United States Department of Agriculture

Forest Service

Agriculture Handbook No. 640

Fiberboard Manufacturing Practices in the United States

Otto Suchsland and George E. Woodson

United States
Department of
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Acknowledgments

People who possess the gentle art of encouraging others to attempt and complete tasks that would otherwise be rejected simply because of their seemingly overwhelming size and complexity are deserving of far greater praise than is normally accorded them. Two such individuals are Dr. Peter Koch and Mr. O. B. Eustis. In addition to constant encouragement, Mr. Eustis, who is a true expert in the field of fiberboard manufacture, freely shared with us his vast knowledge and experience in this field. The major contributions of these two gentlemen are gratefully acknowledged.

During the preparation of this book we visited many fiberboard installations in the United States and had many discussions with individuals in the board industry and in associated industries. All of these people took great interest in our effort and contributed material, suggestions, and special insights into their own specific areas of expertise. We owe all of these individuals and their companies a great measure of gratitude.

Special appreciation goes to Mr. John Olson, Vice President, Abitibi-Price Corporation, who always granted every special request and provided ready access to technical staff and to Abitibi's manufacturing facilities at Alpena, MI, and Toledo, OH.

We are also indebted to the U.S. Department of Agriculture, which through its Southern Forest Experiment Station and its Washington Office provided funding and editorial support.

Finally, we like to acknowledge the important part played by our employers, Michigan State University and Louisiana Tech University, which allowed us the necessary freedom of action and provided the atmosphere conducive to such work.

The high quality of the drawings is due to the expert services of Mr. Kevin Sayer, an engineering student at Louisiana Tech University.

We thank the following fiberboard manufacturers, equipment companies, publishers, and associations for permissions to reprint the listed illustrations.

Ernest H. Abernathy Publishing, 42, 94, 95; Abitibi-Price Corp., Troy, MI: 345, 346, 353 – 355, 362, 363; American Chemical Society, Washington, DC: 23, 83, 175, 189, 207; American Hardboard Association, Palatine, IL: 357 – 361.

C. E. Bauer Combustion Engineering, Springfield, OH: 85–87, 90, 96–98, 107–110, 113; Bison North America, Atlanta, GA: 219, 230–232.

Carthage Machine Co. Southern, Morton, MS: 49, 50; Celotex Corp., Tampa, FL: 371, 372; Coe Manufacturing Company, Painesville, OH: 176, 180, 181.

Dorr-Oliver, Inc., Stamford, CN: 111, 112.

Edge Wallboard Machinery Company, Downingtown, PA: 144, 145, 150, 151, 154; EX-CELL-O Micromatic, Holland, MI: 265.

Food and Agriculture Organization of the United Nations, Rome: 88, 89, 134, 160, 161, 168, 253, 256; Forest Products Research Society, Madison, WI: 12, 92, 126, 198, 201, 210–216, 237, 242, 245, 254, 257, 336–338, 364–370; The Foxboro Co., Foxboro, MN: 115–118.

International Union of Pure and Applied Chemistry, Oxford: 314.

Joint Textbook Committee of the Paper Industry, c/o the Canadian Pulp and Paper Association, Montreal: 40, 43, 56, 76, 137, 139–141, 143, 177, 182.

KMW AB, Board Machinery Division, Motala, Sweden: 160, 161; KMW Systems, Atlanta, GA: 65–67.

Prof. Thom Maloney, Washington State University, Pullman, WA: 130, 157, 162, 193, 195, 196, 214, 217, 218, 220–222, 233, 239; Masonite Corp., Chicago: 80, 81, 349–352; McGraw-Hill Book Company, New York: 10, 11, 15, 39; M-E-C, Neodansha, KS: 194; Miller Freeman Publications, San Francisco: 163; Morbark Industries, Winn, MI: 34, 35.

Peerless, Division of Lear Siegler, Tualatin, OR: 62.

Rader Companies, Portland, OR: 64; Rotex, Cincinnati, OH: 59.

Siempelkamp Corporation, Marietta, GA: 165–167; Springer-Verlag, Heidelberg, Washington, DC: 17, 18, 164, 190–192, 197, 200, 202, 206, 223, 224, 247; Sprout-Waldron Division of Koppers Co., Muncy, PA: 91, 100, 104, 105A; State University of New York, College of Environmental Science and Forestry at Syracuse: 3; Sunds Defibrator, Minneapolis, MN: 70, 78, 102, 103A & B, 310.

TAPPI, Atlanta, GA: 37, 46, 53, 60, 61, 77, 93, 125, 131, 316, 319; Thermal Engineering Corp., Columbia, SC: 290, 298, 300.

Vance Publishing Corp., Prairie View, IL: 79, 171, 261; Van Nostrand Reinhold, New York: 19; VEB Fachbuchverlag, Leipzig: 24, 25, 135, 203, 205, 259, 260.

John Wiley & Sons, New York: 14, 16, 27, 74.

Otto Suchsland and
George Woodson 1986

Contents

1. Introduction

This handbook introduces the reader to the manufacture and fabrication of fiberboard as practiced today in the United States.

A brief history of this industry is followed by a discussion of some important technological and chemical factors as well as a survey of the raw material base. The bulk of the book describes the equipment and the processes including the insulation board process, the wet and dry hardboard processes, and the medium-density fiberboard process. Modern finishing processes are discussed in some detail, and an entire chapter is devoted to the important subject of water use and water treatment. The concluding chapter deals with product properties and applications including a discussion of various commercial standards.

A special effort has been made throughout to illustrate the subject with in-plant photos and to explain important concepts by means of schematic drawings.

Concepts

Several concepts provide a basic approach to the book's subject. They are discussed here as a starting point to the succeeding chapters.

The term **fiberboard** applies to a category of sheet products that is part of the larger family of **wood composition boards** (fig. 1). These wood composition boards are distinct from solid wood in that they are composed of wooden elements of varying sizes held together by an adhesive bond.

The manufacture of these products includes, therefore, these important steps: the generation of elements or particles (a reduction process) and the recombination of these elements in sheet form (a lamination process). Individual products differ most distinctly in size and shape of the particles used. In plywood, for instance, the "particles" are veneer sheets of regular dimensions

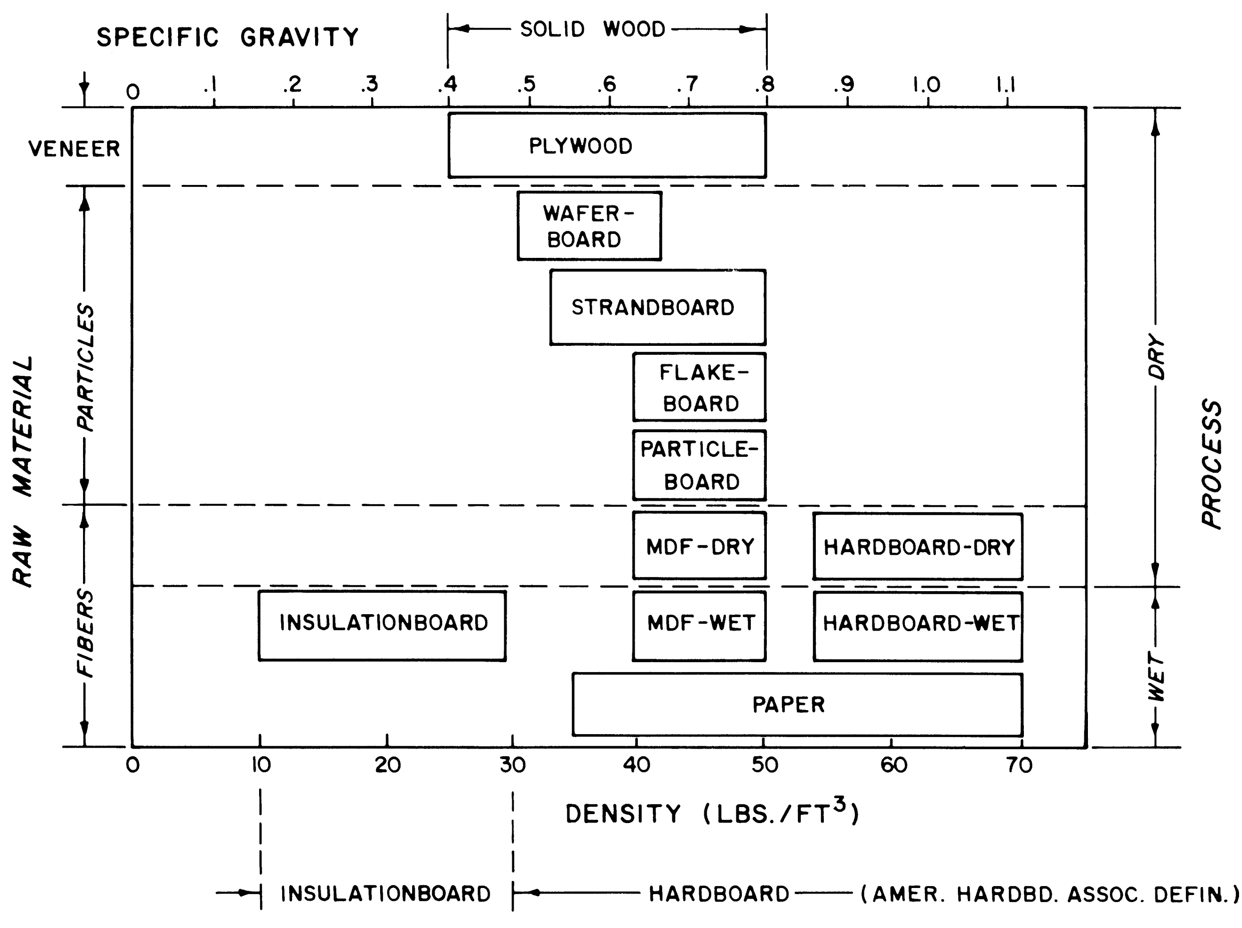


Figure 1—*Classification of wood composition boards by particle size, density, and process type. MDF means medium-density fiberboard.*

that can easily and systematically be assembled and laminated without densification.

Particle board is based on particles that are very small compared with veneer sheets, but many times larger than the wood cell, the basic biological building block of solid wood. Their dimensions are often irregular and they are generally assembled in a random fashion. Glue line contact and development of mechanical properties depend significantly on densification (fig. 2). For this reason the particle board categories in figure 1 are shifted slightly to the right of the natural range of solid wood density. **Waferboard** and **strandboard** are particle boards made from rather large particles and are intended for structural applications.

Fiberboards use a **furnish** consisting of elements with dimensions of the same order of magnitude as those of the wood cells. In this connection the term "fiber" applies to any element of that size and shape, regardless of its origin (fig. 3). In the more precise terminology of

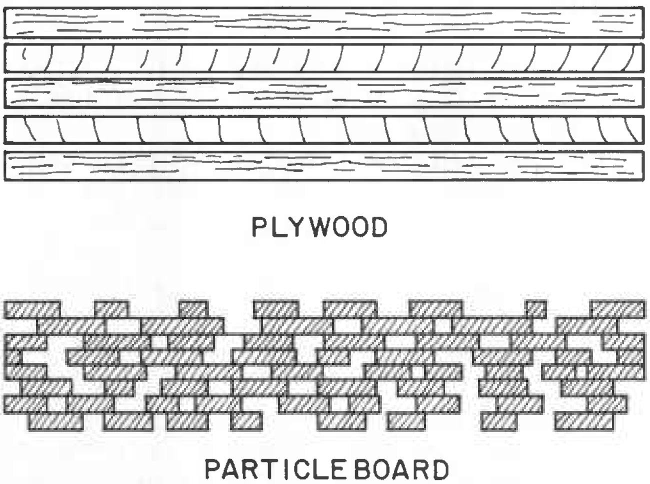


Figure 2—*Arrangements of particles in the manufacture of plywood and particle board.*

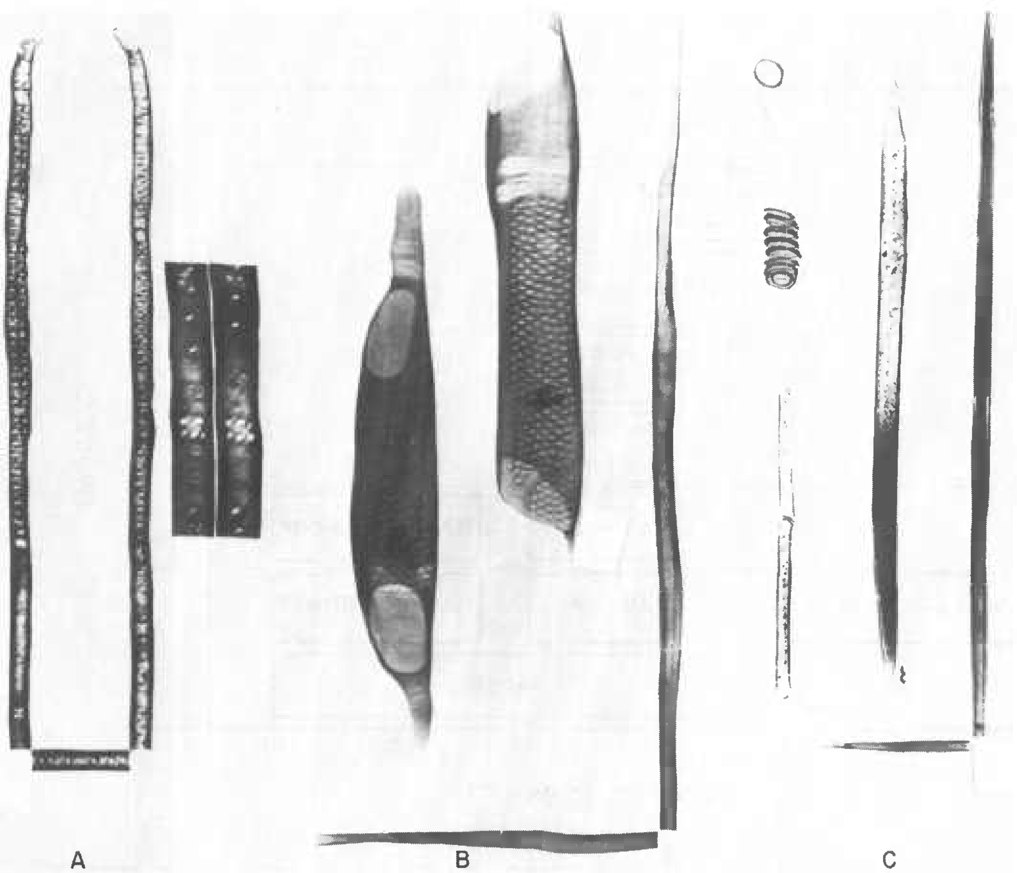


Figure 3—*Examples of fibers used in the manufacture of fiberboard (Carpenter and Leney 1952).* **A**—*Softwood fibers.* **B**—*Hardwood fibers.* **C**—*Sugarcane fibers.*

wood anatomy, the term "fiber" is reserved for a particular cell type in hardwoods, namely the fiber tracheid, which may make up only a small fraction of the total solid wood volume (Panshin and deZeeuw 1970). Five different fiberboard types are shown in figure 1. Two of these are made by dry processes, as are particle board and plywood. The other three are made by wet processes, as is paper. Although made from fibers, paper is not a fiberboard, and it is included here only to indicate its close relationship to fiberboard technologies. Wet processes require enormous quantities of water—up to 100 tons/ton of board produced—but their products are superior in certain respects to dry process boards. **Insulation board** can be produced only by the wet process.

Early fiberboard was all made by wet processes, essentially extensions of paper technology. Dry process fiberboards are more recent developments, and in some cases, at least, extended directly from particle board technology.

Fiberboards are also classified by density. Insulation board (thickness, 3/8 to 3/4 in; density, 10 to 31 lb/ft^3) represents the lowest density class. It is made only by the wet process. **Medium-density fiberboards (MDF)** are made either wet or dry in a density range (about 40 to 50 lb/ft^3) similar to that of particle board. MDF-wet (thickness range: 1/4 to 1/2 in) is generally used as siding material. MDF-dry (thickness, 3/8 to 1 in) competes with particle board as industrial core material (furniture). High-density fiberboard (about 55 to 70 lb/ft^3) is called **hardboard**. Although there are significant differences between hardboard-wet and hardboard-dry, they compete in the same markets. Hardboard thickness ranges from 1/10 to 5/16 in.

The above classification of fiberboard reflects common usage of terms in the industry and does not match in all respects that of the American National Standard on "basic hardboard" formulated by the American Hardboard Association (USDC NBS 1980).

The basic hardboard standard defines hardboard as any fiberboard pressed to a density of 31 lb/ft^3 (specific gravity, 0.50) or greater. The standard does not recognize medium-density fiberboard as a separate category, neither does it differentiate between wet and dry processes. Although by definition included in the basic hardboard standard, MDF-dry is manufactured and traded under a standard developed under the auspices of the National Particleboard Association. Such inconsistencies have resulted from the historic development of these processes and from the fact that MDF-dry competes directly with particle board rather than with other fiberboards in the industrial market. Insulation board is defined by a separate, voluntary product standard (USDC 1973) as a fiberboard ranging in density from 10 to 31 lb/ft^3, equivalent to the specific gravity range from 0.16 to 0.50 (see also American Society for Testing Materials 1983).

