation of hardwoods have been located in the following general areas in the United States: (1) the Northeastern states, (2) the Lake states district, comprising Michigan and Wisconsin, and (3) the South Central states of Arkansas, Missouri, and Tennessee. At the beginning of the 20-year period 1928 to 1948, 52 plants, with a rated annual capacity of about 950,000 cords, were operating; at the end of this



period, only 20 plants, with a rated annual capacity of about 425,000 cords, were active. Of the 20 active plants, the daily capacities vary from less than 30 cords to 200 cords of wood. Direct recovery of acetic acid is practiced in eight plants, five having a daily capacity of about 60 cords each and three having a daily capacity of approximately 200 cords each. These eight plants consume somewhat more than half of the annual wood requirements of this branch of the wood-distillation industry.

The larger units of the hardwood-distillation branch, because of the competition of synthesized products, greater raw-material costs, and higher labor costs, have made strenuous efforts to place the distillation of hardwoods on a scientific basis. The "art" of wood distillation is giving way to new methods for obtaining maximum yields, lower costs, and greater refinement of products. This is most strikingly shown by the diminution of acetate of lime production because of the application of direct methods for extracting acetic acid. Adoption of continuous carbonization processes and development of new mechanical wood-handling devices may increase efficiency and further reduce production costs.

Although large tonnages of charcoal have been replaced by coke in the metallurgical field and by other carbons in the chemical industries, charcoal remains the most valuable product of hardwood distillation. Recent estimates indicate that the largest tonnages of charcoal will be used for domestic and campers' fuel and for specialty uses. Some observers feel that the hardwood-distillation industry is limited more by charcoal-market conditions than by the competition of synthetic methanol and synthetic and fermented acetic acids. The principal income of the industry is dependent on markets for the three primary products, charcoal, acetic acid, and methanol, but the operating rate seems to be determined by the volume of the charcoal sold. These three products are derived in a fairly constant proportion that cannot be altered. To expand production under such conditions, an enlarged charcoal market is necessary. Specialized uses may provide expanded markets. Imports of foreign charcoal, principally from Mexico and Canada, amount to only about 1 per cent of our total production and do not compete seriously in our domestic markets. If present markets for charcoal can be maintained or expanded somewhat, it is estimated that the hardwood-distillation industry will consume about 500,000 cords of wood annually.

#### B. THE SOFTWOOD-DISTILLATION BRANCH

The status of the softwood-distillation branch of the industry virtually parallels that of the hardwood-distillation branch with respect to available supplies of wood, higher chemical-wood costs, higher labor costs, and

competition in the marketing of its products. Supplies of old-growth, highly resinous stumps and other pine wood are becoming less abundant, and second-growth trees lack the necessary resin content for successful distillation by current methods. Despite dwindling supplies of suitable wood, the annual wood consumption, on a cord basis, has remained relatively constant in the last 15 to 20 years. The average annual consumption of wood is about 120,000 cords.

The number of distillation plants operating in the last 15 or more years has also remained fairly constant. Of the five plants now operating, two are in Louisiana and three in Florida.

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## CHAPTER 19

### WOOD SACCHARIFICATION

Stated simply, "saccharification" means "converting to sugar." Wood saccharification is the acid hydrolysis of the cellulosic constituents of wood to produce simple sugars. The sugars thus formed may then be used for the propagation of yeasts to be used as stock feed and as a high-protein food for human consumption, or they may be fermented to produce industrial ethyl alcohol. The sugar wort \* may also be concentrated by evaporation to form molasses, which can be substituted for most of the uses of cane molasses. It is not suited for human consumption because of the presence of pentose sugars.

Commercially, saccharification is accomplished with dilute sulfuric or sulfurous acid (Scholler process) or with concentrated hydrochloric acid (Bergius process). Limited hydrolysis can be accomplished with superheated steam and some organic acids, such as acetic acid. The primary action of acid hydrolysis consists of converting the wood into its major component parts, *viz.*, carbohydrates and lignin. The carbohydrates in wood, composed for the most part of cellulose and hemicelluloses, comprise roughly three-fourths of the wood and are the source of wood sugars. The lignin, being insoluble, is left as a residue.

The celluloses and hemicelluloses are polymers made up of long chains of sugar molecules joined together chemically. Alpha-cellulose, which is the most stable carbohydrate constituent of wood, is composed largely of molecules of glucose, a sugar having 6 carbon atoms. The hemicelluloses contain molecules having both 5 and 6 carbon atoms. Only the 6-carbon sugars (hexoses,  $C_6H_{12}O_6$ ) † are readily fermented to alcohol by brewer's yeast, the 5-carbon sugars (pentoses,  $C_5H_{10}O_5$ ) remaining in solution in the beer after the hexose sugars are converted to alcohol. The pentose sugars are fermentable by various organisms, but the time required to convert them to alcohol is too long to be commercially feasible. They can, however, be used for the harvest of yeasts suitable for protein foods.<sup>9</sup>

During the early stages of experimentation and development, the

\* A sugar solution, neutralized and ready for fermentation.

† Galactose is fermentable with brewer's yeast, but the process is too slow to be commercially feasible.

processes using concentrated hydrochloric and dilute sulfuric acids received the most attention. At the present time the Scholler process, which employs dilute sulfuric acid, is used most widely in Europe and is the one that was introduced into the United States during the Second World War. Briefly, the Scholler process consists of hydrolyzing wood chips under pressure with dilute sulfuric acid and steam, removing the hydrolyzate as rapidly as possible, neutralizing the excess acid, and fermenting the resulting sugar solution with yeast to produce ethyl alcohol. Improvements in this process, developed for incorporation into the federally sponsored plant at Springfield, Oregon, will be discussed in some detail in subsequent paragraphs.

It is worthy of mention that the Scholler process was evaluated in this country in 1935 by the Cliffs Iron Company, which acquired the American rights to the Scholler process. Based on pilot-plant studies conducted at Marquette, Michigan, at that time, it was decided that the process could not compete with alcohol produced from cheap imported molasses, and both the patent rights and the investigations were abandoned.

#### I. THE MADISON WOOD-SUGAR PROCESS

With the entry of the United States into the Second World War, requirements for industrial ethyl alcohol jumped from 155 million wine gallons \* in 1941 to nearly 600 million wine gallons in 1944. Early in 1942, government agencies foresaw that existing sources might be unable to supply the ever-increasing demands, particularly in the event of possible grain shortages. Consequently, steps were taken to explore the possibilities of using wood as a source of industrial alcohol. After many delays and much urging by the U.S. Forest Service, the lumber industry, and other interested organizations, the program was finally implemented. Invaluable technical assistance was given by several German scientists who had been associated with wood-sugar operations in Germany prior to the Second World War.

The purpose of preliminary studies conducted at the U.S. Forest Products Laboratory was to determine the applicability of the Scholler process to indigenous wood species and to acquire the engineering knowledge required for the construction of a wood-sugar plant capable of producing alcohol from wood. Initial experiments were made in an existing pilot plant at Marquette, Michigan, where major commercial species growing in the United States were tested for their suitability as a source of wood sugar.

\* A wine gallon is one U.S. standard gallon of 190 proof alcohol, which is the equivalent of one U.S. standard gallon of 95 per cent alcohol by volume.

Efforts were concentrated on Douglas fir and southern yellow pines, however, because of the availability of large concentrations of sawmill residues from these species. Studies of Douglas fir disclosed that sugar yields of about 50 per cent of the dry weight of wood could be obtained using an 0.5 per cent concentration of sulfuric acid at a water-wood ratio of 8 to 1. Consistent yields of approximately 50 gal. of alcohol per ton of dry wood were obtained, and the adaptability of the process to use with southern yellow pines was also demonstrated, although yields were somewhat lower.

On the basis of these studies, the Springfield, Oregon, plant was designed by the Vulcan Copper and Supply Company of Cincinnati, Ohio, for a daily production of 11,500 gal. of 95 per cent alcohol from 220 tons of dry, substantially bark-free, Douglas fir mill residues; approximately 52 gal. per ton of wood.

Later studies, conducted while the plant at Springfield was under construction, disclosed that continuous percolation was more efficient than the batch process employed by Scholler. The improved process is described in a U.S. Forest Service Publication <sup>11</sup> as follows.

A process known as the Madison wood-sugar process has been developed by the Forest Products Laboratory for hydrolyzing mixtures of wood waste consisting of chipped slabs and edgings, sawdust and shavings, with 0.5 to 0.6 per cent sulfuric acid at temperatures of 150 to 180°C. by allowing the dilute acid to flow continuously through the charge of wood.

Compared with the German Scholler process, hydrolysis was accomplished in less time, because the sugars produced by the hydrolysis were removed more rapidly. Heating was at a lower rate, and more efficient use could be made of the heat given off by the liquors being removed from the hydrolyzer, resulting in a lower steam requirement. Decomposition was less, because the sugars were in contact with the acid for a shorter period of time and, consequently, yields of sugar and alcohol were higher. Fewer by-products inhibitory to fermentation were produced, resulting in more rapid fermentations. Life of valves and other equipment was increased because they were set once for the run and not changed until the end of the run. The sugar produced in 2.8 hours from a ton of dry, bark-free Douglas fir wood waste yielded 64.5 gal. of 95 per cent alcohol as compared to 3.2 hours for 58 gal. by the rapid-cycle method developed earlier, and 13 to 20 hours for 55 gal. by the Scholler process as practiced in Germany.

The prediction of increased yields indicated in the above report was based on laboratory-scale pilot-plant studies. As yet, there are not sufficient data to confirm these predicted yields, nor is it known positively that the original design of the plant can economically be altered to incorporate all the new features that would be required. These new developments, however, hold promise for the future.

Based on the original design, yields of alcohol, raw-materials requirements, and by-product output would be approximately as follows:

Daily production of alcohol (95 per cent).....	11,500 gal.
Annual production of alcohol (95 per cent).....	4,150,000 gal.
Sawmill residues (dry wood, bark-free).....	220 tons
Sawmill residues (dry wood, with bark) *.....	300 tons
Lignin residue (dry basis).....	65-70 tons
Calcium sulfate dihydrate (gypsum, or land plaster).....	20 tons
Still-bottom liquors.....	1,600 tons
	or, approximately, 400,000 gal.

The lignin, calcium sulfate, and still-bottom liquors are separated in the normal operation of the plant. In addition, furfural, methanol, fusel oil, pentose sugars, carbon dioxide, and small amounts of acetic acid can be recovered. The pentose sugars, nonfermentable in the alcohol-fermentation process, amount to approximately 12 tons per day, or 0.6 per cent by weight of the still bottoms. The yield of carbon dioxide would be between 40 and 50 tons daily.

Since the original pilot-plant results described above showed promise of ready translation to commercial-scale operations, the Vulcan Copper and Supply Company prepared a detailed plan for the construction of a modern plant, embodying the original improvements and modifications of the Scholler process which the studies had shown to be desirable. After careful consideration of available supplies of sawmill residues, which took into account the other uses of such materials in various milling centers, the area surrounding Eugene, Oregon, was chosen as being the most suitable. Accordingly, an operating company was formed, and plant construction was commenced early in 1944 at a site near Springfield, Oregon (Fig. 19-1).

## II. THE WOOD-SUGAR ALCOHOL PLANT AT SPRINGFIELD, OREGON

At the time this is written, the wood-sugar alcohol plant at Springfield, Oregon, is shut down while the government decides its disposition.† A study of the facts leading to the initiation of the project is necessary if an understanding of the present status is to be reached.

The urgency of wartime requirements inspired the erection of the plant; consequently plans were based on more meager data than is customary in the commercial development of new processes during normal times. Cost

\* Normal; or average, Douglas fir mill residue contains about 25 per cent bark, which yields little sugar.

† Since this chapter was written, the War Assets Administration has leased the plant to an operating company. It is understood that the company intends to place major emphasis on the production of wood-sugar molasses and yeast.

was no object at the time, yet the plan of financing provided little margin for the engineering changes invariably encountered in the development of a new process from the pilot-plant stage to full-scale production. Had the Second World War continued, there is no doubt that funds would

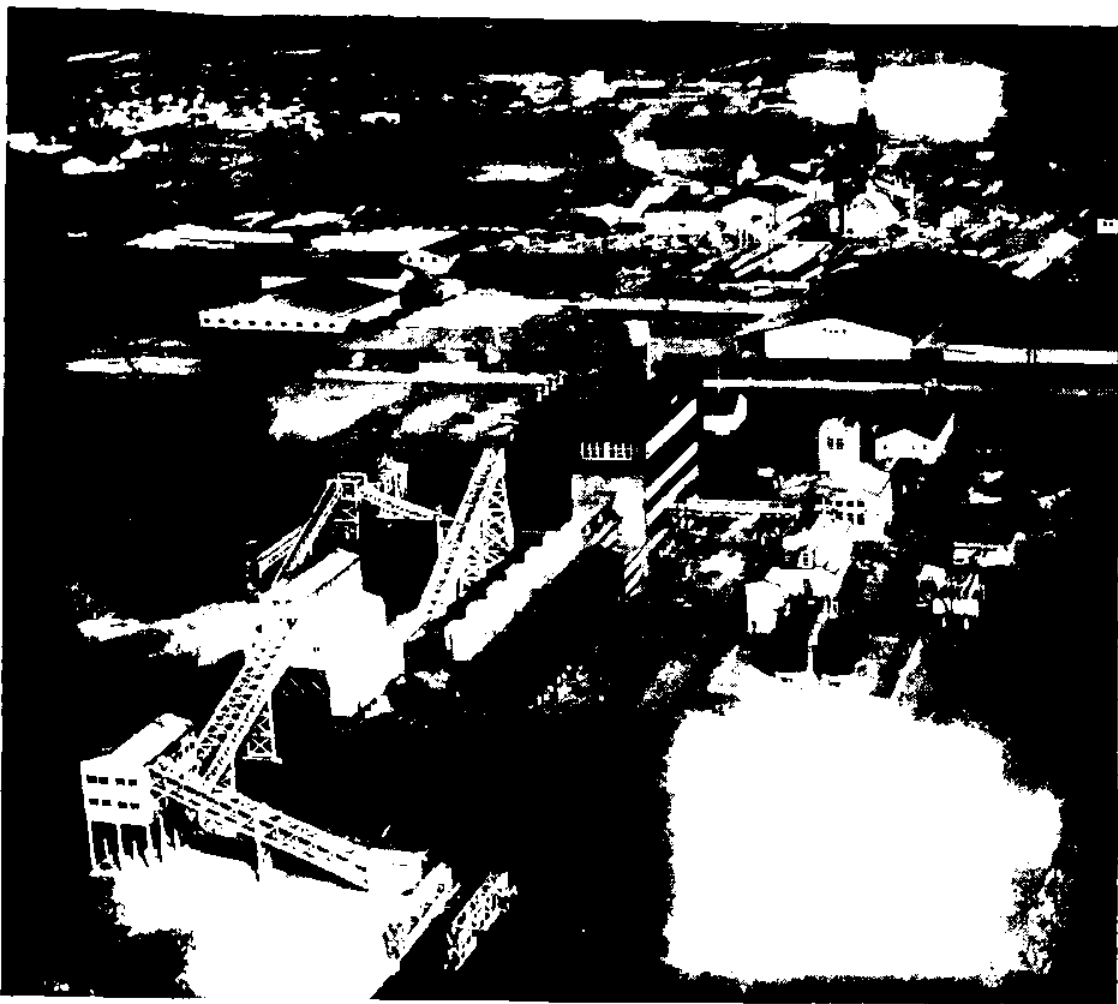


FIG. 19-1. General view of the wood-sugar alcohol plant at Springfield, Oregon. The three large chip conveyers in the foreground are, in order, unloading facilities to screening section, screening section to chip storage, and storage to the percolation section. The remaining conveyers, at the left, are the fuel conveyers to the power plant. The large unit at the center rear is the distillation section. The tanks in the center plant are wort storage, beer wells, and fermenters. (Courtesy of Vulcan Copper and Supply Company.)

have been provided for the minor changes (minor in terms of the total cost of \$3,100,000) which proved necessary. As it happened, the small contingency margin originally provided was soon depleted as a result of several major factors that could not be foreseen at the time the project was planned and financed. Construction was delayed through slow deliveries of vital equipment. Construction, labor, and materials costs rose sharply after the War. Changes based on concurrent research were made while the plant was under construction. At one stage, in the latter part



of 1946, the plant was closed, labor laid off, and materials removed from the job.

Despite these handicaps, the plant was completed in May of 1947 under the sponsorship of the U.S. Department of Agriculture, which assumed responsibility for the project from the War Production Board at the end of the Second World War. The first shipment of alcohol, 8,000 gal., left the plant for a Middle Western destination in the latter part of May. Operations of the plant on a one- and two-percolator basis, however, disclosed engineering problems and operational difficulties that indicated a need for completion of some essential parts of the plant that had been eliminated in the interests of economy. The need for minor changes in both equipment and operating techniques was also indicated. The need for these changes arose in part from extreme variations in the amount of sawdust and bark contained in the wood supply and in part because of process characteristics that could not be predicted in designing a full-scale plant on the basis of laboratory-scale pilot-plant studies. Although the estimated cost of correcting the faults was not great, the Willamette Valley Wood Chemical Company, the lessee, composed of a group of Oregon lumbermen, decided to accept a lease termination pending a final determination by the government of the permanent status of the plant.

In spite of this setback, the trial percolations demonstrated rather conclusively that the plant can be made to function. Specialists in the field are in rather general agreement that the incorporation of relatively minor changes will prove the commercial feasibility of producing alcohol from wood. In fact, the prospects are becoming increasingly promising because of continuing demands for industrial alcohol, improved prospects for obtaining additional returns from by-products, current economic developments, and other factors.

The Springfield plant may play an important part in the future of wood utilization and in the over-all forest economy of the nation. A description of the plant and a discussion of operating practices, in so far as they are known at present, should be of interest.

#### A. WOOD-HANDLING EQUIPMENT

Chips may be brought to the plant by either railroad cars or trucks and are deposited on an unloading conveyer that discharges on an inclined-belt conveyer leading to an elevated revolving screen. This screen is designed to separate enough of the coarse chips (about 10 per cent) from the incoming wood for use as a filter bed in the bottoms of the percolators. Long splinters are rejected and routed to a hammer mill, where they are reduced and then returned to the wood supply.

The coarser chips, which are to be used as a filter bed in the percolators, are transferred to a separate bin by an inclined conveyer, the main body of the wood being conveyed by another inclined belt to a distributing conveyer mounted above the chip-storage bins that have a capacity of a 1-day supply of wood. The wood storage is divided into bins, each of which converges to accommodate a variable-speed, apron-type feeder. Any or all of the feeders may be operated to discharge at the same time in order to deliver chips to a belt collector-conveyer at any desired rate. The latter belt is equipped with a recording and integrating conveyer scale that weighs the wood as the percolators are charged. The collector-conveyer delivers the weighed chips to an inclined belt that elevates them to a horizontal delivery belt over the five percolators. Actuation of a movable automatic tripper permits discharging chips from the conveyer into any one of the percolators. An interesting feature of the conveyer system is the installation of interlocking drives that prevent the belts from being started or stopped in other than their proper sequence.

#### B. HYDROLYSIS

The percolators, lined with an acid-resisting alloy, are approximately 8 ft. in diameter by 50 ft. high, 2,100 cu. ft. in volume, and capable of holding about 27 tons of wood at 40 per cent moisture content, which is the average for mill residues received at the plant (Fig. 19-2). Charging is accomplished by "shocking" successive additions of chips with steam to secure the desired degree of packing, which is approximately 16 lb. of dry wood substance per cubic foot. Following removal of air through a vent at the top of the percolator by the introduction of steam at the bottom, the charge is preheated until a pressure of 60 p.s.i. is attained. This corresponds to a temperature of 153°C.

When the plant was designed, hydrolysis was to be accomplished by a batch process. Water batches were to be metered by time-cycle controllers. It was planned to add the sulfuric acid in the water line between the water tanks and the percolator at a pressure slightly higher than the maximum attained in the percolators, the amount of acid added for each batch being controlled at the proper concentration by a proportioning flow controller. During construction of the plant, however, experiments disclosed that the hydrolysis could be accomplished more efficiently by a continuous method, and the controls were altered to incorporate the necessary changes.

As soon as the charge has been preheated, dilute (0.5 to 0.6 per cent) sulfuric acid at 150°C. is added, and the sugar-bearing acid solution is removed continuously. The steam pressure is raised gradually in order to increase the temperature of the charge an average of about 0.5°C. per

minute until the maximum temperature of 185°C. is attained. When hydrolysis has progressed to the desired limit and all the hydrolyzate has been removed, the wood residue, consisting mostly of lignin, is discharged. The lignin is then conveyed to a continuous dewatering press that reduces the moisture content to 50 per cent or less and recovers the expressed liquid. The latter is returned to the main body of liquor from the per-



FIG. 19 2. Operating floor of the percolation section, showing the chip conveyers above, and the tops of the five percolators with their motor-operated valves at the floor level. (Courtesy of Vulcan Copper and Supply Company.)

colator, while the pressed lignin is transferred by conveyer to the fuel bin. Operating cycles that can be obtained after the plant is modified are not known, but experimental results indicate that 6-hour cycles, including charging, percolation, and discharging, are possible.

The liquor from the percolators and also that recovered in the lignin presses is discharged into a flash tank that is maintained at a pressure of 40 p.s.i. by an automatic pressure-relief valve. Here steam, furfural, methanol, and acetic acid flash off until the liquor has reached the proper temperature for neutralization, the vapors being passed through heat exchangers to preheat the water for the percolators. The chemicals mentioned may be recovered as by-products and thus reduce the cost of alcohol, although the process has not reached this stage of development at the present time.

While the sugar concentration of the first acid solution to pass through the percolator may be as high as 10 per cent and of the last as low as 1 per

cent, the liquor leaving the flash tank has an average concentration of about 5 per cent. This is discharged from the flash tank (controlled by an automatic level controller) by pumps through a system of pipes, where neutralization to a pH of 5.2 is accomplished by the addition of milk of lime. The neutralization treatment produces an insoluble calcium sulfate that is removed by pumping the sugar solution through filter presses. All the foregoing operations are conducted at pressures of 35 to 40 p.s.i. The calcium sulfate filter cake is discharged after being washed with a small amount of water. The filtered liquor then passes through a series of four flash tanks, where sufficient heat is removed to lower the temperature to that required for fermentation. This heat is used to preheat water for the percolators. Finally, the filtered liquor is discharged from the fourth discharge tank through a barometric seal into the cloudy-liquor storage tanks.

### C. FERMENTATION

The transfer from the last stage of the hydrolysis operation to the first step of the fermentation process consists of pumping the cooled liquor from the cloudy-liquor storage tanks to clarifying filters. Nutrients required to promote growth of the yeasts are injected into the line leading to the filters.

The fermentation equipment has been designed so that either a batch or a continuous procedure may be used—it is possible to use the fermenters either individually for the batch process or in series for continuous fermentation. It seems likely, however, that the latter will be used, since it has been learned that less labor is required and that greater yeast efficiency is obtained, because the most actively fermenting yeast is always in contact with the highest concentration of sugar solution. As originally designed, four fermenters will accommodate the daily liquor output of the plant on the basis of a 20-hour fermentation cycle, but, as a result of recent improvements in technique, it is expected that the cycle will be reduced materially.

Following fermentation, the beer is pumped to a "weak" tank from which it flows to centrifuges, where the yeast is separated for return to the fermenters, the clear beer being collected in a beer well that acts as a surge tank between the fermentation and distillation operations. Facilities are also available for propagating fresh yeast, when needed, on molasses or wood-sugar wort.

### D. DISTILLATION

While distillation of the beer is an important step in the production of alcohol from wood sugars, the process will not be described in this text,

since conventional fractional-distillation stills used in distilling grain, cane, and other molasses may be used. The Vulcan vapor-reuse process of distillation is ideally suited to distilling the weak beer produced, which contains only 2.0 per cent by weight of alcohol.

#### E. THE FUTURE OF WOOD HYDROLYSIS

The hydrolysis of wood to produce sugars or molasses, the subsequent propagation of feeding yeasts, or the production of ethyl alcohol by fermentation of the resulting sugar wort is technically feasible. Commercial success will depend, however, on a number of economic factors. There has been an ever-increasing demand for industrial alcohol, and it appears likely that additional sources will be required in the near future to satisfy the needs of the nation. Numerous factors, including limitations of competitive processes, the high cost of grain, and curtailments in importation of molasses, indicate that the use of wood for the production of sugars has a chance of success, particularly if profitable uses can be found for the by-products, notably the residual lignin.

#### III. WOOD-SUGAR MOLASSES

Experiments conducted at the U.S. Forest Products Laboratory indicated that wood-sugar molasses can be produced in one-percolator plants capable of producing approximately 50 tons of 50 per cent sugar-content molasses per day from 50 to 60 tons of wood.<sup>5,6</sup> This is equivalent to about 8,000 to 9,000 gal. of molasses per day. The molasses can be shipped to a central distillery to be fermented to alcohol, used as a preservative for grass silage, fed as a carbohydrate ration for livestock, or used for the propagation of yeast. The yeast, in turn, is an excellent source of high protein for livestock and poultry. Costs have been estimated at 6.5 to 8.9 cents per gallon, or 1 to 1½ cents per pound of sugar contained in the molasses.

This process holds a great deal of promise. Most livestock-raising areas, particularly in the West, are deficient in carbohydrate- and protein-containing feeds. This prevents the proper finishing, or fattening, of meat animals for the market. Consequently they must be shipped to areas where suitable feeds are available. Ample supplies of wood-sugar molasses and yeast, produced in the West, would, therefore, be a boon to the Western livestock industry. The cause of forestry would also be furthered, since unused wood and little-used species would be the logical raw material. Both wood-sugar molasses and yeast can also be fed to dairy cattle, swine, and poultry. The exact amounts and other details

of feeding have not yet been determined. To this end, numerous agricultural experiment stations throughout the country are now conducting feeding and nutrition tests.<sup>6</sup>

While high hopes are held out for this new development, it must be remembered that current predictions have been based on experimental data. Pilot-plant and commercial operations may alter these estimates. It should also be borne in mind that plant costs would be considerable, filters, evaporators, fermenters, separators, and yeast driers being required in addition to the percolator. Nevertheless, the process has good chances of success. The fact that it is well suited to the utilization of residues from relatively small sawmills makes it particularly attractive from the standpoint of the aims of all who are interested in more complete wood utilization.

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\* There are no comprehensive works on wood saccharification. Most of the literature appears as short articles in the chemical and trade journals. The references listed here represent only a small part of the total, but they will lead the interested reader to more extensive bibliographies.

**Part IV**

**DERIVED AND MISCELLANEOUS  
FOREST PRODUCTS**

## CHAPTER 20

### NAVAL STORES

Naval stores are rosin, turpentine, oils, tar, and pitch produced from *oleoresins* obtainable from various species of pine. The term *naval stores* originally was applied to tar and pitch procured by destructively distilling the wood of Scotch pine (*Pinus sylvestris* L.) and appears to have originated with European shipbuilders of the late sixteenth century. These materials were indispensable in the era of wooden ships and were used in enormous quantities for sealing hulls and decks of new vessels as well as for maintaining the seaworthiness of those in service. Time has witnessed great changes in the maritime industry, however, and in this day of merchantmen and naval ships of steel, the demand for these particular commodities in the shipbuilding industry is virtually nonexistent.

The products of the modern naval-stores industry, by contrast, are principally turpentine and rosin. When derived from the gum or oleoresin bled from living trees, they are designated as *gum naval stores*. Turpentine and rosin obtained by the destructive distillation of pine wood or by the action of suitable solvents on chipped or macerated wood are referred to as *wood naval stores*.

In recent years, operators of several of the large Southern sulfate mills engaged in pulping wood of the yellow pines have found it profitable to recover turpentine fractions in relief gases expelled from digesters during early cooking stages. This material is marketed under the name of *sulfate turpentine*. Another by-product of the industry is a liquid rosin, *tall oil* (or *tallol*), recovered from spent sulfate cooking liquor.

#### A. HISTORICAL

The practice of using tar and pitch derived from wood may be traced to very ancient times. It is recorded in Gen. 6:14 that Noah, in building the ark, was instructed to "pitch it within and without with pitch." Archeologists have found that the early Egyptians used a natural oleoresin to make water-repellent varnishes and mummy lacquers that lasted for centuries.

In the Middle Ages production of tar and pitch centered in the region of the Baltic Sea; and Sweden, with her vast unbroken forests of pine,



developed a great export trade in these commodities. Near the end of the seventeenth century, however, the Swedish shippers endeavored to gain control of the movement of these materials by prohibiting their export except in ships of Swedish registry. Fear of monopolies and shortages which might result from this action and their devastating effect upon the economy of a maritime country such as England led the British government to encourage naval-stores production in the American colonies.

Naval-stores production on the North American continent had its beginning in the year 1605, when the French colonists of Nova Scotia distilled a crude turpentine from the oleoresin of white pine. In 1608 the first exports of tar and pitch were made by settlers of coastal Virginia to England, and by 1700, chipping pine for gum was a well-established practice in North Carolina. Tapping operations were conducted in the proximity of navigable streams, where the crude gum was gathered, barreled, and shipped to New York, Philadelphia, or Wilmington, from which ports it was sent to England for processing. Later, distilling centers were established in the colony, and by the middle of the eighteenth century exports exceeded 60,000 bbl. of pitch, 12,000 bbl. of tar, and 10,000 bbl. of turpentine annually. Peak production in North Carolina was attained in 1880, when there were more than 1,500 turpentine stills in operation within her borders. With the approach of the twentieth century, however, that state's industry was in rapid decline and today is practically a non-entity. The history of the industry in South Carolina followed a similar pattern. Only in 1880 did her production ever exceed that of her sister state to the north, and today less than 2 per cent of the annual output of the South is of South Carolina origin.

The year 1875 witnessed the beginning of naval-stores activities in Georgia. By 1880 it had become the state's principal industry, and shortly thereafter Georgia became a world leader in naval-stores production. Today she supplies over 72 per cent of the domestic output and more than one-third of the world's requirements.

From the year 1905 to 1923, Florida led the South annually in the production of rosin and turpentine. In recent years, however, her output has declined, and currently she is producing only about 18 per cent of the total domestic supply.

Small naval-stores-producing centers are currently operating in Alabama, Mississippi, Louisiana, and eastern Texas. The annual production from these states combined with that from the Carolinas comprises about 10 per cent of the total for the industry. The peak year of naval-stores production in the United States was 1909, when 750,000 bbl. of turpentine and more than 2,500,000 bbl. of rosin were produced.

For the past several years the United States has been supplying about

one-half of the world's naval-stores requirements. France is the second-largest producing nation and contributes about 15 per cent of the total supply. The U.S.S.R. production is about 8 per cent, while that of Portugal is about 7 per cent. Most of the residual 20 per cent comes from Spain, Greece, Mexico, Poland, Germany, and India.