In this text the term "hardboard" will be used in accordance with the American Hardboard Association definition, except when qualified to conform with figure 1. Figure 4 shows greatly simplified schematics of the wet and dry fiberboard processes. In both, wood is reduced to fibers **(pulped)** and formed into rigid sheets by recombination and consolidation. Both steps require the application of energy. In the wet process, water in large quantities serves as a conveying and distributing medium for the pulp and promotes the development of **natural bonding**, that is, the activation of adhesive-like wood components and the formation of so-called **hydrogen bonds**. This reduces or eliminates the need for addition of resin adhesives or other bonding agents. The treatment, recovery, and disposal of this process water, on the other hand, is an important and difficult problem.

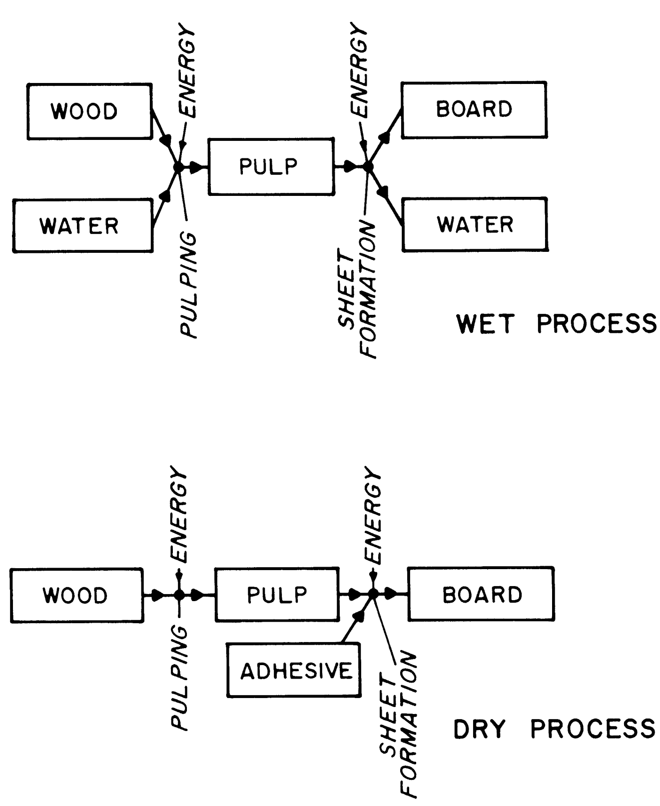


Figure 4—*Simplified schematics of wet and dry fiberboard processes.*

In the dry process, air is the conveying and distributing medium, and without water the conditions for natural bonding do not develop. The development of mechanical and other board properties relies entirely on added adhesives.

There are many significant and many subtle differences among the products of the five fiberboard processes and in the results of process variations within each of them. None of these processes is intrinsically any better or any worse than any of the others, but each may be best for making a particular end product from a given raw material. Relative advantages or disadvantages are often temporary, changing with fluctuations in price structure of important commodities like energy or chemical additives, or as manufacturing costs may be more or less unfavorably affected by environmental regulations and restrictions. The present level of technology is not static but is rather a basis from which refinements, improvements, and altogether new processes and products may evolve.

Definitions

Density. The common usage of the term *density* refers to the weight of a unit volume of a material. Units used for wood and wood products are pounds per cubic foot, grams per cubic centimeter, and kilograms per cubic meter.

Because all wood products are hygroscopic, the density depends to some extent on the moisture content. In the case of composition board, weight and volume are obtained at the same condition, that is, at the same moisture content.

$$\text{density} = (\text{weight at test condition})/(\text{volume at test condition})\ (\text{lb/ft}^3)$$

Specific gravity. This term has no units. It is the ratio of the density of a material to the density of water (62.4 lb/ft^3). It describes the same property of the material and is the preferred form for solid wood. However, here, the volume is determined at the test condition, while the weight is determined after removing the water by ovendrying.

$$\text{specific gravity} = \text{weight (ovendry)}/(\text{volume at test condition} \times 62.4)\ (\text{lb})/[\text{ft}^3 \times (\text{lb/ft}^3)]$$

Disregarding the effect of moisture content, which is small at low moisture levels, density values can be converted to specific gravity by dividing by 62.4. Thus, a medium-density fiberboard with a density of 48 lb/ft^3 has a specific gravity of $48/62.4 = 0.77$.

Bulk density. This term is used to describe the bulking effect of loose materials such as dry fibers, particles, or chips. It is the density of the uncompressed material. Loose dry pulp fiber might have a bulk density of 1 or 2 lb/ft^3.

Moisture content and water content. In solid wood products, moisture content is expressed as the weight of water contained divided by the dry weight. Multiplying this ratio by 100 gives the result as a percentage. Wood consisting of 50% water and 50% dry wood substance has a moisture content of 100%.

In paper technology, the water content is often expressed as part of the total weight. On that basis the above piece of wood would have a water content of 50%.

When moisture contents are low, the differences between the two expressions are small, but at high moisture levels, as in wet fiber mats, the differences are large. A wet fiber mat containing 75% water and 25% dry fiber material has a water content of 75% or a moisture content of 300%.

At very high water contents, as in pulp slurries, the water/solids ratio is defined by consistency, which is the dry fiber content expressed as a percentage of the total weight of the slurry.

References

American Society for Testing and Materials. American National Standard ANSI/ASTM D-1554-78. Standard definitions of terms relating to wood base fiber and particle panel materials. Annual book of standards, section 4, 4(9), wood. Philadelphia; p. 331-334.

Carpenter, C.H.; Leney, L. 91 papermaking fibers. Syracuse, NY: State University of New York, College of Forestry; 1952.

Panshin, A.J.; deZeeuw, C. Textbook of wood technology, 3d ed, vol. 1. New York: McGraw-Hill; 1970. 705 p.

U.S. Department of Commerce, National Bureau of Standards. American National Standard ANSI/AHA A-135.4-1982. Basic hardboard. Washington, DC; 1980.

U.S. Department of Commerce, National Bureau of Standards. Cellulosic fiber insulating board. Voluntary Product Standard. PS-57-73. Washington, DC; 1973. 6 p.

2. The Fiberboard Industry

Historical Background

General

All composition boards shown in figure 1 were invented and/or reached commercial importance in the 20th century. Paper from wood pulp is little more than 100 years old. Manufacture of industrial plywood began around the turn of the century, and manufacture of insulation board began during World War I. The first hardboard plant was built in 1926. Particle board, first developed in Germany during World War II, was introduced into the United States in the early 1950's. Medium-density fiberboard (MDF-dry) and waferboard were both developed in the United States, and their use expanded rapidly in the 1970's.

Insulation board

Insulation board developed as a paper byproduct. Efforts to utilize the large quantities of oversize fiber bundles (called **screenings**) removed from groundwood pulp resulted in the establishment of the first insulation board plant in 1898 in England (Asplund 1956). A second plant of the same type was built 10 years later in Trenton, NJ. In 1914, a pilot plant was established for the manufacture of insulation board at the large Minnesota and Ontario Paper Company at International Falls, MN (Muench 1947). This small plant, under the direction of Carl Muench, produced a rigid insulation board from groundwood and sulfite screenings. A large plant built there in 1916 had its own groundwood operation. The product, sold as Insulite, was used for sheathing, interior finish, and roof insulation (Muench 1947). Insulite is still made at that location. The second insulation board plant using groundwood as raw material was built in Greenville, MS, in 1931. To further reduce costs, pioneers of the insulation board industry, including Muench, investigated sources of fiber in agricultural byproducts such as corn, wheat straw, and **bagasse,** the waste after extraction of the sugar from cane. As natural gas became available for energy in the evaporating process, bagasse became the basis for Celotex insulation board. The first plant was built at Marrero, LA, in 1920 (Lathrop 1930). The Celotex Company is today the largest producer of insulation board in the United States.

Hardboard

The invention of hardboard was stimulated by the desire to utilize the great quantities of sawmill waste such as slabs, edgings, and sawdust accumulating in southern pine mills. William H. Mason, who was operating a process for the extraction of rosin and turpentine from sawn boards in Laurel, MS, experimented with a unique device for converting chips to fiber without loss of the lignin. In this digester, the chips were subjected to a high steam pressure for a short time, after which the pressure was released to atmospheric level. The steam that had penetrated into the wood cells softened the lignin and, upon expansion, fiberized the chips.

Although unsuitable for making paper, the pulp, when compressed in a hotpress, could be converted to a hard, rigid sheet material in which the lignin apparently served as a bonding agent. A very interesting personal account of the invention can be found in Mason's article (1927). The Mason Fibre Company (now the Masonite Corporation) was formed, and the first **Masonite** hardboard plant was completed at Laurel in 1926 (Mason 1927). Today, this plant is the largest hardboard plant in the world. Figure 5 shows the cover page of the Masonite patent, granted in 1926 (Mason 1926). This and other patents gave Mason a virtual monopoly in this field, and the term Masonite became practically synonymous with hardboard.

In 1931, the Swedish engineer Arne Asplund carried out studies and experiments aimed at utilizing the thermoplastic properties of wood for the separation of the fibers. He designed a **defibrator** in which chips could be ground up under elevated steam pressure. Asplund (1956) also gives a personal account of his efforts, which were to play a tremendous role in the development of the hardboard industry. Figure 6 shows the patent drawing of the laboratory version of the Asplund defibrator (Asplund 1935).

Under selected conditions, the defibrator produced a high yield of clean, unbroken fiber uniquely suited for the manufacture of hardboard at relatively low power consumption. The first defibrator fiberboard plant was built in Sweden in 1934. Today, Asplund defibrators are dominant in the manufacture of hardboard throughout the world (Rydholm 1965).

Both Mason and Asplund produced S1S ("smooth one side") hardboards. This is a limitation of the wet process, since a screen must be inserted in the press on one side of the mat of wet fiber to facilitate the escape of water and steam during pressing. As a result, a screen pattern is permanently embossed in the backside of the finished board. In the early 1930's, both the U.S. Gypsum Company, which then owned the insulation board plant in Greenville, and Masonite applied for patents on a process for manufacture of S2S ("smooth two sides") fiberboard by pressing insulation board between smooth platens in a hotpress. After an infringement suit, the S2S patent was awarded to Mason (1938), but U.S. Gypsum,

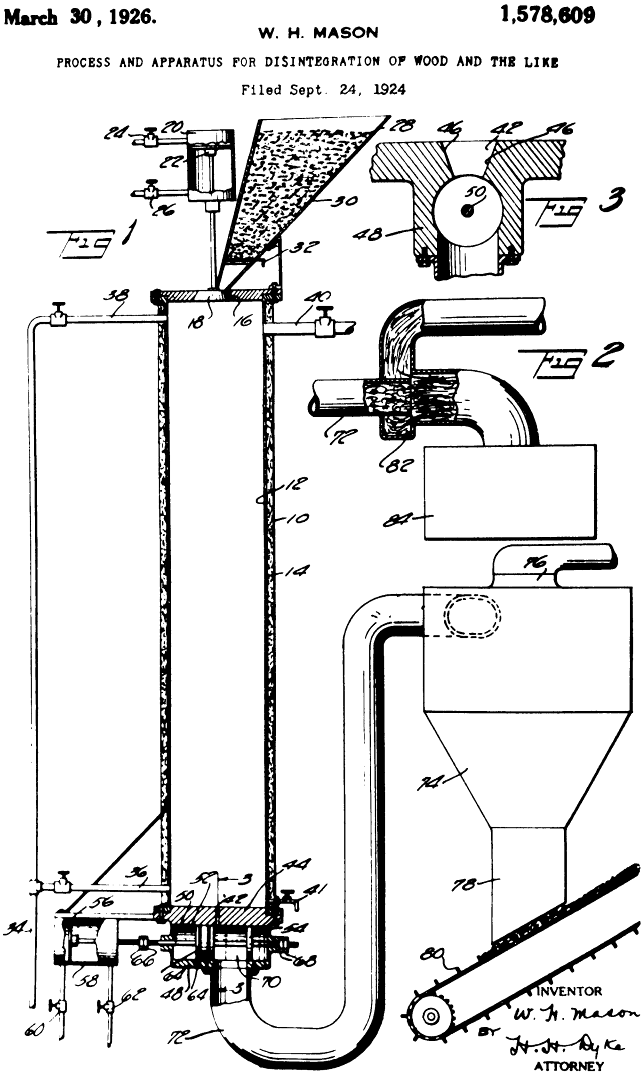


Figure 5—*Cover page of Masonite patent (Mason 1926).*

already in production, continued to make S2S hardboard at Greenville under a license agreement with Masonite. Thus, U.S. Gypsum became the first company to produce S2S hardboard (Eustis 1980).

No new hardboard plants were built in the United States until Masonite's basic product patent ran out in 1945. Sweden's refusal to grant a basic product patent to Masonite allowed the early development of the Swedish hardboard industry, which was based on the Asplund defibrator (Grantham 1953). Defibrators were also used in the first several hardboard plants built after 1945 in the Pacific Northwest (Grantham 1953).

The first hardboard plant built after the war was designed by Ralph Chapman of Corvallis, OR, to substitute hardboard for molded sheet metal parts, then in short supply. When built in 1946, the plant produced 4- by 8-ft sheets of S1S hardboard (Grantham 1953). Among many unique features, the plant included a batch-forming machine, which produced one mat at a time in a deckle box. Chapman proved that hardboard could be produced economically on a relatively small scale. Additional plants using the Chapman process were built in New Westminster, BC, and in Duluth, MN.

Meanwhile, U.S. Gypsum at its Greenville plant expanded the use of mixed hardwoods, which could not be ground satisfactorily on stone grinders, by developing the rapid cycle digester, in which wood chips were steamed or cooked before they were refined in Bauer refiners. C.E. Bauer Combustion Engineering, Inc., of Springfield, OH, still manufactures the rapid cycle digester.

Dry fiberboard processes

The first dry-process hardboard plant in the United States was built in 1952 at Anacortes, WA. It was an adaptation to commercial production of the so-called semidry process developed by the Plywood Research Foundation. Air is used as a conveying and distributing medium, but the furnish is not dry enough to permit pressing without screens (Grantham 1953). Semidry boards are, therefore, S1S boards.

A second, similar plant was built in Coos Bay, OR, in 1952. Here, the fibers were dried to a lower moisture content, allowing the manufacture of S2S board (Robinson 1959). An interesting variation of the dry-formed hardboard process is the "Mende" continuous board process, a German invention introduced into the United States in the early 1970's. It is a truly continuous process using a large drum press. In most other respects the process is similar to other dry processes.

Medium-density fiberboard

Though in the wet process the difference between hardboard and MDF-wet is essentially one of densification, the MDF-dry process is unique and quite different from dry-formed hardboard (Raddin and Brooks 1965). An essential element in its manufacture is the pressurized refiner (originally the Bauer 418), which produces a pulp of very low bulk density. MDF-dry is generally much thicker than dry-formed hardboard. The first MDF plant was built in Deposit, NY, in 1965; the product is sold under the trade name Baraboard.

Industry Statistics

General

The fiberboard industry, with the possible exception of the MDF-dry component, is a mature industry. Initial rapid growth and expansion associated with developments of new markets has slowed down. Future growth is closely tied to activities in the housing construction field, which absorbs a great share of the total fiberboard output. Competition from nonwood products that may be more energy efficient in production and performance, are less flammable, and that carry smaller air and water pollution control burdens may have significant effects on the future development of the fiberboard industry. On the other hand, high yield, relative insensitivity to raw material quality, and great process flexibility for modifying product characteristics should be attractive attributes as competition with solid wood and plywood structural components increases.

Insulation board

Insulation board is produced today in 12 manufacturing plants located mostly in the South and in some of the Northern States. Only one insulation board plant is located in the West (table 1) (EPA 1979). In the last 9 years, only 1 insulation board plant has opened: 11 plants have shut down since 1960 (EPA 1979). Annual capacity and annual production are shown in figure 7 (McKeever 1979).

Insulation board products can be divided into three categories (EPA 1979; McKeever 1979):

Exterior products

Sheathing—a board used in exterior construction because of its insulation and noise control qualities, its bracing strength, and its low price.

Roof decking—a three-in-one component that provides roof deck, insulation, and a finished interior ceiling surface. Insulation board sheets are laminated together with waterproof adhesive.

Roof insulation—insulation board designed for use on flat roof decks.

Aluminum siding backer board—fabricated insulation board for improving insulation of aluminum sided houses.

Interior products

Building board—a general purpose product for interior construction.

Ceiling tile—insulation board embossed and decorated for interior use, valued for acoustical qualities; also decorative, nonacoustical tiles.

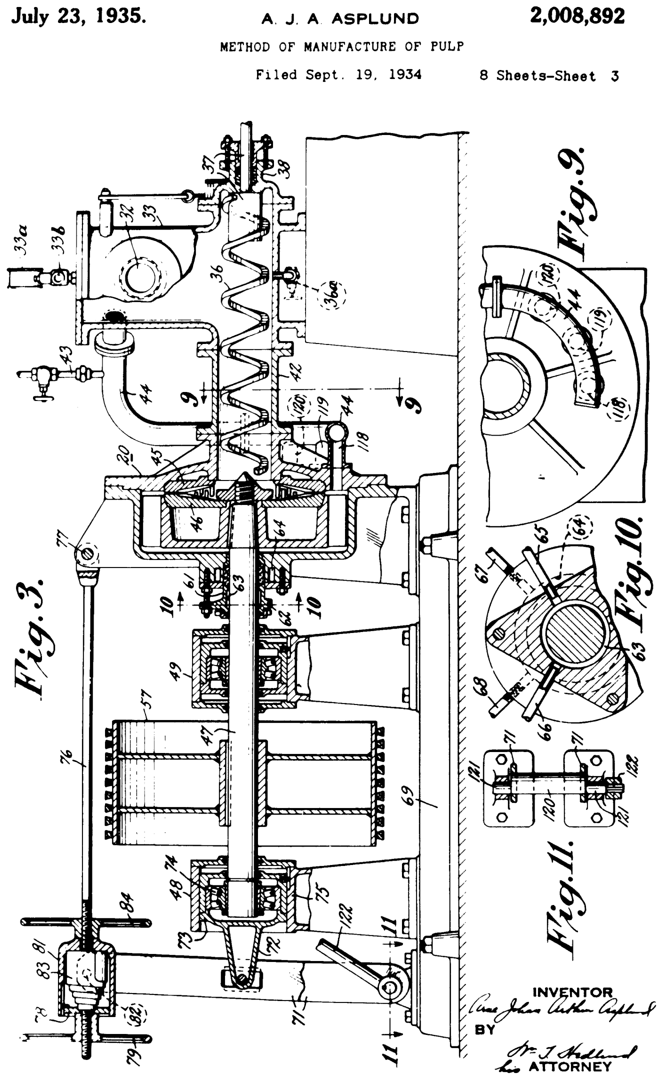


Figure 6—*Patent drawing of laboratory Asplund Defibrator (Asplund 1935).*

Sound deadening board—a special product designed to control noise levels in buildings.