Methods for the manufacture of turpentine and rosin were first described fully in 1783, but until 1820 turpentine had little industrial value and its

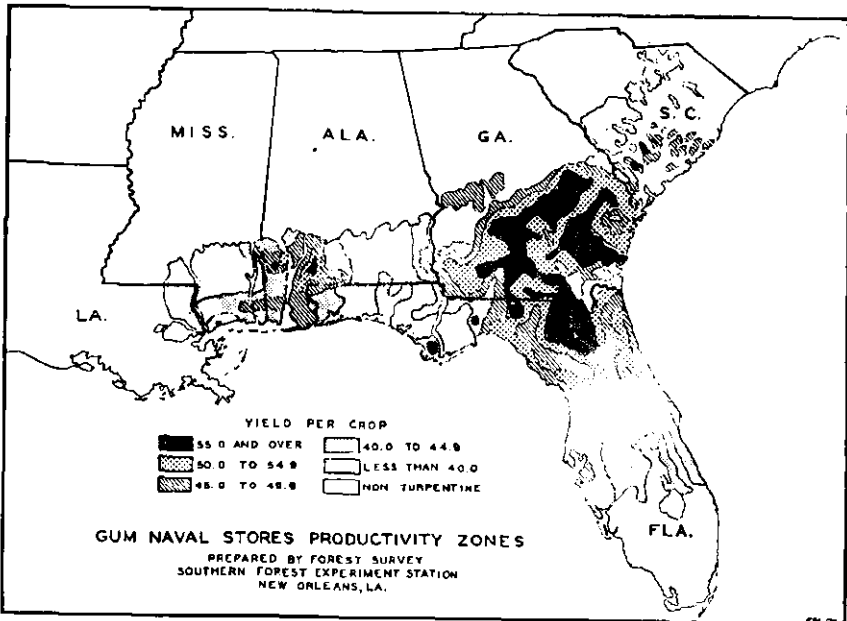


FIG. 20-1. Gum-naval-stores productivity zones. Barrels of gum per crop. (*U.S. Forest Service.*)

production was extremely limited, while rosin was essentially a waste product that created a disposal problem. The replacement of the crude old iron retorts with copper stills, beginning about 1834, did much to improve the quantity and quality of both products. Turpentine production was gradually stimulated through its increased usage in the manufacture of varnishes and paints and later as a solvent for rubber, and as an illuminant in mixture with alcohol. By 1850 the demands for rosin were rising steadily. Increasingly large quantities were being consumed by soap and paper industries, and finally its use in the manufacture of oilcloth, linoleum, and coatings for electric wiring created significant price rises. Thus rosin, a waste product for many years, is now a commodity of numerous and diverse uses and currently is in much greater demand than turpentine.

### I. GUM NAVAL STORES

The gum-naval-stores industry in the United States is confined to the Atlantic and Gulf coastal plains from North Carolina to eastern Texas. It ranks among the major enterprises of the South, with an annual income of more than 35 million dollars, and provides employment to more than 45,000 wage earners. Unlike many forest operations, the production of naval stores is essentially a year-round undertaking. A normal season begins in March and ends in November and provides a cash income every 3 weeks during this period. Daily markets are available throughout the year, and any quantity of resin or its refined products is readily marketable at all times. Unique, too, is the fact that when market conditions are unfavorable and production costs exceed sale prices, operations may be temporarily suspended without damage to the producing trees, to be renewed with the return of more favorable economic conditions.

While the industry, at the present time, is restricted to the South, experiments have revealed that some of the western pines are potential sources of naval stores and, with favorable market conditions, could be worked at a profit.

#### A. GUM-PRODUCING SPECIES

Of the several yellow pines indigenous to the South, only the longleaf pine and the slash pine are exploited commercially. In the past, loblolly and shortleaf pines have been worked, but the chipping frequency of these two species has to be increased materially to assure a sustained flow of gum.

Slash and longleaf pine forests comprise an area of approximately 30 million acres, largely second-growth. Nearly one-fourth of this acreage is currently being worked for naval stores. A second acreage of nearly equal magnitude is in resting or worked-out timber, while the remainder is in reserve as *round, i.e.,* untapped trees.

From the standpoint of gum production, slash pine is regarded as the more desirable of the two, especially in second-growth forests. Longleaf pine must attain an age of from 25 to 45 years before tapping becomes profitable, whereas good yields of gum are obtainable from slash pine trees only 15 to 25 years of age.

Slash pine is becoming manifestly more abundant, and in addition to the millions of trees that have been planted in the past several years, this species, under favorable conditions, preempts cutover lands formerly occupied exclusively by longleaf pine and now occurs naturally north of its original range in the pine belt. Longleaf pine, on the other hand, is the hardier of the two trees and is much more capable of survival following fire or excessive chipping without becoming permanently unproductive.

Although none of the western pines is worked for naval stores at the present time, some of them are potential sources of turpentine and rosin and are worthy of brief mention. An excellent yield of gum is obtainable from *ponderosa* pine. The turpentine and rosin derived from this species differ little from those of the two southern yellow pines in their physical and chemical properties and may be similarly used. Experimental tapping of *ponderosa* pine has revealed that weekly yields of oleoresin actually exceed those of southern pines from trees of similar size. The yearly average is much less, however, because of the shorter growing season.

Gums derived from Jeffrey pine and digger pine yield heptane ( $C_7H_{16}$ ), a hydrocarbon also found in petroleum. These two pines have been worked on a limited scale in California, and the crude distillates of their gums have been used locally in the preparation of pharmaceutical compounds, insecticides, and chewing gum.

#### B. THE OCCURRENCE AND NATURE OF GUM

The gum or oleoresin from which turpentine and rosin are obtained exudes from a tree when a cut is made through the bark into outer layers of the sapwood. These exudations flow from intercellular spaces in the wood known as *resin canals* or *resin ducts*. Resin canals are normal anatomical features of pine wood and occur in longitudinal and radial systems which periodically intersect, forming a continuous network of passages throughout the woody portions of the tree. Formation of a canal is occasioned by the early postcambial separation of growing cells in such a manner that a central opening, or passage, is formed. At maturity these passages are enveloped by a layer of secretory tissue, *epithelium*, from which the gum is secreted. Oleoresin from sapwood is a viscous liquid that flows readily from the canal when exposed by wounding. The gum from heartwood, on the other hand, is not fluid and does not flow from newly opened canals.

Following the initial tapping operation many new canals, known as *traumatic canals* or *ducts*, are formed by the cambium layer in wood immediately above the wound, their presence being manifested by attendant increases in gum flow. Investigations of Gerry<sup>13</sup> indicate that increase in the number of traumatic canals formed in response to wounding is most noticeable for a distance of approximately 18 in. above a wound.

The initial flow of gum in the spring during the first year of turpentering is traceable to the normal resinous systems present in the trees. However, as new wood is formed, the flow of gum from the preexisting canals is augmented by that from traumatic ducts newly developed above the

wound. Thus the yield of gum from wood formed after facing is greater than that from old wood.

Oleoresin obtained by tapping should not be confused with "sap," a watery solution containing sugars and other compounds utilized in the metabolism of the tree. The exact process of oleoresin formation is as yet not fully understood. It is possible that the precursors of the oleoresin-yielding materials undergo transformation in the ray and epithelial parenchyma cells ensheathing resin canals from which the elaborated gum is exuded.

#### C. NAVAL-STORES PRODUCERS

Turpentine woodlands, either owned or leased, are referred to as *turpentine farms* or *orchards*. An individual working his own or leased timber, but selling his crude gum or having it custom-distilled prior to sale, is called a *gum producer*. A person who works turpentine timber and distills the accrued gum at his own plant is called an *operator*. A company or an individual dependent, either in part or entirely, upon a gum producer to provide crude gum for distillation is known as a *gum buyer*.

There are more than 13,000 turpentine orchards in the southern pine belt, about 1,200 of which are controlled by operators. On a crop basis (10,000 faces), however, nearly four-fifths of the working trees are included in these 1,200 operations. Gum producers are usually farmers with small timber holdings who work 1,500 to 2,000 trees annually.

#### D. LEASES

The leasing of timber for turpentine rights is usually handled in one of two ways. In a *cash-lease* contract, the timber is ordinarily leased for a specific sum of cash for a predetermined number of months. Lease prices fluctuate considerably from time to time and are usually dependent upon prevailing prices being paid for naval stores, the quality of the trees to be worked, and competitive demands for timber rights. In the past few years an arrangement of this sort has cost the lessee about 3 cents per face, per year of operation. The *percentage-work basis* lease provides that the producer or operator pay the timber owner a specified per cent of the gross sales, usually 15 to 25 per cent, as rental for the timber.

#### E. FACTORAGE SYSTEM

Naval-stores operators have a method of financing which is unique in industrial circles. Since banks are loath to loan money on intangible assets, *factorage houses*, or *factors*, provide the operators with needed

financial support. These agencies will finance leases and labor and commonly act as wholesale dealers. They are prepared to furnish the operators and their workers with all necessary equipment, commissary supplies, and other essential goods at reasonable prices. In the event of poor management or upon default of payments, however, a factor may take over the actual operation of an orchard or distilling center. A factor may also act as an operator's agent and supervise the transportation and sale of his products to dealers. For these services he receives a commission of  $2\frac{1}{2}$  per cent of the net return. It has been estimated that 90 per cent of the entire naval-stores production is financed and marketed through the 11 factorage houses operating in the turpentine belt.

As previously indicated, a factor disposes of an operator's or a producer's output by selling it to a naval-stores dealer. Dealers buy from factors by lot and build up large inventories of the many different grades of rosin and turpentine. By operating agencies in the principal cities of the United States and in many foreign countries, a dealer keeps in constant contact with consumers and is able to supply the kind and grade of naval stores peculiar to their needs.

#### F. WOODLAND OPERATIONS

Many points must be considered in the selection of a stand of timber for a turpentine operation. Of these, the density of stocking and the general vigor of the trees are of paramount importance. A fully stocked stand suitable for turpentine will contain 100 to 200 trees to the acre. Stands with but 50 turpentine trees to the acre are regarded as good, and when better market conditions prevail, orchards having only 10 workable trees to the acre may be operated at a profit. In fact, at the present time, the average for the entire turpentine belt is about 15 faces per acre.

Ideal naval-stores trees, *i.e.*, those which produce large quantities of gum, are vigorously growing specimens characterized by wide annual rings, large volumes of sapwood, and full-rounded crowns that clothe the boles for one-third to one-half of their length. Trees with small, short crowns, narrow annual rings, and narrow bands of sapwood are invariably poor producers of gum. Young, thrifty trees will produce more gum than older trees of the same diameter, but no tree under 9 in. d.b.h. should be worked.

Large turpentine orchards are divided into standard units known as *croops*. The standard crop comprises 10,000 turpentine faces. In the early days of the industry, operators commonly worked two and occasionally three faces on the larger trees of dense, virgin-forest growth. Under such conditions a worker could chip about 10,000 faces each week during the

tapping season. In the second-growth stands of today, however, the trees are smaller and somewhat more scattered and rarely large enough to stand double facing. As a result the operating crop seldom exceeds 8,000 faces and is commonly somewhat smaller. For the convenience of operators, crops are divided into *drifts*. A drift may have clearly marked boundaries, or it may be delineated by natural limits such as streams, burns, or old fields or by roads and firebreaks. Ordinarily a drift consists of from 2,000 to 5,000 faces. Four to eleven crops, depending upon their



FIG. 20-2. Typical scene in a naval-stores orchard. (U.S. Forest Service.)

locations, constitute a *ride*. This term merely refers to an area which may be adequately supervised by a mounted overseer.

Before actual turpentine operations are initiated in untapped stands, it is desirable to select and mark in advance the trees to be worked. It is customary to place the *mark*, usually a blaze, on the side of the tree where the cup is to be hung. Shortly thereafter the rough outer bark is removed for a distance of from 12 to 20 in. above the ground where the turpentine face will be made. This is done in order to seat properly the cups and gutters and to enable the chipper to make a clean advance streak when starting the face.

**1. Hanging the Cups.** Prior to 1904, the initial operation in the turpentine of a new orchard consisted of cutting a deep cavity in the trunk of each tree near the base in which to collect the subsequent flow of gum. This cavity was called a *box*, and the cutting operation was known as *boxing*. These boxes, shaped like distended pockets and having a capacity

of about 3 pints, were cut during the winter months by experienced Negro crews. Two or three weeks before the commencement of the chipping season the boxes were cornered, *i.e.*, a triangular chip of bark and wood was removed from the bole immediately above the two extremities of the box. This provided a lead line for future chipping operations and channels for guiding the flowing resin into the basal receptacle. This sort of practice was extremely wasteful and resulted not only in large losses of resin but also in permanent damage to the trees. The hazard of fire was prevalent at all times, windthrow was a common aftermath, and conditions for

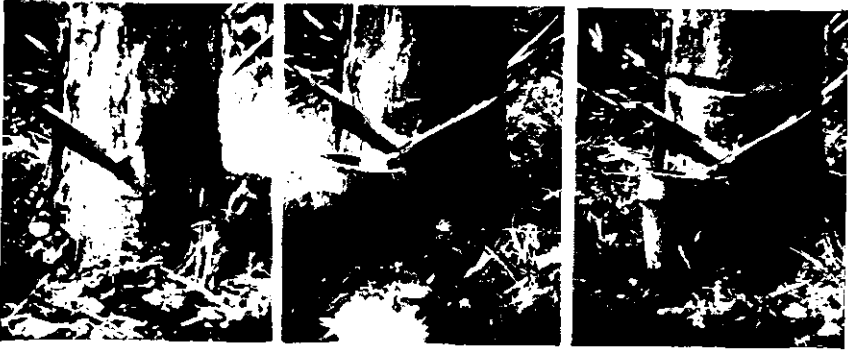


FIG. 20-3. Herty cup-and-gutter system. Note advance streak in the tree to the right. (Courtesy of A. R. Shirley.)

decay or insect infestation were greatly enhanced. Today, fired ceramic or metal containers have replaced the boxes, and resinous exudations from the activated faces are guided into these receptacles by strategically placed metal gutters or aprons. Several types of cups and gutter systems are currently employed, the four most common of which are described.

*a. The Herty System.* This is the oldest of the cup-and-gutter systems and was developed by the late Dr. Charles F. Herty, a pioneer in the modernization of the naval-stores industry. A clay, glass, or metal cup, shaped much like a common flowerpot, and two V-shaped gutters (one about 2 in. longer than the other), made of galvanized iron or aluminum, are used (Fig. 20-3).

Following the removal of the rough outer bark, the first step in facing a tree, a basal incision is made at an angle of about 20 degrees with the ground by driving a broadax into the trunk to a depth of about  $\frac{1}{2}$  in. The shorter of the two gutters is then inserted into this slit by slipping it along the blade of the ax as the blade itself is being slowly withdrawn. A second incision is made at the same height on the opposite side of the face, and the second gutter similarly installed. These gutters are made



from metal strips about  $2\frac{1}{2}$  in. wide and crimped to form a trough. The first is usually 6 to 8 in. long, the second 8 to 10 in. in length and, when properly seated, extending below the first in order to divert the flow of gum into the cup. The length of the gutters used is dependent upon the width of the working face. Gutters are installed as close to the ground as possible, with only sufficient clearance to permit proper seating of the cup. The cup is centered under the longer gutter and is fastened to the

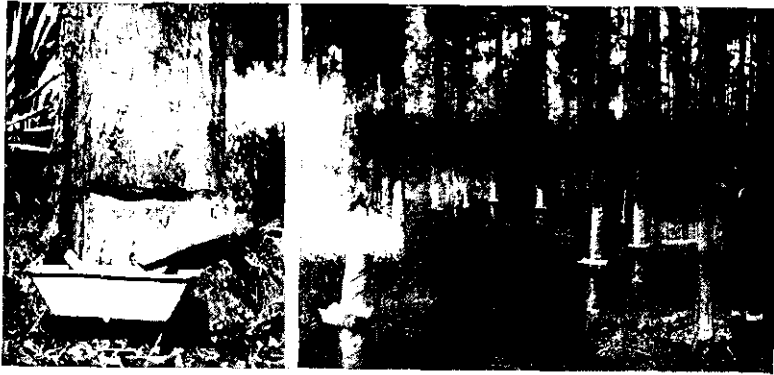


FIG. 20-4. *Left*, Ball system. (Courtesy of A. R. Shirley.) *Right*, One-piece apron system. (U.S. Forest Service.)

tree with a small, usually eightpenny, and commonly cement-coated, finishing nail.

The principal advantage of the Herty system appears to be in the exceedingly small amounts of resin lost where the gutters are properly inserted. Installation costs, however, are slightly higher than in other systems, and because of the shape of the cup, the face is started higher on the tree than when other systems are employed.

*b. The Ball System.* This is merely a modification of the Herty system. The shorter gutter is replaced by a flat, horizontally disposed metal apron with upturned corners, and the resin-receiving receptacle is a flat-bottomed, box-shaped cup which is seated under the apron (Fig. 20-4).

*c. One-piece Apron System.* As the name suggests, a single apron is used. This consists of a strip of metal about  $2\frac{1}{2}$  in. wide and about 2 in. longer than the width of the face. The apron is inserted near the base of the tree in the usual way, the ends are then bent upward and the lip pressed down toward the cup. The cup is similar to that used in the Ball system. While this is the cheapest and easiest installation to make, gum losses are often appreciable, owing to improper seating of the aprons, particularly at the shoulders (Fig. 20-4).

*d. Two-piece Apron System.* This system differs from the previous one in that two tapered aprons are used. Two coalescent incisions are made with a broadax a few inches above and parallel to the ground. The aprons are inserted into the cuts in such a manner that the two tapered ends overlap one another. The ends of the aprons are then bent upward to form the shoulders and their outer edges drawn downward toward the box-like cup.

In each of these systems, as an alternate method, the gutters or aprons may be nailed in shallow streaks made with a hack. This procedure is

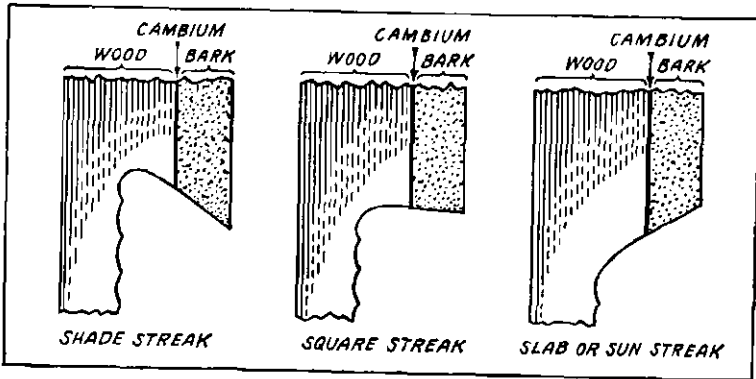


FIG. 20-5. Profile of turpentine faces showing three types of streaks. (U.S. Forest Service.)

avored by some operators who wish to avoid the danger of unnecessarily deep incisions made by inexperienced or careless workmen. Cups and tins are hung by *cupping* or *hanging crews* during the winter from December to February, or at least 6 to 8 weeks in advance of the working season, which usually begins about the first of April. The trees are first rough-faced and then the aprons or gutters are inserted. A laborer then cuts an initial strip of wood and bark, called a *streak*, just above the inserted tins. This is known as an *advance* or *healing* streak. It is held by those in authority that an advance streak not only stimulates the formation of gum in the normal passages, but also induces formation of traumatic resin ducts in the wood upon the renewal of growth activity. Preliminary operations are completed with the installation of the cup.

**2. Chipping.** Regular turpentine operations commence the last of March or early in April, depending upon prevailing weather conditions, and consist of removing periodically a narrow strip of bark and wood above the advance streak. This operation is known as *chipping*. Chipping is necessary to assure a more or less continuous flow of gum, because of the tendency of the ducts to clog when exposed to the air for protracted lengths of time. It is customary in American practice to remove two converging

strips which meet at the center of the face to form a V. The removal of two such strips constitutes a *streak*. Three types of streaks are commonly recognized, viz., the *shade streak*, the *square streak*, and the *sun*, or *slab*, *streak* (Fig. 20-5). The shade streak is favored in hot weather, since it retards the drying of newly exposed wood; the sun streak, on the other hand, is preferred in cool weather, since it permits the sun's rays to strike

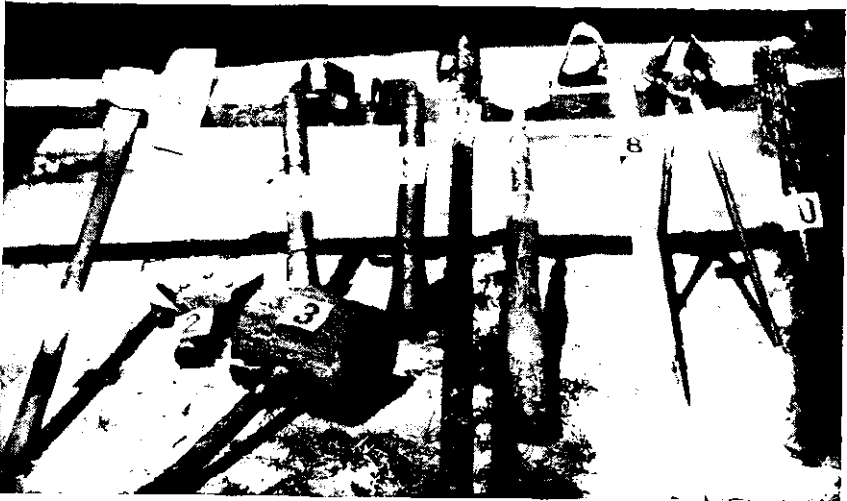


FIG. 20-6. Naval-stores woods tools: 1, broadax, used to remove the bark in preparing a place for hanging the cup and also for making the incision to hold apron; 2, gutter chisel or Pringle ax, used for making incisions for inserting aprons; 3, maul, used to drive broadax into the tree to cut incisions for aprons; 4, hogal, used for removing the rough bark and frequently for cutting the first streak; 5, hack, for cutting streaks on low faces; 6, puller, for cutting streaks on high faces; 7, push-down scraper, for removing serape from low faces; 8, pull-down scraper, for use on high or low faces; 9, apron and gutter puller; 10, dip iron for removing gum from the cups. (U.S. Forest Service.)

the newly exposed wood, thereby inducing the flow of gum. The square streak, which is advocated by the U.S. Forest Service, is a compromise between the two.

The angle of the streaks varies at different heights along the bole of the tree. On lower portions of the trunk they form a wide obtuse angle. The angle becomes more acute as the chipper has to reach farther up the tree when cutting a new streak. The base of these angular streaks is termed the *peak*, while the ends which delineate the sides of the face are called *shoulders*.

Chipping is accomplished with either a *hack* or a *puller* (Fig. 20-6). A *hack* is a steel U-shaped blade capable of cutting a streak from  $\frac{5}{8}$  to about  $1\frac{1}{4}$  in. in width. It is mounted on a stout handle 10 to 30 in. long,

to the end of which is attached a 4- to 7-lb. weight. The puller is a tool resembling a hack, except that the blade is closed; it is mounted on a handle 3 to 7 ft. in length. When the puller is used, the streak is made by a sharp, quick pull, as contrasted to the quick chopping motion used with the hack. Faces are said to be *turned* when they reach such a height (usually about 5 ft. above the ground) that in subsequent chippings the puller must be substituted for the hack.

a. *Recommended Method of Chipping.* For many years it was customary to cut streaks  $\frac{3}{4}$  to 1 in. high and 1 to  $1\frac{1}{2}$  in. deep, thus removing 24 in. or more of wood in a single season's work. The work of the U.S. Forest Service has conclusively demonstrated, however, that during the life of one face, much better yields of gum are secured if lower and shallower chipping is practiced. Moreover, with low chipping, the same tree may be worked for longer periods, since less wood is removed each year. The ill effects from too deep chipping include (1) mechanical injuries resulting in wind-throwing of smaller trees, (2) dry facing, a condition wherein gum ceases to flow even when a fresh cut is made, and which renders the trees more susceptible to attack by insects and decay, and (3) permanent damage to phloem and cambium layers, eventually resulting in the death of the trees.

Frequency of chipping depends upon the length of time gum continues to flow from a new cut and upon the cost of chipping. In general, a new cut should not be made so long as there is an adequate flow of gum from the preceding streak. The flow of gum, in turn, fluctuates with changes in air and soil temperature and with atmospheric conditions. The flow of gum is greatest during the first 24 to 48 hours following chipping, after which it diminishes gradually. The amount of gum exuded the first day following chipping, however, largely depends upon atmospheric temperature. Harper and Wyman<sup>17</sup> report that in the hottest weather longleaf pine may produce about 83 per cent and slash pine about 64 per cent of their weekly flow in the first 24 hours. With an average air temperature of only 52°F., however, it takes both slash and longleaf pines 6 days to produce 90 per cent of their weekly yield. Frequency of chipping, therefore, could be determined largely by the average air temperature. Harper and Wyman,<sup>17</sup> on the basis of their experiments, recommend semiweekly chipping during the months of July and August, weekly chipping from March to July and from September to November, and if winter chipping is carried on, semimonthly chipping from November to March. In general, slightly longer chipping intervals may be used for slash pine.

**3. The Working Face.** The wounded area on the trunk of a tree resulting from periodic chipping is known as a *face*. The *American face* results from many superposed V-shape streaks, usually beginning 7 to 12

in. from the ground. Such faces will increase in height from 9 to 24 in. or more annually for the 2 to 8 years the trees are worked. If the tree is a good producer, chipping is continued until the face attains such height that the operation is no longer practicable.

The face made during the initial season of orchard operation is known as a *virgin face*; that made in the second year, a *yearling face* (Fig. 20-7).



FIG. 20-7. Tree with virgin, yearling, buck, and pulling faces. Note raised cup. (Photograph by A. R. Shirley.)



FIG. 20-8. Typical French face. (U.S. Forest Service.)

*Buck faces* are produced during the third year of operation, while those made in the next succeeding seasons are called *high*, or *pulling*, *faces*.

The number of faces that may be worked at the same time on any one tree depends upon its diameter. Conservative operators will work only one face at a time regardless of diameter, although trees 15 in. or more d.b.h. may be safely double-faced. When a face is discontinued because of its height, the tree is usually given a rest period of from 1 to 4 years before a new face is started. The first face to be worked on a tree is called a *front face*; faces cut after the front face has been discontinued are called

*back faces.* As many as three faces may be worked successfully, provided the width of the first face does not exceed one-third of the circumference of the tree. If turpentine operations are initiated when trees are about 9 in. d.b.h., two faces could be worked over a period of 10 years, allowing 5 years for each face. However, if the trees are permitted to rest until they attain a d.b.h. of 11 in., three faces could be worked through a 15-year interval. The 11-in. trees at the end of 15 years of turpentine should be large enough to produce poles or sawlogs, but the 9-in. trees at the end of their turpentine cycle would be suitable only for pulpwood. When *back facing* is begun, it is also customary to *front-face* all the round timber in the orchard which may have attained workable size in the 5 to 7 years that have elapsed since the original cupping operations were started.

Attempts to introduce the *French face* in this country have never gone beyond experimental stages. This type of face is in the form of an inverted U,  $3\frac{1}{2}$  to 4 in. in width. The initial streak is about  $1\frac{1}{2}$  in. high and  $3\frac{1}{2}$  in. wide. Successive chippings are accomplished with an adze-like tool. In practice it is customary to increase the height of the face about  $\frac{1}{2}$  in. with each new streak. With the cutting of a new streak, the wood from 4 to 6 in. immediately below is also carefully shaved off in order to reopen the myriad of minute horizontal resin canals that empty into the wound. As a result of this practice, the face soon takes on a dish-like aspect and is approximately  $\frac{1}{2}$  in. deep along its vertical, medial axis.

Experiments conducted at the Southern Forest Experiment Station have revealed that during the first 2 years of operation, French faces produced more gum than did American faces of the same width. The yield from French faces during the third and fourth years, on the other hand, was less than that from American faces for the same period. This was attributed primarily to the fact that proper types of tools were not available when chipping the high French faces. For the 4-year period, however, the French system produced 7 per cent more gum. It is possible to work two French faces on trees too small for more than a single face of the American type and thus secure appreciably higher yields of gum. The rapidity with which the French face heals is rather startling. Two 4-in. faces of this sort will commonly close in 8 or 9 years, while 15 to 16 or more years is required to heal an 8-in. American face.

**4. Dipping.** The practice of emptying the cups as they become filled with gum is known as *dipping*; the gum itself is commonly referred to as *dip*. These terms originated in the days when gum was collected in boxes, later to be dipped out with a trowel-shaped ladle.

The current methods of collecting resin are much simpler. A cup is merely detached from its supporting nail, inverted over a bucket, and the gum pushed out with a trowel-shaped dip-iron or wooden paddle, after

first decanting any rain water that may have accumulated. The buckets in turn are emptied into large wooden barrels or steel drums placed at convenient points throughout the orchard. When these receptacles are filled they are sealed and hauled or trucked to the still. The frequency of dipping depends on the capacity of the cups, weather, periodicity of chipping, and productive capacity of the trees, but the average operator dips about every fourth week.

Some of the oleoresin, as it runs down the face, solidifies before reaching the cup to form a hardened gum called *scrape*. The hardening action probably results from evaporation of some of the more volatile constituents in the resin and oxidation of others. Some operators remove this scrape with each dipping and require their dippers to punch the recently hardened resin off the face into the cup along with the liquid dip. In this way the scrape is removed from the face several times during the season. Better yields of turpentine and higher grades of rosin are obtainable from the scrape collected in this manner. Other gum producers await the end of the turpentine season before removing the scrape, then take it all in one operation. Dull-bladed tools that remove the scrape without chipping or gouging the wood are the most practicable. Scrape collected at the end of the season is usually dirty and ordinarily produces less turpentine and a lower quality of rosin. In a normal season, 5 to 10 per cent of the yield of slash pine gum is in the form of scrape, while in longleaf pine, scrape constitutes 20 to 30 per cent of the total gum yield.

**5. Raising Cups.** As a turpentine face grows in height, the distance that the gum must travel before reaching the cup also increases. This results in the formation of more scrape with proportionate losses in liquid resin. Because of this and other reasons to be noted presently, it is customary to raise the cups and tins to the top of the face before the beginning of another working season. Probably the most important raise is that made between the first and second seasons. As previously indicated, cups on virgin faces are close to the ground, where they are easily knocked off by livestock grazing in the area and the liquid gum is more readily contaminated with wind-blown soil and sand, forest litter such as pine straw and bark, and with insects. A second or third raise is usually left to the discretion of the operator, since the additional expense involved is unwarranted when market conditions are unfavorable or when there is but little price differential among various grades of rosin.

New tins should be used with at least every other raise if rosin grades of better quality are to be maintained. If rustproof tins are employed, they may be used as long as they are serviceable.