Industrial products

Mobile home board, expansion joint strips, boards for automotive and furniture industries.

Production of insulation board by categories in 1981 is show in table 2 (USDC Bureau of Census 1983).

The market for exterior insulation board products (58 percent of the total) is expected to decline in the future by 2.5 to 3 percent annually (EPA 1979). This is mainly due to inroads in the sheathing market by gypsum sheathing and foil-backed structural foams. Also, many

Table 1—*Insulation board plants in the United States, 1982 (EPA 1979)*[1]

Company	Location	Annual capacity (million ft²) ½-in basis
Armstrong Cork	Macon, GA	400
Boise Cascade	International Falls, MN	210
Celotex	Marrero, LA	—
Celotex	L'Anse, MI	700
Celotex	Sunbury, PA	—
Flintkote	Meridian, MS	200
Georgia Pacific	Jarratt, VA	210
Huebert Fiberboard	Boonville, MO	50
National Gypsum	Mobile, AL	192
Temple Industries	Diboll, TX	220
U.S. Gypsum	Lisbon Falls, ME	200
U.S. Gypsum	Pilot Rock, OR	
TOTAL		2,382

[1]Updated by authors in 1983.

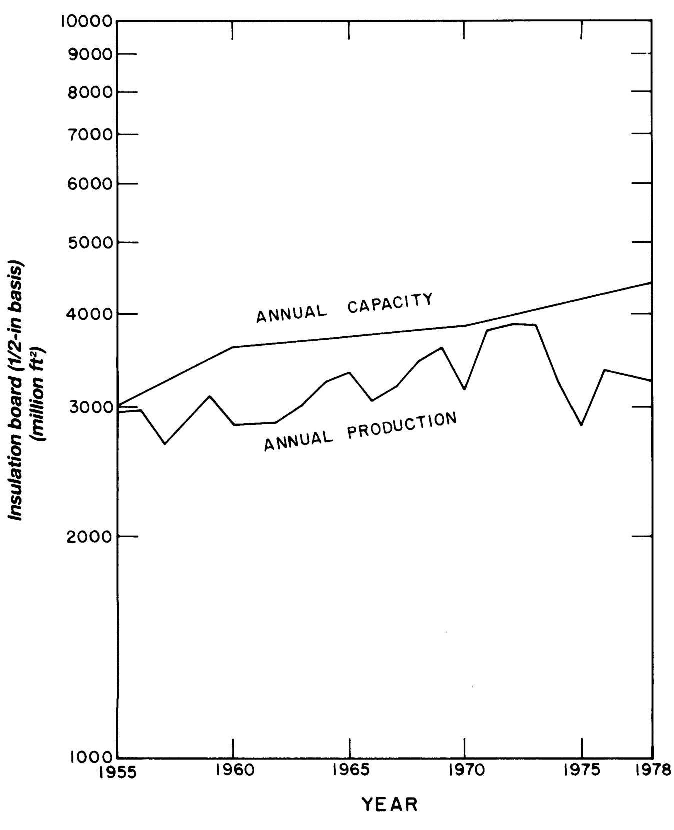


Figure 7—*Annual capacity and production of insulation board (McKeever 1979).*

building codes now permit exterior wood siding to provide rack resistance previously provided by insulation board sheathing and plywood (EPA 1979). Because insulation board sheathing does not add significantly to the insulation value of a wall, it can readily be eliminated.

The interior market (30 percent of the total) is also expected to decline by 5 to 6 percent annually (EPA 1979). Here, insulation board is being pushed out of the market by stricter flame spread standards in building codes, which favor plastic and mineral board substitutes.

The industrial market (12 percent of the total) is expected to decline 7 to 8 percent annually. This will be caused by significant losses in the mobile home market resulting from flame spread requirements (EPA 1979).

Hardboard

Hardboards produced by all processes, with the exception of the MDF-dry process, are more or less interchangeable in their applications and are described together. MDF-dry is discussed separately.

The plants that manufacture wet- and dry-process hardboard are listed in table 3 (American Hardboard Association 1982). Seven of the 23 plants are located in the West, 9 in the South, and 7 in the Northern States. No new wet-process hardboard plants have been built since 1971, but several mills have greatly expanded capacity (EPA 1979).

Table 2—*Shipments of structural insulating board by grade, 1981 (USDC Bureau of Census 1983)*[1]

Grade	Value (thousands of dollars)	Weight (short tons)	Area (thousand ft²) ½-in basis
Total structural insulating board (density less than 31 lb/ft³)	230,614	814,506	1,925,584
Insulating boards for the retail trade or for use directly in building construction	193,602	721,529	W
Interior products	58,035	152,496	409,964
Building board, 7/16 in or thicker, mostly painted or factory finished	6,400	16,497	40,173
Sound-deadening board, nominal ½ in thick, natural finish	10,076	29,228	77,790
Tile and lay-in panels, except accoustical	36,386	91,782	250,335
Other (including plank, trim, moldings, and other insulating board for retail or for use directly in interior building construction); also wallboard, under 7/16 in thick, etc.	5,173	14,989	41,666
Exterior products	135,567	569,033	W
Sheathing board	67,852	363,669	844,366
Shinglebacker	W	W	W
Roof insulation board, preformed above deck	62,557	189,557	383,130
Other exterior products, including insulating roof deck and insulating fiberboard formboard	W	W	W
Insulating boards for industrial uses (for further manufacture, processing, or assembly)	37,012	92,979	263,929
Trailer board	17,677	42,083	121,891
Insulating board for all other industrial uses, such as automobile industry, furniture industry, etc.	19,335	50,896	142,038

[1]W = Withheld to avoid disclosing figures for individual companies.

The major types of hardboard can be categorized as follows:

Interior paneling	—	generally prefinished.
Exterior siding	—	lap or panel siding, generally primed or completely prefinished.
Industrial board	—	wide range of products: automotive, construction, furniture industry, etc.

Annual capacity and annual production are shown in figure 8 (McKeever 1979).

Hardboard is closely tied to the building industry (fig. 9), and 60 percent of all hardboard is used directly in construction (EPA 1979). Hardboard is cost competitive with many conventional building products such as plywood wall panels and many types of exterior siding. The development of simulated wood grain and other natural surface patterns has brought hardboard's share to about 20 percent of the total wall paneling market. The growing market is in siding. Hardboard siding is prob-

Table 3—*Hardboard plants in the United States, 1982 (National Particleboard Association 1978)*[1]

Parent company	Mill location	Area (thousand ft²) 1/8-in basis: Total hardboard	Siding	Siding weight (tons)
Abitibi-Price	Alpena, MI	549,000	—	—
	Roaring River, NC	577,500	165,000	131,175
Boise Cascade	International Falls, MN	702,812	200,804	133,535
Celotex	Paris, TN	192,000	64,000	53,680
Champion	Catawba, SC	230,000	77,000	61,000
	Dee, OR	84,000	—	—
	Lebanon, OR	107,000	—	—
Evans	Corvallis, OR	138,500	—	—
Forest Fiber	Forest Grove, OR	114,136	26,088	30,132
Georgia Pacific	Conway, NC	208,000	—	—
	Jarratt, VA	210,000	60,000	57,000
Masonite	Laurel, MS	1,610,000	(Variable)	—
	Towanda, PA	652,000	(Variable)	—
	Ukiah, CA	600,000	(Variable)	—
Superior	Superior, WI	160,000	—	—
Superwood	Duluth, MN	350,000	—	—
	N. Little Rock, AR	175,000	—	—
	Bemidji, MN	105,000	—	—
	Phillips, WI	96,000	—	—
Temple-Eastex	Diboll, TX	477,858	136,531	98,985
U.S. Gypsum	Danville, VA	230,000	—	—
	Pilot Rock, OR	50,000	—	—
Weyerhaeuser	Klamath Falls, OR	420,000	120,000	96,000
TOTAL		8,038,806	849,423	661,507

[1]Updated by authors in 1983.

ably the cheapest exterior wall cladding available. Improvement of finish durability and well-engineered hanging systems will favor this material in the future. Hardboard's share in the construction market has been increasing, and this trend is expected to continue. Long-term growth in consumption will average up to 2 percent annually.

Medium-density fiberboard (MDF-dry)

MDF-dry is produced in 11 manufacturing plants (table 4) (Dickerhoof and McKeever 1979); all have been built within the last 15 years. Annual production is shown in table 5 (National Particleboard Association 1978). Although the first MDF-dry plant was designed to produce exterior siding, it was soon converted to produce industrial core stock (furniture panels). Most of the output of this industry today is sold for this use. MDF-dry successfully competes with particle board, a lower cost core material, on the strength of its more uniform structure and its solid edges, which allow direct finishing.

It is expected that MDF-dry will make further inroads into the core stock market in the future. Annual growth of this industry for the next few years has been estimated at about 10 percent.

Table 4—*Medium-density fiberboard plants (MDF-dry) in the United States, 1983 (Dickerhoof and McKeever 1979)*[1]

Company	Location	Production capacity (million ft²) ¾-in basis
LA-Pacific	Eufaula, AL	60.0
Willamette Industries	Malvern, AR	46.0
LA-Pacific	Rocklin, CA	75.0
Plum Creek Lumber	Columbia Falls, MT	80.0
Weyerhaeuser	Moncure, NC	60.0
Masonite	Spring Hope, NC	74.0
Weyerhaeuser	Broken Bow, OK	70.0
Medford	Medford, OR	80.0
Holly Hill Lumber	Holly Hill, SC	68.0
Celotex	Marion, SC	57.0
Bassett Industries	Bassett, VA	22.0
Montana de Fibra	Las Vegas, NM	80.0[2]
TOTAL		692.0

[1]Updated by authors in 1983.
[2]Under construction in 1983, not included in total.

References

American Hardboard Association. Communication; Palatine, IL. 1982. 1 p.

Asplund, A.J.A. A method of manufacture of pulp. U.S. patent 2,008,892. 1935 July 23. 14 p.

Asplund, A.J.A. The beginning and development of the fiberboard industry. Svensk Papperstidning. 59(12): 441-448; 1956.

Dickerhoof, H.E.; McKeever, D.B. Particle board, medium density fiberboard, and Mende process board plants in the United States—capacity, production, and raw material trends, 1956-1976. Res. Bull. FPL-6. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1979. 20 p.

Environmental Protection Agency. Economic impact analysis of alternative pollution control technologies: wet hardboard and insulation board subcategories of the timber products industry. EPA-440/2-2-79/017. Washington, DC: 1979. 88 p.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

Grantham, J.B. Review of hardboard developments in the Pacific Northwest. Journal of Forest Products Research Society. 3(3): 89-91; 1953.

Lathrop, E.C. The Celotex and cane-sugar industries. Industrial and Engineering Chemistry. 22(5): 449-460; 1930.

Mason, W.H. Process and apparatus for disintegration of wood and the like. U.S. patent 1,578,609. 1926 March 30. 5 p.

Mason, W.H. Pulp and paper from steam exploded wood. Paper Trade Journal. 84(8): 131-136; 1927.

Mason, W.H. Process of making ligno cellulose fiber products. U.S. patent 2,120,137. 1938 June 7. 3 p.

McKeever, D.B. Hardboard and insulation board plants in the United States—capacity, production and raw material requirements, 1955-1978. Res. Bull. FPL-7. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1979. 12 p.

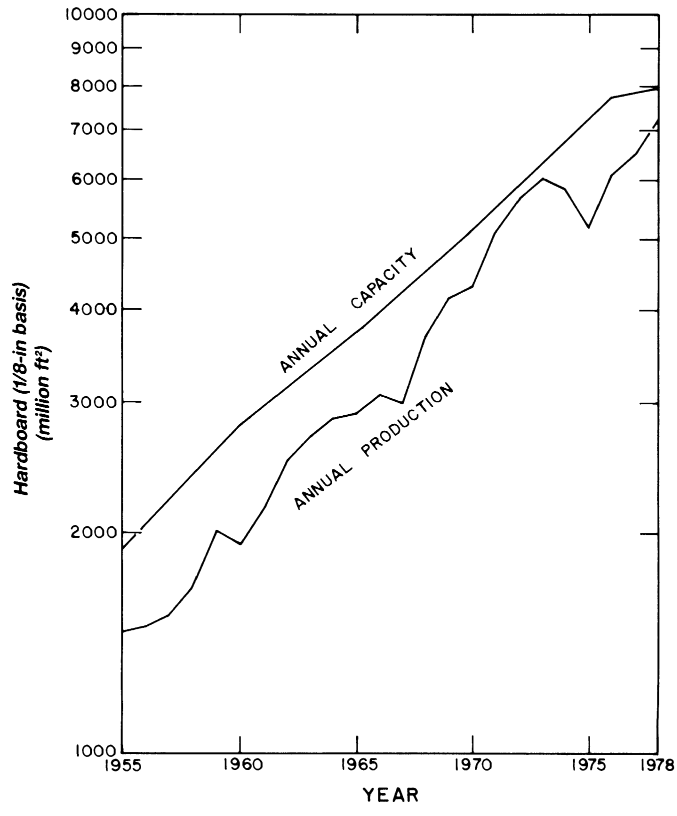


Figure 8—*Annual capacity and production of hardboard (McKeever 1979).*

Table 5—*Medium-density fiberboard (MDF-dry) production, shipments, and value of shipments (National Particleboard Association 1981)*[1]

Year	Area (million ft²) ¾-in basis: Production	Shipments	Value of shipments (millions of dollars)
1975	215.5	177.0	31.4
1976	280.0	278.9	54.4
1977	441.4	413.2	84.9
1978	538.8	508.4	114.9
1979	534.0	506.8	136.7
1980	513.2	493.1	145.2
1981	529.9	516.1	175.4
1982	460.0	—	—

[1]Updated by authors in 1983.

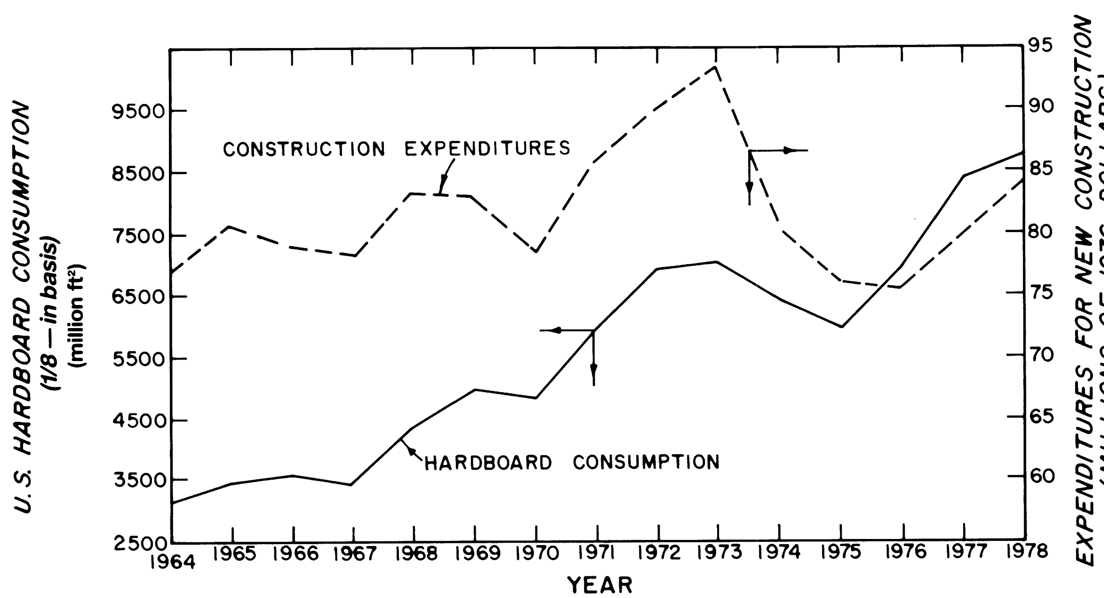


Figure 9—*Hardboard consumption and construction expenditures, 1964-78 (EPA 1979).*

Muench, C.G. An outline of the insulation board industry. Paper Trade Journal. 125(5): 48-50; 1947.

National Particleboard Association. Particle board and medium density fiberboard annual production and shipments, 1981. Silver Spring, MD; 1981. 4 p.

Raddin, H.A.; Brooks, S.H.W. Method of making fiberboard. U.S. patent 3,207,819. 1965 September 21.

Robinson, J.G. Dry process hardboard. Forest Products Journal. 9(7): 11A-14A; 1959.

Rydholm, S.A. Pulping processes. New York: Interscience Publishers; 1965: 1269 p.

U.S. Department of Commerce, Bureau of Census. Current industrial reports. MA 26A(81)-1. Washington, DC; 1983. 23 p.

3. Some Chemical Aspects of Fiberboard Manufacture

General

Pulping processes are classified as either full-chemical, semichemical, or mechanical. This classification refers to the nature of the defiberizing process. In the **full-chemical** process (book papers, writing papers, etc.) the wood cells are separated from one another primarily by dissolving and removing the natural bonding agent. The chemical reactions occur under conditions of elevated temperature and pressure and are very complex. In the **mechanical** pulping processes (newsprint) the wood cells are separated by frictional forces often aided by steam pressure. **Semichemical** processes use a combination of both chemical reactions and mechanical power.

Pulping processes used in the manufacture of fiberboard are mechanical. No chemicals are added for the purpose of dissolving the natural bonding agent. However, a number of important chemical reactions occur during the pulping stage and during subsequent manufacturing steps. The principles of some of these reactions are discussed in this chapter.

Chemical treatments such as those related to fireproofing of hardboard and to water pollution control measures are discussed in later chapters.

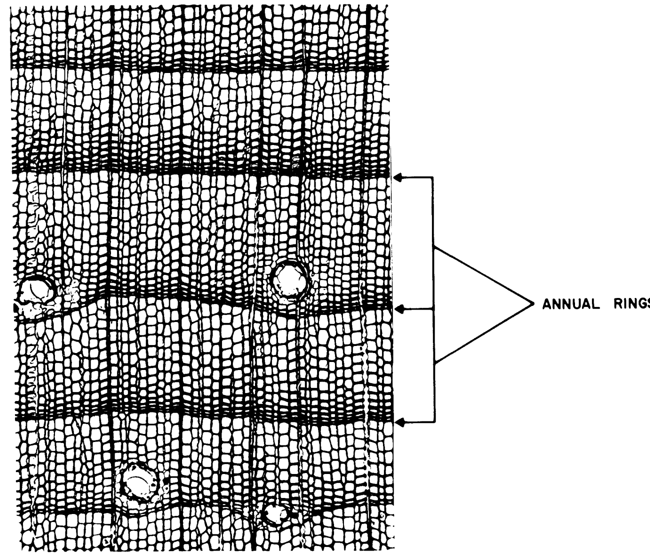


Figure 10—*Cross section of eastern white pine,* Pinus strobus *X75 (Panshin and deZeeuw 1970).*

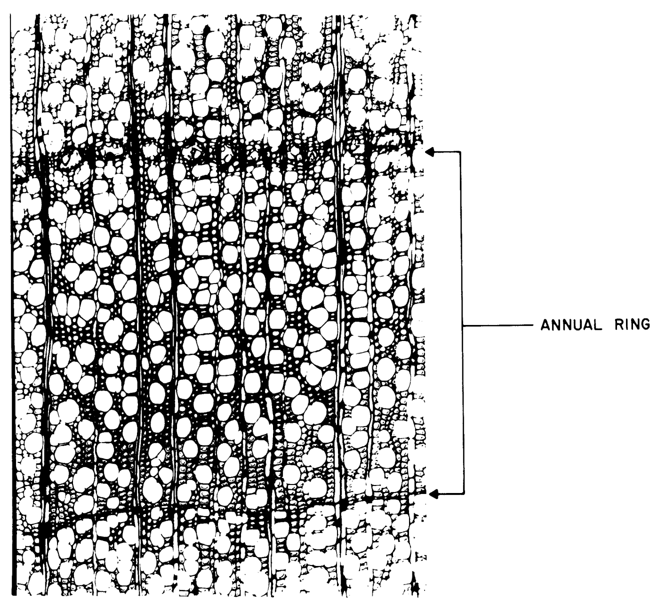


Figure 11—*Cross section of sweetgum,* Liquidambar styraciflua *X75 (Panshin and deZeeuw 1970).*

The Structure and Chemistry of Wood Cells

Cell structure

The cellular structure of wood can be perceived only through a strong hand lens or the microscope. Figures 10 and 11 (Panshin and deZeeuw 1970) show cross sections of wood of a coniferous (softwood) tree and a broadleaf (hardwood) tree. The long dimensions of these cells, oriented with the tree axis, are many times those of the cross sections visible here. In cross section, as viewed in these figures, the cells tend to be aligned, both peripherally and radially. Cells formed early in the growing season **(earlywood)** are larger and have thinner walls than cells formed later in the year **(latewood)**. The earlywood and latewood of a single growing season comprise an **annual ring**; these, in aggregate, form pleasing and characteristic patterns on solid wood surfaces.

Figures 12 and 13 (Howard and Manwiller 1969, McMillin and Manwiller 1980) show three-dimensional drawings of small cubes of wood from white pine and sweetgum. Various cell types that differ in size and function are identified. Softwood consists primarily of longitudinal tracheids that are relative long, four- to six-sided, prismatic elements with tapered, closed ends; see table 6 (Panshin and deZeeuw 1970). These tracheids are the important pulp fibers. In hardwoods, the vessels, which are large tubelike structures, are the most prominent elements, occupying a large portion of the total wood volume. However, they are relatively thin walled and therefore contribute little to the pulp mass. Wood rays in hardwood consist of parenchyma

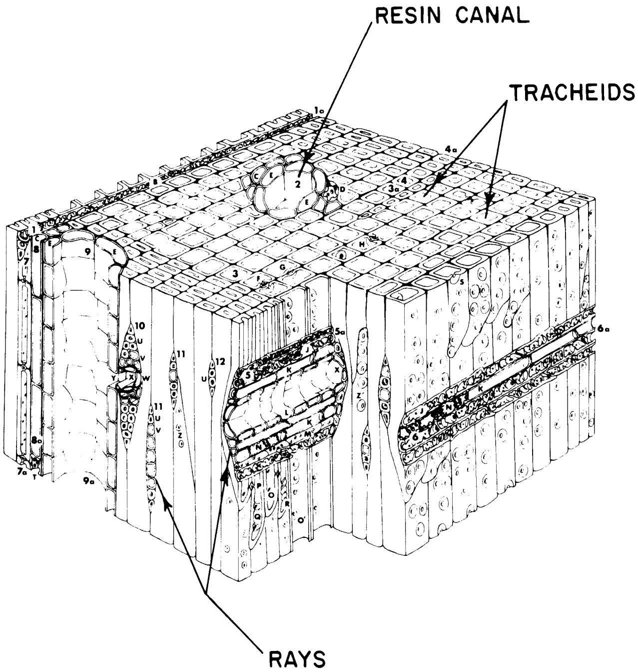


Figure 12—*Schematic drawing of typical southern pine wood (Howard and Manwiller 1969). Rays are horizontally arranged cell aggregates that transport nutrients.*

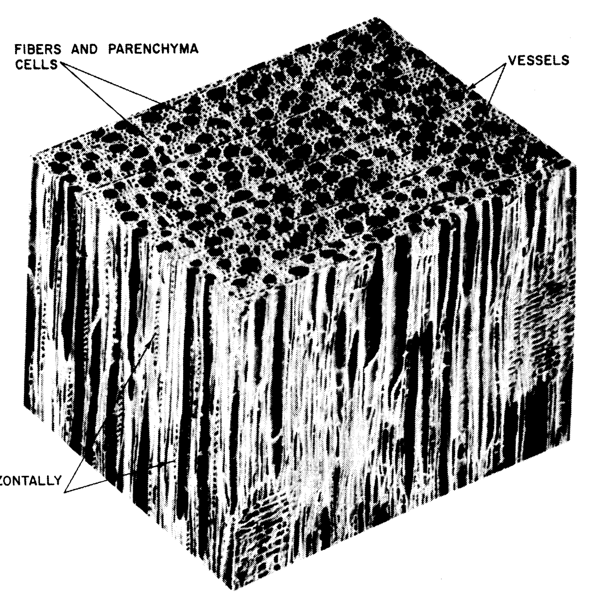


Figure 13—*Scanning electron micrograph of sweetgum,* Liquidambar styraciflua *(McMillin and Manwiller 1980). Rays are horizontally arranged cell aggregates that transport nutrients.*

Table 6—*Volumetric composition of representative softwood and hardwood (Panshin and deZeeuw 1970)*

Structure	Percentage
Softwood (white pine)	
Longitudinal tracheids	93
Longitudinal resin canals	1
Wood rays	6
Hardwood (sweet gum)	
Vessels	54.90
Fiber tracheids	26.30
Longitudinal parenchyma	.50
Wood rays	18.30

cells that also are thin walled and short and contribute little to the pulp mass. The important cell type is the fiber tracheid. It is similar to the softwood tracheid, rather thick walled and long with pointed ends. Hardwood parenchyma cells and vessels break up readily in the pulping process and produce much of the "fine" fraction of the pulp. Volumetric composition of sweetgum wood is shown in table 6 (Panshin and deZeeuw 1970). Tables 7 and 8 (Panshin and deZeeuw 1970) show cell dimensions of some of the important softwood and hardwood species of the United States.

All wood cells have walls consisting of layers, the primary wall, commonly denoted by P, and the three layers of the secondary wall, commonly denoted by S_1, S_2, and S_3, see figure 14 (Rydholm, 1965). The basic construction elements of these layers are fine submicroscopic strands **(fibrils)** that are embedded in an amorphous matrix much as glass fibers are embedded in a matrix of polyester resin in the common fiberglass. The distinguishing features of the individual layers are the organization and the orientation of the strands or fibrils. In the primary wall the fibrils are randomly arranged. In the S_1 layer there exist a number of thin layers (lamellae) of parallel fibrils with alternating angles of orientation relative to the cell axis (50° to 70°). The S_2 layer shows a parallel alignment of fibrils oriented at about 10° to 30° from the cell axis. The fibrils in the innermost layer (S_3) of the secondary wall describe a rather flat helix about 60° to 90° to the cell axis. The relative contributions to the total cell wall volume of these cell wall layers have been reported for some softwoods as follows (Panshin and deZeeuw 1970): primary wall plus middle lamella (P), 2 percent; secondary wall: S_1, 16 percent; S_2, 74 percent; and S_3, 8 percent.

Table 7—*Average length of longitudinal tracheids of the coniferous woods of the United States (determined from specific samples; arranged in order of longest average length for the species) (Panshin and deZeeuw 1970)*

Common name	Scientific name	Average length (mm)	Standard deviation
Redwood	*Sequoia sempervirens*	5.79	1.03
		7.39	1.31
Baldcypress	*Taxodium distichum*	3.14	.58
		5.23	1.42
		5.79	1.10
Sitka spruce	*Picea sitchensis*	5.22	.85
		5.37	1.06
		5.45	.98
Sugar pine	*Pinus lambertiana*	5.14	.94
		5.24	.96
		5.40	1.03
Longleaf pine	*Pinus palustris*	4.90	.83
Shortleaf pine	*Pinus echinata*	4.46	.91
		4.64	.92
		4.85	.76
Slash pine	*Pinus elliottii*	4.58	.87
Loblolly pine	*Pinus taeda*	4.33	.91
Eastern hemlock	*Tsuga canadensis*	3.37	.57
		3.80	.82
		4.24	.99
Western larch	*Larix occidentalis*	2.82	.48
		2.97	.55
		4.09	.71
Ponderosa pine	*Pinus ponderosa*	3.53	.75
		3.71	.86
		4.08	.98
Eastern white pine	*Pinus strobus*	3.00	.55
		3.70	.66
		3.99	.69
		4.00	.91
Douglas-fir	*Pseudotsuga menziesii*	3.00	.31
		3.32	.39
		3.88	1.41
Black spruce	*Picea mariana*	3.25	.40
		3.60	.72
		3.81	.52
White fir	*Abies concolor*	3.79	.63
Western white pine	*Pinus monticola*	2.83	.59
		2.97	.58
		3.79	.69
White spruce	*Picea glauca*	2.92	.41
		3.24	.51
		3.76	.79

Table 7 — *continued*

Common name	Scientific name	Average length (mm)	Standard deviation
Pitch pine	*Pinus rigida*	3.57	.74
		3.75	.83
Tamarack	*Larix laricina*	2.86	.39
		3.00	.46
		3.68	.65
Englemann spruce	*Picea engelmannii*	2.49	.48
		2.75	.66
		3.63	.55
Noble fir	*Abies procera*	3.60	.58
Incense-cedar	*Calocedrus decurrens*	3.60	.59
Balsam fir	*Abies balsamea*	3.33	.43
		3.37	.50
		3.53	.61
Grand fir	*Abies grandis*	3.05	.47
		3.35	.43
		3.53	.65
Atlantic white-cedar	*Chamaecyparis thyoides*	3.20	.45
		3.34	.42
California red fir	*Abies magnifica*	3.27	.52
Lodgepole pine	*Pinus contorta*	3.19	.44
		3.26	.44
California torreya	*Torreya californica*	3.23	.67
Jeffrey pine	*Pinus jeffreyi*	3.20	.61
Port-Orford-cedar	*Chamaecyparis lawsoniana*	3.18	.47
Western redcedar	*Thuja plicata*	3.00	.45
		3.18	.48
Red spruce	*Picea rubens*	3.01	.49
		3.01	.61
		3.17	.60
Western hemlock	*Tsuga heterophylla*	2.87	.40
		2.91	.58
		3.10	.59
Rocky Mountain Douglas-fir	*Pseudotsuga menziesii* var. *glauca*	2.85	.45
Florida torreya	*Torreya taxifolia*	2.76	.39
Pond pine	*Pinus serotina*	2.73	.36
Red pine	*Pinus resinosa*	2.51	.54
		2.63	.45
		2.67	.27
		2.70	.89
Southern redcedar	*Juniperus silicicola*	2.38	.62
Pacific yew	*Taxus brevifolia*	2.31	.34
		2.32	.45

Table 7—*continued*

Common name	Scientific name	Average length (mm)	Standard deviation
Alaska-cedar	*Chamaecyparis nootkatensis*	2.24	.39
Northern white-cedar	*Thuja occidentalis*	2.16	.43
		2.17	.47
Eastern redcedar	*Juniperus virginiana*	2.15	.50
Utah juniper	*Juniperus osteoperma*	1.18	.29
Virginia pine	*Pinus virginiana*	2.80[1]	—
Sand pine	*Pinus clausa*	2.85[1]	—
Spruce pine	*Pinus glabra*	4.60[1]	—

[1]Koch (1972)

Table 8—*Average length of vessel elements and fibers (fiber tracheids) of hardwoods of the United States (Panshin and deZeeuw 1970)*[1]

		Vessel elements		Fibers	
Common name	Scientific name	Average length (mm)	SD	Average length (mm)	SD
Bigleaf maple	*Acer macrophyllum*	0.33	0.05	0.77	0.15
Red maple	*Acer rubrum*	.42	.05	.92	.12
Silver maple	*Acer saccharinum*	.41	.07	.76	.13
Sugar maple	*Acer saccharum*	.41	.09	.92	.13
Yellow buckeye	*Aesculus octandra*	.44	.08	1.00	.13
Red alder	*Alnus rubra*	.85	.14	1.19	.18
Pacific madrone	*Arbutus menziesii*	.53	.10	.79	.14
Yellow birch	*Betula alleghaniensis*	.84	.16	1.38	.17
Sweet birch	*Betula lenta*	.91	.12	1.52	.22
Paper birch	*Betula papyrifera*	1.00	.26	1.35	.15
Gray birch	*Betula populifolia*	.74	.15	1.26	.14
American hornbeam	*Carpinus caroliniana*	.42	.10	1.17	.18
Bitternut hickory	*Carya cordiformis*	.44	.11	1.38	.22
Pecan	*Carya illinoensis*	.41	.08	1.28	.20
Shagbark hickory	*Carya ovata*	.47	.09	1.34	.28
Mockernut hickory	*Carya tomentosa*	.44	.06	1.62	.26
American chestnut	*Castanea dentata*	.58	.12	1.22	.16
Giant chinkapin	*Castanopsis chrysophylla*	.67	.11	.87	.11
Northern catalpa	*Catalpa speciosa*	.28	.09	.64	.11
Hackberry	*Celtis occidentalis*	.26	.03	1.13	.17
Yellowwood	*Cladrastis kentukea*	.23	. 03	.61	.14
Flowering dogwood	*Cornus florida*	1.04	.17	1.74	.29
Pacific dogwood	*Cornus nuttallii*	1.13	.20	1.64	.27
Common persimmon	*Diospyros virginiana*	.36	.04	1.39	.20
American beech	*Fagus grandifolia*	.61	.11	1.28	.21
White ash	*Fraxinus americana*	.29	.03	1.26	.17
Oregon ash	*Fraxinus latifolia*	.23	.05	1.20	.16