There are at least three methods in current use for raising cups.

*a. Jump Streak.* This method is especially recommended where turpentine operations are at a standstill during the winter months. The chipper, in making an advance streak for the yearling (or buck) faces, leaves a horizontal strip of bark  $\frac{1}{2}$  to  $1\frac{1}{2}$  in. wide between this streak and the old face. In this way the new face is started above any lightwood \* that may have formed under the last streak of the previous season. The streak itself serves as a lip upon which the tins may be securely tacked. The cup is then hung immediately in the customary manner.

*b. Hack or Puller Streak.* Here a hack or puller is used to cut shallow grooves in the wood near the top of the old face. These grooves serve as a seat upon which the tins are tacked in place and as a shelf to direct the flow of resin onto the tins and into the cup below.

*c. Broadax Incision.* The broadax method is the least desirable of the three, since there is a tendency among woods crews to make incisions much deeper than the depth of  $\frac{1}{2}$  in. which is regarded as the allowable maximum. Deep cuts in the boles of trees are largely responsible for the breakage occasioned during periods of high wind.

#### G. ACID STIMULATION PRACTICES

As an aftermath of the First World War, the Germans, and later the Russians, as a part of their national programs toward self-sufficiency in the production of raw materials for essential industries, sought ways and means to enlarge their naval-stores industries. In 1933, both the Germans and the Russians began exploratory studies in the use of chemicals to stimulate the flow of gum in Scotch pine. Many chipping techniques were devised, and a variety of chemicals, including acids, bases, and salts, were tried. From the wealth of resulting data, it was determined that certain chemicals actually retarded the flow of gum as much as 40 per cent, but several others stimulated flow from 5 to more than 200 per cent.

The first work on chemical stimulation in the United States was begun in 1936 at the Olustee Experimental Forest, Lake City, Florida, as a cooperative project between the Southern Forest Experiment Station and the Bureau of Agricultural and Industrial Chemistry. Unfortunately, this study was undertaken at a time when there were large inventories of both turpentine and rosin; and because of low prices prevailing at the time, little interest in the project was evidenced by the industry itself. Moreover, the results were rather inconclusive. Additional studies were conducted from 1938 to 1941 that indicated chemical stimulation was prac-

\* Pitch-soaked wood.



tical, and in 1942 and 1943, recommended procedures for woods operations were released to the industry. While the use of chemical stimulants is still somewhat in its infancy, the U.S. Forest Service strongly recommends acid stimulation practices, and operators who are using them are greatly pleased with the results. Although many chemicals give similar results, it has been found that a 40 per cent aqueous solution of sulfuric acid is an effective stimulant for slash pine, while for longleaf pine best results are attained with a 60 per cent solution of sulfuric acid.

**1. Recommended Procedures.** When acid stimulation is practiced, better yields of gum are obtainable by modifying the usual chipping pro-



FIG. 20-9. *a*, bark hack developed for acid-stimulation practice; *b*, conventional wood hack. (U.S. Forest Service.)

cedures. Advance or conditioning streaks are unnecessary, and in making the face a bark hack should be used in place of the conventional chipping tool. The bark hack is so designed that it will remove a strip of bark about  $\frac{1}{2}$  in. in width without molesting the wood. Chippings of this sort do not cut into the sapwood, require less effort to make, and leave the boles essentially full-rounded at the completion of tapping operations (Fig. 20-9).

Acid should be applied over the freshly cut streak in the form of a fine mist. Either the Florida lung gun (Fig. 20-10) or the more recently developed combination bark hack and spray gun are suitable tools for this purpose. Especial care should be exercised to assure a light but uniform spray over the streak. An excess of acid should be avoided at all times, as it serves no useful purpose and can be detrimental to the efficiency of the working face.

In working virgin faces, each of the first six to eight streaks should be treated with acid immediately following the chipping operation. Weekly

chipping, but biweekly acid spraying, is satisfactory once the face is well started; yearling and older faces may be treated similarly.

**2. Yields.** Acid stimulation treatment on virgin faces will increase seasonal yields over the older conventional method by 50 to 100 per cent. Timber chipped weekly and treated on alternate weeks with acid will

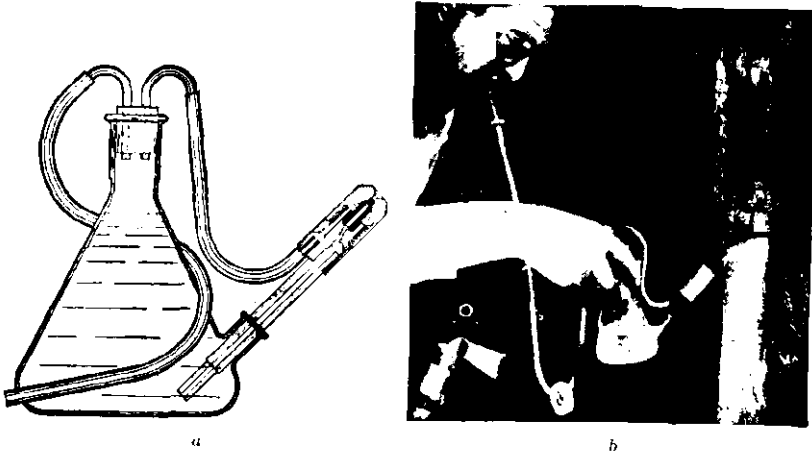


FIG. 20-10. *a*, Schematic sketch showing details of the Florida lung gun. (Photograph by Norman Bourke.) *b*, Florida lung gun in use. (U.S. Forest Service.)

yield 30 to 40 per cent more gum than trees of comparable size where acid stimulation is not practiced.

There is nothing in the behavior of acid-treated trees that suggests that such treatment is in any way detrimental to their continued health or vigor. Faces not infrequently acquire the aspect of dry face, but upon examination it has been determined that lightwood is but poorly developed, either behind the wound or above it.

#### H. EFFECT OF TURPENTINING UPON TREE GROWTH

Annual growth increments of trees worked for turpentine are less than those of untapped trees exhibiting similar physical characteristics. It has been estimated that conservative turpentine with one face will reduce wood formation 25 to 33 per cent, and if two faces are worked simultaneously, volumetric reductions of as much as 40 per cent may be expected during the working cycle. Such retardations in growth are due to (1) diversion of photosynthetic products to gum rather than to wood substance and (2) the interruption of translocation and flow of solutes by the face.

copper retort or kettle of from 10- to 30-bbl. capacity and a condenser. The kettle is mounted on a stone or brick furnace, fired with oil or more commonly with wood, and so constructed that the basal portions of the kettle may be heated uniformly. A coiled copper pipe, the *worm*, submerged in a tank of water comprises the condenser. Connecting the kettle and the worm is a removable kettle head or *cap* and extension arm.

In charging a still, fires are drawn, and as soon as the rosin is turned out from the previous run and the tailgate is closed, the cap is removed



FIG. 20-11. Typical fire still in Florida naval-stores region. (U.S. Forest Service.)

and 2 to 3 gal. of cold water are run into the kettle for each barrel of gum to be distilled. This water not only materially aids in cooling the kettle, but as will be indicated later, it has a part also in the actual distillation process. Cooling of the kettle reduces both the hazard of fire and the loss of turpentine through vaporization at the time of charging. There is also much less chance for the residual rosin in the kettle to scorch or burn and take on objectionable colors that would lower its grade.

Dip is dumped into the kettle immediately after the prescribed amount of water has been delivered. In practice a kettle is filled to about two-fifths of its capacity when liquid gum is to be distilled, but if scrape is used, the still is charged to one-third of its capacity. Overcharging of a still is a dangerous practice, for should it boil over, a disastrous fire is inevitable. Following the charging operation, the cap is set into place, sealed with clay, and the fire started. As the temperature inside the kettle rises, water and turpentine vapors begin to pass out through the cap and arm into the worm, where they are cooled and liquefied. The resulting conden-

sate flows out through the tailpipe of the worm into a separator, usually nothing more than a common wooden barrel, but since water and turpentine are immiscible liquids they are readily separated by gravity. The turpentine, which is the lighter of the two, rises to the top and is periodically decanted into a receiving barrel. The water, or *low wine*, a waste product, is run into a sump or sewer. In some operations the turpentine fraction of the distillate is passed through salt dehydrators in order to remove the last

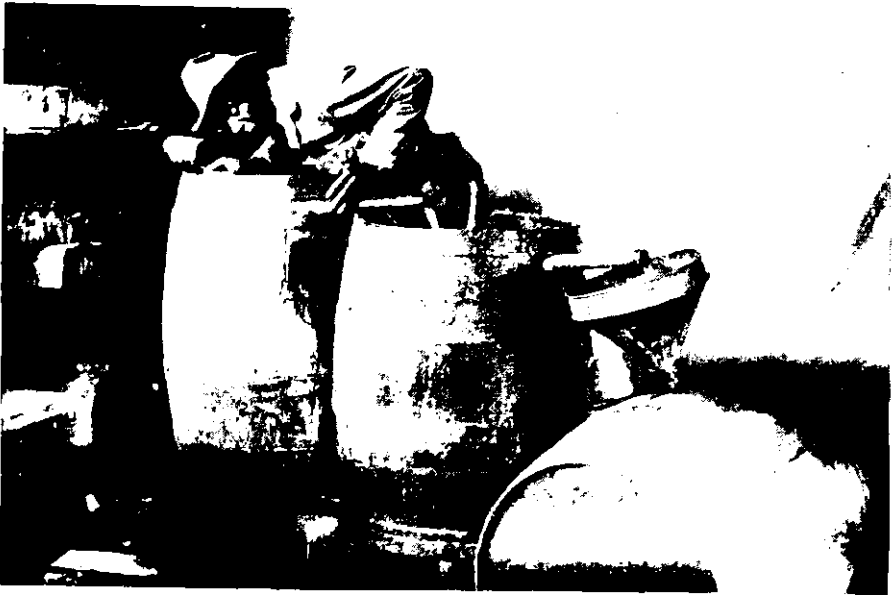


FIG. 20-12. Listening for the "call for water." (U.S. Forest Service.)

traces of water which may be present. Turpentine may be pumped from the receiving tank to storage tanks or to tank cars, or it may be graded and packaged immediately for shipment to consumers.

During distillation of a charge, which requires about 2 hours, the temperature inside the kettle must be regulated within certain predetermined limits. This is accomplished by periodically adding water to the kettle to replace that lost through vaporization. Some distillers add water by the so-called "sound method." In such instances the distiller listens at the tail pipe of the worm for a peculiar rumbling sound made by boiling resin when most of the water has been expelled from the kettle. This sound or "call for water" (Fig. 20-12) is his signal that temperatures are rising and that water should be added to the boiling mass. This is not a reliable means for determining kettle temperatures, and better grades of rosin are made in stills equipped with recording thermometers.

At the beginning of a run, turpentine and water start coming over in equal portions soon after the kettle attains a temperature of about 212°F. After 30 or 40 minutes, most of the water in the still has come over and the temperature has risen to about 240°F. At this point more water is added until the distillate runs approximately 60 per cent water and 40 per cent turpentine. Distillation is continued and water is added as required until the distillate is about 90 per cent water and 10 per cent



FIG. 20-13. Modern fire still and rosin-storage yard. (U.S. Forest Service.)

turpentine. At this point the kettle temperature should be between 275 and 290°F. If the turpentine fraction is not noticeably discolored, distillation is continued until the condensate contains but 5 per cent of turpentine. The temperature of the kettle at this point should *not exceed* 305°F. Here distillation ceases, but cooking continues until the temperature rises to 315 to 330°F. The hot residual rosin is then *turned out*.

In turning out rosin, a tail gate at the bottom of the kettle is opened and the hot fluid rosin is run into *strainers* in order to remove extraneous material.

The strainers, usually in batteries of three, are made of woven wire. The first and coarsest merely screens out large chips of bark and wood, pine straw, and other refuse which may have fallen into the cups prior to dipping. These screenings are known as *chip dross*. The second strainer is provided with a much finer screen and retains sand and other fine particles

of trash not caught on the first screen. These retentions are termed *rock dross*. The third wire is covered with a layer of cotton batting and withholds all foreign materials passing through the first two screens. The residual screenings from this strainer are known as *batting dross*. Since there is an appreciable amount of rosin in dross, such screening rejects represent a sizeable industrial loss which may be as much as 150 lb. or more of rosin per charge. Expressed in terms of a 10-crop orchard, rosin losses to the extent of 70 bbl. or more per year may be anticipated. During periods when high prices prevail, dross may be reworked at a profit.

Rosin losses resulting from dross, particularly chip dross, may be reduced materially by keeping cups covered during chipping operations or by compelling chippers to remove any trash that may have fallen into the cups while they are engaged in putting on new streaks.

**2. Central Processing Plants.** The first central processing plant was erected in 1932 near Savannah, Georgia, but its operation was unsuccessful, largely because of strong opposition on the part of factors and dealers. Today, however, there are at least 29 plants of this sort throughout the pine belt, the success of which is due largely to the development by the Southern Naval Stores Experiment Station of an efficient method for washing and cleaning gum prior to distillation. The majority of the central processing plants are owned and operated by gum buyers, each representing an initial capital expenditure of from \$20,000 to \$250,000.

The cleaning process consists of two separate operations. Dip or scrape, or a mixture of the two, is melted in hot turpentine (200°F.), sufficient turpentine being added to bring the specific gravity of the resulting solution to approximately 0.95. All solid materials are removed in filter presses, and the water-soluble constituents are then removed by washing the hot filtered gum with hot water (150°F.) and allowing this mixture to settle out by gravity. Following separation, the wash waters are drained to a sump or sewer and the gum is pumped to a still.

The still is usually much larger than the one previously described and is heated with internal steam coils. Live steam may be admitted also to expedite distillation. Operation of the still follows the same general pattern of the fire still, except that much more efficient condensers are employed. The rosin, when turned out, needs no straining and is ready for packaging.

The principal advantages of these modern plants over the older fire stills are (1) greater capacity; (2) uniformity of product; (3) higher yields of rosin; (4) better grades of rosin; (5) economical operation; (6) better prices for the small gum farmer.

**3. Continuous Still.** Recently, a continuous still of pilot-plant proportions was erected and operated by the Naval Stores Experiment Station

at Olustee, Florida. Results have been most gratifying and give indication that the general use of such apparatus may readily render obsolete the batch-type stills, since installation and maintenance costs are appreciably lower than those of the larger stills in current use.

In the operation of a continuous still, clean gum is pumped into concentric preheated pipes (345 to 350°F.) which lead into a flash chamber sur-

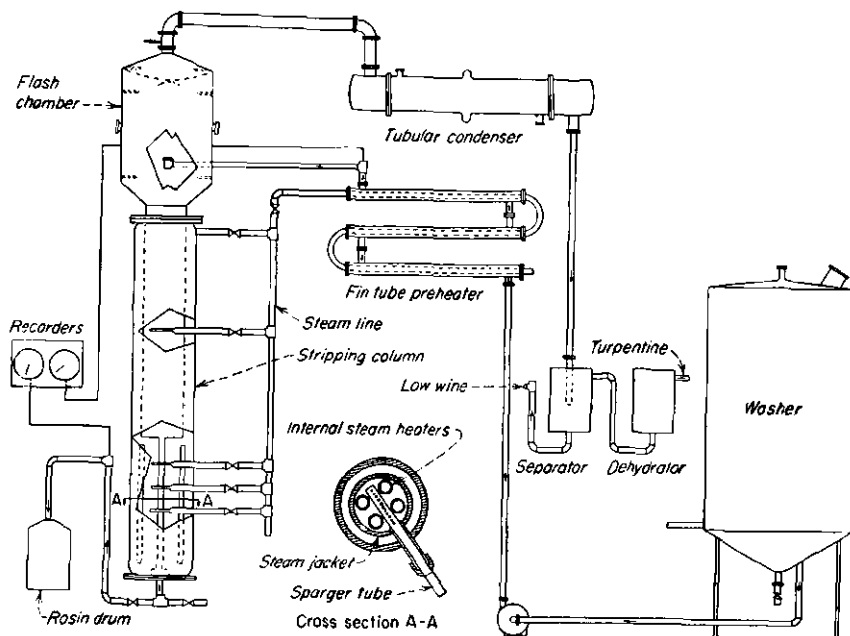


FIG. 20-14. Diagrammatic sketch of continuous still for pine gum. (Courtesy Naval Stores Research Division, Bureau of Agricultural and Industrial Chemistry.)

mounting a 15-ft. steam-jacketed column. The gum enters the flash chamber through a small nozzle where about 80 per cent of the turpentine is removed. The remaining 20 per cent is released, while the resin settles to the bottom of the column. Turpentine vapors are drawn off through a condenser and the rosin is removed from the bottom of the column as required. No further processing is needed, and both rosin and turpentine are ready for packaging.

## L. TURPENTINE

As indicated previously, turpentine is not a simple chemical compound but is rather a mixture of essential oils of the terpene series. Turpentine of American origin is composed of several terpenes, of which alpha-pinene

comprises about 80 per cent of the complex. The residual components include beta-pinene, champene, sylvestrene, and dipentene in varying quantities.

Statistics reveal that 5 bbl. of dip are required to produce one 50-gal. drum of turpentine. Nine to ten barrels of scrape are necessary to produce a drum of turpentine, since most of its terpene constituents were lost on the face through volatilization. It is estimated that about one-fifth of the terpenes present in fresh gum are lost before distillation is possible. A final loss may occur (2 to 5 gal. per charge) when open separators or receiving barrels are employed.

The bulk of the turpentine produced today is marketed in tank-car lots of from 6,000 to 10,000 gal. Many of the smaller producers package turpentine in 50- or 55-gal. metal drums or wooden barrels for delivery to dealers or for export trade. During the past few years large quantities of turpentine have been packaged in small tins of from 4-oz. to 5-gal. capacity and retailed under a variety of trade names or brands.

Gum spirits of turpentine is offered to the trade in four grades, viz., *water white*, *standard*, *one shade off*, and *two shades off*. Prices are usually quoted on the basis of the standard grade. Government specifications for the standard grade require that not less than 90 per cent of the complex shall distill over at 170°C. and that the liquid be clear of suspended matter and water and have a mild aromatic odor.

Turpentine consumption in the United States amounts to about 500,000 bbl. annually, the bulk of which is used in the manufacture of paints, varnishes, lacquers, pharmaceuticals, and chemicals.\*

### M. ROSIN

Rosin, also known as *colophony*, is a brittle and friable solid with a faint aromatic odor, the major constituent of which is abietic acid. Abietic acid reacts readily with metallic salts to form soaps and with alcohols to form esters. It is insoluble in water but is readily dissolved in ether, benzene, and chloroform.

Rosin varies in color from a pale-yellow hue through shades of amber to dark red. Color is dependent upon the source of gum, the nature of metallic equipment used in its collection, and the method of cleaning and manufacture. Thirteen grades of rosin have been established by the Food and Drug Administration under the Federal Naval Stores Act. The lightest shades bring the best prices, but it is not always possible to obtain them in production for the reasons already noted. These grades, beginning

\* For complete statistics on the annual consumption of turpentine, see Gamble's International Naval Stores Yearbook, Savannah, Georgia.



with the lightest, are *X*, *WW* (water white), *WG* (window glass), *N*, *M*, *K*, *I*, *H*, *G*, *F*, *E*, *D*, and *B*. A large portion of the rosin offered for sale falls between the *M* and *G* grades. Type color standards for each grade, in the form of tinted glass cubes, are deposited in the offices of the Department of Agriculture. A limited number of duplicate sets are available for use by inspectors, distributors, and consumers.\*

Most of the rosin from fire-still operations is packaged in wooden barrels or metal drums of from 515 to 530 lb. of rosin (net) per container. Filtered rosin is not infrequently pumped directly into insulated tank cars which are so routed as to deliver hot rosin directly to the consumer. A small percentage of the filtered rosin is also packaged in multiwall paper bags of 100 lb. capacity.

More than one million drums of rosin are used annually by American industries. Heavy consumers include the manufacturers of soaps, paints, varnishes, lacquers, paper, adhesives, plastics, rubber, synthetic resins, chemicals, and pharmaceuticals. †

#### N. BUSINESS ASPECTS OF THE INDUSTRY

Financial returns from turpentine operations, like those from other consumer goods, fluctuate with business cycles, although until very recently there has been a definite downward price trend since 1930. The average price per unit ‡ for 1925-1926 was \$89.00 on the Savannah market. By 1932-1933 the unit price had dropped to \$30.65. A rise in price in 1937-1938 to \$54.31 per unit was occasioned by the better prices offered for rosin, offsetting the low prices of turpentine which then prevailed. With the removal of price controls during the latter part of 1946, naval-stores prices skyrocketed. Turpentine was \$1.26 a gallon in 100-gal. lots at the end of the year, and rosin sold for \$8.06 per hundredweight from *X* through *F* grades. At these prices, a unit was valued at nearly \$170.00.

Fluctuations in cash returns from the sale of naval stores are traceable to volume production, large inventories, and changes in business activity. Increased production is usually accompanied by lower prices. Prices also are usually depressed when large inventories are at hand. The carry-over on Apr. 1, 1945, the beginning of a new turpentine season, was 202,546 bbl. of turpentine and 388,266 bbl. of rosin. On Mar. 31, 1946, the carry-over was but 100,749 and 388,682 bbl. respectively. This represents a decrease

\* Type samples made from rosin are available for purchase through H. H. King, Savannah, Georgia.

† For complete statistics on the annual consumption of rosin, see Gamble's International Naval Stores Yearbook, Savannah, Georgia.

‡ One unit equals one 50 gal. barrel of turpentine and 3½ bbl. of rosin.

of 101,797 bbl. of turpentine and only a small and insignificant increase of 416 bbl. of rosin available for purchase at the beginning of the 1946 season. In the years before the Second World War carry-overs often exceeded 1,600,000 bbl. of rosin. Invariably such inventories adversely affect market prices. Other factors influencing the market value of gum turpentine and rosin are (1) increased gum-naval-stores production abroad, (2) increased production of wood and sulfate turpentine, and (3) expanded competition of petroleum solvents and synthetic resins.

## II. WOOD NAVAL STORES

Large quantities of naval stores are also obtained by the action of steam and suitable solvents on chipped or macerated heartwood from the stumps and boles of longleaf pine trees. Turpentine and rosin oils, together with tar, pitch, and charcoal, are obtained in the destructive distillation of similar materials (see Chap. 18).

*Sulfate turpentine* is obtained from digester relief gases when wood of the various southern yellow pines is pulped by the sulfate process. Sulfate turpentine is a potential by-product from sulfate cooks of spruce wood, but there is little or no attempt to recover it at the present time because of production costs and limited markets. It is estimated that the sulfite mills of the United States and Canada could produce from 1,500,000 to 2,000,000 gal. of sulfite turpentine annually, should occasion demand. Turpentine obtained from spruce wood differs somewhat in its terpene complex from that derived from gum of the southern yellow pines.

### A. STEAM AND SOLVENT PROCESS

Recovery of turpentine, rosin, and pine oils \* from the wood of old pine stumps was begun in 1909, when Homer T. Yaryan built the first steam and solvent extraction plant at Gulfport, Mississippi. This plant had a daily capacity of 100 tons of wood and in its initial year of operation produced 14,307 round barrels of wood rosin, 1,700 bbl. of turpentine, and 25,000 gal. of pine oil. Today there are 14 modern steam and solvent extraction plants operating in the states of Florida, Georgia, Alabama, Mississippi, and Louisiana. These represent a capital investment of about 15 million dollars and currently account for about 51 per cent of all the rosin and nearly 30 per cent of all the turpentine produced in the United States.

\* Pine oils are not found in gum from living trees, and it is believed that their formation results from the gradual oxidation of pinenes and other terpenes over a protracted length of time.

Raw materials for the steam and solvent process consist of stumps and heartwood of slash and longleaf pines which is left after logging. Heartwood from the stumps of old trees will yield as much as 25 per cent of oleoresin; that from the bole, 7 to 10 per cent. Sapwood, by contrast, contains only about 2 per cent of oleoresin. Accordingly, operators prefer wood that has been in or on the ground for 10 to 15 years, with bark and sapwood well rotted away.

Stumps are removed in various ways. Blasting is commonly practiced, but powder often merely shatters the stump, and much rich, resin-yielding wood is left in the ground. In recent years several mechanical devices, including tractors, have been used in stump-removal operations. One specially devised stump puller consists of a boom crane fitted with a nut-cracker jaw and mounted on a tractor of the crawler type. The jaw, when dropped over a stump, grasps it firmly at or near the ground and then pulls it from its anchorage much as a dentist would handle a troublesome bicuspid. The stumps and any suitable slash are transported to concentration centers, where they are split and trimmed. The stumps, roots, and bole wood are then loaded either on trucks or on gondolas for shipment to the extraction plant. The larger companies work their own woods crews, who clear cutover lands on a lease arrangement with the land owners. At other plants wood is purchased from farmers upon its delivery at the yard.

**1. Raw-material Supply.** It has been estimated that the annual requirements of existing steam and solvent plants are between 300,000 and 350,000 tons of wood, 75 per cent of which is stump wood. A partial inventory of available stump wood, made by the Southern Forest Survey in 1934-1935 on 20 million acres of cutover land in South Carolina, Georgia, and Florida, indicated that the supply of merchantable stumps in the surveyed regions alone was approximately 21 million tons and that there was a potential reserve of another 9 million.

**2. Manufacturing Procedures.** The high quality of the products derived from steam and solvent extraction plants is the result of long years of chemical research and engineering skill, and the modern plant bears little resemblance to the original Yaryan installation. In the early days, steam-distilled wood turpentine was a strong, ill-scented distillate of uncertain physical and chemical properties. Many consumers of gum turpentine refused to use it, and others who did regarded it merely as a turpentine substitute. Wood rosin, too, was a consumer's nightmare. Although characteristically dark red, the color also varied. It was a product of questionable solubility and melting point and tended to crystallize and precipitate when blended with many petroleum and vegetable oils. When heated, it darkened appreciably and was generally considered to be inferior

to gum rosin of similar grade. Pine oil in those early days was a straight-run distillate with limited use and a limited market.

Like the modern pulp mill, a steam and solvent extraction plant carries large wood inventories in the yard as a safeguard against the possible interruption of wood deliveries. Before the wood is suitable for treatment, it must be chipped or physically macerated in order to assure efficient extraction. Accordingly, the stumps are passed through a hog, or shredder, that reduces them to chips approximately  $1\frac{1}{2}$  in. long and  $\frac{1}{4}$  in. in width. Better rosin recovery is possible if wood is chipped or shaved across the grain, since larger numbers of resin ducts may be exposed in this way, but because of increased handling costs this is seldom done. Wood so milled is not screened, so both slivers and wood dust accompany the chips to the extractor. An extractor is a vertical steel tower 16 to 24 ft. tall with a capacity of from 10 to 13 tons of shredded wood. The first phase of the extraction process is steaming. Live steam is admitted at the bottom of the vessel through sparging rings or perforated coils. The steaming phase requires from 3 to 4 hours, during which interval most of the volatile oils are removed. The condensate, which includes turpentine and other oils, is known as *crude turpentine*.

Dry steam is then turned into the extractor in order to dry the chips before treatment with solvent. The solvent, a hot petroleum naphtha, is used to extract the residual rosin. Rosin extraction employs the counter-flow principle; hence several extractors are treated as a battery. Concentrated rosin extract removed from the last extractor is subjected to a preliminary refining operation during which oxidized resins and wood dust are removed. From this point the solvent-rosin extract is handled in diverse ways, depending upon the degrees of refinement desired.

In some instances the extract is pumped into evaporators under *reduced* pressure, where the solvent and some pine oil are removed. The residual rosin, ruby-red in color, is then packaged for shipment and distributed as *FF* wood rosin. Some plants treat the hot liquid rosin with fuller's earth, an absorbent that removes much of the pigmentation present. In recent years furfural, an oily liquid obtained from oat hulls, has been found very useful in the refinement of wood rosin. Solvent-rosin extract is mixed with furfural, and the two liquids are agitated. Since the two are immiscible, they separate into two layers when at rest. The furfural layer includes essentially all the pigment, and the solvent contains the clear yellowish-white rosin. Rosin obtained in this manner will yield grades from *I* to *X* and may be used in a manner similar to gum rosin of identical grades.

In a recent development, the steaming of chips has been eliminated and turpentine, pine oils, and rosin are all extracted simultaneously with a

suitable solvent. This complex is then fractionally distilled in order to separate the turpentine, various terpenes of higher boiling point such as dipentene, terpinene, and terpinolene, and finally pine oil. The residual component in the still is crude wood rosin.

The resin-free chips in the extractor (irrespective of process used) are steamed in order to recover any solvent. This recovery, together with that from the evaporators, is used in subsequent extraction cycles. The resin-free chips are then discharged and the extractors are recharged with fresh wood.

Attempts to use resin-free chips for kraft pulp have so far been unsuccessful. A plant at Pensacola, Florida, however, converts them into mechanical pulp which is used to manufacture an insulation board offered to the trade under the name of Temlock.

**3. Yields.** The yield of wood turpentine, pine oil, and rosin depends upon the resin content of the wood and the efficiency of the extraction. Average recovery per ton of air-seasoned wood amounts to about 6 gal. of turpentine, 1.5 gal. of intermediate oil (high-boiling terpenes), 4.5 gal. of pine oil, and 350 to 400 lb. of grade *FF* wood rosin.

The refined turpentine has the same general properties as gum turpentine and is used for the same purposes. Refined rosin is now a competitor of gum rosin, grade for grade.

Pine oil is a mixture of terpene alcohols and some few terpenes of high boiling points. The production of pine oil now stands at about five million gallons annually. About 40 per cent of the output is used as a frothing agent in the separation of metal by flotation. Large quantities are consumed in laundries and in dyeing cotton, wool, silk, and rayon textiles. It is also employed in the manufacture of soaps, polishing compounds, paint, varnish remover, germicides, insecticides and pharmaceutical preparations. The intermediate oils are used largely as solvents for special purposes.

#### B. SULFATE TURPENTINE

The condensate of relief gases from *sulfate* pulp-mill digestors contains appreciable quantities of turpentine. Cooks of jack pine and eastern white pine yield from 1.5 to 3.1 gal. of turpentine per ton of air-dry pulp; loblolly, shortleaf, and Virginia pine from 1.5 to 2.7 gal.; and longleaf and slash pines from 2.8 to 4.3 gal. Yields of more than 2.0 gal. of turpentine per ton of pulp are, however, exceptional for species other than slash and longleaf pines. Figure 20-15 depicts a typical recovery system.

Crude sulfate turpentine has an extremely disagreeable odor because of the presence of mercaptan, an inevitable product of all sulfate cooks. Mercaptan is usually removed by treating the crude with an oxidizing

agent such as hypochlorite. The refined product, representing a yield of about 80 per cent of the original crude, sells for about 10 cents less per gallon than the prevailing price for gum turpentine.