Table 8—*continued*

Common name	Scientific name	Vessel elements Average length (mm)	SD	Fibers Average length (mm)	SD
Black ash	*Fraxinus nigra*	.27	.04	1.27	.17
Green ash	*Fraxinus pennsylvanica*	.26	.03	1.27	.17
Blue ash	*Fraxinus quadrangulata*	.23	.04	1.03	.15
Honey locust	*Gleditsia triacanthos*	.19	.03	1.24	.11
Kentucky coffeetree	*Gymnocladus dioicus*	.27	.06	1.12	.15
American holly	*Ilex opaca*	.88	.24	1.74	.27
Butternut	*Juglans cinerea*	.36	.14	1.13	.17
Black walnut	*Juglans nigra*	.51	.08	1.21	.14
Sweetgum	*Liquidambar styraciflua*	1.32	.30	1.82	.16
Yellow-poplar	*Liriodendron tulipifera*	0.89	0.13	01.74	0.29
Tanoak	*Lithocarpus densiflorus*	.57	.11	1.10	.15
Osage-orange	*Maclura pomifera*	.18	.02	1.14	.16
Cucumbertree	*Magnolia acuminata*	.72	.15	1.39	.28
Southern magnolia	*Magnolia grandiflora*	.99	.14	1.81	.29
Red mulberry	*Morus rubra*	.21	.03	.91	.12
Water tupelo	*Nyssa aquatica*	1.11	.28	1.89	.33
Black tupelo	*Nyssa sylvatica*	1.33	.34	2.30	.36
Eastern hophornbeam	*Ostrya virginiana*	.68	.11	1.23	.18
Sourwood	*Oxydendrum arboreum*	.47	.09	1.05	.16
Sycamore	*Platanus occidentalis*	.63	.12	1.08	.17
Bigtooth aspen	*Populus grandidentata*	.64	.09	1.33	.17
Quaking aspen	*Populus tremuloides*	.67	.18	1.32	.22
Black cottonwood	*Populus trichocarpa*	.58	.09	1.38	.19
Black cherry	*Prunus serotina*	.39	.06	1.21	.18
White oak	*Quercus alba*	.40	.09	1.39	.20
Swamp white oak	*Quercus bicolor*	.41	.07	1.19	.17
Scarlet oak	*Quercus coccinea*	.43	.09	1.61	.26
Overcup oak	*Quercus lyrata*	.42	.08	1.35	.20
Bur oak	*Quercus macrocarpa*	.35	.07	1.20	.19
Pin oak	*Quercus palustris*	.46	.09	1.30	.20
Willow oak	*Quercus phellos*	.45	.08	1.38	.25
Chestnut oak	*Quercus prinus*	.40	.09	1.45	.22
Northern red oak	*Quercus rubra*	.42	.09	1.32	.29
Shumard oak	*Quercus shumardii*	.45	.08	1.44	.20
Post oak	*Quercus stellata*	.43	.09	1.35	.21
Black oak	*Quercus velutina*	.43	.08	1.44	.29
Black locust	*Robinia pseudoacacia*	.18	.02	1.13	.16
Black willow	*Salix nigra*	.42	.09	.85	.17
Sassafras	*Sassafras albidum*	.39	.06	1.02	.14
American basswood	*Tilia americana*	.43	.09	1.21	.17
White basswood	*Tilia heterophylla*	.48	.04	1.34	.18
American elm	*Ulmus americana*	.22	.04	1.55	.20
Slippery elm	*Ulmus rubra*	.22	.03	1.30	.15
Rock elm	*Ulmus thomasii*	.25	.03	1.21	.16
California-laurel	*Umbellularia californica*	.37	.06	.94	.14

[1]SD = Standard deviation.

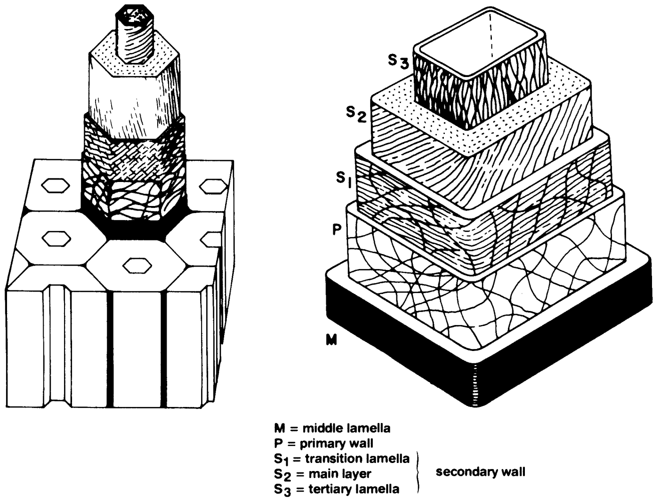


Figure 14—*Cell wall architecture, schematically (Rydholm 1965).*

The layered construction of the cell wall and the organization of the fibrils in the layers have, of course, an important bearing on the strength properties of individual fibers, which in turn will be reflected in the behavior of solid wood and wood products (Mark 1967).

The cells in their natural arrangement in solid wood are bonded together by a layer of amorphous cementing material called the **middle lamella.** It is this bonding that must be broken in the pulping process, by either chemical or mechancial means.

Chemical composition of the cell wall

The major chemical components of wood are cellulose, the hemicelluloses, lignin, and a very small fraction of so-called **extractives.** Table 9 (Thomas 1977) shows average analyses of softwoods and hardwoods.

The cellulose molecule is the building block of the fibrils in the cell walls. Hemicelluloses and lignin are the matrix material in the secondary cell wall layer, and lignin is the primary component of the middle lamella, cementing the wooden cells together. The distribution of these components in the cell wall is illustrated in figure 15 (Panshin and deZeeuw 1970). Extractives are low-molecular-weight chemical compounds found in small amounts particularly in the **heartwood,** which is the dead, inner part of the stem. They are responsible for coloration of wood and its resistance to insect and fungus attack. Extractives are soluble either in neutral organic solvents or in water and are volatile in steam.

The **cellulose** molecule is a chain molecule measured in terms of the number of glucose units it contains (fig. 16). This number is called the degree of polymerization (DP), which for wood ranges between 3,000 and 10,000 depending on species (Rydholm 1965). Both the strength of the wood fiber and the insolubility of cellulose in water or dilute alkali and acids derive from the chainlike arrangement of the molecule and from its length. In the cell

Table 9—*Average chemical composition of softwoods and hardwoods (Thomas 1977)*

Component	Percentage	
	Softwoods	Hardwoods
Cellulose	42 ± 2	45 ± 2
Hemicellulose	27 ± 2	30 ± 5
Lignin	28 ± 3	20 ± 4
Extractives	3 ± 2	5 ± 3

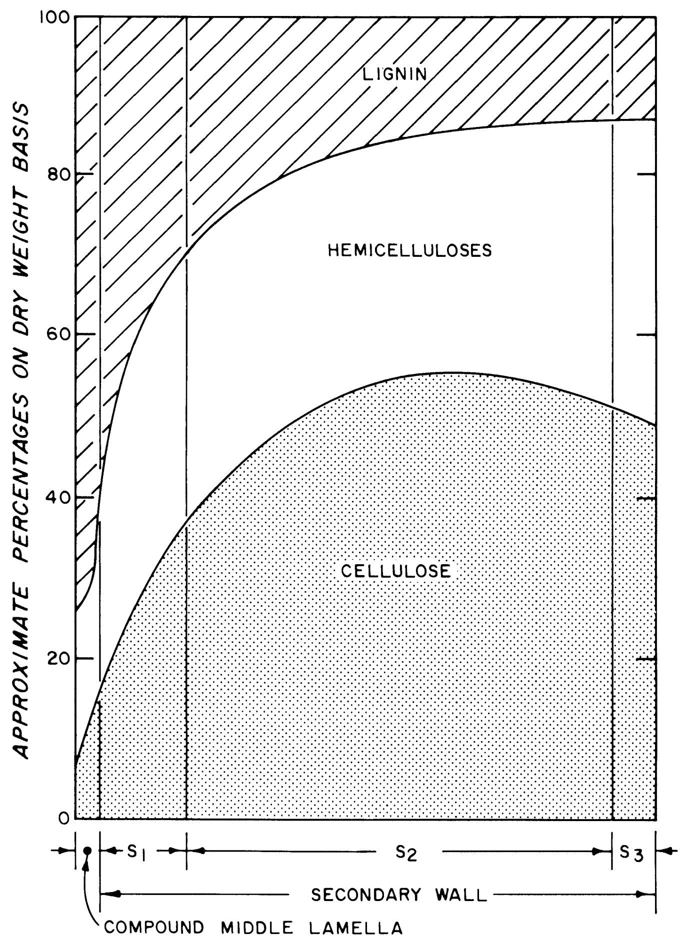


Figure 15—*Distribution of the principal chemical constituents within the various layers of the cell wall in conifers (Panshin and deZeeuw 1970).*

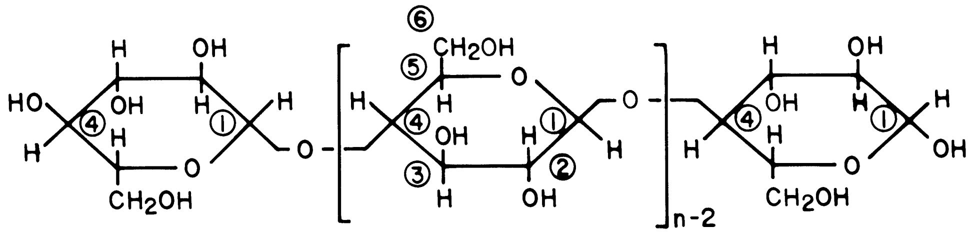


Figure 16—*Molecular structure of cellulose (Rydholm 1965).*

wall, cellulose molecules associate to form strands of parallel chains that in part assume crystalline character. This has important consequences for the physical and mechanical behavior of solid wood.

The **hemicelluloses** are polysaccharides like cellulose but of much lower molecular weight. They are, therefore, more soluble, contribute little to the strength of cell walls, and are amorphous in character. There are several forms that are classified according to the monomers they contain. Hexosans break down to hexoses, sugars with six carbon atoms, such as glucose. Mannan is an important hexosan found chiefly in softwoods with a DP of around 150 (fig. 17) (Treiber 1957). Pentosans are composed of pentose monomers, sugars with five carbons. An important example is xylan, found in both softwoods and hardwoods. However, the xylan content of hardwoods is higher than that of softwoods (fig. 18) (Treiber 1957). Other forms of hemicellulose, such as galactan and arabinan, occur in smaller quantities.

Lignin is a three-dimensional cross-linked polymer built up from phenylpropane units and therefore aromatic in nature (fig. 19) (Sarkanen 1970). Lignin is part of the amorphous matrix in which the cellulose fibrils are embedded in the cell wall. It is highly concentrated in the middle lamella, the cementing layer between cells. The chemistry of lignin is complex. No single struc-

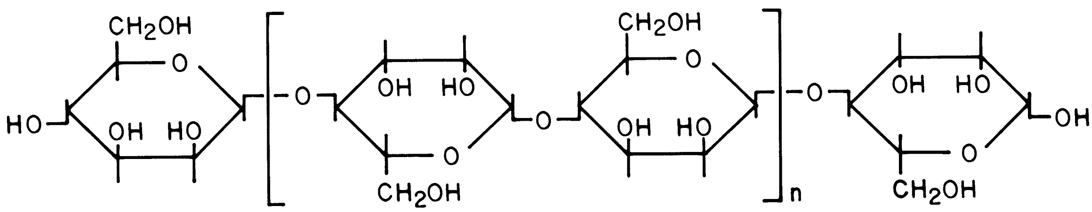


Figure 17—*Molecular structure of mannan A (Treiber 1957).*

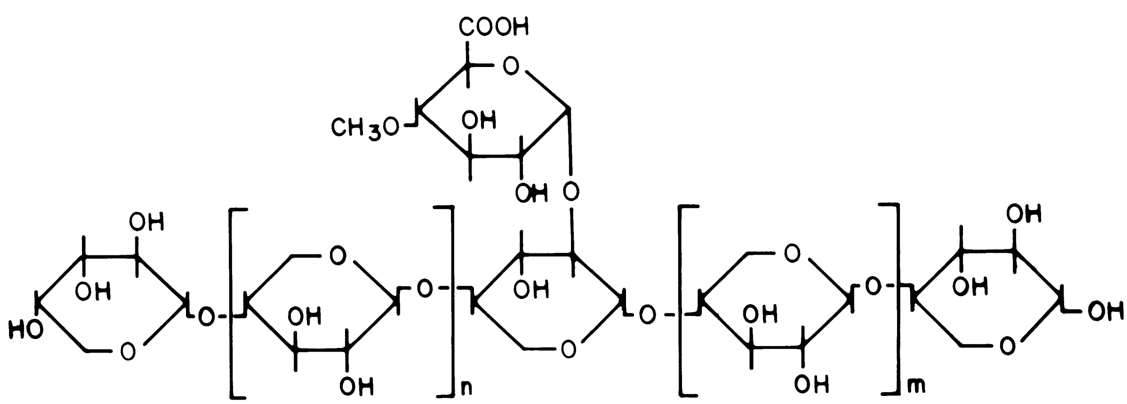


Figure 18—*Molecular structure of birch xylan (Treiber 1957).*

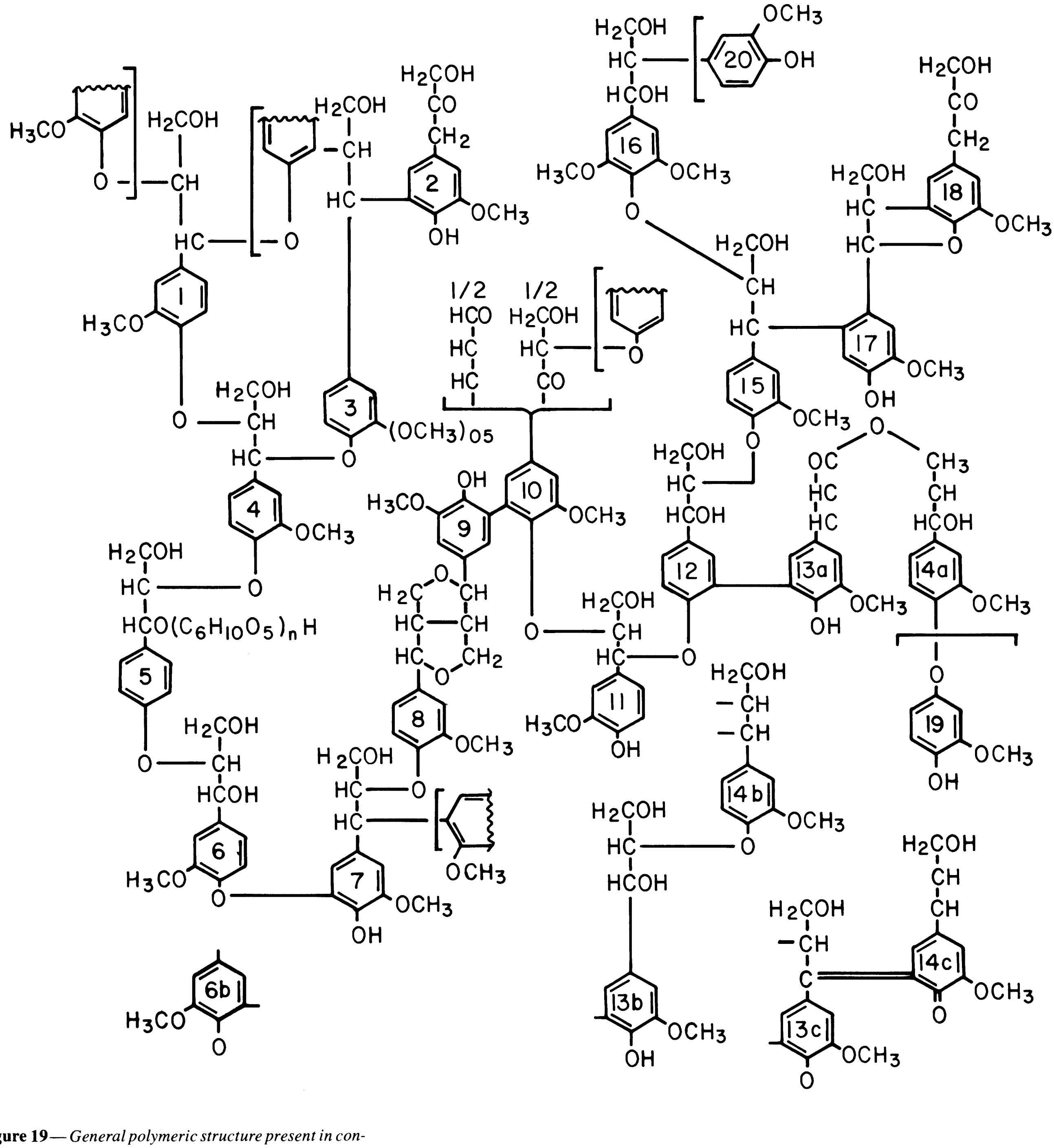


Figure 19— *General polymeric structure present in conifer lignins (after Sarkanen 1970).*

tural scheme can be established. Efforts at the industrial utilization of lignin, which makes up 25 percent of the total wood substance, have been only partially successful. In chemical paper processes, lignin is transformed into a soluble form and removed. In the fiberboard process, lignin contributes to the development of the fiber bond in the hotpress.

A very instructive breakdown of wood into its chemical components is shown in figure 20 (EPA 1973). The percentage figures are average values.

Chemical Reactions in Fiberboard Manufacture

Most chemical reactions in the fiberboard process occur during the pulping stage, in which fiber bonds are broken, and in the hotpress in which the sheets are consolidated and bonds are formed.

Hydrolysis

Hydrolysis is a chemical reaction in which water reacts with and splits another substance to form one or more entirely new substances. Examples are the breakdown of sucrose (cane sugar) to glucose and fructose and the conversion of starch to glucose in the presence of suitable catalysts (fig. 21). Glucose is the basic component of cellulose. Hydrolysis reduces the chain length or the size of the molecules. This increases solubility. Acid hydrolysis (hydrolysis in the presence of acid catalysts) is a very important reaction in the manufacture of fiberboard. In the pulping process it causes a breakdown and subsequent loss of part of the hemicelluloses. The acidity necessary for the hydrolysis reaction is developed by the simultaneous formation of acetic acid and formic acid from wood carbohydrates. The hydrolysis of the hemicelluloses reduces pulp yield and loads the process water with biodegradable sugars.