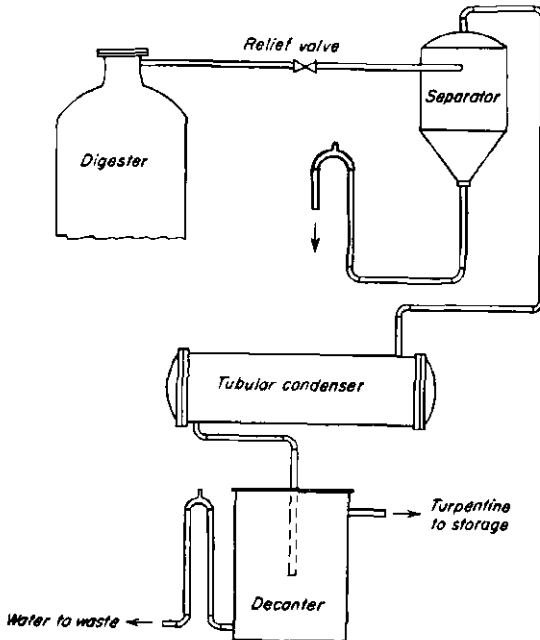


FIG. 20-15. Schematic diagram illustrating turpentine recovery in sulfate pulping process (Courtesy of the Technical Association of the Pulp and Paper Industry.)

Some pine oil is also recovered, but it is inferior to that obtained from the steam and solvent process and is used only for flotation in ore separation and in the manufacture of certain floor-cleaning compounds.

### C. TALL OIL

Increased interest is being manifested by sulfate pulp-mill operators in the recovery of liquid rosin from spent cooking liquor. As indicated elsewhere (see sulfate method of pulp manufacture, page 316), the spent cooking liquor or black liquor is reprocessed in order to obtain valuable chemicals. Associated with the black liquor is a frothy mass that may be readily skimmed from its surface. This is "soap," crude tall oil, or liquid rosin. The acidification of this soap liberates fatty and resin acids which comprise tall oil and which constitute about 45 per cent of the original crude.

Refined tall oil is light yellow in color and free from obnoxious odors. It is used in the manufacture of both hard and soft soaps, or it is processed into solid fatty acids that are suitable substitutes for the more expensive vegetable and animal fats. A product similar to linseed oil and suitable for the manufacture of varnish, is produced by esterification with glycerine.

In the 1945-1946 naval-stores year, 200,130 tons of black-liquor soap were produced, from which 94,814 tons of refined tall oil were obtained. For the past few years crude soap has sold at 2 cents per pound and refined tall oil at 4.5 cents per pound.

Solid rosin and pitch are also obtainable from the crude soap. The former is similar to gum rosin, but it has a slightly higher melting point. The pitch is used in the manufacture of lac-varnishes, printer's ink, and as a substitute for asphalt in road construction.

### III. NAVAL-STORES PRODUCTION ABROAD

The most significant change in the world's production of naval stores has been the comparative decline in American output since 1907. In that year the United States supplied 79 per cent of all consumers' requirements; since then, however, production elsewhere throughout the world has increased steadily, and today only about 50 per cent of the total annual output of naval-stores commodities is of American origin.

#### A. FRANCE

France is the second-largest producer of naval-stores products. The French industry is based upon the exploitation of the maritime pine [*Pinus pinaster* Solander (*P. maritima* L.)], and to a lesser extent the Aleppo pine (*Pinus halepensis* Mill).

The French turpentine region is an area of approximately two million acres adjacent to the Bay of Biscay in the departments of Gironde and Landes. On this small area, which is no larger than a few of Georgia's coastal-plain counties, is produced about 15 per cent of the world's output of turpentine and rosin. One hundred years ago this area was virtually uninhabitable. A dearth of vegetation, poor drainage, and migratory sands made the area worthless, but far-sighted French authorities of the nineteenth century began the stupendous task of reclaiming these wastelands through the establishment of extensive pine forests.

Only about 20 per cent of the acreage in the French turpentine belt is government owned, although a degree of governmental control is exercised over the entire region. France regards her naval-stores industry as a permanent enterprise upon which the welfare of the region is largely de-

pendent. The forests are therefore managed in such a way that a substantial and continuous yield of gum and a variety of wood products may be secured.

#### B. U.S.S.R.

Prior to 1926 only a negligible quantity of naval stores was produced in the U.S.S.R. The products of her industry were low in quality and were produced largely from dried gum and destructive distillation of wood. In 1926, however, a small area of pine forest was set aside for turpentine experiments. The original area has since been increased, and today it is believed to exceed some two million acres. It is estimated that the U.S.S.R. has some 225 million acres of pine forest available for naval-stores operations, thus giving her an opportunity for almost unlimited industrial expansion, provided labor continues to be cheap under direct governmental control.

Pine forests of the U.S.S.R. are composed largely of Scotch pine (*P. sylvestris* L.), a poor oleoresin producer. Low yields coupled with a short working season \* are major obstacles to expansion. On the other hand, significant increases in the yield of gum through chemical stimulation practices may more than offset these difficulties.

Statistics relating to Russian production are both fragmentary and inconclusive. Her output of crude gum in 1926 was only 413 metric tons, but 10 years later she was producing about 89,000 metric tons annually. As a direct result of her expanded industry, American shipments of rosin to Russia, amounting to from 50,000 to 100,000 bbl. annually, ended abruptly in 1934. A London report in 1935 indicated that under the 5-year plan Russian production would be stepped up from 80,000 units to 240,000 units annually. Since 1931 Russia has been an exporter of both turpentine and rosin. Her peak year appears to have been 1934, when approximately 40,000 drums of rosin and 60,000 bbl. of turpentine were released to export trade. The bulk of these stocks was purchased by the United Kingdom, Germany, and Italy. It is significant to note that Russian exports of rosin virtually ceased after 1935, thus suggesting that her total production was consumed by her own expanding manufacturing industries.

#### C. PORTUGAL

Portugal's turpentine forests comprise an area of approximately three million acres, largely of maritime pine. The industry operates under government control, and a considerable portion of her output is exported.

\* The U.S.S.R. pine belt is found in northern European Russia, the Ural Mountains and Siberia.



Prices for Portuguese commodities on the London market have been consistently below American prices for similar grade; as a result the Portuguese producers have made significant inroads on European markets formerly held by the United States.

#### D. OTHER COUNTRIES

In recent years considerable progress has also been made in the naval-stores industries of Greece, Poland, and Mexico. Prior to the Second World War, each of these countries was producing about 3 per cent of the world's output of rosin and turpentine. India accounts for about 1 per cent of the world's production.

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## CHAPTER 21

### MAPLE SIRUP AND SUGAR

The production of maple sirup and sugar is a typically North American industry, confined to the Northeastern regions of the United States and to the provinces of Quebec and Ontario in Canada.

In the United States the importance of the industry rests in the fact that it is largely a farm activity. Sugar bushes are owned and operated mostly by farmers, who have come to rely on maple products as a source of small but regular income from their woodlots.

The six states leading in production of maple products are Vermont, New York, Ohio, Pennsylvania, New Hampshire, and Michigan; Vermont and New York account for more than 70 per cent of the total domestic output. In Canada more than 70 per cent of the production is in the province of Quebec.\*

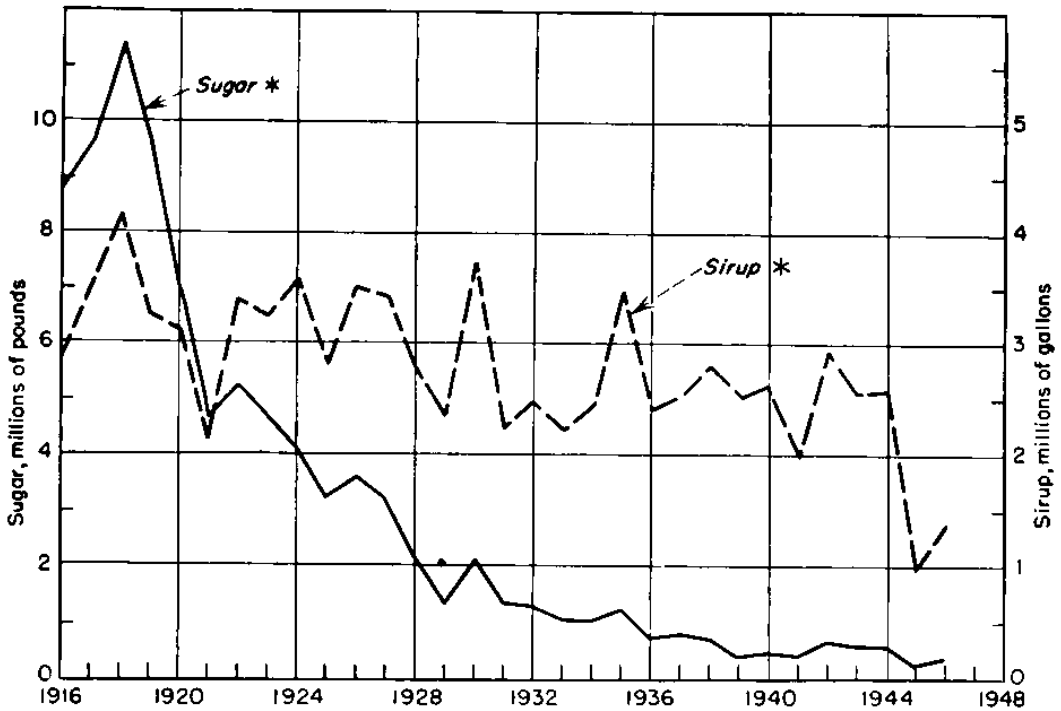
In colonial days, because of the prohibitive price of cane sugar, maple sugar and sirup were classed as staple products. Most of the maple sugar was for home use, though considerable quantities of it were also used to adulterate cane sugar. This remained true until about 1875, when lower prices of cane sugar placed it within the reach of almost everyone. Since then the relative position of maple products and cane sugar has been reversed, and maple sugar and sirup have become articles of luxury, valued for their distinctive flavor. Prior to 1900 more maple sugar than sirup was made. Today, however, as the demand for sirup is increasing, more than 90 per cent of the total production in this country leaves the farms in the form of sirup (Fig. 21-1).

#### I. WOODS OPERATIONS

##### A. SPECIES OF MAPLE TAPPED

Although all native maples have sweet sap, practically the entire commercial production of maple products comes from the sugar maple and its variety, the black maple. The red maple, the silver maple, and the big-leaf maple are also tapped locally, but it is generally felt that the amount of

\* Since 1938 Canada's production of maple sugar and sirup has exceeded that of the United States.



\* Does not include varying quantities of sugar and sirup produced each year on nonfarm lands in Somerset County Maine  
Data for 1946 are preliminary

FIG. 21-1. Maple-sirup and maple-sugar production in the United States, 1916 to 1946. (Bureau of Agricultural Economics, U.S. Department of Agriculture.)

sap they yield and its low sugar content will not allow profitable commercial production of sirup and sugar. A comparison between the average sap flow of sugar maple and soft maple in Somerset County, Pennsylvania, was made by McIntyre<sup>11</sup> (Table 21-1).

TABLE 21-1. THE AVERAGE FLOW OF SAP IN SUGAR AND SOFT MAPLE<sup>a</sup>

Diameter class, in.	Average number buckets hung	Sugar maple		Soft maple	
		Number of trees	Aver. flow, qt.	Number of trees	Aver. flow, qt.
9-16	1.0	14	8.9	14	5.5
17-23	1.5	19	15.1	15	7.4
24-28	2.2	42	17.7	23	12.5
29-33	2.8	50	22.4	20	13.4
34-36	3.6	18	27.7	4	20.3
37-45	3.8	28	31.7	6	18.9

<sup>a</sup> McIntyre, A. C. The Maple Products Industry of Pennsylvania. Pa. Agr. Expt. Sta. Bull. 280. 1932

He also reports that the sugar content of sap from soft maples was approximately 34 per cent less than that of the sugar maple, and the sirup and sugar were darker.

### B. SUGAR BUSH

Woodlands containing a sufficient number of sugar maple trees for commercial tapping are commonly designated as a *sugar bush* or *sugar grove* (Fig. 21-2). At least three types of sugar groves can be differentiated: (1)



FIG. 21-2. Sugar bush. (Photograph by Vermont Department of Agriculture, Montpelier, Vermont.)

those that are merely a part of a mature mixed-hardwood forest with a large number of sugar maples in the mixture, (2) more or less open and usually overgrazed groves consisting of old and frequently overmatured maple trees remaining from the original forest, and (3) second-growth mixed-hardwood stands, from which a sugar bush can be easily developed by judicious thinning and liberal cutting, working toward the elimination of species other than hard maple.

Since the yield of sap from the maple tree is in direct relation to the size of its crown,\* the ideal grove is considered to be one that contains the max-

\* In a recent study conducted at the Pennsylvania State Forest School,<sup>14</sup> it was found that the average sugar content of the sap from the roadside trees with large, spreading crowns was  $3.72 \pm 0.047$  per cent, as compared with that of the open-grown trees (crown length averaging 75 per cent of the total height) of  $3.34 \pm 0.034$  per cent and the forest-grown trees (crown length averaging less than 50 per cent of the total height) of only  $2.25 \pm 0.21$  per cent.

imum number of trees per acre, consistent with full crown development. Other requirements of a good sugar bush include provision for ample reproduction to take the place of overmature or diseased trees and to provide adequate shade for the forest floor. When possible, grazing should not be allowed in the grove, since cattle not only destroy the reproduction but also tend to harden the soil by tramping.

The ideal mature stand of sugar maple should contain 50 to 60 trees per acre, but the average number of trees is usually 30 or less. Younger stands of 60 years and under may contain as many as 300 or 400 stems per acre; however, not more than 25 maples per acre will be of tapping size; in still younger stands only 10 or 15 trees may be tapped.

### C. SAP FLOW

Sap flow begins from the middle of February in the southern section of the commercial range and the middle of March toward its northern limits. It lasts an average of 4 to 6 weeks, although under extremely favorable conditions it may continue for 8 to 9 weeks. The length of the season depends entirely upon weather conditions. Ideal "sugar weather" consists of alternate freezing and thawing, as represented by warm days when the temperature may rise to 40 or 50°F. and cold nights with temperatures below freezing. The run of sap may stop if weather conditions are unfavorable and begin again when suitable conditions prevail. During a season there are usually several such runs of a few days' duration each.

### D. MAPLE SAP

Maple sap at the time of flow consists of 90 to 98 per cent water and 0.5 to 10 per cent solids, roughly 90 per cent of which is sucrose; small amounts of invert sugar are also present. The average sucrose content of sap is usually between 2 and 3 per cent. The sugar content of sap ordinarily decreases with the advance of the season; it increases slightly during the day and not infrequently varies even in the sap taken from different taps on the same tree.<sup>10</sup>

Toward the end of the season sap frequently acquires a greenish color and a peculiar taste. This colored sap, known as *buddy sap*, is attributed to physiological changes within the tree connected with the swelling of buds; the tendency for microorganisms to multiply rapidly at higher temperatures may also be a contributing cause to formation of *buddy sap*.<sup>15</sup> Other discolorations in the maple sap, known as *red sap* and *milky sap*, also called *sour sap*, are likewise caused by bacterial action. The souring of maple sap may be largely eliminated by washing the spouts and buckets clean fre-

quently with hot water, collecting sap often and boiling it as soon as possible, and boring new tap holes if the old ones become infected.

#### E. TAPPING

Before tapping a tree, that portion of the trunk where the tap hole is to be located should be brushed with a stiff broom so as to remove all dirt and loose bark. Tapping itself consists of drilling holes into the wood with a bit. To insure a hole with clean-cut sides, the bit should be sharp, since a dull cutting edge will cut a hole with uneven, feathered sides that will materially reduce the amount and duration of the sap flow. All shavings should be carefully removed. The holes are drilled with a slight upward slant to facilitate drainage of sap.

Time spent in tapping may be reduced considerably by using a portable power tapping machine, weighing approximately 30 lb. These machines are operated by a lightweight gasoline engine which drives a tapping bit inserted at the end of a flexible shaft. One man can tap with this machine as many as 3,500 holes in 12 hours.<sup>13</sup>

Experiments in Vermont and Michigan clearly indicate that about 80 per cent of the sap flows from the sapwood portion of the trunk. It is therefore generally recommended that the hole be drilled only through the width of the sapwood. The width of sapwood in the hard maple generally ranges from 1 to 3 in., depending largely on the size and age of the tree.

The right diameter of tap hole is still very much a matter of personal preference. Most operators agree that the size of the hole should be such that it will heal over in one or, at the most, two growing seasons. The general practice is to use bits  $\frac{5}{16}$  to  $\frac{19}{16}$  in. in diameter. It is customary as the season progresses to freshen up the holes by reaming them. It is recommended that reamers  $\frac{1}{8}$  in. larger than the original hole be used. If a reamer of lesser diameter is used, difficulty is encountered in centering the tool, with the result that only one side of the hole is freshened. Some operators prefer to drill new holes when old ones have dried. This, however, is considered a more wasteful practice than reaming. The holes are usually located about waist high for convenience in drilling.

Murphey<sup>12</sup> reports that "each tap hole bored into a maple dries out and kills a strip of sapwood equal to the depth of the hole, a little wider than its diameter, and from 2 to 5 ft. up and down the tree (usually much more above than below the hole) [Fig. 21-3]. This wood remains permanently dry, and a tap hole bored into it later will not yield sap." This dead wood will start decaying unless the tap hole is grown over within a few years. Some operators plug the tap holes with sticks or corks. This practice is no longer recommended, as the wedging of plugs tends to inflict additional

injury to the bark and wood tissues and to interfere with the natural healing process.

There is little difference in regard to which side of the tree is tapped. If operations are carried on each year, eventually all sides of the tree will be tapped. On the larger trees, big enough for several tap holes, some operators prefer to start tapping on the south side, where earlier runs of sap can be secured, and then proceed around the trunk as the season progresses. It has been shown, however, that the average yield of sap and the weight of sugar contained in it for the entire season is about the same, regardless of the direction in which the bucket is hung.<sup>13,15</sup>

Trees under 8 in. in diameter cannot usually be tapped at a profit. Trees more than 12 in. in diameter may have two tap holes and those more than 20 in. three tap holes. Heavier tapping is apparently not justifiable, since the slight increase in the yield of sap is more than offset by the rapidity with which the tree is completely encircled by tap holes, with a resulting decrease in the number of years a tree can be tapped. Moreover, the danger of decay is



FIG. 21-3. Injurious effects of excessive tapping. Note areas of discolored (dead) sapwood above and below the tap holes. (From *The Maple Products Industry of Pennsylvania*, by A. C. McIntyre, *The Pennsylvania State College Bulletin* 280.)

greatly increased by excessive tapping. A new tap hole should be placed at least 10 in. away from the previous hole. The practice of placing two holes in such a way that they will drain in one bucket is considered unwise, since it definitely impairs the health of the tree.

#### F. SPOUTS

The *spouts*, or *spiles*, are tubes inserted into tap holes to conduct the flow of sap into the bucket. Today the spouts are made of metal, although in some places hollow reeds and elder and sumac stems from which the pith has been removed are still used. Wooden spouts are difficult to clean, tend to sour quickly, break easily, and cannot be used to support the sap buckets.



There are many forms of metal spouts on the market. A good metal spout should be round in cross section, of even taper, and smooth, so that it can be inserted or removed easily without inflicting injury to the surrounding tissue. Other points to be considered in selection of a spout are as follows: a good spout should not project into the hole to such a depth that it may interfere with free flow of sap; it should be so constructed as to prevent drying out of the hole; it should fit the hole after reaming; it should lend itself to easy cleaning; finally, it should be provided with hooks to hold a sap bucket and be strong enough to support it when it is filled with sap.

### G. SAP BUCKETS

*Sap buckets* are containers hung on the tree to catch sap; they are of two general types, wooden and metal. Formerly wooden buckets were universally used, and even today they are still found in some sections. Wooden buckets have a number of disadvantages, however. They are very heavy and do not hang well from the spout, frequently necessitating driving nails into the tree; they are difficult to keep clean, and in warm weather they tend to become sour; they must be painted in order to prevent sap leakage and decay. For this purpose red iron oxide paint is most commonly employed. Bakelite, enamel, and aluminum paints have also been found very satisfactory. Lead paints were also formerly used quite extensively; it has been found, however, that lead may get into the sap in quantities sufficient to be injurious to health. In consequence of this finding, the U.S. Food and Drug Administration ruled that beginning Jan. 1, 1937, any maple product found to contain lead would be classed as adulterated and its sale prohibited.\*

Metal buckets have the advantages of being light, strong and easy to clean, and requiring less space in storage. A good metal bucket should be rustproof. Aluminum would be the best metal for sap buckets but is too expensive. Tin plate and galvanized iron, in the order of preference, make satisfactory and inexpensive buckets. The only objection to galvanized buckets is that after a time they begin to peel, permitting the iron surface to rust.

Buckets with a gentle slope or with straight sides are preferred to the widely flaring type, because with the former better contact with the tree surface is obtained; an offset rim is also considered highly desirable, as this feature facilitates stacking and prolongs the life of buckets, eliminating pounding in separating them at the beginning of each sap season. A metal

\* Further details in regard to satisfactory paints for sap buckets (wooden and metal) can be obtained by writing to the New York State Agricultural Experiment Station, Geneva, New York.

bucket is suspended on the spout by means of a hole made in the side of the bucket under the rim or by a wire loop through it.

More recently sap buckets have been equipped with metal covers, either hinged on the spout or provided with a crimped edge by which the cover is fastened to the top of the bucket. In no case should the cover fit tightly over the bucket, since the sap tends to sour quickly in a tightly closed container. The main reason for the cover is to keep rain and snow from diluting the sap and to keep bark, twigs, insects, and dirt from falling into it. The only objection made to the use of covers is that it takes a longer time to empty the buckets. However, considering the saving in time needed for boiling the rain water and the higher quality of sirup obtained when the buckets are covered, this objection is not very serious. It is said that some operators paint the covers with contrasting colors, turning the covers when the buckets are emptied. In this way they can keep an easy check on the containers which need attention.

The sap is emptied periodically into gathering pails, large galvanized-iron pails with a capacity of 15 to 20 qt. These should preferably have broad bottoms and tapering sides, to prevent tipping.

#### H. HAULING AND STORAGE TANKS

When only a few trees are tapped, the sap may be carried away in the pails. In most sugar groves, however, some means for transporting the sap is required. This is usually provided by various hauling tanks mounted on wagons or sleds. Smaller operators use open barrels with a faucet fixed near the bottom for draining sap. In larger groves wooden tanks with a capacity of 4 to 5 bbl. may be used. The same objections apply to the use of wooden tanks as to the wooden buckets, the most serious of which is the tendency of sap to sour if left standing in the tank. In place of wooden tanks, many types of metal tanks with a capacity of 2 to 6 bbl. are available. These are equipped with a drain pipe at the bottom of the tank. The chief advantage claimed for metal tanks is the ease with which they can be thoroughly washed. All the tanks should be equipped with strainers of metal and flannel or cheesecloth to remove debris.

In woodlots with a favorable slope, gathering tanks have occasionally been replaced by a pipe-line system extending to elevated points throughout the grove (Fig. 21-4). The ends of the lines are provided with funnels into which gathering pails are emptied. The sap flows by gravity to the storage tank near the boiling house. Still more recent is the pipe system which connects each tree. The pipe is made of tin tubing in sections, which are grooved together so that they will fit well. The pipes are suspended by wires, strung on trees, or supported by stakes. Such a pipe system entails

a high initial and assembly cost. However, some of the operators who have tried it feel that they are repaid by the labor saved in gathering the sap and the higher yield of sap secured by avoiding costly overrunning of the buckets. An improved quality of sirup may also be secured by prompt boiling of fresh sap which has no time to sour in buckets or tanks. The chief



FIG. 21-4. Maple sap-gathering pipeline. (Photograph by Vermont Department of Agriculture, Montpelier, Vermont.)

difficulties encountered in this system are that of cleaning the pipes and the danger of pipes being displaced by wind and falling limbs.

## II. PROCESSING OF SIRUP

### A. BOILING HOUSES

When only a few trees are worked and the yield of sap is small, the sap may be boiled on the kitchen stove, in a shed oven, or over an open fire. However, where 200 or more trees are tapped it is necessary to have a separate building to house the evaporating equipment. In selecting a location for the sugar camp, particular attention should be paid to an adequate supply of good water. The building should be located, if possible, so that the sap can be handled from the gathering tanks by gravity.

The size of the house is determined by the size of the evaporating equipment, which in turn is determined by the number of trees to be tapped.

The house should have sides high enough to insure good ventilation, and a well-slanting, gabled wooden roof is considered more satisfactory than a metal one, because it causes less condensation. There should also be a woodshed to store the necessary supply of wood to be burned in the evaporator.

The equipment of a boiling house includes *evaporators* and *sugaring-off pans*. The simplest type of evaporating equipment consists of a home-made

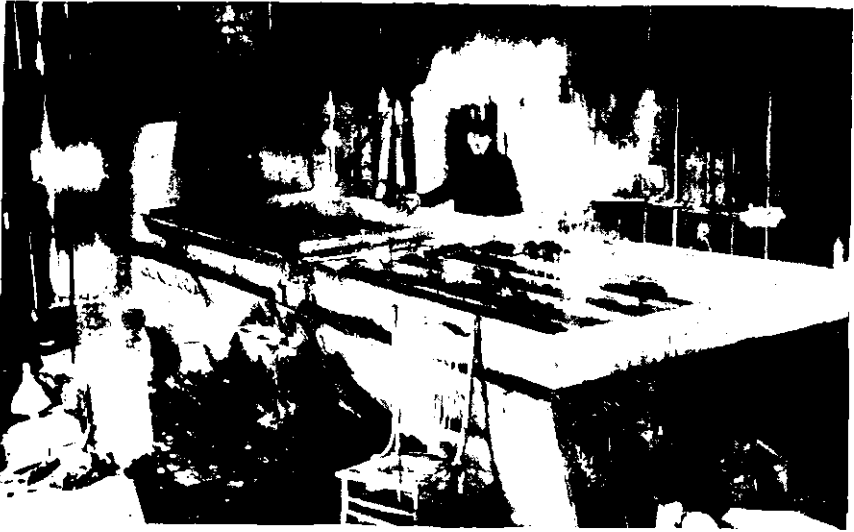


FIG. 21-5. A modern evaporator capable of evaporating  $1\frac{1}{4}$  tons of water an hour. (From *The Maple Products Industry of Pennsylvania*, by A. C. McIntyre, *The Pennsylvania State College Bulletin* 280.)

sheet-iron or stonework structure known as an *arch*. As described in *U.S. Department of Agriculture Farmers' Bulletin* 1366,<sup>2</sup> the arch is

... 3 or 4 ft. wide and from 8 to 15 ft. long, inside measurements. The sides are usually  $2\frac{1}{2}$  to 3 ft. high. Between these two walls the bottom is bricked or cemented, and the walls are held together and in place by iron stays, which also support the pans. At the back the arch ends in a flue and a brick or metal chimney extending through the roof. In the front, grate bars may be provided and an excavation made for an ashpit.

Usually two pans are used; when partially concentrated, the sap is transferred into the second pan for finishing.

A number of well-constructed, patented evaporators are now available on the market (Fig. 21-5); these usually come with metal, brick-lined arches. The pans are commonly made of sheet iron coated with tin, galvanized iron, or copper. Copper pans, although they cost twice as much

as galvanized iron, will last much longer and will generally produce a lighter colored sirup. The pans are partitioned to give a zigzag course to the sap. In the modern evaporators the sap enters automatically at one end and progresses through the pan with a speed regulated by the heat under the pan. The sap is drawn off continuously at the other end of the pan either in the form of finished sirup of a standard weight or as a partially condensed sap which is brought to the standard concentration in the sugaring-off pans.

Where steam boilers are available, evaporation by means of steam is recommended. It is claimed that if the condensed steam is returned to the boiler while hot, a considerable saving in fuel and labor will result. Other advantages claimed for steam evaporation are the uniformity of flavor and good color of the resulting products.

The size of evaporators is governed by the amount of sap handled. The patented evaporators come in sizes from 2 by 7 up to 6 by 24 ft. It is usually considered that the modern evaporator will evaporate about 2 gal. of sap an hour for each square foot of bottom. Another rough estimate is that about 10 sq. ft. of bottom are necessary for every 100 buckets set out in the orchard. It takes 1 cord of wood to produce 8 to 10 gal. of sirup.

#### B. SUGARING-OFF EQUIPMENT

The evaporating pans used for further concentration of sap, especially in the manufacture of maple sugar, are called sugaring-off pans. These are much shorter but deeper pans than the evaporators, set on separate arches and provided with faucets for drawing off the sirup. The usual sizes of patented sugaring-off pans range from 2 to 2½ ft. in width, 3 to 6 ft. in length and 12 to 14 in. in depth.

#### C. THE BOILING PROCESS

The best grades of sirup and sugar, in terms of good flavor and light color, are obtained when the sap is boiled quickly but at as low a temperature as possible and when a batch of sap is reduced to the finished product without the addition of fresh sap. Long boiling and high temperatures tend to decompose the sugar and destroy the flavor of the sirup. Rapid concentration can be best accomplished when the depth of sap in the evaporator does not exceed 1½ in.

When the sap is heated, scum forms on the surface; this should be continuously removed. As the concentration of the sap increases, its mineral contents begin to precipitate in the form of a fine sediment. Some of it is deposited on the pan, and some remains in suspension in the sirup. This

sediment is variously known as *sugar sand*, *niter*, or *silica*. The main constituent of sugar sand is calcium malate, but the calcium salts of a number of other organic acids (*d*-malic, *d*-tartaric, citric, and others) are also present. It is believed that more mineral matter appears in the sap as the season progresses. The presence of sugar sand in the sirup, although not harmful, detracts from the appearance of the product. The sugar sand can be removed by filtering the sirup through flannel. This should be done before boiling is completed, since the fine particles of sugar sand settle more readily in the less concentrated sirup. After filtering, the sap is reboiled to the standard concentration. White of egg, whole milk, butter, or lard can also be used to remove sugar sand. These substances cause flocculation of suspended material, which can then be removed by skimming. Baking soda is also used, but its use is not recommended since it darkens the sirup and alters its flavor.

According to regulations of the Federal Food and Drugs Act, maple sirup must contain not less than 65 per cent total solids (of which about 95 per cent is sucrose) and weigh not less than 11 lb. per gal. Standard maple sirup will then contain 65 per cent solids and 35 per cent water. A sirup containing more water will sour, and a more concentrated product will tend to crystallize. Therefore, in order to secure sirup of standard quality, it is necessary to determine its density. The Vermont Agricultural Experiment Station has found that maple sirup of standard density, *i.e.*, weighing 11 lb. per gal., is obtained when a boiling point of 219°F. is reached. The boiling point is lowered 1° for each 500 ft. above sea level. A variation of 1 to 2° may also occur, depending on the run of the sap. It is therefore necessary to check the density of sirup by weighing a quantity of sirup after it has cooled.