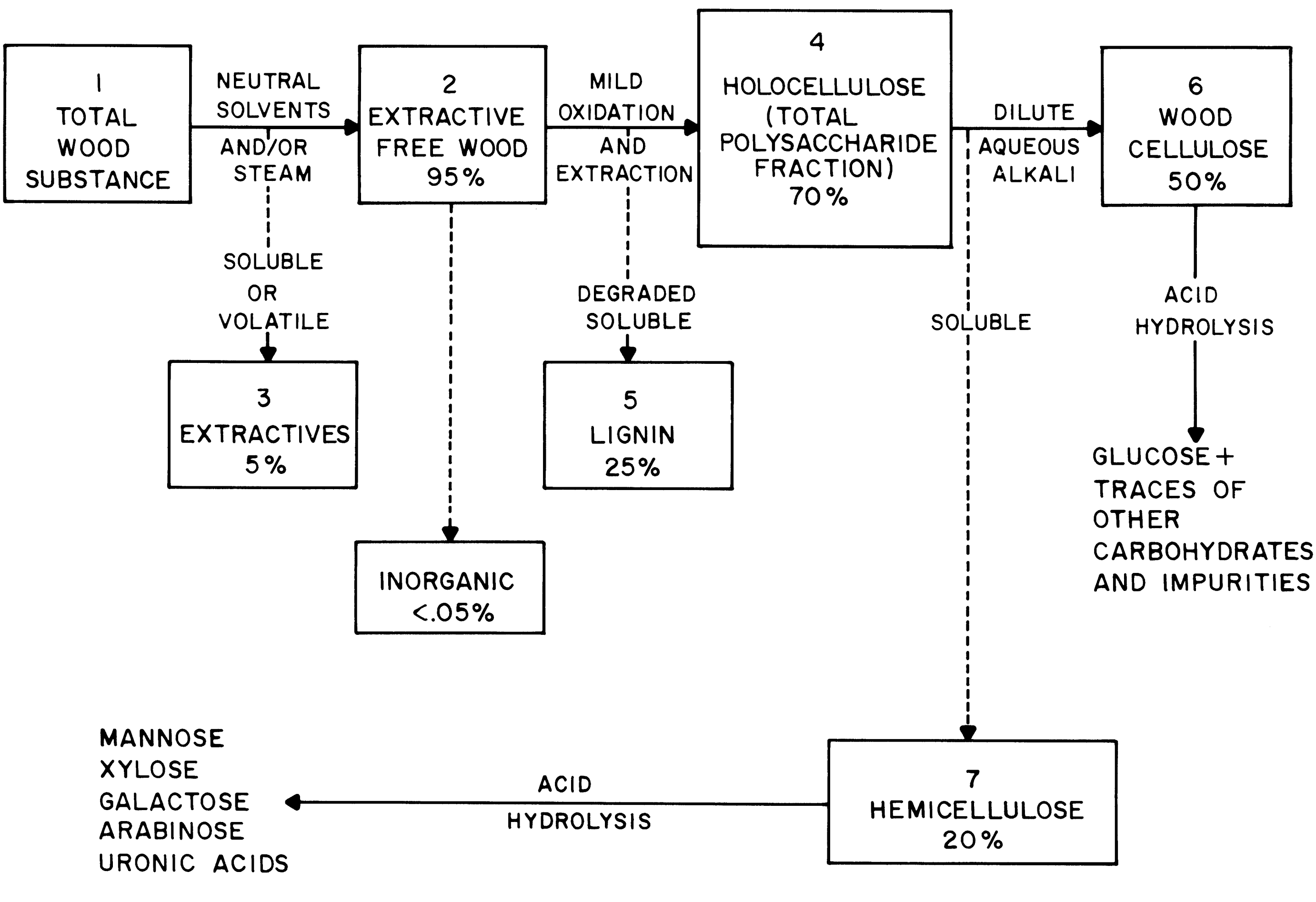


Figure 20—*Schematic breakdown of solid wood into its chemical components (EPA 1973).*

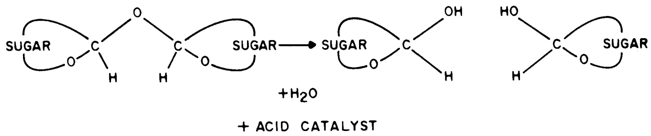


Figure 21—*Schematic of acid hydrolysis of sugar molecule.*

Condensation

Condensation is a chemical reaction in which two or more molecules combine, with the elimination of water. Condensation is thus the exact reverse of hydrolysis. A condensation reaction important in fiberboard manufacture is the curing of phenolic resins, which are added to the fiber as binders (fig. 22). This reaction takes place at elevated temperature, developing a large three-dimensional network forming a permanent bond between fibers. Similar condensation reactions may occur between cell wall components in the hotpress, resulting in **fiber bonds** without the benefit of added resin adhesives.

Pyrolysis

Pyrolysis, or thermal degradation of wood substance, is effected by chemical breakdown of the various constituents of solid wood. The degree to which pyrolysis affects wood and the rate at which it occurs depend mainly on the temperature at which the reaction takes place, the amount of air present, and the time the reactions proceed (Beck 1979).

The most obvious result of pyrolysis of wood is weight loss. As figure 23 (Shafizadeh and Chin 1977) shows, the weight loss of wood and its major components is relatively minor at temperatures encountered in fiberboard manufacture, which would not exceed 300 °C (572 °F). Hemicelluloses, as represented by xylan, are the least stable wood components, whereas cellulose is practically unaffected. Lignin decomposes gradually at temperatures below 300 °F.

In the fiberboard process, pyrolysis occurs in the hotpress and during heat treatment of the finished board. Further degradation of the products of hydrolysis at the pulping stage also occurs in the hotpress, with the subsequent formation of condensation products, which in turn are believed to be responsible for the discoloration of wood at high temperatures. The pyrolytic removal of hemicelluloses, which are particularly hygroscopic, reduces water absorption (Topf 1971). During hotpressing and also during heat treatment, the discharge of volatiles presents an air pollution problem.

pH and its control

pH is the negative logarithm of the hydrogen ion concentration and indicates the acidity or alkalinity of a solution. Pure water is neutral and has a pH value of 7. pH values from 0 to 7 indicate acidity and pH values from 7 to 14 indicate alkalinity. Wood is slightly acidic. This means that if a piece of wood is immersed in water, the pH of the water becomes more acidic (Stamm 1964).

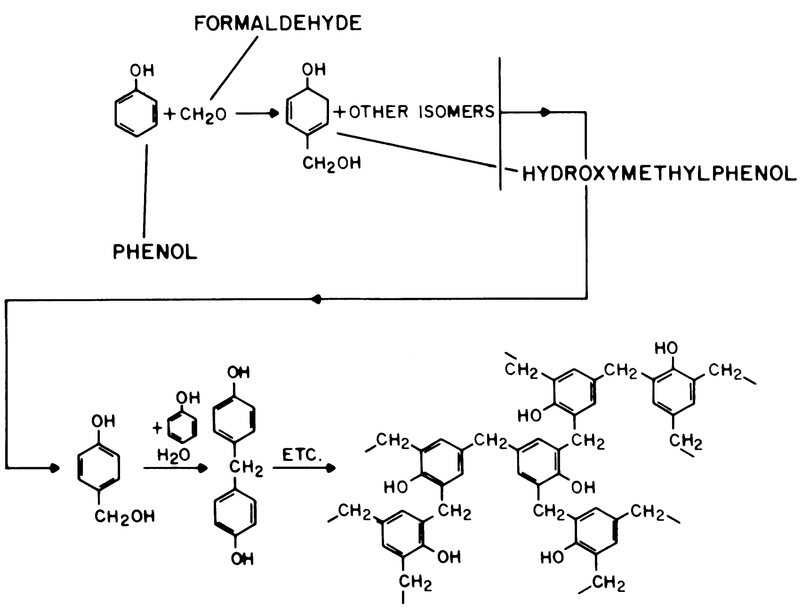


Figure 22—*The condensation of phenol-formaldehyde resin.*

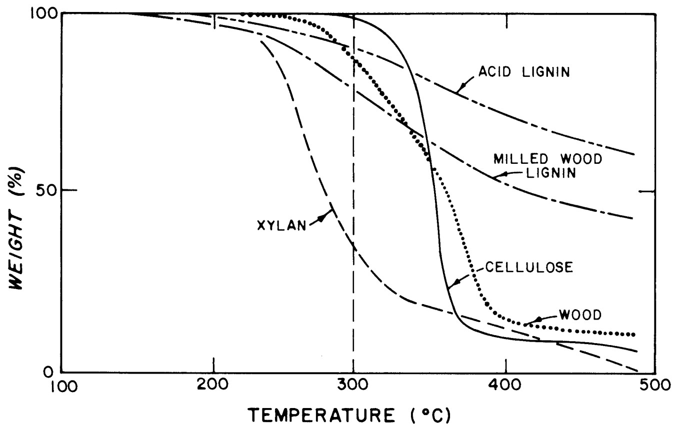


Figure 23—*Weight loss of wood and wood components as functions of temperature (Shafizadeh and Chin 1977).*

In the manufacture of fiberboard, pH control is particularly important in the **sizing** operation. Sizing is the addition and fixation on the fiber of chemicals that reduce water absorption and improve fiber bonding. Waxes and asphalt are used to improve water resistance; phenolic resins and drying oils are added as binders. These chemicals are added as solutions or emulsions to the dilute fiber slurry and are precipitated onto the fiber by reducing the pH value of the stock.

Aluminum sulfate, or **papermakers' alum** ($Al_2(SO_4)_3$), is generally used as a precipitator. The hydrated aluminum ion forms a complex with the sizing material that is insoluble and attaches itself to the fiber surface.

Pulp coming from the refiner has a pH of less than 4. Sometimes, in order to remove dissolved solids from the pulp in the pulp washer more efficiently, the pH is increased to about 5 by adding fresh water or caustic soda. Then, after sizing materials are added, the pH is again reduced for precipitation. Fine adjustments of pH are often made by the addition of sulfuric acid.

In the dry processes there is no control of furnish pH. Adhesives and wax emulsions are added to the dry fibers. The pH value of the resins themselves is adjusted so that in interaction with the generally acid furnish, the proper conditions for curing of the adhesive can develop. For the purpose of accelerating the cure in the hotpress, pH adjusters (catalysts) are added in many cases to the resin just prior to application.

Chemistry of the Adhesive Bond

The development of durable adhesive bonds between wood elements is fundamental to most industrial uses of wood. In many products the adhesive bond is the critical link and dominating factor in the development of useful properties.

Hydrogen bonds

All bonding between solids relies on extremely short range attractive forces of surface molecules. If uncontaminated surfaces can be joined so that the distance between them is reduced to the range of these forces, then bonding is possible without the use of an adhesive. Such bonding is very important in the manufacture of paper and insulation board. In most bonding, however, an adhesive is required, which in liquid form can contact and interact with both surfaces, and which upon solidification develops a cohesive strength comparable to that of the solids it joins together. This type of adhesive joint is developed in the manufacture of dry-formed fiberboard.

In both cases the adhesion between the two solids or between solid and adhesive "bridge" is believed to be due to hydrogen bonding, the attractive forces developing between the positively charged hydrogen atom and any negatively charged atom such as oxygen (fig. 24). In fiberbonding without adhesive, as in the manufacture of paper and insulation board, the close contact between fibers is brought about by the surface tension of water, which pulls fibers together as the water evaporates (fig. 25) (Lampert 1967, Lyne and Gallay 1956, Nissan 1962, Jayme and Hunger 1962).

Bonding with adhesives

Bonding with adhesives requires the transformation of the adhesive from a liquid to a solid after the liquid has interacted with the solid surfaces and established hydrogen bond linkages. This transformation can occur by drying (removal of solvent), by cooling, or by chemical reaction. The quality of .the solid glue line depends largely on whether the transformation is reversible or not. If it is reversible, the addition of water or heat will destroy the cohesive strength of the adhesive. If it is irreversible, however, the glue line may have considerable resistance to water and heat or may be completely waterproof and boilproof. Transformations due to drying and cooling are reversible, those due to chemical reactions are not. Resin adhesives such as urea-formaldehyde and phenol-formaldehyde are solidified by chemical reaction (fig. 26), triggered either by a change in pH or by application of heat, or both.

Phenol-formaldehyde resins are used in the manufacture of hardboard, urea-formaldehyde resins in the manufacture of MDF (medium-density fiberboard). In both cases the chemical reaction occurs in the hotpress. Phenol-formaldehyde resins form waterproof and boilproof glue lines; urea-formaldehyde resins have considerable water resistance but are not considered exterior-type adhesives. The weather resistance quality of a glue line does not necessarily guarantee the weather resistance of composition boards. Swelling of the wood elements during exposure can cause rather severe local swelling stresses on wood and glue line. Partial failures due to these stresses, rather than the deterioration of the glue line, can cause permanent strength loss after severe exposure of composition boards, including fiberboard.

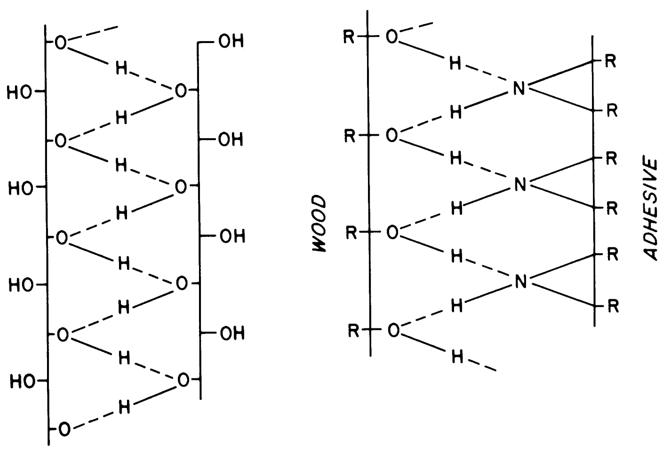


Figure 24A—*Hydrogen bonds between two cellulose chains. The bond develops between hydroxyl groups (-OH) of the cellulose molecules and is indicated by dotted lines.* **B**—*Hydrogen bonds between adhesive and wood. The vertical lines indicate the wood and adhesive surfaces possessing hydroxyl groups (wood) and -NH groups (adhesive). R = radical and indicates the remainder of both wood (cellulose) and adhesive molecules. Hydrogen bonds are indicated by dotted lines (Lampert 1967).*

Lignin bonds in fiberboard

Even without the use of resin adhesives, bonds can be established between fibers. These bonds are based on chemical and physical interactions occurring in the hotpress between various wood components or their derivatives. According to one theory (Runkel and Wilke 1951), pentoses, derived by hydrolysis from hemicellulose, are converted into furfural, which reacts in the hotpress with phenolic substances obtained from lignin to form condensation products similar to phenol-formaldehyde resins.

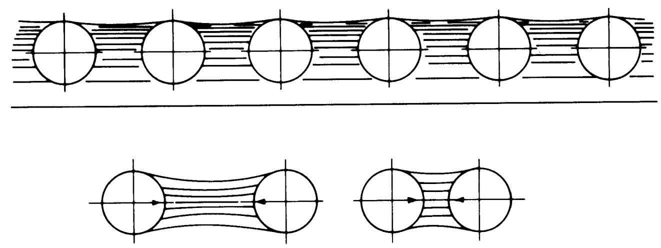


Figure 25—*Attractive forces between fibers due to surface tension of evaporating water. In the upper portion of the picture, fibers are shown (in cross section) in suspension in water. The lower portion shows the attraction developing between drying fibers as the water is being removed. This will lead to fiber contact and the formation of hydrogen bonds (Lampert 1967).*

Another theory (Goring 1971) views lignin as a thermoplastic adhesive that softens at temperatures around 265 °F. Under pressure, fibers with lignin-rich surfaces would be fused together by mechanical entaglement of the softened lignin molecules, possibly accompanied by the formation of covalent bonds. Hemicelluloses have been found capable of forming similar bonds.

Figure 27 (Goring 1971) shows the softening of lignin as affected by water content. The softening point is indicated by the peak velocity of a plunger under which a column of powdered lignin collapses as the softening temperature is reached. The significant effect of the water content may be part of the reason that such bonds have not been achieved in dry-formed board.

References

Beck, S.R. An overview of wood gasification. In: Rogers, K.E., ed. Technology and economics of wood residue gasification: Proceedings, 10th Texas Industrial Wood Seminar; 1979 March 13, Lufkin, TX: Texas Forest Service, Texas Forest Products Laboratory; 1979: 20-37.

Environmental Protection Agency. Development document for proposed effluent limitations guidelines and new source performance standards for the plywood, hardboard and wood preserving segment of the timber products processing point source category. EPA 440/1-73/023. Washington, DC: 1973. 317 p.

Goring, D.A.I. Polymer properties of lignin and lignin derivatives. In: Sarkanen, K.V. and Ludwig, C.H., eds. Lignins, occurrence, formation, structure, and reactions. New York: Wiley-Interscience; 1971: 695-761.

Howard, E.T.; Manwiller, F.G. Anatomical characteristics of southern pine stemwood. Wood Science. 2: 77-86; 1969.

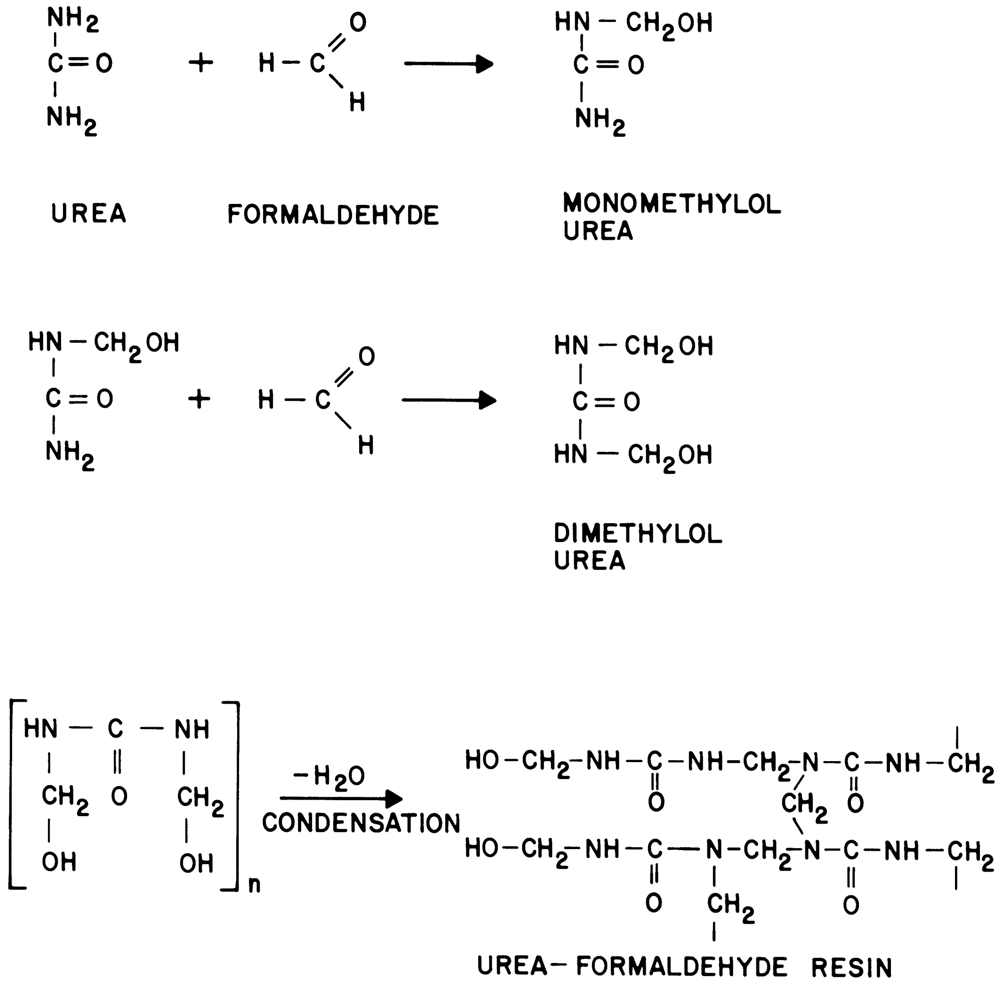


Figure 26—*Schematic of urea-formaldehyde condensation to form three-dimensional resin molecule.*

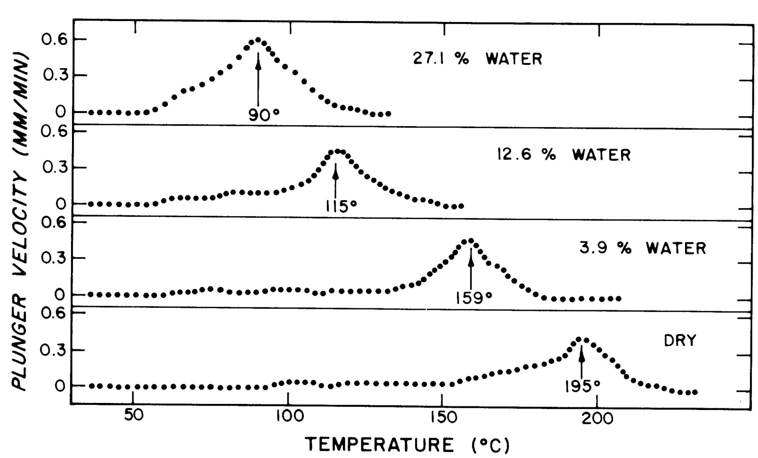


Figure 27—*The softening temperature of lignin as affected by water content (Goring 1971).*

Jayme, G.; Hunger, G. Electron microscope 2- and 3-dimensional classification of fiber bonding. In: The formation and structure of paper. London: Technical Section of the British Paper and Board Makers Association; 1962: 135-170. Vol. 1.

Koch, P. Utilization of the Southern pines, Vol. 1. Agric. Handbk. 420. Washington, DC: U.S. Department of Agriculture; 1972: 134-137.

Lampert, H. Faserplatten. Leipzig: VEB Fachbuchverlag, 1967. 453 p.

Lyne, L.M.; Gallay, W. Studies in the fundamentals of wet web strength. Tappi. 37(12): 698-704; 1956.

Mark, R.E. Cell wall mechanics of tracheids. New Haven: Yale University Press; 1967. 310 p.

McMillin, C.W.; Manwiller, F.G. The wood and bark of hardwoods growing on southern pine sites—a pictorial atlas. Gen. Tech. Rep. S0-29. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1980. 58 p.

Nissan, A.H. General principles of adhesion with particular reference to the hydrogen bond. In: The formation and structure of paper. London: Technical Section of the British Paper and Board Makers Association; 1962: 119-130. Vol. 1.

Panshin, A.J.; deZeeuw, C. Textbook of wood technology, 3d ed. New York: McGraw-Hill; 1970. 705 p. Vol. 1.

Runkel, R.O.H.; Wilke, K. Zur Kenntnis des thermoplastischen Verhaltens von Holz. Part 2. Holz als Roh- und Werkstoff. 9: 260-270; 1951.

Rydholm, S.A. Pulping processes. New York: Interscience Publishers; 1965. 1269 p.

Sarkanen, K.V. Lignin. In: Britt, K.W., ed. Handbook of pulp and paper technology, 2nd ed. New York: Van Nostrand Reinhold Company; 1970: 33-36.

Shafizadeh, F.; Chin, P.S. Thermal deterioration of wood. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, DC: American Chemical Society; 1977: 57-81.

Stamm, A.J. Wood and cellulose science. New York: Ronald Press; 1964. 549 p.

Thomas, R.I. Wood: structure and chemical composition. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, DC: American Chemical Society; 1977: 1-23.

Topf, P. Thermal decomposition of wood at temperatures up to 180 °C. Holz als Roh- und Werkstoff. 29: 269-275; 1971.

Treiber, R. Hemicellulosen. In: Treiber, E., ed. Die Chemie der Pflanzenzellwand. Berlin: Springer Verlag; 1957: 224-250.

4. Raw Materials

General

The results of laboratory experiments seem to indicate that fiberboard can be made from almost any lignocellulosic raw material (Lathrop and Naffziger 1948, 1949a, 1949b; Laundrie and Fahey 1973; Laundrie and McNatt 1975; Myers 1977; Myers and Fahey 1976; Schwartz 1952, 1953, 1960; Schwartz and Baird 1952; Steinmetz 1973; Sweeney and Arnold 1937; Yao 1978). However, because of its relative abundance and year-round availability (it can be stored on the stump), wood is by far the most important raw material for fiberboard in the United States.

It is also clear that the great number of tree species in the United States introduces considerable variability to the raw material. If not controlled, this variability causes difficulties in processing and large property tolerances of the product. For these reasons the fiberboard industry tries to be selective in procuring its raw materials.

Being products of relatively low value, fiberboards are sensitive to raw material costs. Competition from other users may therefore deny the fiberboard industry access to some desirable raw materials.

Substitution of one raw material for another requires process modification or entirely new approaches to wood processing.

Finally, fiberboards are manufactured by a number of processes in varying qualities to meet different applications. Some raw materials are better suited than others for a given process and/or end use.

These and other factors have established raw material use patterns and preferences in the fiberboard industry. These patterns are not static, but change with the shifting dominance of one or another factor. The future success of the fiberboard industry will depend in part on its ability to solve the double-edged problem of producing competitive products from increasingly less desirable raw materials.

The Importance of Fiber Characteristics

Paper technologists have intensively studied the relationships between physical, mechanical, and morphological properties of the fibers and the strength of the paper. Many of the results and conclusions apply, at least generally, to fiberboard.

Fiber strength

Fiber tensile strength would appear to have considerable importance in developing strength in paper and board. Actually, the effect is very limited. Although the tensile strength of individual fibers is very high (Mark 1967), only a fraction of it is utilized in the structural configuration of a paper sheet or a fiberboard. This is true because the total bonding area between fibers cannot transmit the shear stresses required to stress the fiber to its limit, either because of the limited size of the total shear area or because of the quality of the bond. This is illustrated in figure 28, where L_S = the length of overlap between two fibers, which may be considered to be proportional to the relative bonding area in a paper sheet. As L_S is shortened, that is, the quality of the bond is reduced, the failure due to applied tensile forces will occur in the bond rather than in the fiber, regardless of the fiber strength. Such bond failures have been observed in paper (Page and others 1962). In low- and medium-density fiberboard, failures occur predominantly in the bond. However, at high board densities, failure occurs in the fiber (Jones 1960). This reflects both more intimate contact between fibers at high density and possible modification of fiber characteristics under the severe conditions existing in the press.

Fiber morphology

Fiber morphology, that is, the form and structure of the fiber, or, as far as this discussion is concerned, the dimensional relationships, is of greater significance in the

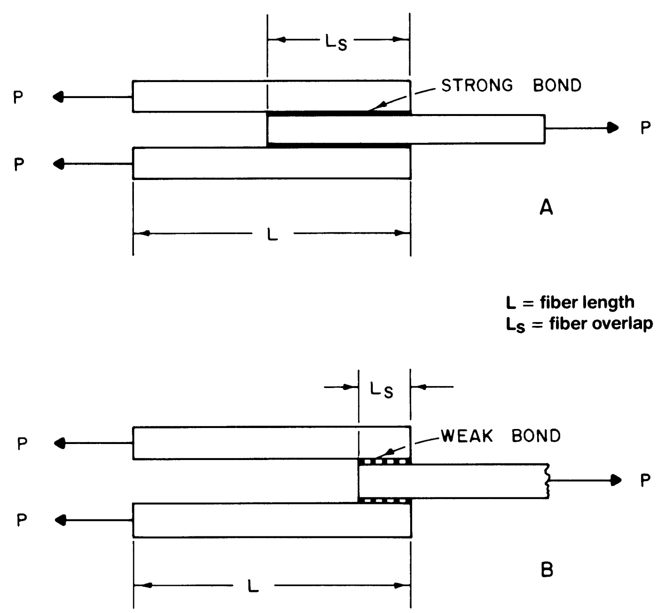


Figure 28—*Fiberbonds under tensile stress (schematic).* **A**—*Conditions favoring fiber failure (maximum strength).* **B**—*Conditions favoring bond failure (low strength).*

development of sheet properties than are the actual mechanical properties of the fiber.

Fiber length, for instance, has a strong effect on the tearing strength of paper. This is explained by the larger number of bonding areas in the sheet, which may allow tensile stresses in the fiber to reach the breaking strength (Dadswell and Watson 1962). Fiber length also affects sheet formation. Longer fibers have a tendency to yield sheets with more open structure and higher bulk than do shorter fibers. Fiber length may also be a factor controlling the orientation of fibers in fiberboard. Shorter fibers are much more likely to develop a vertical or z-component of fiber orientation than are longer fibers (Suchsland and others 1978) (fig. 29). Longer fibers would also lend themselves better to artificial alignment in one of the principal dimensions of the board by mechanical or electrical means. Figure 30 shows the effect of fiber length on tear factor, breaking length, and fold of a beaten and an unbeaten pulp prepared from Parana-pine (*Araucaria angustifolia*). This graph is also a good illustration of the strong interactions between raw material and process variables (fiber length and beating).

Cell wall thickness, which is directly related to the specific gravity of wood, affects sheet properties indirectly. If cell walls are thin, the fiber may collapse, and this in combination with greater flexibility of the thin-walled fiber will lead to more intimate contacts and therefore better interfiber bonding. This will be reflected in higher folding strength and greater sheet density. If cell walls are thick, as in coniferous summerwood, cells may not collapse, and the reduced fiber flexibility will lower folding strength and sheet density. These relationships are shown qualitatively in table 10 (Jayme 1962).

In the case of fiberboard, with the exception of insulation board, board density is determined by the degree of compaction of the mat in the press. High specific gravity wood will generally result in higher bulk density of the fiber furnish and the mat and, at a given board

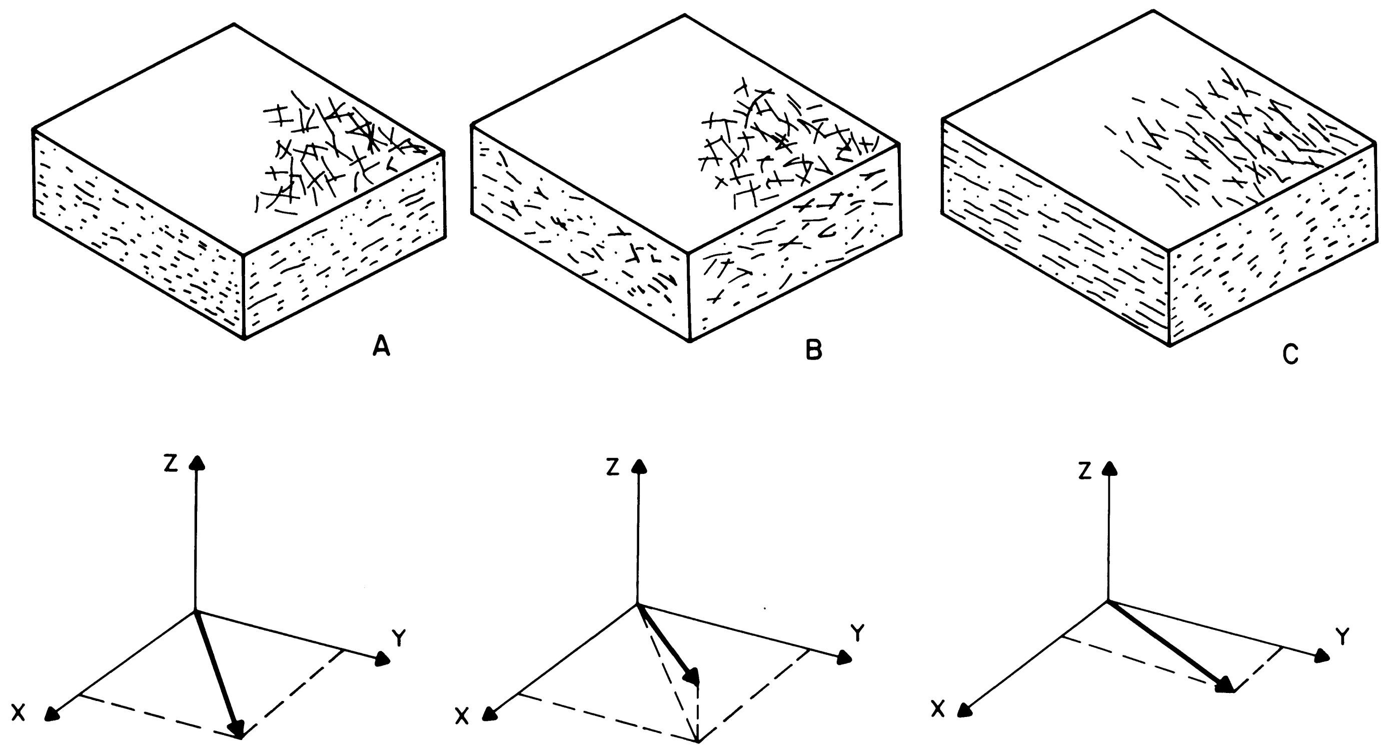


Figure 29—*Orientation of fibers in fiberboard.* **A**—*Random orientation in plane of board, no vertical components.* **B**—*Random orientation in plane of board, small vertical component.* **C**—*Oriented in y-direction, small x-component, no vertical component.*

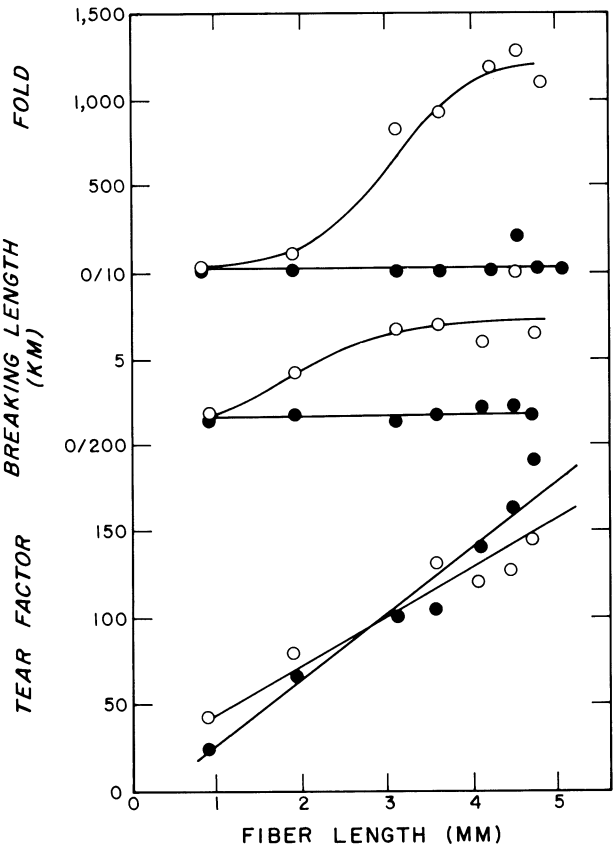


Figure 30—*Influence of fiber length on strength properties of Parana-pine* (Araucaria angustifolia) *pulp (after Dadswell and Watson 1962). Black circles = unbeaten pulp; open circles = beaten pulp, 30 min in high-speed laboratory stirrer.*

density, in a lower compression ratio (ratio of board density to wood specific gravity). High compression ratios obtained with low wood specific gravity promote more intimate contact between fibers. This is why hardboard strength properties, at least when dry-formed, are negatively influenced by wood specific gravity and by mat bulk density (specific weight of the formed fiber mat in pounds per cubic foot) (Woodson 1976) (fig. 31). The dimensional changes in the plane of the board due to water absorption or desorption are significantly affected by fiber length; the longer the fiber, the smaller the length changes of the hardboard (Woodson 1976). Studies on dry-formed medium-density fiberboard confirmed the negative effect of species specific gravity on strength properties (Nelson 1973). Wood specific gravity had a positive effect, however, on mechanical properties of experimental loblolly pine hardboards (McMillin 1968). Complicating the picture here is the strong contrast in specific gravities of springwood and summerwood of loblolly pine.