The density of the maple sirup may also be determined by means of a hydrometer. The hydrometer usually used is that of Baumé, graduated from 0 to 50° and standardized at 60°F. Sirup of standard density, when cooled to 60°F., should have a Baumé reading of 35.6°. If determination of density is made at a temperature other than 60°F., a correction is necessary. This correction is obtained by subtracting 60 from the number of degrees at which the sirup is tested, multiplying the difference by 0.0265, and adding the result to the hydrometer reading if the temperature is above 60°F. and subtracting if it is below.

A direct determination of sugar content in hot or cold sirup can be made with a hand refractometer. With this instrument accurate and direct readings can be obtained using only one drop of sirup. This instrument has a range from 40 to 85 per cent of sugar and is, therefore, useful in making not only sirup, but also maple sugar and candy.

The color of maple sirup varies from light straw to a very dark reddish

brown. In most states sirup is graded on the basis of color as fancy, grade A, grade B, and grade C, fancy being the lightest. The flavor of maple sirup is usually described as fine, mild, strong, woody, buddy, and molasses-like. The differences in flavor of maple products are due mainly to the methods of handling rather than to any specific characteristics peculiar to a region. The color of maple sirup depends to a great extent on the alkalinity of the sap and its invert-sugar content. The growth of bacteria causes increased alkalinity and inversion of sugar; these changes result in a darker colored sirup.<sup>5</sup> Lighter colored sirup therefore results when equipment is kept free from contamination and the sap is kept at a low temperature and processed as rapidly as possible.

After the sirup is properly strained, it is put into various containers: glass, tin cans, or, if produced on a large scale, barrels. To prevent fermentation the containers must be carefully sterilized by boiling. Operators disagree as to whether the sirup should be canned hot or cold. It is claimed that hot-canning causes crystallization. Cold-canning, on the other hand, increases the danger of souring.

When sirup is contaminated with lead, the lead can be precipitated as lead phosphate and then removed by filtration. This method is adapted only to large-scale handling of sirup. The farmer-producer can achieve good results by deleading the sirup with milk.<sup>15</sup> Whole, skimmed, or dried milk can be used. Five to ten per cent of milk is added in the sirup pan, and the sirup is allowed to boil until the desired density is obtained. The lead is precipitated with the milk curd and is filtered out through a felt strainer when the sirup is withdrawn.

Some maple sirup is also made by dissolving maple sugar in water. This is usually described as *maple-sugar sirup* to distinguish it from maple-sap sirup made by evaporating maple sap.

#### D. MAPLE SUGAR

Maple sugar is produced by further concentration of the sirup. The process is known as *sugaring off* and is conducted either in ordinary iron pots on the kitchen stove or, on a large scale, in sugaring-off pans. On the basis of hardness of the resulting product, maple sugar is differentiated as soft and hard sugar. Soft sugar is produced by boiling sirup until a temperature of 238 to 240°F. is reached and then stirring continuously during cooling. It is then put in tubs, tins, or glass containers. Hard sugar is made by boiling sirup to a higher concentration, until the thermometer reaches 242 to 245°F., and stirring it rapidly while cooling. Hard sugar is molded into cakes, the sizes ranging from 1 oz. to 5 lb. The cake sugar is also called *maple concrete* and *brick sugar*. Formerly maple sugar was pro-

duced entirely on farms. The demand by commercial consumers for maple sugar of more uniform grade started a development in the industry which has largely removed the conversion of sirup to sugar, for commercial uses, from the farms to factories. Conversion factories in the United States are owned and operated almost exclusively by independent dealers.

#### E. OTHER MAPLE PRODUCTS

Among other maple products is *maple cream*, made by boiling sirup to the concentration of soft maple sugar and then rapidly cooling it, stirring it vigorously all the time. A light-colored sirup boiled to the density of strained honey is sold under the name of *maple honey*. *Maple vinegar* is made of maple-sirup skimmings and slightly scorched or slightly soured sirup, by adding small amounts of ammonium and sodium phosphate and inoculating the sirup with vinegar-making microbes.

#### F. YIELDS

A tree will produce 5 to 40 gal. of sap a season,<sup>2</sup> with an average of 10 to 20 gal. The sugar content of sap ranges from 0.5 to 10 per cent, with an average of 2 to 3 per cent; hence one tree will produce from 1 pt. to 1 gal. of sirup, or 1 to 7 lb. of sugar in a season. The average yield from year to year is about 3 pt. of sirup and 3 lb. of sugar. In a normal year it takes about 40 to 50 gal. of sap to make 1 gal. of sirup. One gallon of sirup will produce 6½ to 9 lb. of sugar, with an average of 7½ to 8 lb.\*

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\* J. L. Van Camp recorded an average flow of 7.51 gal. of sap per spile for a 3-year period on a 1-acre plot in the sugar bush at Michigan State College, East Lansing, Michigan, while P. W. Robbins reported an average flow of 12.87 gal. of sap per tree for 3 years in the Dunbar Forest Experiment Station property at Sault Ste. Marie, Michigan.



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## CHAPTER 22

### TANNINS AND DYES

Tannins and dyes are extractives, used principally in the leather and textile industries, obtained from the wood, bark, leaves, or other parts of many plants in forest vegetation. It is known that about 30 per cent of the seed-plant families contain tannin in substantial quantities, but the number of tannin-bearing plants having commercial value is small. In only one instance has tannin been recorded in the animal kingdom; the granary weevil [*Sitophilus granarius* (L.)] produces a substance possessing the properties of a tannin.

Prior to the middle of the nineteenth century, dyers had to be content with less than half a dozen natural dyes of quality, but since that time artificial dyes have become available to such an extent that they virtually replaced the natural ones. Two red dyes are secured from the bodies of the females of the insects kermes (*Kermes ilicis* L.) and cochineal (*Dactylopius coccus* Costa). Kermes is obtained from southern Europe, and cochineal comes from Mexico. Another natural dye, Tyrian purple, known to the ancients, is extracted from two Mediterranean shellfish, the straight-spine murex (*Murex brandaris* L.) and the banded murex (*M. trunculus* L.).

#### I. TANNINS

Tannins are amorphous (or in rare cases crystalline), more or less water-soluble substances, characterized by an astringent taste and an ability to form colored solutions and precipitates with iron and other metals, and capable of combining with proteins to form rather insoluble substances. Tannins can be precipitated from solution by albumen, gelatin, other proteins, and certain alkaloids. They are widely distributed in the vegetable kingdom and may occur in any plant part. Tannin exists in the vacuoles of the cell (particularly in parenchyma), and for a given plant, it may be most plentiful in the bark or its exudations, the wood, leaves, roots, rhizomes, fruit, or insect galls. Heartwood usually contains more tannin than sapwood, and the living cells of the bark contain a greater amount than the older layers.

## A. CLASSIFICATION OF TANNINS

The chemical structures of tannins are very complex, and many are not too well understood. As a result, several systems of classification have been devised. Table 22-1 presents a list of tannins classified according to the

TABLE 22-1. A PARTIAL LIST OF IMPORTANT TANNINS

Kind of tannin	Botanical name	Source	Part used	Tannin, %
<b>Hydrolyzable:</b>				
Algarobilla.....	<i>Caesalpinia brevifolia</i> Baill.	Chile	Pods	43-67
Divi-divi.....	<i>Caesalpinia coriaria</i> Willd.	Central America	Pods	30-59
Chestnut.....	<i>Castanea dentata</i> (Marsih) Borkh.	Eastern U. S.	Wood	6-10
Valonia.....	<i>Quercus aegilops</i> L.	Mediterranean	Acorn cups	17-40
Knoppers.....	<i>Quercus cerris</i> L.	S. Europe	Acorn galls	35
Aleppo.....	<i>Quercus infectoria</i> Olivier	Turkey	Galls	24-60
Sumac.....	<i>Rhus coriaria</i> L.	Sicily	Leaves	25-32
Chinese galls	<i>Rhus semialata</i> Murr.	Asia	Leaf galls	70
Myrobalans.....	<i>Terminalia chebula</i> Retz.	India	Fruit	30-40
<b>Condensed:</b>				
Malleto.....	<i>Eucalyptus occidentalis</i> Endl.	Australia	Bark	20-26
Kino.....	<i>Eucalyptus</i> spp.	Australia	Gummy exudations of bark	28-73
Chestnut oak.....	<i>Quercus montana</i> Willd.	United States	Bark	9-12
Black oak.....	<i>Quercus velutina</i> Lamarck	United States	Bark	6-12
Mangrove.....	<i>Rhizophora mangle</i> L.	Tropical coasts	Bark	15-42
			Leaves	22
Quebracho.....	<i>Schinopsis lorentzii</i> Engl.	S. America	Wood	20-30
Eastern hemlock...	<i>Tsuga canadensis</i> (L.) Carr.	United States	Bark	7-12

system devised by Freudenberg.<sup>4</sup> He divided tannins into two main groups as follows:

1. Hydrolyzable tannins: those that can be hydrolyzed by acids and enzymes and whose nuclei are held together by oxygen atoms

2. Condensed tannins: those that cannot be hydrolyzed by acids and enzymes and whose nuclei are held together by carbon linkages

Each of Freudenberg's groups is further divided into three specific classes that need not be considered here.

## B. USES OF TANNIN

The greatest use for tannin, from the standpoint of quantity at least, is in the manufacture of leather. Its ability to combine with proteins to form insoluble substances renders skins unalterable by those agents that tend to decompose them in their natural state. This is the basis of the tannin process in which animal fiber is converted into leather.

About 40 per cent of the total tannin used for all purposes in the United States is consumed by the petroleum industry as a dispersant to control the viscosity of mud in oil-well drilling. Tannin is also used in the manufacture of iron gallotannate ink, by combining iron and tannin; this kind of ink is used in larger quantity than any other. A limited amount of tannin is used as an astringent in medicine in preference to mineral astringents because it is said to be free from irritant and poisonous action. Not a few tannins may be used as dyes directly, and quantities of certain tannins are used as mordants for fixing dyes.

### C. PRINCIPAL TANNINS USED BY THE AMERICAN TANNING INDUSTRY

The American tanning industry is more highly developed than that of any other country. Conservative estimates indicate that production of leather in the United States is equal to the total production of Europe, including the United Kingdom, and that, on the basis of productive capacity, the United States could produce virtually as much leather as the rest of the world. It naturally follows that the United States uses approximately one-half of the world's consumption of tannin.

While most tanneries are now using extracts in liquid, solid, or powdered forms, a few still purchase raw materials and make their own extractions. The variations in tannin content of raw and extracted materials make it very confusing to interpret data as to the actual amount of tannin consumed when the usual statistics, in terms of tons of raw material, liquid extract, solid extract, and powder, are given; our actual tannin consumption in this country averages about 150,000 short tons annually.

The two outstanding sources of tannin used in this country are from the woods of chestnut and quebracho. These two sources account for about 65 per cent of the total amount of tannin consumed. The two sources next in order are eastern hemlock bark and chestnut oak bark, which supply about 20 per cent of the total. Of the four main sources of tannin, three are indigenous to the United States, while quebracho is imported from Argentina and Paraguay. Domestic sources have provided about 55 per cent of our total consumption of tannins, but imports of foreign tannin are increasing steadily.

In comparing the costs of various tannin extracts, the user is not so concerned about the price per unit of extract as sold as he is about the cost per pound of available tannin, or, in other words, the cost per *tannin unit*. For example, chestnut extract containing 25 per cent tannin, currently selling for 4.65 cents a pound, means a tannin-unit cost of 18.6 cents, whereas quebracho extract containing 35 per cent tannin, currently selling for 9.5 cents a pound, indicates a tannin-unit cost of 27.14 cents.

## D. HARVESTING OF RAW MATERIALS

Prior to the introduction of the vacuum pan for concentrating tannin extractions, bark was the principal raw material used in tanneries. It was customary for tanners to buy bark, store it under cover, and then, as required, make extracts by leaching crushed bark in hot water. This practice still exists, but only on a small scale.

Bark for tanning-extract manufacture is usually peeled in the woods, cut into 4-ft. lengths, piled, and air-dried before sale. The process is simple; before the tree is felled, two girdling rings are cut around the butt of the tree, one near the ground and the other one 4 ft. higher. The bark is split vertically, and then it is pried off with axes or spuds. This first "coil" of bark is removed from the standing tree because its removal prevents loss of valuable bark when making the undercut for felling and because it is more easily removed while the tree is erect. If the coil is very large, it may be split into several narrower pieces to facilitate seasoning and to permit better piling, for the bark when drying has a tendency to roll up. After the tree has been felled, girdling rings are cut at 4-ft. intervals along the bole and the remaining bark is taken off.

The first step in seasoning is to expose the inner, or "flesh," side of the bark to sun and wind by standing it against the log or by laying it on the ground with the inner face upward to obtain rapid drying for mold prevention. This preliminary drying is allowed to continue for several days, after which time the bark is gathered and piled on pole skids to keep it off the ground. The outer, or "ross," side of the bark is placed upward as a protection against leaching by rain. The seasoning period ranges from 2 to 3 months.

In eastern hemlock and oak stands, two men can fell trees and peel 2 or 3 cords of bark per day, while in the tanoak region on the Pacific Coast, because of larger sized trees, expert men have peeled 4 to 5 cords in one day, although the average is about the same as in the East.

The peeling season usually begins in May and ends in August for all regions. Peeling, in general, can be started after the sap begins to flow actively. The ease of peeling seems to be influenced by weather conditions; the bark will adhere, or "bind down," on cold days and on hot, dry days. Workers do not attempt to peel a tree unless they can complete the bark removal during the day; the bark may bind down overnight. Peeling is also affected by injury from fire and other causes.

The usual unit of sale for bark is the cord, which is occasionally on the basis of volume but usually in terms of weight. The volume cord varies from 4 to 4½ ft. high, 8 ft. long, and 4 ft. wide; the weight cord varies from

2,000 to 2,600 lb., the average being between 2,250 and 2,400 lb. In California, tanoak bark that has been seasoned a year is sold on a 2,300-lb.-cord basis. The moisture content of the bark should be the determining factor in defining the weight of a cord. Well-seasoned bark should have a moisture content of 20 per cent or less, oven-dry basis; bark of higher moisture content cannot be stored in bulk without deterioration.

#### E. WOODS-PEELED VERSUS DECK-PEELED BARK

Some sawmills and paper mills are interested in a more profitable disposal of bark from logs and wood used in their plants, notably those using hemlock. Smoot and Frey<sup>11</sup> reported the results of a study made on western hemlock as a potential source of tannin. They concluded that, under current mechanical methods of bark removal and water log storage at manufacturing plants, woods-peeled bark is superior to deck-peeled bark. Deck-peeled bark may contain low-tannin-content wood particles and salt (where logs are stored in tidewater), and it is subject to tannin leaching because of water storage. They indicated, however, that western hemlock bark may be suitable if stored in fresh water for a period of not more than 7 days and if bark-removal methods are modified to eliminate the presence of wood on the bark. They stressed the necessity for immediate artificial drying at the plant and indicated that this can be done in 2 to 3 hours at a temperature of 250 to 280°F., provided the air flow is adequate to keep the relative humidity below 40 per cent. Experiments have shown that the quantity and quality of the tannin are not materially altered under these conditions. Bark from logs stored in salt water was considered to be definitely unsuitable for tannin extraction.

Smoot and Frey also concluded that western hemlock bark peeling will have to be seasonal because of the fluctuation in tannin content. Data quoted from a study made by Clark and Andrews<sup>2</sup> show that the tannin-content variation is from 9 to 15.5 per cent throughout the year, with an average of 14.69 per cent from February to July and an average of 10.73 per cent from August to January. Fortunately, the highest tannin content occurs during the months when peeling is easiest.

#### F. METHODS OF EXTRACTING TANNIN FROM BARK

The two general methods of extracting tannin from bark are the *open-tank diffusion* and *percolation* methods. In the open-tank diffusion method, shredded bark is put into a series of large, open-top wooden tanks and subjected to water that is heated by steam coils or perforated steampipes located under the false bottoms of the tanks. Not all tanks are filled at

the same time; tanks are filled in rotation so as to get a countercurrent operation in which the fresh water first comes in contact with the bark that is the most leached. The resulting liquor is pumped successively through the series of filled tanks so that the strongest liquor comes in contact with the freshest bark in the tank at the end of the series. The temperature of the water in the tank containing fresh bark is usually kept at about 140°F., and at some plants the liquor in the last, or "tail," tank is heated to a temperature of about 180°F. For barks yielding condensed tannins, it is especially desirable to keep the temperature of the water below the boiling point, because boiling facilitates the formation of "insoluble reds," with a consequent loss of tannin and a darkening of color. The open-tank diffusion process usually requires about 3 to 4 days for an extraction.

In the percolation method, the bark in a filled tank is steamed from perforated pipes underneath the false bottom. This is done to cause the bark particles to settle uniformly. Then hot water is sprayed on the bark from the top, and the resulting liquor is drawn off at the bottom of the tank. This method requires about half the time needed for an extraction by open-tank diffusion. The tannin-free, or "spent," bark from these methods may be squeezed between rolls to remove excess water or dried and then used for fuel, covering of floors in stock pavilions, etc.

#### G. METHODS OF EXTRACTING TANNIN FROM WOOD

In extracting tannin from wood, the wood must be reduced to small particles. This is accomplished by using chippers similar to those used in paper-pulp manufacture or those of the hog type used to convert wood into chips for fuel. Because these chips are too large for extraction, they are further reduced in shredding mills. In addition to open-tank diffusion and percolation, two other methods are generally employed to extract tannin from the shredded wood. These are the *decoction* and *autoclave* methods.

The decoction method consists of boiling the wood in wooden or copper tanks at atmospheric pressure. These tanks, also, are often arranged in a series, or battery. In practice, a tank is filled with nearly saturated liquor, immersing the wood. This is heated until the strongest liquor possible is attained. The liquor is then drawn off, and the tank is filled with weaker liquor from a preceding tank; that is, the liquor from the first tank goes to the second, and the liquor from the second goes to the third, and so on to the final tank. The extraction time for this method is about 1 day.

As mentioned previously, boiling has the facility to produce water-insoluble reds from condensed tannins. Quebracho wood is extracted by the decoction method, and the liquor is treated in the last stage of extrac-

tion with sodium sulfite, sodium bisulfite, or other sulfites. These sulfites dissolve the reds and difficultly soluble tannins, keep them soluble in cold water and in the acidulated liquor of the tanning vat, and prevent their precipitation in sour liquors, thereby saving and utilizing tannins that otherwise would be precipitated and regarded as waste. Two Italian chemists, Lepetit and Tagliana, were responsible for this valuable discovery; because of it, quebracho extract so treated has become one of our cheapest and also one of the best tanning materials for special types of leather.

Sodium bisulfite treatment is also given to the Australian kino from the bark of marri (*Eucalyptus calophylla* R. Br.) to yield liquors that can be concentrated into clear extracts of good color.

The extraction of tannin from wood of the American chestnut at temperatures above the boiling point of water, in copper autoclaves which operate at pressures up to 30 p.s.i., is common at the larger plants. The autoclaves are commonly in a battery of eight units, each of which holds about  $1\frac{1}{2}$  cords of shredded wood. Modern autoclaves are fitted with drop bottoms operated by hydraulic cylinders, thereby reducing the discharging and filling cycle to about 3 minutes. Autoclaves are economical, because less water is required for an extraction and the diffusion time is only 45 minutes. The spent wood of chestnut has been used in the manufacture of paper and fiberboard, and as fuel.

#### H. CONCENTRATION OF EXTRACTIONS

The tan liquor resulting from any of the extraction methods mentioned is often concentrated to reduce transportation costs, especially if the material is to be shipped any great distance. The usual concentrations fall into three classes: liquid, containing 25 or 35 per cent tannin; solid, containing 40 to 65 per cent tannin; and powdered, containing 55 to 70 per cent tannin. Before the original liquor is concentrated it is at least strained to remove particles of bark or wood, and frequently it is clarified to produce a better color.

In the production of liquid extracts, the liquor is evaporated, usually in a vacuum evaporator, until it reaches the proper consistency. The vacuum evaporators may be single, double, triple, or even quadruple effect; *i.e.*, the liquor is evaporated by passing through one, two, three, or four vacuum chambers. In a quadruple-effect evaporator for chestnut-extract manufacture, the temperatures and vacuums considered as satisfactory are as follows: first effect, no vacuum, 227°F., as a maximum; second effect, 7 in. vacuum, 199°F.; third effect, 17 in. vacuum, 172°F.; fourth effect, 24 in. vacuum, 114°F.; fourth effect to condenser, 28 in. vacuum, 116°F. In



order to avoid using the first vacuum chamber as a heater, the liquid is heated prior to entering that chamber. The value of vacuum evaporation lies in the low fuel consumption for supplying heat and in the lower temperatures to which the liquor is subjected.

The liquid is circulated through the system continuously until it has reached the proper consistency. If a liquid extract is desired, evaporation is not carried so far and the concentrate is pumped into settling tanks. After cooling and settling, the liquid extract may be decanted and pumped into tank cars or drums for shipment. Tank cars are lined with a paste of red lead and linseed oil or with special varnishes or lacquers to protect the iron from corrosion and to prevent extract discoloration that results from contact with iron.

If solid extract is desired, the evaporation is continued until the concentrate is thick enough to be run into paper-lined gunny sacks or into casks, where, upon cooling, it solidifies into an amorphous and brittle product containing about 20 per cent moisture. The evaporation time required for the production of solid extract is roughly 1 day.

Powdered extract is made in several ways. One method is to concentrate the original extraction in a vacuum evaporator to a point where it contains about 45 per cent solids and then to place this concentrate in a vacuum drum drier to reduce it to a powder containing about 5 per cent moisture. A second method of making powdered extract consists essentially of atomizing preheated tan liquor into a drying chamber, where the excess water is evaporated by a circulating air stream. The powder is collected by a blower system. This method formerly found little favor because of danger from dust explosions and the rather high cost of operation, but recent improvements, which increase efficiency and eliminate or greatly minimize the possibility of explosions, may be responsible for its adoption in future installations. It is said that spray drying gives a better product of excellent uniformity.

### I. SYNTHETIC TANNING MATERIALS: SYNTANS

Many synthetic tanning materials are sulfonated\* products of benzene, toluene, phenol, naphthalene, and cresylic acid. Nonsulfonated products possessing tanning properties may be obtained from resorcinol and pyrogallol by condensation with formaldehyde or acetaldehyde. These have been found to possess hide-filling properties greater than the sulfonated products mentioned, and they are capable of producing a good quality of leather for some purposes.

\* Sulfonation is the process of introducing the sulfonic group,  $-\text{SO}_3\text{H}$ , into an organic compound, in which it attaches to a carbon or nitrogen atom.

### J. USE OF SULFITE CELLULOSE EXTRACT AS A TANNING MATERIAL

Sulfite cellulose extracts are prepared from the waste liquors discharged from mills manufacturing sulfite paper pulp. A study made by the National Bureau of Standards<sup>18</sup> indicates that sulfite cellulose extract can be used for tanning leather, especially when blended with other vegetable extracts. Tanning tests on light skins showed sulfite cellulose to be satisfactory from the standpoint of color, and tests with hide powder showed that the tanning materials in this extract are firmly held by hide substance. The chemical, physical, and aging properties of the tanned leathers compare favorably with those of leathers prepared without the use of sulfite cellulose. Their use as a pretannage or in blend reduces the time required to produce leather of the same degree of tannage that is obtained by the use of vegetable tanning materials alone.

Sulfite cellulose extract offers a cheap and quick-acting material to tanners, and it is of direct advantage to the paper-pulp manufacturer in helping to solve a liquor-disposal problem as well as increasing the utilization of a forest product. Sulfite cellulose extract has also been suggested as a mordant in the textile and leather industries.

To produce sulfite cellulose extracts suitable for use in leather manufacture, the sulfite waste liquor, which is acid, is neutralized with a slight excess of dolomite lime. The excess lime is precipitated by sulfuric acid, and the precipitate is filtered out. The resulting liquor is then concentrated to the desired density, usually about 30° Baumé. The exact characteristics of the constituents that have tanning properties (materials absorbable by hide) are not known, but they are termed *lignosulfonic acids*.

### K. POSSIBLE FUTURE SOURCES OF TANNIN

The American chestnut is at the present time our most valuable native tanning material. Its existence, however, is virtually doomed because of the chestnut blight [*Endothia parasitica* (Murr.) A. & A.]. Even if blight-resistant species can be introduced, the present supply of chestnut is insufficient to bridge the gap between its extinction and the growth of a new crop of a blight-resistant species, the search for which still continues. The death of a chestnut stand does not, however, spell the immediate end of the extract industry, because the wood loses its tannin slowly. Trees that have been dead for 25 to 30 years contain tannin in quantities not materially lower than those in living trees. If the wood is sound it can be used for extract manufacture, but it is said that wood from trees that have been dead for a long time gives some difficulty in the extraction process.

The inevitable depletion of chestnut and our dependence on foreign tanning materials have caused a search for other native materials. In the event of a national emergency, in which our foreign sources might be cut off, it is even more imperative that our tannin requirements be met from domestic sources. Among the many possible tannin sources that have been investigated, western hemlock and second-growth Douglas fir bark \* on the Pacific Coast, mangrove bark (*Rhizophora mangle* L.) from Florida, sumac leaves of *Rhus copallina* L., *R. glabra* L., and *R. typhina* L. from the Eastern states, and canaigre root (*Rumex hymenosepalus* Torr.) from the South-western states offer abundant supplies in an emergency or at a time when American costs of manufacture and transportation can compete with foreign materials. In certain instances, however, these materials are inferior to imported products. American sumac produces a leather of inferior color to Sicilian sumac, and western hemlock tannin, when used alone, produces leather of a deeper color than is now considered desirable; but when used in a blend of chestnut and quebracho, it is satisfactory.

In order to offset these disadvantages, it has been suggested that the United States should try to cultivate Sicilian sumac (*Rhus coriaria* L.) and some of the wattles. The wattles are indigenous to Australia but are now cultivated in Africa, where such cultivation has assumed the proportions of a large industry. Golden wattle (*Acacia pycnantha* Benth.) produces the richest bark, but the black wattles (*Acacia decurrens* Willd. and *A. millissima* Willd.), while yielding slightly less tannin, have the advantages of being larger, hardier, and better bark producers. Silver wattle (*Acacia dealbata* Link) is the poorest in tannin content.

Wattle has not been grown in the United States on a commercial scale, but experimental plantations have been grown successfully in California. It is probable that areas in Arizona, New Mexico, and Florida possess the characteristics necessary for wattle culture. Of the species producing the best results in Africa, the two black wattles are the most outstanding; California experience seems to indicate the same thing.

Wattle bark has been grown on a commercial scale in South Africa for more than 50 years, and some plantations have reached their fifth rotation. The trees are fast-growing and comparatively short-lived and reach ma-

\* Research at the Oregon Forest Products Laboratory has revealed that Douglas Fir bark contains from 8 to 18 per cent (based on oven-dry weight of bark) of a condensed tannin, that produces a lighter-colored leather than hemlock bark tannin. Thin bark from young trees and tops of old trees yields the highest percentages of tannin. Potential annual production of Douglas fir tannin in Oregon and Washington, from sawlogs alone, exceeds the total quantity of vegetable tannins consumed yearly by the domestic leather industry.

turity for bark in 8 to 12 years. The average bark exported has a tannin content of 35 per cent or more, often reaching almost 50 per cent for choice lots. The British have a monopoly on the world's supply of wattle, and strict government regulations protect the sale and growing of wattle bark. As an indication of the rapidity of bark production, 1 acre of wattle trees, 7 to 10 years of age, will yield 6 tons of bark, compared to 4 tons of oak bark and 8 tons of hemlock bark at an age of 80 years.

The heartwood of redwood and the leaves of mountain misery (*Chamaebatia foliolosa* Benth.), a low evergreen shrub growing on the Sierra Nevadas in California, are other possible native sources of tannin. The development of new domestic supplies of tannin, preferably in the form of new farm crops, has received some attention by various government agencies.

## II. DYES

The first authentic records of dyeing are found in the tombs of ancient Egypt in the paintings depicting every phase of contemporary life, including the operation of the textile and dyeing industries of five to six thousand years ago. The origin of dyes used in the earlier days is unknown. Later, however, such familiar organic dyestuffs as indigo and madder made their appearance. From that time until the middle of the nineteenth century, natural dyestuffs remained the only source of dyes for coloring fabrics.

The whole art and practice of dyeing was completely revolutionized in 1856, when a young student of chemistry, William Henry Perkin, of London, accidentally oxidized a coal-tar derivative, aniline. The resultant product was the first artificial dye, mauve, or mauvine. This discovery was followed by others, leading to rapid development of a new aniline-dye industry. Today, the cheap and varied aniline dyes have almost completely supplanted natural dyes. Only a small group of the latter still retain a place in the world market. Among them, several are products of the forest. The few examples described in the paragraphs that follow will serve to illustrate this type of forest product.

### A. Logwood

Logwood, also known as *campechy wood*, is a product of *Haematoxylon campechianum* L., a member of the legume family. This tree is indigenous to the West Indies, Central America, and the warmer parts of South America. The best commercial stock is now obtained from Mexico, Honduras, Santo Domingo, Jamaica, and Haiti.

The coloring principle of logwood is a compound called *haematoxylin*. This substance is not, however, the dyestuff but only its progenitor. When oxidized, haematoxylin yields the actual dye, *haematine*. Since haematine is an adjective dye, it can be applied to material only through the medium of a second substance known as a *mordant*. Some of the more common mordants used with haematine are the salts of ammonium, iron, copper, and tin. Depending on the type of mordant applied, the color imparted to fabrics ranges from blue to black.

Logwood is used by dyers either in the form of chips or as an extract; the former method has largely been abandoned in favor of the latter. The principal products dyed with haematine are silk, wool, cotton, leather, and straw. It is also used for staining thin sections of biological materials, particularly wood, prepared for examination with a microscope.

#### B. FUSTIC

*Old fustic*, otherwise known as Cuba or yellowwood, is the product of *Chlorophora tinctoria* Gaudich., a tree belonging to the Moraceae family, native to Brazil, Mexico, and the West Indies. Old fustic is an important natural yellow dyestuff. It produces fast olive-yellow and old-gold shades with chromium, iron, and copper mordants; when used with logwood extracts, it will form black and various compound shades of brown and olive.

At present, old fustic is used principally for dyeing leather and wool and to some extent for producing green silks. The olive shades produced by old fustic are particularly adapted for dyeing khaki cloth, and for this reason, the fustic is able to retain a place of some importance in the world's dyestuff commerce.

A dyestuff very closely related to old fustic is produced by native osage orange, another member of the Moraceae. Investigations by the U.S. Forest Service indicate that the same dyeing principles found in old fustic are present in extracts of osage orange and that the latter could very well be used as its substitute in the textile and leather industries.

#### C. QUERCITRON

Quercitron is obtained from the inner bark of the native black oak. The bark is removed from the tree, dried, and ground between millstones. It often comes into the market as a mixture of wood fiber and fine powder of a yellow or buff color. As a rule, the more fine powder present, the greater the value of the sample, because the fibrous portion contains little coloring matter. A freshly made decoction of quercitron bark is transparent and

of a dull orange-red color, but in a short time it becomes turbid and deposits a yellow crystalline mass. It should, consequently, be prepared only as required for immediate use.

A much stronger preparation of quercitron bark comes under the name of *flavin*. It yields brighter shades than the original bark and is found on the market in the form of a very fine powder of a buff or brown color. There are several methods of preparing flavin, but most of them are secret. One method of preparation consists of boiling 100 parts of ground quercitron bark with 300 parts of water and 15 parts of sulfuric acid for several hours. After cooling, the resultant mixture is run through woolen filters and the paste is washed until free from acid. It is then dried and ground. The coloring properties of good flavin are 12 to 20 times as great as that of quercitron bark.

Quercitron is applied with the aid of chromium, aluminum, and tin mordants; the resulting shades are very similar to those produced by old fustic. Bark extracts of quercitron are used to a considerable extent in cotton and woolen printing. Flavin is used principally in wool and silk dyeing.

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## CHAPTER 23

### WOOD IN THE PLASTICS INDUSTRY

The term *plastic*, as used in industry today, is applied to numerous compounds or mixtures of compounds that may be given definite form with the application of heat or pressure (commonly both) and which will preserve such form when removed from press or mold.

Plastics may be either thermosetting in character or thermoplastic. Thermosetting plastics are those in which the binding matrix, under heat and pressure, polymerizes to form hard, infusible substances that can neither be remelted nor remolded at the completion of the polymerization reaction. By contrast, thermoplastic binding materials can be softened by reheating them following complete polymerization and hence may be reworked or even remolded at will. Not all thermosetting plastics are heat-resistant, however, and several of them char badly and eventually decompose completely at only moderately high levels of heat. On the other hand, thermoplastic materials which are normally softened by heat often have good heat resistance, and a number of them can withstand temperatures as high as 200°F.

The bulk of plastic materials on the market today is derived from synthetic resins, protein complexes, wood and cotton cellulose, and some of the natural resins.

#### A. COMPOUNDING INGREDIENTS

Chemically, a marketable plastic product is composed of several organic \* compounds, each one of which plays an important role either in the molding or casting processes, or by imparting certain desirable physical or chemical properties to the finished product. The basic ingredients of plastics are classified as binders, fillers, plasticizers, solvents, lubricants, and coloring materials.

1. **Binders.** The binder is the principal constituent of a plastic; in fact, in some cases it may be the only substance used in the manufacture of a particular product. Most plastic materials today are classified according

\* In some plastics, inorganic materials such as asbestos, mica, or color pigments are incorporated.



to the binder used; *e.g.*, a plastic made with a cellulose acetate binder is called a cellulose acetate plastic. The principal binders used in the plastic industry are thermosetting and thermoplastic synthetic resins, derivatives of cellulose, casein and soybean proteins, and, to a lesser extent, lignin complexes. Among the important synthetic-resin binders, mention should be made of phenolic- and urea-formaldehydes, acrylates, indenenes, styrenes, and vinyl resins. The principal cellulose binders are cellulose acetate, cellulose acetate butyrate, and cellulose nitrate, all cellulose esters; and the ether, ethyl cellulose. These are prepared using either highly purified wood pulp manufactured by the sulfite process (see pages 301 to 311) or cotton linters.

**2. Fillers.** Fillers play a major role in plastic-products manufacture, particularly in the phenolic types, where they are used in quantity to increase the bulk of the molding matrix and to impart many desirable physical and chemical properties to finished articles. Fillers may be of either organic or inorganic origin, the choice of one being largely dependent upon the properties it will impart to the product.

The essential requirements of a good filler are cheapness and availability, good strength properties (particularly under impact and tension loads), low rate of moisture absorption, ease of wetting by resins and dyes, low specific gravity, and nonabrasiveness. When the specific use of the finished product is carefully considered, other desirable properties such as high dielectric strength, heat resistance, machinability, nonflammability, chemical inertness, particle size, color, and odor also become important.

Wood flour, walnut-shell flour, cotton linters, alpha-cellulose (see page 48), paper, asbestos, mica, graphite, diatomaceous silica, and glass fiber are among the filler materials most commonly used.

*a. Wood-flour Filler.* Because of its cheapness, availability, and reasonably good over-all physical properties, wood flour is used in much greater quantity than other plastic fillers. The lighter colored woods of low density such as white pine, basswood, cottonwood, yellow poplar, balsam fir, and spruce are preferred, but quantities of flour made of heavier woods such as maple, oak, birch, and red gum are also used.

Wood flour suitable for filler stock must be made in an attrition mill. Wood reduction by grinding is more a matter of fiberization, and the resulting particles retain much more of the strength characteristics of the original fibers than do flours made in ball or rod mills where impact disintegration is employed. Particle size is, of course, variable, and the freshly ground stock must be screened to obtain a material of reasonably uniform texture. Nothing coarser than 60-mesh screenings is usually acceptable.

Moisture absorption by wood flour is higher than that of many other

fillers but lower than that of straight cellulose types. Numerous substitutes have been tried, but most of them are either too heavy or fail to impart sufficient mechanical strength to molded articles.

*b. Walnut-shell Flour.* Walnut-shell flour is a suitable filler for many applications in both cast and molded phenolic plastics. The shells are obtained from walnut processors and shipped to mills where they are reduced to flour.

Walnut-shell flour contains appreciable amounts of both cutin and lignin. The cutin, being waxy and highly impervious to water, causes the filler to resist the absorption of the binder, although the flour itself has good absorbent properties. The lignin acts as a binder as well as a filler.

Plastics made with walnut-shell filler are smooth and glossy and possess good bending and impact strength, but only fair tension and compression resistance. They are superior to wood-flour-filled plastics in both heat and water resistance and in dielectric properties.

**3. Other Constituents of Plastics.** Although not derivatives of wood, other materials used in compounding plastics are mentioned briefly here in order that the reader may have a better appreciation of the composition of a plastic product.

*a. Plasticizers.* Plasticizers are multipurpose materials added to plastic formulations to increase their flow characteristics during molding processes and to render finished products less brittle or more flexible. Plasticizers are organic liquids or solids with low melting points that must be compatible with other constituents in the formulation, yet chemically stable and essentially nonvolatile. Camphor is nearly a universal plasticizer for the cellulose nitrate-type plastics. Methyl and ethyl phthalates are most generally used with the cellulose acetate and cellulose acetate-butylate compounds. These and many others are used with the ethyl cellulose-type plastics. A mixture of aniline and furfural is a suitable lignin plasticizer. A whole host of compounds is used to plasticize the various synthetic-resin plastics, but space does not permit of their inclusion here.

*b. Coloring Materials.* A few finished plastic products are black or nearly so, but on the other hand, many of them are colorless or essentially so, and their general appearance and "eye appeal" may be materially improved by addition of dyes, lakes, or pigments to the molding matrix.<sup>4</sup>

*c. Lubricants.* Materials are occasionally added to plastic mixes to increase flow during the molding operation and to prevent the cured plastic articles from sticking to the molds. Such materials are called lubricants, the most common of which are waxes, stearic acid, or metallic stearate salts.

*d. Solvents.* Several solvents, including numerous alcohols, acetone, and blends of ether alcohol, are used in the manufacture of plastics. Many

of them are used as carriers for plastic coatings especially prepared for metal finishing. Cellulose nitrate dissolved in ether alcohol is the familiar pharmaceutical preparation known as "new skin." "Plasticwood" is cellulose nitrate dissolved in acetone with a wood-flour filler.

### B. LIGNIN PLASTICS

Under certain conditions it is possible to plasticize lignin and use it as a binder in the manufacture of a number of plastic materials. Some lignin-plastic materials, although suited for several industrial purposes, have never been developed beyond the pilot-plant stage, as they offer no special advantages over well-established competitive materials. On the other hand, there are a few of them that are now produced commercially.

Lignin per se is a very brittle substance, and unless used as a binder with fiber, sawdust, or wood-flour fillers, it has little utility in the plastics field. Lignin-plastic materials are available in powder form for molding, in sheets suitable for the manufacture of laminates, and as hardboard.

1. **Hydroxylin.** This is the name applied to lignin-plastic materials developed at the U.S. Forest Products Laboratory. Hydroxylin is made from mill-run hardwood residue.\* The wood, in whatever form, is hydrolyzed with a dilute acid or with aniline in order to convert a considerable portion of the carbohydrate constituents present to water-soluble sugars, which may be subsequently removed by repeated washings. In effect this increases the ratio of lignin to cellulose in the hydrolyzed product. Maples, red gum, oaks, hickories and cottonwoods are species commonly used.

*a. Acid-hydrolysis Method.* Furnishes to digesters have been variable during experimental work, but a typical charge consists of a mixture consisting of 100 parts by weight of dry wood residue, 250 parts of water, and 3 parts of concentrated sulfuric acid. These are placed in a rotary digester and cooked with direct steam for a period of 30 minutes at a pressure of 135 p.s.i. The acid cooking liquor and its hydrolysis products are then drained off, and the residual lignocellulose complex is water-washed until neutral to litmus, then dried, and finally milled to a particle size ranging from 40 to 100 mesh. The powder, which in effect is a lignin binder with cellulose filler, may be molded at 190°C. with the mere addition of water. A product with better properties is obtainable, however, if a plasticizer such as a mixture of aniline and furfural is used.

One such molding mixture consists of 100 parts of the powdered lignin-cellulose complex, 8 parts of aniline and an equal amount of furfural, 0.5 part of zinc stearate, and 2 parts of water. This mixture, when pres-

\* Recent work has revealed that softwoods may be similarly utilized.

sure-molded for 3 minutes at 150°C. under 3,000 to 4,000 p.s.i., produces a lustrous, jet-black plastic with a specific gravity of about 1.40.

*b. Aniline-hydrolysis Method.* As an alternate method of hydrolysis, aniline may be substituted for acid. Plastics made by this method exhibit greater mechanical superiority and better water resistance than those made by the acid-hydrolysis method. A typical furnish consists of 100 parts of dry wood residue, 100 parts of water, and 21 parts of aniline. This

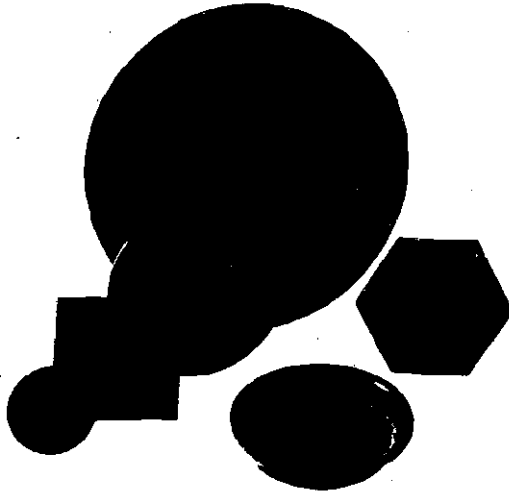


FIG. 23-1. A lignin plastic from wood. (Courtesy Forest Products Laboratory, Madison, Wisconsin.)

mixture is cooked for 3 hours with live steam at 160 p.s.i. The spent cooking liquor is then removed and the residual wood washed until neutral, dried, and then milled to powder having a particle size ranging from 40 to 80 mesh.

A suitable molding formulation is comprised of 100 parts of powder, 8 parts of furfural, 2 parts of water and 0.5 part of zinc stearate. When pressure-molded for 3 minutes at 155°C. under 3,500 to 4,000 p.s.i., a product similar in color and density to that made with acid-hydrolysis molding powder is obtained.

Although black in color, the hydroxylin plastics may be coated readily with enamels of nearly every hue, lacquers, paints, or finishes with incorporated metallic dusts. They are easily machined and practically indestructible under normal usage. Hydroxylin plastics have been found suitable for the manufacture of storage-battery boxes, distributor heads

in the ignition systems of gasoline engines, many parts for electrical appliances, knobs, ash trays, and similar items.

While these plastics have created considerable interest, they are as yet not manufactured in any commercial quantity.

*c. Hydroxylin Laminate Sheet.* If wood chips similar in size to those used in the manufacture of wood pulp are used instead of mill-run wood residue, it is possible to produce a sheet of hydrolyzed wood suitable for the production of high-strength laminates.

Following acid hydrolysis of the chips, the residual wood is washed until neutral and then reduced to pulp in a disk mill. The pulp is then screened and the accepted stock made into a sheet on a Fourdrinier paper machine. When dried, the sheets may be laid up and pressed at 2,000 p.s.i. and 175°C. to form laminates of desired thickness.

To increase water resistance and dimensional stability and to minimize delamination, the hydrolyzed wood sheets may be impregnated with a phenolic-type resin before laminating. While better physical properties for the laminate are obtained in this way, its mechanical properties are only slightly improved.

*d. Hydroxylin Hardboard.* In making hardboard, hydrolyzed chips are run through a disk mill or beating engine, then passed through coarse screens, and finally made into mats  $1\frac{1}{2}$  in. or more in thickness. The mats are placed between platens and pressed at from 300 to 500 p.s.i. in order to remove excess water. Following this, the pressure is reduced to 65 to 75 p.s.i. and the platens heated to a temperature of 185°C. Polymerization of the lignin is complete in about 20 minutes, and a hardboard about  $\frac{1}{4}$  in. thick and having a specific gravity of about 1.00 results. This hardboard is similar to other hardboards now on the market and may be used for the same purposes.

**2. Benalite.** This is a lignin-plastic hardboard manufactured by the Masonite Corporation and has the distinction of being the first American lignin-plastic material ever to be produced commercially. In the manufacture of Benalite, wood chips are placed in "guns" having a capacity of about 12 cu. ft. and subjected to live steam at pressures ranging up to 1,200 p.s.i. During the short interval of from 30 to 45 seconds, acetic and formic acids developed from wood substance itself under such heat and pressure bring about a rapid hydrolysis of the hemicellulosic constituents present. The gun is then quickly opened, and upon their sudden return to normal-atmosphere conditions, the hydrolyzed chips with their highly developed internal pressure explode into fiber masses and bundles. The products of hydrolysis are then removed, and the residual wood, consisting largely of reactivated lignin and hydrated but otherwise unchanged cellulose, is ready for rebonding into panel form.

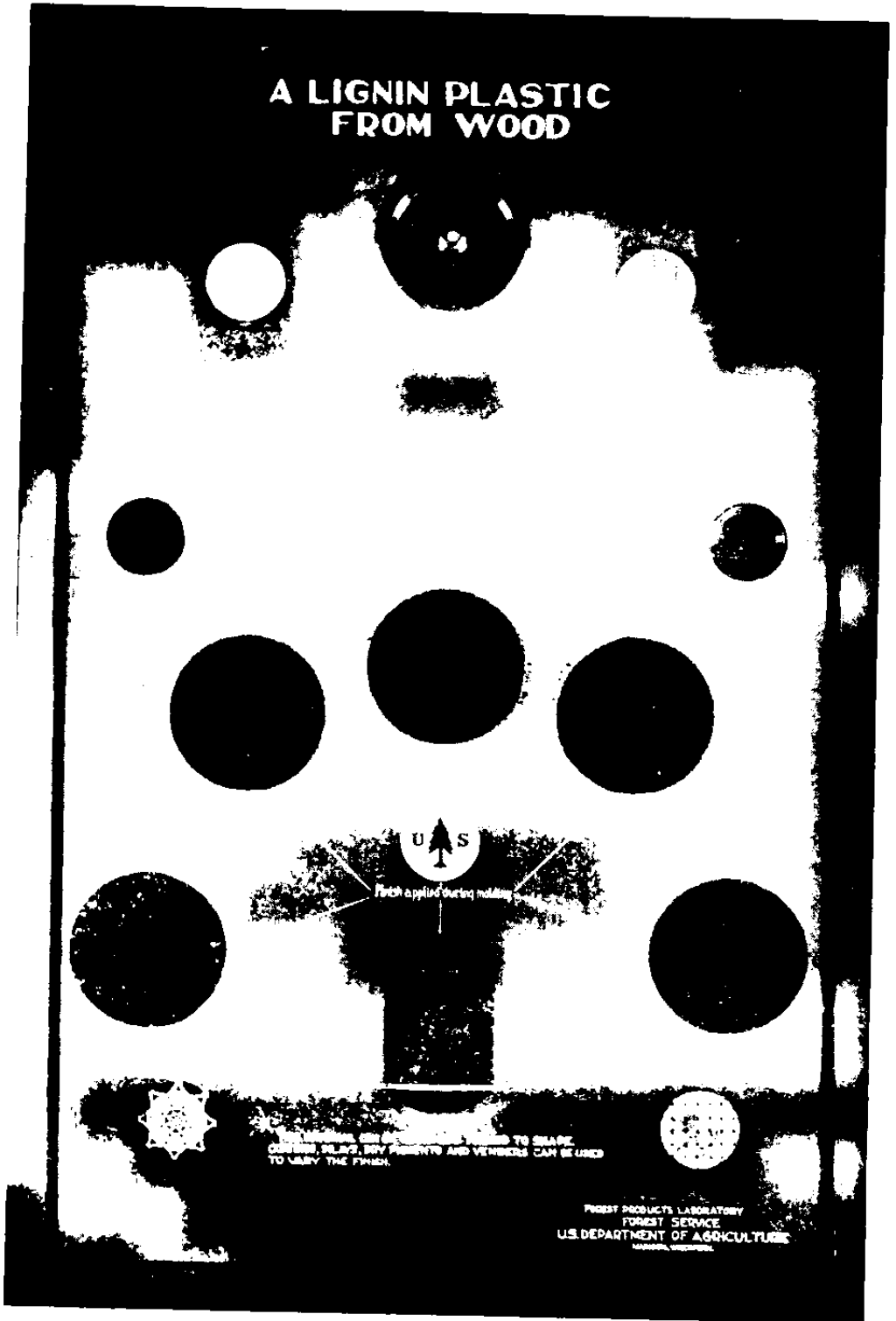


FIG. 23-2. General character of lignin-plastic material, adaptable to many forms and products. (Courtesy Forest Products Laboratory, Madison, Wisconsin.)

In panel manufacture the fiber masses are formed into mats and placed in multiplaten presses capable of producing boards 4 ft. wide, 12 ft. long, and from  $\frac{1}{10}$  to 1 in. in thickness. The press platens are fitted with heating and chilling devices and are carefully machined to assure a uniform pressure across their faces. When charged, the presses may be adjusted to exert a unit pressure of from 50 to 1,500 p.s.i. or more, depending upon density and thicknesses of the panel required. As platen temperatures rise, the reactivated lignin begins to flow, and by the time temperatures have reached 175 to 180°C., the fibers have been recoated with the binder and full cure has been effected. In practice, the platens are chilled before the panels are removed.

Benalite has many applications as a sheathing material and wallboard. It may be finished to simulate tiling, and a considerable quantity with enameled surfaces is used as a wallboard in bathrooms. Because of its dimensional stability it is also suitable for template stock.

Most of the early uses of the resinboard were for reinforcing around lugs and sections of molded pieces that required extra impact strength. It is believed that in the future this product may find wide application in the manufacture of refrigerator doors, sewing-machine cases, and many other products.

#### C. UREA-PLASTICIZED WOOD

Wood soaked with a solution of urea and then dried may be easily bent when reheated to temperatures ranging from 212 to 220°F. This discovery has led to the development of a plastic material made of urea-impregnated sawdust. In this process sawdust is mixed with 25 per cent by weight of dry urea. Enough water is added to make a paste, after which the mix is dried to 2 or 3 per cent moisture. One to five per cent zinc stearate is added as a lubricant, and the mix is placed in a mold and subjected to pressures of from 1,000 to 1,500 p.s.i. and temperatures ranging from 180 to 185°C. for from 3 to 5 minutes. The mold is then cooled to about 60°C. and the product removed. This urea-plasticized wood material is gray to nearly black, noncorrosive, and possesses machining characteristics and strength properties comparable to many other plastics. It exhibits poor water resistance, which is to be expected, since urea is known to increase the hygroscopicity of wood.

#### D. CELLULOSE PLASTICS

As previously pointed out, cellulose plastics are manufactured from esters such as cellulose nitrate, cellulose acetate, and cellulose acetate-butyrate and from the ether, ethyl cellulose. The bulk of these plastic

materials is made from cotton linters, although highly purified wood cellulose has been used in ever-increasing quantities during the past few years. All these plastics are of the thermoplastic type.

**1. Cellulose Nitrate Plastics.** Celluloid, a cellulose nitrate derivative, was the first successful plastic material ever to be manufactured. Cellulose nitrate plastics are prepared by treating cotton linters with nitric acid in the presence of sulfuric acid, which acts as a catalyst. The Germans have developed wood-pulp nitrocellulose, but in the United States, linters are still preferred. Recently "dense cellulose," partially nitrated wood pulp in sheet form, has found favor with several manufacturers.

In processing, the nitrocellulose, of whatever origin, is dehydrated and plasticized with camphor in the presence of alcohol until a stiff dough-like mass is formed. At this point the mixture is filtered and dyed or pigmented as required and finally rolled into sheets. The sheets are usually laid up and pressed into billets or blocks in order to facilitate their handling. These blocks contain appreciable quantities of water and alcohol and must be seasoned before they are suitable for marketing. Seasoning rooms are usually equipped with temperature and humidity controls in order that the seasoning process may progress at a slow and uniform rate.

Cellulose nitrate plastics are inflammable and have a tendency to become brittle with prolonged exposure. On the other hand, they are among the cheapest to produce and they lend themselves to many interesting and diverse uses. Enormous quantities are used in the manufacture of liners for safety glass. Another major outlet is in the production of photographic film. Among other large users are the manufacturers of fountain pens and mechanical pencils, combs, brush and mirror backs, hairpins, ping-pong balls, dolls and toys of every description, piano keys, organ stops, and slide fasteners. The 1946 production of cellulose nitrate products has been unofficially estimated at more than 110 million pounds.

**2. Cellulose Acetate Plastics.** Cellulose acetate binders are made by treating cellulose with glacial acetic acid and acetic anhydride in the presence of a catalyst such as sulfuric acid. Such a mixture, when thoroughly aged, has the consistency of molasses and is composed largely of cellulose triacetate. At this point water is added to the mixture. This dilution effects a partial hydrolysis or deacetylation of the triacetate, and cellulose acetate settles out of solution as a white precipitate. This is permitted to mature for several days in a constant-temperature bath held at 86°F., after which the precipitate is filtered and dried.

Cellulose acetate in the hands of a skilled chemist is a versatile material, and with carefully selected plasticizers it may be molded into many useful products with desirable physical properties. Because of the large number of useful plasticizers and the various properties each of them im-



parts to the plastic matrix, many cellulose acetate formulations are available to industry.

Once a plasticizer or plasticizers have been selected, they are suitably blended with the cellulose acetate in a mixing machine, usually in the presence of solvents such as acetone and alcohol. Dyes or color pigments are added if needed. When intimately mixed, the batch is run through warm rolls and sheeted. The sheets may be cut into molding-powder pellets, block-pressed, fed into extruders to form rods or tubes, or pressed through slots to form thinner sheets.

A complete list of all the cellulose acetate molding-powder compounds and the many and diverse articles made from them would occupy a space of several hundred pages. Cellulose acetate plastic materials are commonplace in our daily lives. The steering wheel of our automobile, cases of small table radios, housing for motors of electric shavers, our favorite bass and salmon plugs, knobs, handles, name plates, grommets, toilet articles, and flashlight cases are but a few of the many cellulose acetate products that we now use in going about our daily chores and pleasures.

It has been estimated that more than 90 million pounds of cellulose acetate were used in 1946.

**3. Cellulose Acetate-Butyrate Plastics.** This cellulose ester is made by treating cellulose with a mixture of butyric and acetic acids and anhydrides in much the same manner as cellulose acetate is prepared. The molding compounds are very similar to those of the cellulose acetates and are used for the fabrication of similar products. As a group, the acetate-butyrate plastics exhibit better dimensional stability, as they are more moisture-resistant and less affected by temperature than the straight acetates.

**4. Ethyl Cellulose Plastics.** These are the most recent additions to the family of cellulose plastics. They have been on the market for a comparatively short time, but because of their many superior properties they have become firmly established in industrial circles.

Ethyl cellulose is an ether of cellulose. In its preparation, cotton linters or purified wood pulp is treated with a strong base such as sodium hydroxide. Under carefully controlled conditions this alkali cellulose complex is then treated with ethylating agents such as ethyl sulfate or ethyl chloride, which introduce ethyl groups into the cellulose molecule. The ether thus formed is washed; when dried it is a white granular residue. With suitable plasticizers it may be molded, extruded, or cast. Like other cellulose derivatives, it is compatible with many brilliant dyes and color pigments.

Ethyl cellulose plastics have many outstanding properties. They are the lightest (specific gravity of 1.07 to 1.18) of the cellulose plastics and exhibit excellent resistance to heat, cold, water, alkalis, and weathering. Their dimensional stability leaves little to be desired, and from machin-

ability and mechanical standpoints they compare favorably with any of the thermoplastic materials.

Ethyl cellulose is available in powder form for extrusion, injection, and compression processing, in sheets up to 0.020 in. thick, in thin films and foils, or uncompounded for use in lacquer coatings or protective films on metals. The various compositions of this material enjoy many of the same uses as other cellulose plastic derivatives.

### E. PLASTICS INDUSTRY

Although no figures are available to indicate the total consumption of wood in the plastics industry, some idea of the rapid growth and present size of the industry as a whole may be gained from the fact that in 1933 there were only 101 establishments engaged in the manufacture of finished plastic articles from cellulose ethers and esters, vulcanized fiber products, and pressed pulps, while today there are more than 500 firms engaged in such production.

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## CHAPTER 24

### MINOR FOREST PRODUCTS

In addition to the forest products described in the preceding chapters, there are numerous other commercially valuable products derived from forest vegetation. It is beyond the scope of this book to attempt to deal with all of them, but a few representative examples have been selected to illustrate the wide variety of other products that come from forests. In this connection it must be remembered that many important articles of commerce, such as rubber, cocoa, and quinine, although originally products of forests, are today obtained almost exclusively from plantation-grown trees. It is only logical to expect, that as our knowledge of the world's forest vegetation expands and increasingly larger numbers of other products such as drugs, foods, and oils become known, other plants also will be grown under intensive cultivation in order to improve quality and yield of the desired products.

#### I. BARK

##### A. CASCARA BARK

Cascara bark is the trade name for the bark of the cascara tree, *Rhamnus purshiana* DC.,\* a small tree 20 to 40 ft. in height and under 15 in. in diameter. This tree is found in the Pacific Northwest states and in adjacent Canada.<sup>7</sup> Its commercial range, as reported by Starker and Wilcox,<sup>26</sup> is confined to northwestern California, western Oregon and Washington, and southern British Columbia.

Cascara bark is considered one of the most important natural drugs produced in North America and is widely used for laxative preparations and as a tonic, both at home and abroad, under the name of *cascara sagrada* (from the Spanish "cascara" meaning "bark" and "sagrada" meaning "sacred"). The bark is collected during the growing season, from early spring and as long as the bark will slip off, which is usually from about the middle of April until the end of August. The collecting season varies greatly, however, with weather and locality.

\* Other species of *Rhamnus* are found on other continents; of these *R. cathartica* L. and *R. frangula* L., native to Europe, northern Africa, and Asia, are the most important. Neither of these two species, however, has attained the popularity of *R. purshiana* since its acceptance by the medical profession in 1877.

The trees are first girdled near the ground, and then the bark is peeled off in large pieces as far up the trunk as possible. The tree is then felled and the bark peeled from the remaining portion of the trunk and from branches up to about 2 in. in diameter. Ordinarily, before the bark is peeled, all moss and lichens are removed, because clean bark commands a better price. The peeling tools used are an ax and a spud, the latter being usually devised by the collector.

The peeled bark is placed on a canvas or a wooden platform to dry. At the end of the summer the dried bark is broken into small pieces and placed in burlap sacks, each of which contains from 50 to 75 lb. of bark. The United States Pharmacopocia states that cascara bark must be cured for at least 1 year before it can be used as a drug. This further aging is usually done by dealers in crude bark rather than by collectors.

The collection of cascara bark is usually carried on by ranchers, woods workers, and Indians, entire families frequently setting up a camp in the woods for the summer. The average earnings for adults are said to be about \$4 a day; under exceptionally good conditions, *i.e.*, with a good stand of cascara trees and good prices for bark, daily wages may equal two or three times that figure.

The total annual collection of cascara bark is very difficult to estimate but apparently ranges between 2,000 and 3,000 tons, representing a collectors' income of about one million dollars.

The collectors' prices for cascara bark since 1931 have ranged from a low of 3½ cents a pound for the period of 1933 to 1935 to a high of about 39 cents a pound in 1947. Several hundred tons of cascara bark are exported, the largest consumer being the United Kingdom.

A survey of the remaining cascara stands leads Starker and Wilcox<sup>25</sup> to conclude that the available supply of cascara is being rapidly exhausted, and they estimate the residual merchantable cascara bark on the Pacific Coast, including British Columbia, at about 150,000 tons. However, the tree reproduces itself well by seed or by sprouting and grows rapidly. With proper protection from fire and more conservative methods of peeling, such as placing definite restriction on the minimum diameter of trees that may be peeled and insisting that all trees be felled after peeling (this to encourage coppicing), the present stands of cascara may suffice to meet the demand for some time.

The possibility of growing cascara trees under cultivation, either as fillers in existing coniferous forests of the Pacific Northwest or in plantations, should also be considered. Several successful plantations have already been established in Oregon, with the owners optimistically estimating a return at the end of 10 to 15 years of \$1,000 to \$2,000 per acre, at prevailing prices for bark. At that age the average tree should be 5 to

6 in. in diameter and should yield 12 to 15 lb. of bark. The coppice growth which will result from cutting the trees should be thinned during the first year to the three or four most vigorous stems; these may be allowed to mature into crop trees. A second crop should be ready for harvesting in 10 to 12 years, if sprouts are properly trimmed. Since the vigor of the coppice will gradually diminish, new seedlings should eventually be introduced.<sup>4</sup>

### B. CORK

Commercial cork is obtained from the outer bark (phellem) of the cork oak (*Quercus suber* L.), a small to medium-sized forest tree widely distributed through countries bordering on and adjacent to the western Mediterranean.

It is estimated that the forests containing cork oak comprise an area of five million acres and that the annual production of cork bark is from 200,000 to 260,000 metric tons. Portugal, the leading cork-producing country, has an annual output of about 100,000 metric tons, or nearly 50 per cent of the world's production. Other important production centers include, in their order of importance, Spain, Algeria, French Morocco, France, Italy, Tunis, and Spanish Morocco. The largest areas of unexploited cork forests, aggregating about two million acres, are found in Algeria and in French and Spanish Morocco.

**1. Cork Formation.** Young woody stems are protected against desiccation by an outer layer of cells, the *epidermis*. In the majority of woody plants this layer is ruptured as the tree increases its girth, because there is no provision in the epidermal layer for further cell division.

Before the epidermis is ruptured, a new protective layer, the first periderm, is formed underneath it. This layer originates from mature living parenchyma cells in the primary tissues (epidermis, cortex, or pericycle). The new tissue completely surrounds the stem and is composed of cork cambium (*phellogen*) and the layers of cells formed by it; the *phellem* on the outside, composed of layers of cork cells, and the *phelloderm* on the inside, consisting of a few layers of thin-walled, nonsuberized cells.

As the tree continues to increase in girth, the primary tissues ahead of the cork cambium die and the resulting desiccation induces the death of the first *phellogen*. New lines of cork cambium are then formed deeper in the bark tissues, eventually reaching the secondary phloem. This invasion of the secondary phloem by lines of cork cambium (*secondary phellogen*) marks the beginning of deep cork formation in trees and is manifested by roughening of the outer surface of the bark. In most woody plants the secondary *phellogen* does not form a continuous layer of cells around the tree trunk but exists in discontinuous or anastomos-

ing layers. The result is an outer shell consisting of alternating cork and dead inner-bark (secondary phloem) tissue. Such cork is of no commercial value.

In the cork oak, the secondary phellogen forms a continuous layer over the entire trunk. This layer produces each year a great number of cork cells toward the outside. If the cork trees were not stripped, this initial layer of cork cambium would persist for a long time, forming cork of considerable thickness. When, however, the first stripping is performed, the initial layer of cork, known as *virgin cork*, is removed, exposing a deeper cork-cambium layer. This layer dies, but a new one is formed in the bark behind it. This growth phenomenon is repeated at each successive stripping, with the result that new phellogen layers are developed in the inner bark (secondary phloem).

**2. Collection of Cork.** Portuguese laws require that cork trees should be at least 5 in. in diameter at breast height before the first stripping can be performed. At this size the trees are about 20 years old. The first, or virgin, cork is very coarse and rough and of very minor commercial value. Subsequent strippings are performed at intervals of about 9 years. The cork from the second stripping is finer in texture and hence of better quality, but the best grades of cork are obtained only beginning with the third stripping.

The average productive age of cork oak trees is about 100 years. The amount of cork produced varies with the size and age of the tree, site, local climatic conditions, rate of growth, and the intervening time between strippings. On the basis of a 9-year rotation, 40 to 200 lb. of cork per tree is to be expected; however, individual trees have been known to yield as much as 500 lb. The thickness of cork removed at each stripping ranges from  $\frac{1}{2}$  to about 3 in.

The stripping operations are conducted from May to August, except for days when a hot wind, known as the *sirocco*, is prevalent. Stripping is avoided on such days to prevent the desiccation of newly exposed cork cambium. In Spain and Portugal cork is stripped with a long-handled hatchet (Fig. 24-1). In other places, especially in Algeria, crescent-shaped saws are sometimes employed. Two cuts are made around the tree, one near the ground and the other below the main branches. This is followed by two vertical cuts. Care is taken to cut only through the cork region without injuring the last-formed phellogen. The bark is pried loose with the wedge-shaped handles of the hatchet.

Frequently cork is also removed from the larger branches; this is of fine texture, although normally not very thick. In French government-controlled forests, however, stripping of branches is prohibited, and the minimum diameter of the trunk for stripping is limited to 6 in.

In general, trees grown at higher altitudes produce cork of a finer quality than those in the lowlands, but the quality of cork is never uniform even within the same locality. Usually only about 60 per cent of any stripping can be used for bottle stoppers and other *natural cork products*. The remaining 40 per cent, known as *refuge*, is good only for composition



FIG. 24-1. The method of stripping corkwood. (Courtesy Armatroy Cork Company.)

products, in the manufacture of which the cork is granulated or reduced to flour.

After the cork is removed from the trees, it is left in the woods to dry for a few days. It is then transferred to a central station, where it is boiled in large open vats. The object of boiling is to remove tannins, as well as to make the cork more pliable, facilitating the straightening of pieces. At the same time the rough outer layers are scraped off, thus reducing the weight of the cork by about 20 per cent. The scraped sheets are flattened, dried, and made up into rough bundles. These bundles are transported on the backs of burros to manufacturing or shipping centers. In the latter instance, bundles of cork intended for export are opened,



graded according to quality in about 25 groups, trimmed, and baled for shipment.

When cork finally reaches the manufacturer, it is re-sorted into as many as 80 different grades. Aside from defects caused by such natural agents as insects, the basis for grading is porosity as expressed by the number and size of air passages (*lenticels*), and the presence of lignified tissues. The former decrease the impermeability of cork, and the latter account for a decrease in its elasticity. Specifications for some of the finer grades

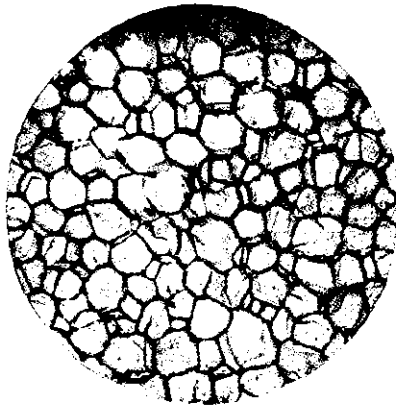


FIG. 24-2. Photomicrograph of cork, tangential view. (Courtesy Armstrong Cork Company.)

are so exacting that it takes a specialist with many years of experience to grade cork for industrial uses.

**3. The Properties of Cork.** Cork possesses a combination of many valuable properties which accounts for its wide industrial use. The chief properties of cork are resistance to liquid penetration, compressibility, resilience, high frictional qualities, buoyancy, low thermal conductivity, chemical inertness, and stability.<sup>3, 5, 20</sup> Most of these characteristics are traceable directly to its cellular structure.

Cork, as it appears under a microscope, consists of innumerable small cells which are more or less rectangular in the transverse and radial sections and polygonal in the tangential section (Fig. 24-2). These cells are so compactly grouped that an average cork cell is in contact with 14 other cells. The only breaks between the cells are due to the lenticels, small intercellular air passages surrounded by loosely arranged cells; these intercellular passages extend from the surface of the bark to the last-formed cork cambium. There is, however, no connection between these open spaces and the surrounding cells; therefore neither air nor moisture

can penetrate into the adjacent cells, but can travel only along these open channels.

Cork cells possess very thin but strong walls of cellulose, heavily impregnated with a moisture-resistant substance called *suberin*. From 50 to 85 per cent of the total volume of cork is occupied by the cell cavities filled with air. The resistance of cork to liquid penetration is due to the compactness of its box-like cells with closed ends and the impenetrability of their suberin-coated walls. This property accounts for its universal use for bottle stoppers. The only leakage possible in a cork stopper is through the lenticels. This, however, is avoided by stamping out the corks in such a way that the lenticels run crosswise through the tissue.

Since more than 50 per cent of the volume of cork is occupied by air, it is very light (specific gravity 0.15 to 0.25). The lightness of cork, coupled with its impenetrability to water, accounts for its buoyancy, a property which adapts it for use as floats. When under a load, the air in the cells is compressed, and since the cells are airtight, cork tends to resume its original size and shape as soon as pressure is released. Moreover, when compressed, cork does not spread laterally; the only dimension that changes is the thickness of the block. This ability to resist permanent deformation under a load, or its resiliency, accounts for many industrial uses of cork, e.g., gaskets, machinery isolation for absorption of shock and vibration, and seals and closures of many kinds.

Because of its myriads of air-filled cells, cork reacts very slowly to changes in temperature and to passage of sound; on this score it is used extensively for insulation. Moreover, because of its low thermal conductivity and chemical composition, cork will not burn or maintain combustion, except in direct contact with flame.

Cork is a highly frictional material, and this property is retained even when it is wet or coated with oil or grease. Because of this it is used in power transmission, in friction drives, and in feed rolls, especially in the textile and paper industries. Finally, cork is very resistant to the action of many chemicals, except alkalis and strong acid solutions. Under ordinary conditions cork is practically indestructible. It is not affected by atmospheric conditions and shows no signs of deterioration with the passage of time.

**4. Cork Uses.** Cork is used either in its natural, or unmodified, state or in the form of compositions, achieved by grinding and mixing it with various binders. The uses of natural cork are more or less restricted by the size and lack of uniformity of the raw product. The most important articles made of natural cork are bottle and jar stoppers (Fig. 24-3), insulating materials,<sup>26</sup> gaskets and washers, life preservers, and tool handles. On the other hand, cork compositions, while retaining many desirable

qualities of natural cork, are characterized by uniformity of structure and the readiness with which they lend themselves to manufacture in any size. Of cork composition materials, linoleum is the most important; others include cork carpet, cork bricks, shoe pads, and bottle crowns.

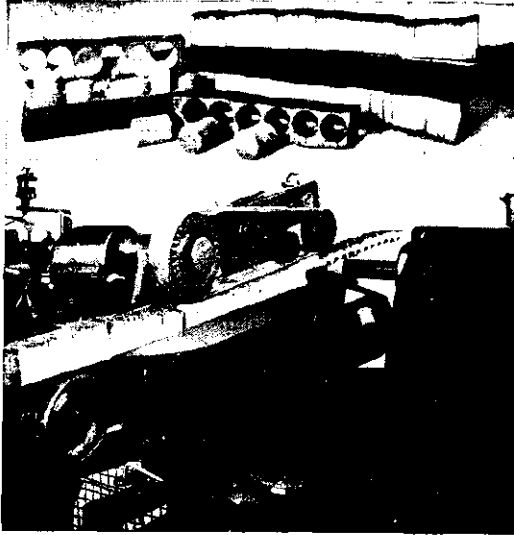


FIG. 24-3. Cork slabs and cork-punching machine. (Courtesy Armstrong Cork Company.)

**5. Possibilities of Cork Production in the United States.** The first recorded attempt to introduce the cork oak tree into the United States was made by the agricultural division of the Patent Office in 1858, when a large shipment of acorns was received in San Francisco from Spain. A number of other attempts have since been made to establish cork oak in various sections of California and the Southeast. According to Metcalf and others,<sup>20</sup> "most of the trees from those early plantings occur as individual specimens or small groups, some of which have reached a large size and great beauty." There are about 2,000 cork oak trees growing in California today, the larger trees measuring more than 40 in. in diameter.

In 1940, experimental stripping of cork oak trees was undertaken as a cooperative project between the Agricultural Extension Service of the University of California and the Crown Cork and Seal Company. In the course of these operations, 248 trees with a d.b.h. of more than 8 in. were stripped the first year, and more than 240 additional trees were stripped in subsequent years. A total of more than 25,000 lb. of cork was removed.

A second stripping, conducted in 1946, indicated satisfactory regeneration of cork amounting to almost 1 in. in a 6-year period. Subsequent commercial tests on virgin and second-growth cork indicated that domestic cork is equal in quality in every respect to imported cork of the same grade.

On the strength of the showing made by the scattered plantings of cork oak trees, it is felt that a flourishing cork industry could be established in California, where there are thousands of acres of hilly land believed to be suitable for growing cork oak trees that are now used only for grazing.

Although earlier attempts to plant cork trees in the Southeast were generally unsuccessful, Hopp,<sup>14</sup> on the basis of planting records, concluded that the failure of the plantings was due largely to unfavorable local conditions, not representative of the South as a whole. He further concluded that the southeastern coast, from Virginia to Louisiana, offers definite possibilities for growing cork oak as a hill-culture crop for sloping farm lands; further knowledge of the propagation requirements and of the growth habits of this species is required before large-scale planting of the cork oak in the Southeast can be recommended.

As a result of the interest aroused by the experimental stripping of cork oak trees in California, extensive plantings of acorns are now being made annually in California and Arizona and in the South and Southwestern states. Starting with less than 500 lb. of acorns in the 1940-1941 season, the distribution of acorns exceeded 10,000 lb. in the 1945-1946 season. Most of the acorns used in planting were collected from California-grown trees. Generally good results have been obtained, as indicated by 50 to 80 per cent acorn germination in the field plantings. Nursery-raised cork oak seedlings, when shipped with earth in paper pots, show a better than 90 per cent survival. Handling of bare-root seedlings, on the other hand, results in a high degree of mortality.\*

### C. DOUGLAS FIR BARK

The Second World War emergency, which brought about the possibility of a drastic curtailment of cork imports from the Mediterranean region, prompted a survey of temporary domestic sources of cork. A number of coniferous species were investigated,<sup>15,17</sup> but only the bark of Douglas fir offered some commercial possibilities as a source of granulated cork.

In Douglas fir the corky layers commence to form when the stem reaches

\* The promotion of cork oak planting is aided by the cork project originated by the late Charles E. McManus, former president of the Crown Cork and Seal Company. Under this project the company assumes the cost of collecting acorns, growing seedlings, and distributing acorns and seedlings, in cooperation with state and Federal agencies. After planting, the trees become the property of the planter.

5 to 6 in. in diameter. The first cork layer is formed about  $\frac{1}{8}$  in. from the outer surface of the bark, but as the tree grows, other cork cambia are initiated deeper in the bark and form discontinuous lenticular-shaped layers, separated by masses of dark-brown phloem cells.

Because of this discontinuity of the cork layers, Douglas fir cork can be salvaged only in granulated form, which, if it meets manufacturers' requirements, may be suitable for such items as stopper disks, linoleum, and insulation products. Though it has been suggested that the Douglas fir cork may be obtained as a by-product of lumbering and milling operations, it is extremely doubtful that this product could compete with the oak cork, except in time of dire emergency.

A number of products suitable as a plastic filler, an absorbent for explosives, a magnesium floor ingredient, and an active ingredient in phenolic adhesives have been developed from Douglas fir bark by the Weyerhaeuser Timber Company. These products are marketed under the trade name of Silvacon.

Under the Weyerhaeuser process, Douglas fir bark is separated, by grinding and screening, into cork flakes, "tissue powder," short fiber, cork-fiber combination, and a cork-fiber-powder combination.

The first of these products consists of flake-like particles of cork, similar in their physical properties to commercial cork, and ranging upward to  $\frac{1}{4}$  in. in size. This product is suitable as a soil conditioner and is said to be an acceptable ingredient in phenolic-resin manufacture. This fraction represents approximately 20 per cent of the total Silvacon production.

"Tissue powder" is a finely powdered, amorphous material, obtained primarily from the highly friable parenchymatous tissue of the bark. It represents about 10 per cent of the Silvacon production. The material is thermoplastic in nature and can be used as a conditioning agent in insecticide dusts and in match-igniting compounds. The average size of particles in this fraction is 5.5 microns, with 90 per cent of the dust passing through 325-mesh screens.

The remaining 70 per cent of the plant's output is suitable for a filler in compounding plastics, as an extender in phenol-type adhesives, and as an absorbent filler in explosives. This material is separated into three fractions, *viz.* (1) A fiber product consisting almost entirely of spindle-shaped bast fibers; about 53 per cent of the particles are small enough to pass through a 100-mesh sieve and 44 per cent through a 200-mesh screen. (2) A combination of 20 per cent cork particles, 40 per cent lignified fiber, and 40 per cent powder. The product is dark brown in color and represents 45 per cent of Silvacon production. Nearly 95 per cent of the particles pass through a 200-mesh screen. (3) A mixture of 25 per cent particles and 75 per cent lignified fiber. About 55 per cent of the particles in this

fraction will pass through a 65-mesh screen and another 34 per cent through a 100-mesh screen.

#### D. OTHER BARKS

The bark of many other trees is used in medicine or for the extraction of tannin, dyes, and other materials. Among the native barks, mention should be made of the stem bark of the northern white pine, which is used in the preparation of cold medicines, usually together with the bark of black cherry and the buds of Balm-of-Gilead. The barks of eastern and western hemlocks and Douglas Fir contain extractable tannins, while flavin, a dye, is obtained from the bark of black oak. The bark of redwood is used as an insulation material and as a textile fiber (see page 517).

### II. OILS, OLEORESINS, AND RELATED PRODUCTS

Oils, resins, gum, and related substances are widely distributed in both the animal and vegetable kingdoms; those of vegetable origin are obtained from various parts of plants, including seeds, fruits, leaves, trunks, and roots. The origin of these substances in the plant is not well understood. In general they are by-products of the metabolic processes of life; some arise as a result of injury and hence are the result of pathological processes. Among these plant products there are a number of commercially valuable substances derived from forest vegetation.

#### A. OILS

1. **Tung Oil.**<sup>13,21</sup> The tung oil of commerce, otherwise known as *China wood oil*, is expressed from the seeds of the tung-oil tree, *Aleurites fordii* Hemsl., a native of central and western China; another species, *A. montana* (Lour.) Wilson, native to southwestern China, also produces oil practically identical in composition and properties with tung oil. This species, however, is less hardy and less widely distributed than *A. fordii*.

Tung oil has been used in China for many centuries, but its important properties were not fully appreciated until the second half of the nineteenth century. The first large shipment of this commodity reached the United States in 1869, the year which marks the beginning of world trade in this valuable product. Ever since, the world's consumption of tung oil has increased annually; the United States consumes more than 70 per cent of the total production.

The increasing importance of tung oil in the paint and varnish industries and the uncertainty of supply and quality of oil from China led to extensive experimental plantings of tung trees in the United States. The first success-

ful planting of tung seeds was made in 1905 by the Division of Foreign Plant Introduction of the United States Department of Agriculture, at Chico, California. The seeds were supplied by the American Consul General, L. S. Wilcox, at Hankow, China. The seedlings raised at Chico were set out in experiment stations, parks, cemeteries, and private holdings throughout the Southern and Pacific Coast regions.

It is estimated that there are now more than 75,000 acres of planted tung-oil trees. The greatest acreage is in Mississippi, followed closely by Florida. Experimental evidence has indicated that the area most suitable for growing tung-oil trees is a belt of land about 100 miles wide along the Gulf Coast.

The importance of establishing a native tung-oil industry must not be measured only in terms of the saving in money now spent in China for this commodity. Planting of tung-oil trees in the South is expected to solve some of its agricultural problems, as the establishment of any new industrial crop will help to introduce the desired diversification into agricultural activities of that region. It may also partially solve the wasteland and erosion problems in the Gulf coastal region. Moreover, since tung oil, turpentine, and rosin are essential raw materials in paint and varnish manufacture, the development of the tung-oil industry in the South may lead eventually to the development of a paint and varnish industry in that part of the country.

The production of native tung oil had reached five million pounds in 1942, and as more plantations come into bearing age, production will steadily increase. Much of the present crop of nuts is used for further planting. Domestic tung oil obtained by expression with modern machinery is considered superior in quality to that imported from China and commands a premium of a few cents above the price paid for the imported oil.

A considerable amount of experimental work on the tung tree is now being carried on at the Florida Experiment Station at Gainesville, Florida. Some superior strains of tung trees have been developed, and these are extensively propagated by grafting and budding. The tung trees are planted much like orchard trees (Fig. 24-4). They begin to bear fruit at the age of 3 or 4 years, and after the eighth year an acre containing about 100 well-cared-for trees should produce about 2,000 to 2,500 lb. of nuts, from which may be obtained 400 to 500 lb. of oil.

Tung oil is expressed from the seeds, four to seven (usually five) of which are contained in the spheroid fruit, with a pulpy exterior and a nut-like shell (Fig. 24-5). The fruit matures in September or October and is allowed to fall to the ground. In China the fruit is allowed to remain on the ground until the outer husk deteriorates, after which the seed is picked



FIG. 24-4. Tung-oil plantation at the Florida Agricultural Experiment Station; photographed in the fourth year after planting. (Courtesy University of Florida Agricultural Experiment Station, Gainesville, Florida.)

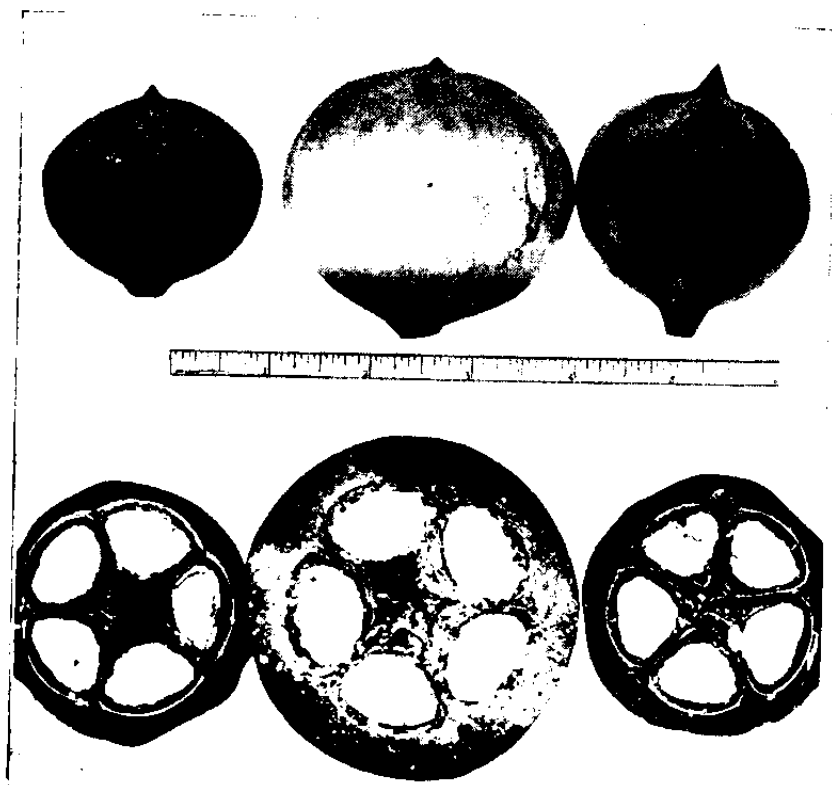


FIG. 24-5. Typical mature fruit of *Aleurites fordii*. (Courtesy University of Florida Agricultural Experiment Station, Gainesville, Florida.)



by hand. To facilitate the breaking down of the husk, the fruit is frequently gathered in heaps and covered with straw or grass, inducing rapid fermentation. Decortication may be conveniently accomplished with a mechanical disk huller and separator, as has been demonstrated in Florida.

In China the seeds are roasted in large wooden tubs with iron bottoms and pulverized in primitive mills by means of stone wheels. The pulverized seed is then steamed in large wooden vats. The hot mixture is formed into cakes and the cakes placed in hand presses consisting of hollowed logs, in which pressure is exerted by means of wooden wedges. A considerable amount of oil is wasted in this way, since much of it remains in the residue. The expressed oil is strained and then carried to concentration centers, from which it is transported to the coast. At first oil was shipped in barrels and 5-gal. kerosene tins. However, with the increase in the tung-oil trade, tank steamers and tank cars were adopted.

Formerly much of the tung oil of Chinese origin was adulterated with soybean, sesame, peanut and other cheaper oils. In recent years, however, the Chinese government, realizing that continuation of this practice would lead to adoption of other oils or the establishment of tung-oil plantations elsewhere, has inaugurated compulsory examination of tung oil at the shipping centers.

In the United States, the oil is expressed in modern mills, which are equipped with a decorticator and an expeller press. Analysis of the oil content of American-grown tung fruits indicates that about 20 per cent by weight of the whole dry ripened fruit is oil. It therefore takes about 5 lb. of dry fruit to produce 1 lb. of oil.

Tung oil is pale yellow to dark brown in color. It dries very rapidly to form a hard, glossy film. In addition this oil possesses preservative and waterproofing qualities which add to the durability of the finished product. Tung oil is used principally in the manufacture of waterproof or spar varnishes, enamel and other paints, and in paint driers. In this country tung oil has largely replaced copal and other natural gums in paint and varnish manufacture. Large quantities are used in the manufacture of linoleum and oilcloth and in the waterproofing of cloth and other manufactured articles. It is also used in insulating compounds in the electrical industries, in brake lining, and as an undercoat for body finishing in the automobile industries. Other uses include printing and drawing inks, dressing for leather, and soap manufacture. In some sections of the South the tung meal remaining after the milling process has been utilized as a fertilizer.

**2. Walnut Oil.** This oil is obtained from the kernels of the English walnut, *Juglans regia* L. The production of walnut oil in the United States, as a by-product of shelling plants, has been estimated at about

50,000 lb. a year. Crude walnut oil is used largely in the manufacture of soaps, in enamel paints, oil colors, and printing inks. The refined oil is used in foods. Pulverized walnut shells, called walnut-shell flour, are employed in plastics (see Chap. 23) and in the extending of synthetic-resin adhesives.

**3. Turpentine.** Oil of turpentine is by far the most important volatile oil produced in the United States. Its production and uses are discussed in the chapter on Naval Stores (Chap. 20).

**4. Conifer-leaf Oil.** Conifer-leaf oil is obtained largely from black spruce, white spruce, eastern hemlock, red juniper, and arborvitae. The oils of black and white spruce and those of eastern hemlock are very similar in composition and are usually sold in mixture; cedar oils are sold either separately or mixed. The conifer-leaf oils as a group have pleasant odors and chemically are composed mainly of terpenes and their derivatives.

The conifer-leaf oils are usually distilled in small quantities by farmers during the winter months. The average yield of oil is said to be up to 1 per cent of the weight of the green material. The yield is greatest from needles collected in January, February, and March. In northern New York the distillers of white cedar are said to gross about \$25 to \$30 a week.

The distillation plants are usually small homemade affairs, consisting of a low-pressure boiler from which steam is piped to a large tub fitted with a tight cover. The cover is weighted down with pieces of iron or stone to press upon the boughs packed in the tub. From this tub a pipe leads to a barrel of water by means of which the steam and leaf oils are condensed. The oil floats to the top, from whence it is skimmed off.

Spruce- and hemlock-needle oils are used in perfuming greases and shoe blacking, also in liniments and other medicinal preparations. Cedar oil from *Juniperus virginiana* L. is used mainly in insecticides, while the oil from *Thuja occidentalis* L. is blended in liniments, insecticides, furniture polish, and floor oils.

**5. Cedar-wood Oil.** This oil is obtained from the heartwood of eastern red cedar by steam distillation of sawdust and other wood residues procured from mills making pencil slats, cedar-closet liners, chests, and other red cedar articles. The yield of oil is from 1 to about 3½ per cent by weight, depending on the relative percentage of heartwood, since sapwood contains essentially no oil.

Cedar-wood oil has a fragrant aroma and is used extensively in the manufacture of soap, deodorants, furniture polish, sweeping compounds, and perfumes. It is also used in the preparation of liniments and finds a wide application in the manufacture of insecticides because of its reputation as a moth repellent. Because of its high index of refraction, refined cedar-wood oil is used as a clearing agent in preparing objects for the microscope.

Finally, cedar oil is used to extend sandalwood, geranium, and other more expensive oils. Some of the heaviest fractions are suitable for mineral flotation. The annual production of red cedar oil is estimated at 150,000 lb.\*

**6. Oil of Sassafras.** Sassafras oil is obtained from the roots and stumps of the sassafras tree by steam distillation. The oil is primarily obtained from stumps that are removed in clearing ground for agricultural purposes. The stumps are cut into small chips, which are placed in large retorts with a capacity of as much as 20,000 lb.

The root bark contains 6 to 9 per cent of oil and the root-wood only about 1 per cent. The average yield per ton of material is about 20 lb. of oil. Sassafras oil is used in medicine, in the manufacture of soft drinks, and in soaps and perfumes. The industry is confined to the South and is best developed in Tennessee, Maryland, and Virginia.

**7. Birch Oil.** Birch oil is obtained from the bark of sweet birch. This oil is identical with wintergreen oil, and since it is more abundant in birch bark than in the wintergreen plant, the former has largely replaced the latter as a source of natural wintergreen.

Wintergreen oil is not found as such in birch bark but is formed by the chemical reaction between a glucoside present in the bark and an enzyme, when the bark is treated with water. Some operators utilize only bark that is peeled from the trunk and the larger branches in the late summer. Such bark is cut into small pieces and placed in a copper still, then saturated with water and kept warm overnight. The more common practice, however, is to utilize entire stems, limbs, and twigs. The stem wood is cut into 5- to 8-ft. lengths, while branches are tied into bundles, and the material is then packed into the still, with the heavier wood on top. One cord of such material will yield approximately 4 lb. of oil, while 1 ton of bark will produce about 5 lb. of birch oil.

Stills are ordinarily located on cutover areas<sup>23</sup> where sweet birch is the dominant second-growth species. The site is located near a good supply of water. A crew of two men is required to operate one still, while three men can cut and skid enough wood and tend two stills located nearby. A horse or a mule is generally used to skid green material and draw away the spent wood.

According to Ritter,<sup>23</sup>

The distillery is generally built of 2- or 3-in. dimension material in the form of a 6-ft. cubical vat. Sometimes it is completely lined with copper, but usually this high-priced material is placed only on the bottom. The walls are made vaportight by tongue-and-groove construction held together by adjustable bolts. The cover,

\* E. H. Bonberger and L. F. Baker, Oil Extraction from Texas Cedar. *South. Forest Expt. Sta. Note* 41, September, 1941, report that both foliage and wood of Mexican cedar are also used on a commercial scale for extraction of cedar oil.

operated by block and tackle, is sealed with clamps and wire; old automobile inner tubes are stretched along the edges as gaskets.

One and sometimes two outlets for vapor, 6 to 8 in. in diameter, are placed near the upper part of one vat wall. From these vents the vapor is passed through a funnel into a series of copper condensers which parallel each other in a water-filled trough. The cold water in the trough chills the copper tubing sufficiently to condense the vapor. Both crude oil and condensed vapor trickle through the pipes into a jar placed beneath the outlet. The oil, which is heavier than the water, sinks to the bottom. This milky water, often called "low wine," overflows the jar into a barrel or tub and is eventually returned to the vat to be used again.

Each run takes about 8 to 12 hours. The distillation is generally continued on a 24-hour basis. The still is unloaded while it is hot. About  $\frac{1}{2}$  cord of "stilled" wood, which can be used without additional seasoning, is burned each day in the firebox; the remainder is generally cut for household fuel.

This industry is scattered through New England, Pennsylvania, and the southern Appalachian region, with the larger centers of distribution in Connecticut and Tennessee. The Northern oil brings \$3.60 to \$3.75 per pound as compared to \$1.65 to \$2.00 per pound for the Southern product.

Oil of wintergreen is used extensively in medicinal preparations, for flavoring confectionery and chewing gum, in soft drinks, and in the manufacture of disinfectants and insect powders. At the present time the natural wintergreen oil is being rapidly supplanted by a synthetic product derived from coal tar.

## B. OLEORESINS

The most important native oleoresins are *crude pine gum* and *Canada* and *Oregon balsams*. Crude pine gum, which is an exudation from the stems of several species of pines, is discussed under Naval Stores (see Chap. 20).

**1. Canada Balsam.** Canada balsam is an oleoresin of the turpentine group, obtained from blisters in the bark of balsam fir, a coniferous tree indigenous to Canada and Eastern United States. The term *balsam* is incorrectly applied to this oleoresin, since the true balsams are characterized by the presence of benzoic and cinnamic acids, both of which are absent in Canada balsam. A more correct term would be *Canada turpentine*, the name under which this substance is listed in materia medica and in pharmacy.

This oleoresin is secreted normally in canals formed by the separations of the cells in the bark of the tree. It collects in small cavities under the epidermis, the cavities appearing as prominent blisters on the smooth

bark of young trees and branches. Canada balsam is collected by puncturing and draining the blisters with a hollow metal tube or spout projecting from the rim of a can, into which the balsam flows. A better tool, producing cleaner balsam, consists of a steel-pointed glass syringe with a rubber bulb. The collection of balsam is made from June 15 until snowfall. It should be collected only during dry weather, since moisture getting into the balsam causes cloudiness, which decreases its market value.

Canada balsam is largely collected in the province of Quebec by the inhabitants of small villages. Whole families of balsam gatherers camp in the woods for 2 or 3 summer months<sup>18</sup> while making collections. The average yield of oleoresin per tree is about 8 oz., and it takes an average of 150 blisters to yield a pint. A man working alone can draw about  $\frac{1}{2}$  gal. of oleoresin a day, but with the assistance of two boys to climb the trees, the output may be increased to about 1 gal. a day.

When enough resin is collected, the balsam is strained and put into 5-gal. cans and transported to the nearest village; there it is exchanged for provisions or sold to a wholesale dealer.

Canada balsam is a transparent, viscid oleoresin, yellowish in color, with a distinct greenish fluorescence and pleasant turpentine aroma. When exposed to the air it loses its volatile oil and thickens, ultimately drying into a transparent resinous substance. When used in thin films it is colorless. Canada balsam has an index of refraction of 1.518 to 1.521 at 20°C.; it is soluble in ether, chloroform, xylol, benzol, and other substances but only partially soluble in alcohol.

Canada balsam is used to some extent in medicine as an antiseptic dressing for cuts and wounds; it is also used in the preparation of flexible colloidion, ointments, and plasters. When mixed with wax it is used to bind the component parts of pills and as a sealing wax to prevent deliquescent constituents from attracting moisture. The chief use for Canada balsam, however, is in the mounting of specimens for examination with a microscope and as a cement for glass in optical apparatus, for which purposes it has no equal.

Canada balsam is sometimes adulterated by the addition of rosin and turpentine. Such adulteration can be detected by determination of the acid value of the dry resin, which is 120 to 124 for pure Canada balsam. If the acid value is more than 130, the presence of extraneous rosin or turpentine can usually be suspected.

**2. Oregon Balsam.** This is an oleoresin, similar to Canada balsam, obtained from Douglas fir and found in bole cavities of wind-shaken trees. These cavities, in time, fill with oleoresin, and when an opening is cut into such a pocket, the oleoresin flows out. Trees containing such pockets can frequently be spotted by the one-sided crowns and bent trunks. As much as 1 to 3 gal. is frequently obtained from a single pocket.

Oregon balsam is less viscous than Canada balsam, completely soluble in alcohol, and very slow in drying. It can be distinguished from Canada balsam by its higher acid value, which is about 150, and by a slightly different odor. Oregon balsam can be used for the same purposes as Canada balsam except for microscopic work, since its refractory index is distinctly lower.

**3. Spruce Gum.** Spruce gum is an external oleoresinous exudation from normal resin ducts and develops as a result of injury to the sapwood of red, black, and white spruces, all native to Canada and the United States. The injuries which produce these exudations may be caused by animals such as porcupines or by windbreaks, frost, or lightning.

The flow of oleoresin commences in the early spring and is stimulated by hot summer weather. Fresh exudations gradually harden with the advent of cold weather but remain light-colored and somewhat sticky for at least a year. After that the gum begins to turn darker in color; it has little utility unless it is allowed to remain on the tree for at least 3 years. When collected, the gum is chipped off the tree with an ax. Sometimes the tree is climbed or even cut down, if good lumps are out of reach.

The gum is cleaned by steaming and straining. The strained gum is put through rollers, the last one having dies cut in the face to divide the gum into small sticks. The gum sticks are wrapped in paper for marketing. Spruce gum is used in such medicinal preparations as cough sirup and was formerly used as a chewing gum.

Crude gum brings collectors from 50 cents to \$1.50 a pound, with the best grades (medicinal) bringing as much as \$4 to \$7 a pound. In the past the production of spruce gum in Maine, New Hampshire, and Vermont reached considerable proportions. However, since the advent of chewing gum made of chicle, the importance of this minor industry has declined almost to the vanishing point. In Maine the annual production has declined from a high of 150 tons a year, valued at \$300,000, to a mere 4 to 6 tons.

### C. TRUE BALSAMS

The term *true balsam* is applied to a group of resins and oleoresins whose fragrant aroma and pungent taste are due to the presence of benzoic or cinnamic acid, or both. The best known of these are storax, gum benjamin, balsam of Peru, and balsam of Tolu.

**1. Storax.** Storax is a balsam obtained from *Liquidambar orientalis* of Asia Minor as an exudation from resin passages developed in the wood as a result of wounding. A similar substance may also be obtained from our native red gum. Storax is obtained by wounding the trees so as to expose new wood; when the balsam begins to flow it is collected in a cup. The imported storax is a semitransparent, brownish-yellow liquid of honey-

like consistency, with a strong aromatic odor and taste. It is used for perfuming soap and talcum powder and flavoring tobacco, also in the preparation of adhesives and for medical purposes.

The possibilities of developing a native storax industry were first investigated by Dr. Eloise Gerry, who pointed out that it should be possible to obtain additional revenue through storax production. The production of storax from red gum was stimulated during the Second World War by the high prices for the oriental product. This industry is now centered in Clark County, Alabama, where the estimated yearly value of storax is around \$250,000.

Operation gets under way in the spring, when the leaves reach full size. Production is started by removing a ring of outer bark about 2 ft. from the ground and peeling the bark down to the ground. A bar of bark 4 to 6 in. is left undisturbed. The exuded gum is scraped from the face every 2 or 3 weeks. When the upper edge of the face forms a new ring of bark or callus, a thin slice  $\frac{1}{4}$  in. to  $\frac{3}{8}$  in. is cut off to stimulate the flow of resin. The yearly yield is  $\frac{1}{2}$  to 1 lb. of storax per tree. A tree will continue to produce for 3 to 5 years. Following tapping operations, young healthy trees will then develop a new layer of bark over the face.\*

### III. FRUIT

#### A. PECANS<sup>16</sup>

Pecans are a product of a forest tree native to the South Central states, where pecan trees are found growing abundantly in the alluvial flood plains and delta lands of the lower Mississippi River and its tributaries and along the banks of all west Gulf rivers. In the last decade selected varieties of pecans have been planted in large numbers throughout the South, and today pecan nuts are an important source of farm income in many sections of the South.

The main productive belt of pecans from forest trees includes the Southern states west of the Mississippi, with Texas accounting for more than one-half and Oklahoma about one-quarter of the total production. The improved varieties, however, come largely from the states east of the river, with Georgia producing about 35 per cent of the crop. The most popular improved varieties are the Stuart and the Schley.

Pecan trees begin to bear when about 10 years old. The improved varieties are largely marketed and distributed to consumers unshelled, while the unimproved varieties are mostly shelled commercially and used

\* Charles R. Ross. Storax from American Red Gum. *Amer. Forests*, 53(9):404-405. 1947.

in confectioneries, baked goods, and ice cream. Pecan holdings range from a few trees to orchards containing 2,000 or more trees. Pecan orchards in general are developed in connection with some interplanted cash or feed crop for harvest; this practice is usually continued until the orchards reach bearing age.

#### B. PIÑON OR PINE "NUTS"

Piñon or pine "nuts" are the seeds of several species of pine native to the Southwestern United States. These include the Mexican piñon, the single-leaf piñon, the Parry piñon, and the nut pine. Annual production ranges from less than a million pounds to bumper crops of more than six million pounds. The piñon pines are found over an area of some 42 million acres in Arizona and New Mexico alone, with large areas also present in Colorado and Utah.

The pine "nuts" are collected by Indians, Mexicans, and white settlers, entire families often taking part in the harvesting. The harvest begins late in September and is continued until the first snow. The average market value of the "nuts" is estimated at about \$500,000 a year.

### IV. VEGETABLE FIBER

#### A. SPANISH MOSS

Spanish moss, *Tillandsia usneoides* L., which grows in long, hair-like strands suspended from forest trees (Fig. 24-6), is a seed-bearing epiphyte of the pineapple family. Its natural range extends along the coastal plains from Virginia to Texas. Like all true epiphytes, Spanish moss derives its food from rain and dust in the air, using its host only for support. It is rarely propagated by seed, but rather by fragments of festoons blown by wind or by birds which utilize the strands in building their nests.

The commercial value of Spanish moss is based on the utilization of the central hair-like strand of fibrovascular tissue which is left when the outer cortical cells are removed.\* The moss is gathered by farmers, who collect and sell it to supplement their farm income.<sup>19</sup> The picking season begins in November and lasts until April. Several tons of green moss are piled in stacks or placed in trenches or pits and wet down until thoroughly soaked. This is done to rot off the outer layers of tissue which cover the elastic inner fiber that forms the core; at the same time the chemicals in the bark are said to tan and toughen the fibrous cord. The green moss is

\* Aside from its commercial and aesthetic value, Spanish moss is a wintering place for the cotton boll weevil. The U.S. Bureau of Entomology reports that on an average 365 weevils winter in a ton of moss.



left piled for 4 to 6 months, during which time it is watered frequently to prevent heating.

When curing is completed, the top layer of the pile is discarded and the rest is spread or hung upon lines to dry. When thoroughly dry, the product is sold by the collectors to a gin operator. The rotted outer surface and all impurities are combed out by means of a toothed drum revolving against toothed concaves. The pure fiber that is left is pressed into bales weighing 60 to 150 lb. or more and shipped to the factories under the name of



FIG. 24-6. Spanish moss on oak trees. (Courtesy V. H. Sonderegger, Louisiana Division of Forestry.)

vegetable fiber. One short ton of swamp-cured moss, or 5 short tons of green moss, are required to produce 1,000 lb. of ginned moss. Spanish moss is used for stuffing mattresses, upholstered furniture, pillows, and dolls, as a substitute for hair.

According to V. H. Sonderegger, formerly state forester of Louisiana, an average picker can gather about 500 lb. of moss a day. He also reports that one family of five gathered and sold in one year 100,000 lb. of green moss and 20,000 lb. of cured moss, at an average price of  $2\frac{1}{2}$  cents per pound for the former and 3 cents per pound for the latter. Prices for green moss fluctuate from year to year, ranging from about  $1\frac{3}{4}$  cents a pound for the lowest grade to 3 cents for the highest. The average price for ginned moss is about \$9 per hundred pounds.

Mr. Sonderegger estimates the annual revenue from the Spanish moss industry in Louisiana at one and one-half to three million dollars, depending on supply and demand, most of this money going to the gin operators

and pickers. Probably an equal revenue is obtained from moss gathering in Florida and smaller amounts in other Southern states. In spite of the large quantity of Spanish moss gathered every year, there seems to be no danger of destroying the supply, because of its prolific growth.

There are three main grades of Spanish moss produced: 2-X (light brown), 3-X (dark brown), and 4-X (black). The 4-X is more thoroughly cured and somewhat better cleaned than the other two grades and costs a few cents a pound more. The difference in quality and price between the three grades results from the selection of raw material and the extent of curing, rather than from the processing of the moss subsequent to curing.

#### B. REDWOOD-BARK FIBER<sup>1</sup>

The fibrous bark of redwood yields a number of commercially valuable products, the principal of which are (1) loose-fill insulation, (2) bark fiber used for mattress filling in combination with cotton, and (3) textile fiber for use with wool. Large residual quantities of bark dust, resulting from shredding of the crude bark, are used also as a soil conditioner to increase the moisture-holding capacity of the soil and to permit better aeration.

The bark of mature redwood trees ranges from 2 to 3 in. in thickness in the upper part of the stem to 6 to 12 in. in a basal log. The outer bark, which constitutes the greater proportion of the total bark present, is reddish in color and contains 5 to 10 per cent of long (up to 7 mm. in length) and very strong fiber, while the thinner layer of the inner bark is whitish in color and contains 10 to 18 per cent of the fiber. Because of its thickness and its fibrous nature, the bark is peeled before the logs are placed on the sawmill carriage; otherwise it impedes the efficiency of the sawmill operation and affects adversely the quality of lumber by dulling saws.

In the procedure as developed at the Pacific Lumber Company mill, bark is pried loose with chisel-head crowbars. The long bark slabs are carried by a conveyer to a large circular swing saw, where they are cut into 5-ft. lengths. These slabs are then delivered to a hammer-mill shredder by an overhead crane bucket. The shredded bark is put through a series of screening and textile-picker operations, in the course of which the finer fiber and bark dust are separated from the coarser bark. The coarse fiber is dried in a tunnel-like conveyer drier and baled in a hydraulic press into 300-lb. packages; these are sawed into three sections for convenient handling. This product constitutes the "wool" insulation of the trade and finds considerable favor as loose-fill insulation in places where low temperatures are involved, such as cold-storage, locker, and ice plants, as well as a loose fill for home insulation.

The fiber and the dust collected in screening and refining operations are

fed into a mechanical air separator, in which the fiber is separated from the granulated material (the dust). The highly refined fiber recovered in this operation comprises textile redwood fiber. Since this fiber is reddish brown in color, it can be used only in material having a dark shade. Blended with wool in amounts up to 50 per cent, redwood fiber produces a satisfactory material for inexpensive men's suits, overcoats, and mackinaws, low-priced blankets, and similar items.

### C. PINE NEEDLES

Locally pine needles, called "pine straw," are used extensively in the South for mulching strawberry beds. A patented process \* has recently been developed in Harrison County, Mississippi, for the use of longleaf pine needles as litter for poultry houses. In this process dry pine needles are fed, together with a few cones, into a mill which cuts the needles into pieces about 1 in. long. Shorter pieces and debris are blown out by a fanning mill, and the remaining litter is sprayed with disinfectant oil. It is claimed that such pine litter, when used in poultry houses, absorbs moisture without becoming matted, while the pine odor of the chopped green cones tends to overcome unpleasant odors. After the litter has been used for a week or two it is discarded; when allowed to decompose, it makes a suitable fertilizer, equivalent in value to commercial fertilizer at \$10 a ton. Needles are delivered at the mill by the local farmers for \$5 a ton, while the mill sells sacked litter locally at \$15 a ton. Attempts have also been made in recent years to use longleaf pine needles for mattress stuffing.

## V. CHRISTMAS TREES AND GREENS

### A. CHRISTMAS TREES<sup>8</sup>

The custom of bringing green boughs into the house during religious festivals is very ancient. The Egyptians, for instance, celebrated the shortest day of the year by bringing into their homes green date palms as a symbol of the triumph of life over death; in Norse mythology, green boughs symbolized the revival of Balder, the sun god. It could, therefore, be said that the Christmas-tree custom is a heritage of the sun-god religions, in which trees symbolized the revival of Nature. The custom of decorating and lighting the trees apparently came from Germany. It is believed that it was first introduced into the United States by Hessian soldiers at the time of the American Revolution.

\* See A. L. Shepard, in *South. Forestry Notes*, 34, Southern Forest Experiment Station, New Orleans, La. 1940.

Today the decorated Christmas tree has become an indispensable part of the Christmas celebration in most American homes. It is variously estimated that the United States now consumes between 8 and 12 million trees and Canada about 1 million trees each year.\* One-third to one-half of the trees used in the United States (or three to five and one-half million) come from Canada, including Nova Scotia and Newfoundland. In the United States, Maine, Washington, Minnesota, Montana, Vermont, and New Hampshire each supply a million or more trees for out-of-state markets, while Wisconsin, Michigan, New York, and Pennsylvania also produce large quantities for local markets.

It is estimated that about 70 to 75 per cent of the total number of trees offered for sale are shipped to market in carload lots by large-scale producers; the remaining 25 to 30 per cent are divided fairly evenly among farmers, small-scale producers who retail in truck-load lots, and individuals who cut trees for their own use. In answer to a questionnaire, two large producers reported shipments of three million and two million trees, respectively, for the 1939 season, or roughly half of the total consumption for that year. These companies operate both in the Eastern and the Western United States, cutting their trees in the Canadian provinces, as well as in the United States. In general, the Illinois-Indiana line serves as a dividing line between the distribution of Eastern and Western trees, although occasionally trees from the Northwest are shipped as far east as Pittsburgh and even to New York City. The center of Christmas-tree consumption lies in the big cities of the East and the Middle West.

Christmas trees are cut between October and mid-December, depending upon the distance to markets and the anticipated demand. Trees for outside markets are usually graded roughly by size and appearance and tied in bundles of from two to a dozen trees, depending on their size and facilities for hauling. Trees are shipped by truck, rail, and boat. Trucks are used for short hauls; a 3-ton truck will carry about 600 trees of average size. Flatcars or boxcars used for longer hauls will carry 500 to 550 bundles, or from 1,000 to 5,000 trees per car. Shipments from the West generally contain 4,000 to 5,000 trees, while those from the Eastern states and Canada contain 2,000 to 3,000 trees per car.

The principal native species used as Christmas trees in the East and Middle West are balsam fir, spruce, and jack and scotch pines; in the West, Douglas fir, true firs, and Colorado blue spruce; and in the South, several species of pine and eastern red cedar.

The largest number of Christmas trees in the East and Canada come

\* The number of trees cut every year for Christmas trees is considerably higher, ranging perhaps between 12 and 16 million, thus resulting in waste estimated at about 4 million trees annually.

from forest stock, although in New England and New York State many trees are also harvested from pasture lands. The trees from pasture lands are very bushy in appearance and if allowed to grow to maturity will produce knotty lumber, but as Christmas trees they are highly desirable. In Minnesota the majority of trees come from the northern black spruce swamps. Because of unfavorable growing conditions, the trees are stunted and of considerable age; a tree 4 to 6 ft. in height is frequently 60 to 100 or more years old. The exceedingly slow-growing wood from these trees is unsuitable for pulp and other wood uses, but their bushy appearance makes them very desirable for Christmas trees. A number of companies in Minnesota specialize in trees 30 to 36 in. in height for the table trade. These trees are placed in cartons or crated and kept in cold-storage rooms until shipped. A recent survey of the black spruce swamps in Minnesota indicates that even with the present rate of cut of more than a million trees a year, the supply of stock suitable for Christmas trees is practically inexhaustible. In the Rocky Mountain and North Pacific states, Christmas trees, principally Douglas fir, are either removed in improvement cuttings on national forests or produced in carload lots by private forest owners.

The practice of removing young, well-formed trees for Christmas trees from forest stock has caused considerable concern to some conservationists, who visualize wholesale devastation of our forests. It has even been suggested that the production of all Christmas trees be limited to thinnings from young stands and to tops and branches from logged trees. However, trees removed in thinning operations are as a rule of poor form; moreover, stands needing thinning are usually located at a considerable distance from markets and are often incapable of supplying the demand.

Many states recognize the necessity of protecting young stock and reducing waste resulting from indiscriminate cutting. Only a few states, however, have actually attempted to regulate the cutting of trees for the Christmas trade by licensing the operators. Laws requiring some type of state license are now in operation in Minnesota, Wisconsin, Washington, and Oregon. In Minnesota a law enacted in 1935 and amended in 1937 gives the Conservation Commission complete control over the Christmas-tree industry. Under the act, the sale of Christmas trees is subject to licensing, tagging, or both, under two classifications:

1. A duly licensed dealer may secure a license for which he pays \$200 and which entitles him to sell within or outside the state.
2. The license fee is waived but the dealer is required to buy and attach a 2-cent tag on each tree sold or transported within or outside the state.

All trees within the state must have a tag attached, regardless of whether

they were cut in the state or imported. The money thus collected goes toward policing the black spruce territories against improper cutting.

A somewhat similar law requiring a 1-cent tag for each tree shipped outside the state was recently enacted in the state of Washington but has been declared unconstitutional by a state court.

The planting of Christmas trees as a crop has also been advocated. It is pointed out that raising conifers for the express purpose of selling them at Christmas time should prove a very attractive investment to farmers near cities that are somewhat removed from a source of natural-grown trees. Stock grown in plantations makes ideal Christmas trees, because even spacing favors the development of a compact, symmetrical crown. Such plantations can be handled entirely as a cash crop and the cut trees replaced by seedlings, or growing of Christmas trees can be combined with timber production, by judicious selection of a number of stems to be left as crop trees.

The species best suited for such plantings are Norway spruce, *Picea abies* (L.) Karst., white spruce, jack and scotch pines and balsam fir; other suitable species, where the climate is not too severe, are white fir, blue spruce, Douglas fir, and eastern red cedar. Because the demand for Christmas trees is not limited to any one size and there is an ever-increasing call for table trees, a limited number of trees could be harvested from a plantation of Norway spruce 4 to 5 years old. However, since the greatest demand is for trees 4 to 7 ft. tall, Norway spruce should be ready to harvest in 7 to 10 years and other species in 10 to 15 years. Today there are a number of such plantations in New England, New York, Pennsylvania, and the Lake states.

The sale price for Christmas trees varies greatly with locality, species, size, appearance, and the demand and supply. Ordinarily, trees 5 to 6 ft. tall have been sold for 25 to 50 cents in city markets; trees 6 to 10 ft. tall bring \$1 or more, according to symmetry.\* In the large cities, such as New York, larger trees may bring from \$5 to \$30 apiece. There is very little profit for those who furnish trees for large-city markets. In normal times woodlot owners get from 1 to 5 cents for trees which retail at 25 cents each and 25 cents for those sold for more than \$1. In small towns, where the demand is supplied directly by the farmers, a considerable profit may be realized from Christmas-tree sales. Since at present there is no possibility of controlling the volume of shipments into the larger markets, profit to the retailers is uncertain; when the markets are not glutted, good profits may be anticipated, but when the supply exceeds the demand, losses are almost inevitable. For example, in 1936 the Chicago market was short because heavy snowstorms in eastern Canada and the Lake states mate-

\* Pre Second World War prices.

rially reduced the volume of trees shipped to that city; as a result the trees brought a very good price. The following year, however, the market was flooded by small producers shipping from one to three cars apiece. The market was oversupplied, and during the last week before Christmas, trees sold for considerably less than the freight charges and many were burned.

An interesting instance of organized effort in cutting and marketing of Christmas trees is found in the activities of the Forest Products Association, Inc., of Groveton, New Hampshire. This is a cooperative marketing organization of about 1,000 forest-land owners and dairy farmers in a region controlling more than 25,000 acres of land from which Christmas trees can be harvested as needed. The number of producers participating in the cutting of trees is from 150 to 200. The selection of stands and the cutting are carried on under the supervision of competent men and in cooperation with the State Forest Extension Service. The trees are carefully graded into fancy, standard, and ungraded selected grades, and each tree bears an Association tag designating its grade. In addition to these three selected grades, the Association will also supply pasture-grown trees, but in carload lots only. All the trees are carefully bundled and shipped in flatcars, mostly to Ohio, Pennsylvania, and northern New York. During the last few years the Association has averaged about 10 cars each year.

In addition to Christmas trees, there is also an extensive market for evergreen boughs, which are obtained either from trees of poor form or from lopped branches. R. H. Butler reports that in the 1936 Christmas season, 50 tons of boughs was sold from the Pike National Forest, bringing \$1 a ton if picked from slash by the purchasers and \$12 a ton if delivered by the U.S. Forest Service. The Forest Product Association of Groveton, New Hampshire, markets many wreaths of northern conifers made by the families of the Association members. These wreaths are shipped by express or freight.

#### B. EVERGREEN HOLLY

Growing holly for Christmas greens offers farmers in some sections of the Southeastern United States an opportunity to supplement their farm income. The American holly, valued for its rich green leaves and persistent round scarlet berries, formerly had a natural range from Massachusetts to Missouri, thence south to Florida and Texas.\* Destructive harvesting has, however, practically eliminated this tree from Massachusetts to

\* The English holly, *Ilex aquifolia* L., and its many varieties, bears fruit more plentifully than the American species. The English holly is now successfully propagated in the Pacific Northwest. Holly farms have paid good dividends.

central New Jersey. The region most favorable for growing this species commercially extends in a strip 50 to 60 miles wide from Norfolk, Virginia, south to Florida, and westward in the Gulf region to Louisiana. Most of the holly used in the Eastern United States comes from the Delmarva Peninsula, east of Chesapeake Bay.

Holly may be propagated by seed, cuttings, layering, and grafting. Propagation by layering or cuttings has a distinct advantage over reproduction by seed, because plants reproduced vegetatively run true to type.

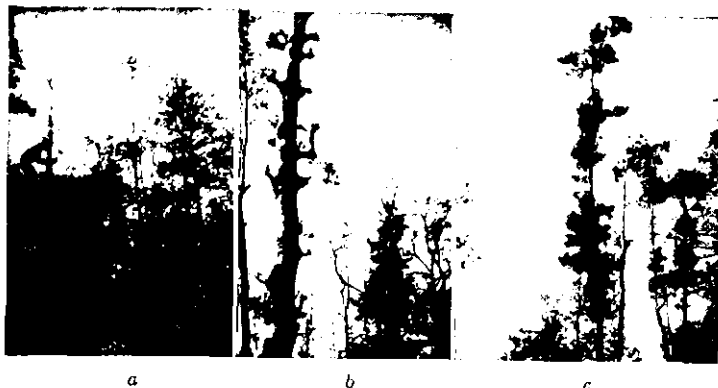


FIG. 24-7. Destructive harvesting of holly: *a*, a tree being completely stripped; *b*, a stripped tree; *c*, a stripped tree starting to come back. (Photographs courtesy N. H. Fritz, Maryland Department of Forestry.)

Pure plantations of holly on open lands are recommended in preference to underplanting in woodlands.<sup>22</sup> In the East most holly, however, comes from forest-grown trees.

Harvesting of holly commences when the trees are 12 to 20 years old. Early in the fall, dealers scout the countryside and buy from the woodland owners their holly crops. Harvesting begins about December first and continues until Christmas time. The branches are cut off with a hatchet or a corn knife, 6 in. or more from the trunk. Not infrequently even the top of the tree is sawed off. The branches are collected either on a canvas or in large buckets. Some of the sprays are then made into wreaths, while loose sprays are packed into standard crates 2 by 2 by 4 ft. The destructive methods used in harvesting holly, appropriately known as "breaking of holly," lead to serious damage to the trees (Fig. 24-7). Severely pruned trees will not produce another holly crop for the next 15 or more years and may die.

The average price paid to woodland owners by holly dealers is about 50 cents a crate; holly crops from large areas of from 50 to 500 acres of woodland are purchased for as little as \$5 to \$25, while some dealers buy



holly on a percentage basis, paying the owner a certain percentage of the profit, 1 to 3 months after the Christmas season. According to Fritz,<sup>10</sup> the dealers resell to a commission merchant for \$2 to \$5 per crate. The commission dealers sell to florists and other retailers for \$8 to \$10 per crate, who in turn sell to consumers at the usual margin of profit of about 100 per cent. Thus holly usually changes hands four times, returning a good profit to all except the woodland owners.

There is little information to indicate the total income to farmers from this source. Some idea of the local importance of this industry can be

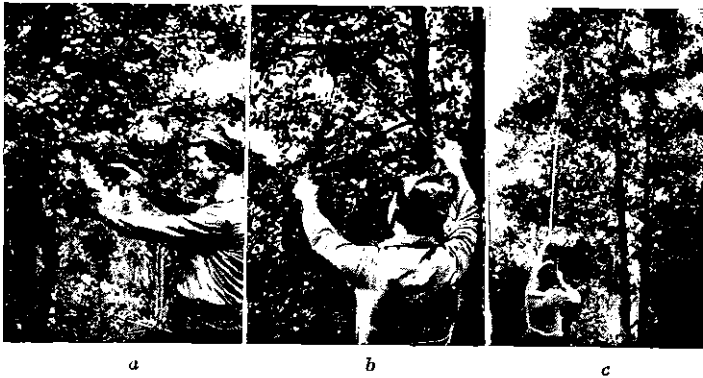


FIG. 24-8. Proper way of harvesting holly: a, clipping lower branches; b, clipping branches higher up the tree; c, clipping branches from the top of the tree. (Photographs courtesy N. H. Fritz, Maryland Department of Forestry.)

gained from the estimate that in an average year some 10,000 people in southern Maryland alone are engaged in harvesting holly, obtaining an income of about \$150,000. A survey conducted in Delaware in 1927 disclosed that holly products valued at approximately \$400,000 were shipped annually and that about \$100,000 of this sum was received by the farmers who gathered holly and made wreaths. The annual shipment was estimated at 7,000 cases containing one and a half million wreaths and some 600 cases of loose sprays.

To reduce the destruction of naturally grown holly and to increase the cash returns to forest owners, the Maryland Department of Forestry is now sponsoring the production of "certified holly." The department holds harvesting demonstrations in the various parts of the state where holly grows naturally. At these demonstrations the proper method for pruning trees is demonstrated, and it is shown that large quantities of holly sprays can be obtained, still leaving the trees in a productive state (Fig. 24-8). Individuals interested in these methods of harvesting sign

up as cooperators in the production of "certified holly." The department attempts to secure orders for holly from retailers and individuals, and these are distributed among the cooperators; the department also supplies the cardboard packing boxes. The holly is packed in boxes of three sizes: boxes 12 by 12 by 24 in. hold enough holly to decorate a small house; a 16 by 16 by 24-in. package, sufficient for a large house; and a 2 by 2 by 2-ft. box is used for holly distribution to florists and other retailers. Before the Second World War, boxes were sold for \$1.75, \$2.50 and \$4.50, respectively, plus shipping charges. Each box contains only No. 1 grade holly, pruned from trees in accordance with instructions from the department. Each box is inspected at designated stations, and if the holly meets all requirements, the inspector pays the cooperator cash for his materials, the equivalent of about \$6.00 a crate. The boxes are then sealed and a certification tag attached by the inspector. The middleman is thus eliminated and the savings passed to the forest owners, as the department makes no charge for its services. The difference between the selling price and that paid to the cooperator pays for boxes, inspection, and clerical help. The stumbling block to further development of this conservation movement at present is the small number of orders that the department is able to secure for the large number of cooperators. It is estimated that 99 per cent of the American holly sold each year is still produced by destructive harvesting methods.

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