Fiber morphology also has an important bearing on wet mat formation. Longer fibers drain water more quickly, allowing faster line speeds. Longer fibers are also more likely to form clumps in the forming process, which may result in small surface distortions, especially in high-density hardboard. Longer fibers promote strength development in wet and dried mats, which is important in high-speed mat handling.

Table 10—*Influence of morphological factors on strength properties of paper (Jayme 1962)*[1]

Factors	Factor change	Tensile and bursting strengths	Tearing strength	Folding strength	Sheet density[2]
Fiber length	Rising	0 to +	2+	0 to +	0 to −
Cell wall thickness late wood fraction (tube structure)	Rising	−	0 to +	2−	2−
Cell wall thickness early wood fraction (ribbon structure)	Falling	+	0 to −	2+	2+
Ratio fiber length to fiber width	Rising			+	
Curling of fibers	Rising	2−	+	+(?)	−

[1]0 = no influence or no distinct influence, + = marked positive influence, 2+ = decisive positive influence, − = marked negative influence, 2− = decisive negative influence.
[2]Porosity, absorbency, air permeability, and bulk have a contrary trend.

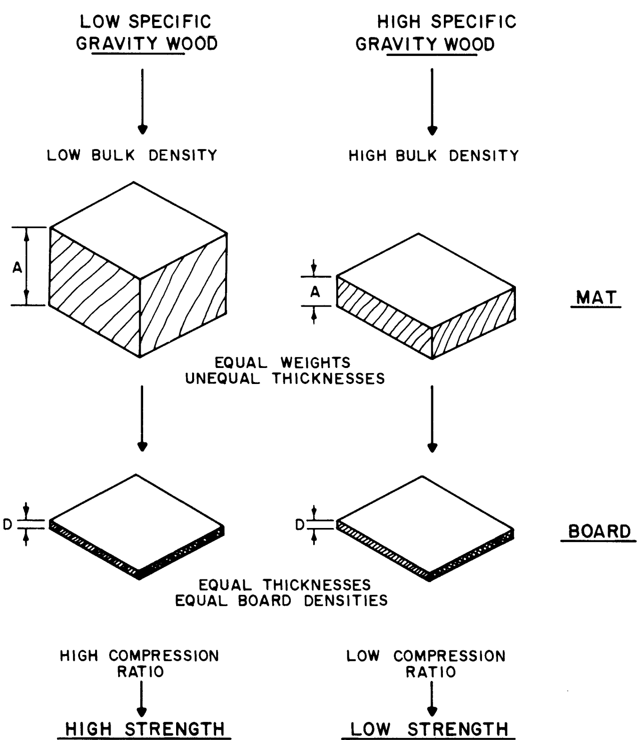


Figure 31—*Manufacture of fiberboards of equal thickness and equal board density from low- and high-specific-gravity wood.*

Softwoods Versus Hardwoods

The terms "softwood" and "hardwood" are used here in the botanical sense, with softwood referring to coniferous trees and hardwood to broadleafed trees. Many hardwoods are considerably lighter and softer than some softwoods.

In general, hardwoods make better hardboards (wet process) and softwoods make better insulation boards (Eustis 1980). The advantage of hardwoods for hardboard is the shorter fiber, which produces less "cockle" (high density spots due to uneven fiber distribution in the wet forming process). On the other hand, components of the furnish consisting of very short fiber elements (fines) promote the development of cockle, because they resist water drainage. In insulation board, the longer and softer softwood fibers provide well-draining, strong pulp. Cockle is no problem with these species.

Softwoods require more energy in the pulping process. In the steam-cooking process, softwoods need longer steaming cycles than hardwoods. The heavier the hardwoods, the shorter the cooking cycle. Softwoods and hardwoods must therefore be handled separately. The content of volatiles in softwoods tends to be higher than in hardwoods. This increases the potential of blister formation in wet-formed S2S hardboards and requires longer press cycles (Eustis 1980).

One important advantage of softwoods is the fact that they occur in pure stands, so that processing conditions can be adjusted to a single species, producing greater process and product uniformity. Uniformity of raw material input is at least as important as its quality for maintaining consistent product performance levels (fig. 32). The only hardwood enjoying this advantage is aspen, which occurs in large pure stands in the Great

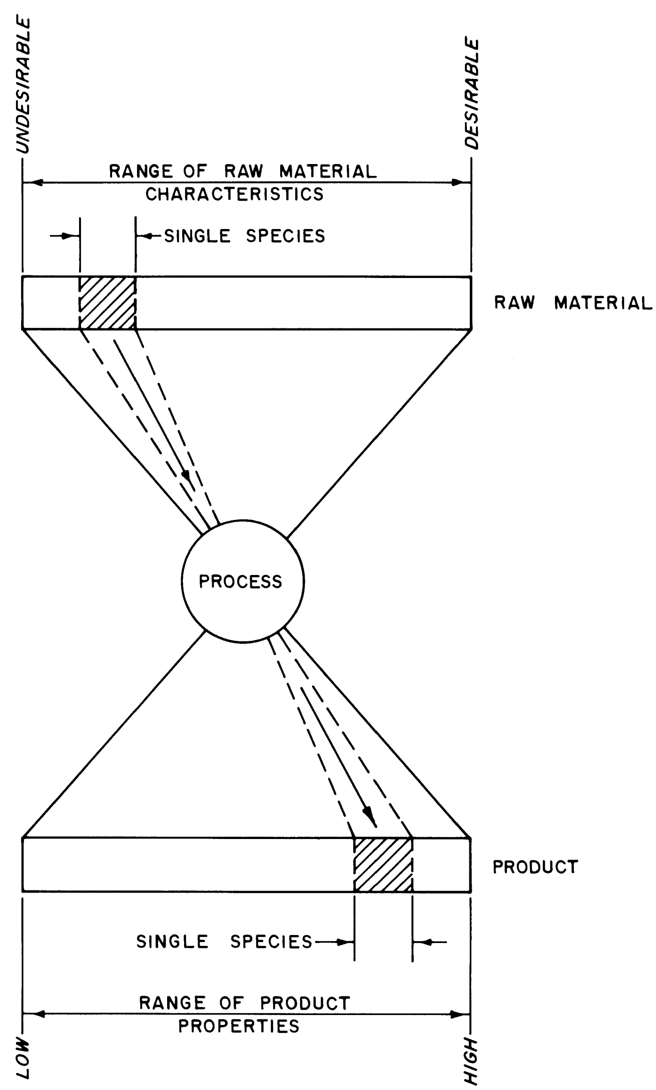


Figure 32—*Schematic illustration of the advantage of single species furnish in the manufacture of fiberboard.*

Lakes States and Canada and plays an important role both in the fiberboard and paper industries of this region (fig. 33).

Other hardwoods have to be used in mixtures requiring compromises in pulping schedules or separate pulping cycles and subsequent mixing of the pulps. Maintaining uniformity of mixture composition in these cases becomes an important quality control element.

Dry-formed boards, both hardboard and medium-density fiberboard, appear to be less sensitive to species characteristics than are wet-formed boards.

Individual Species and Mixtures

Most of the following comments apply specifically to wet-process fiberboards. Comments regarding cooking cycles refer to the steam cooking of chips before defiberizing in attrition mills. This pulping technique, because of the physical separation of softening and milling, allows considerable flexibility in chip treatment.

Effects of pulping conditions on pulp quality in the case of the Masonite, defibrator, and other pulping processes are discussed in the chapter on pulping.

Softwoods

Southern pines. All of the species are similar enough to be mixed indiscriminately in the fiberboard furnish (Eustis 1980).

Western pines. White, red, jack, ponderosa, sugar, and lodge pole pines can be handled simultaneously and mixed indiscriminately (Eustis 1980).

Spruce and fir. These two species have the same furnish characteristics. Spruce, however, is not much used for fiberboard because of the strong demand for it by the papermills (Eustis 1980).

Douglas-fir. This species produces a furnish sufficiently different from that of other western softwoods to warrant separate handling (Eustis 1980).

Redwood. Redwood is a difficult raw material; it is friable and the pulp contains little chunks that do not bond well in the board surfaces. It is satisfactory, however, for boards with moderate surface quality requirements such as embossed boards (Eustis 1980).

Hardwoods

Because most hardwood species do not occur in pure stands, single-species hardwood furnishes are used rarely. Hardwoods cannot be mixed indiscriminately, however, because of possible incompatibility in the pulping process and other process elements. Some hardwoods are acceptable only when mixed with others.

Oak mixtures. The oaks are the most difficult category of raw material for fiberboard. They cook quickly, are readily overcooked, and produce a short-fibered, slow pulp. Pure oak boards are brittle (both hardboard and insulation board). Oak is therefore mixed with other species. A 50:50 oak–pine mixture is used successfully in hardboard siding, for instance, and a 50:50 oak–birch mixture is used for the manufacture of paper-overlaid S1S hardboard. Hickory behaves similarly to oak and can be mixed with oak. Oak bark is highly acidic. It interferes with the settling of suspended solids in the waste water treatment system and wears out dust pipes in the dry process. In the North, oak can cause difficulties in the chipping department during the winter months because frozen oak is extremely difficult to chip (Eustis 1980).

Other high- and medium-density hardwood mixtures. Northern hardwood mixtures provide very satisfactory fiberboard furnish. They may be separated into two categories according to their cooking characteristics. The heavier hardwoods—like beech, sugar maple, and yellow birch—pulp much like oak but do not cook quite as quickly. The medium-weight hardwoods—including soft maple, cherry, and other species of similar specific gravities—require more cooking than the heavy hardwoods but cook more easily than aspen. White birch, which by weight belongs in this category, should be kept separate, because it is difficult to debark. The bark particles, which are hydrophobic, tend to float on the forming machine and turn black in the hotpress.

Mixed northern hardwood tend to produce more **shives** (solid chip fractions) and a greater range of fiber-bundle diameters than a single-species furnish. This can be overcome by reducing the cooking cycle and applying more energy in the primary refiners.

Hardwoods make very springy fibers. This is important in the wet fiberboard process, because springy fibers release water more quickly from the wet mat. This allows faster line speeds and shorter drying or press cycles (Eustis 1980). Southern hardwoods have much the same characteristics as their northern counterparts. Oaks, hickory, and pecan are very difficult to debark, requiring very high tool pressures in ring debarkers. They should not be mixed with softer hardwoods, which under high tool pressures would suffer considerable wood losses.

The medium-weight southern hardwoods include the gums, sycamore, maples, and hackberry. They work about the same as northern mixed medium-weight hardwoods. However, the southern hardwoods produce board with greater color variation (Eustis 1980).

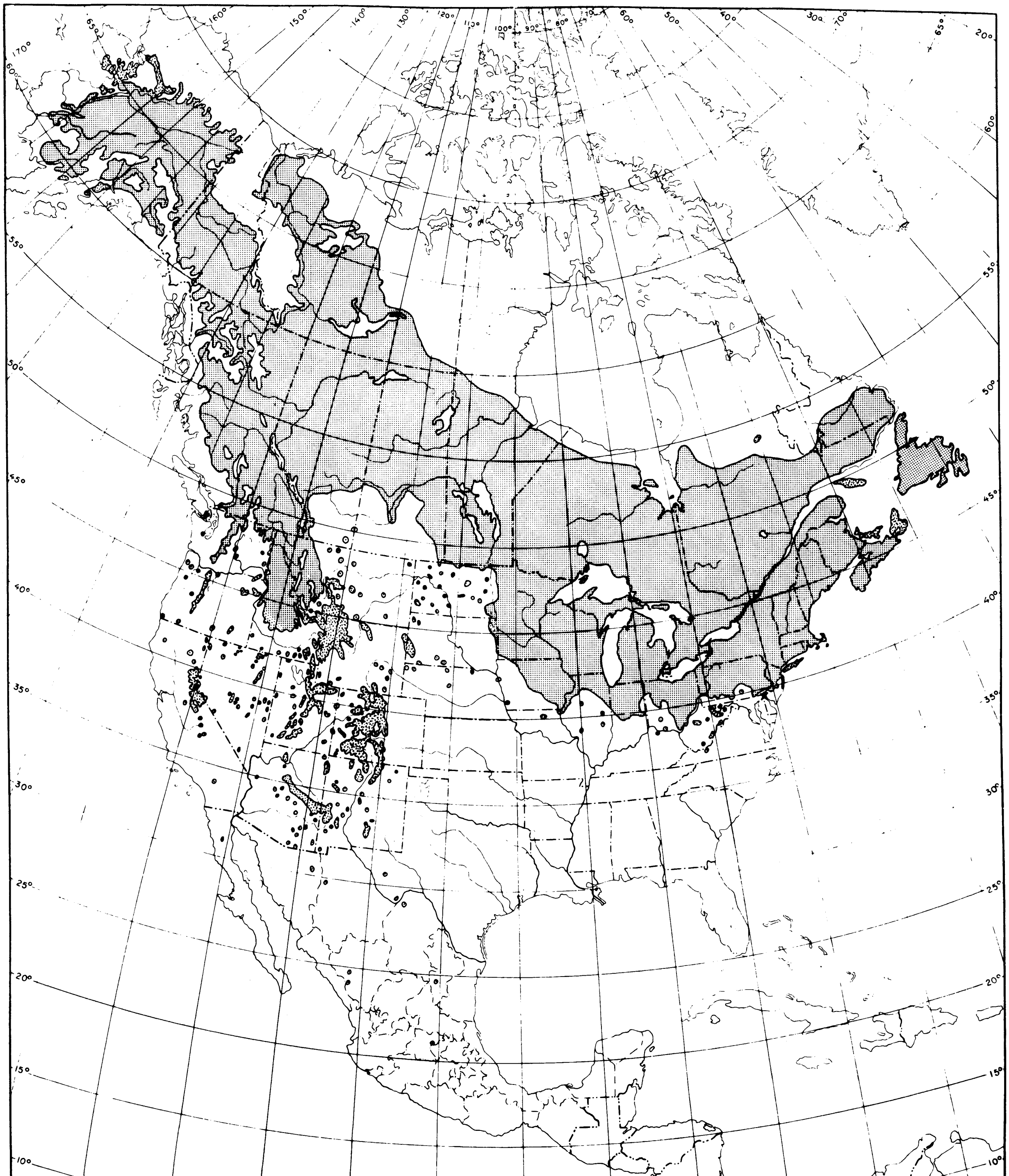


Figure 33—*Range of quaking aspen,* Populus tremuloides *Michx. (Little 1971).*

Low-density (soft) hardwoods. Aspen, including the species quaking aspen, bigtooth aspen, and balsam poplar, are considered the best northern woods for the manufacture of top quality hardboard. This is in part due to the fact that these species occur in large stands in the Great Lakes States and Canada, assuring important uniformity of furnish characteristics. Aspen requires a little more cooking than the heavier hardwoods, and its fibers are longer and stronger. This results in a stronger mat, which is particularly important in the wet S2S process, where frequent mat handling often results in expensive mat and board damage. It is estimated that mat and board breakage may be the largest cause of rejects in all hardboard manufacturing (Eustis 1980).

Aspen may be blended with other mixed hardwoods to improve drainage and increase mat strength. However, the higher percentage of shives in the mixed hardwood furnish causes surface problems in very high-density boards, like 1/8-inch board in the density range of 65 lb/ft^3 and up. Such mixtures work best in lower density board (55 lb/ft^3 and below). These mixtures have an economic advantage where pulpwood is bought by volume, since the price per ton of dry fiber would then be lower in the case of species with higher specific gravities (Eustis 1980).

Cottonwood and willow in the South are comparable to aspen as fiberboard furnish. They can be mixed together and have the same pulping characteristics except that willow makes a much darker colored board than does cottonwood. The second insulation board plant in the United States, established in Greenville, MS, in 1931, produced insulation board from 100-percent cottonwood-groundwood furnish. They later added a pressing department to the mill that produced wet-formed S2S hardboard from willow, which had a desirable dark color. Later, other hardwoods had to be added; this caused difficulties in the grinding operations and resulted in the development of steam cooking and disk refining.

Another superior fiberboard raw material in the south is yellow-poplar. It grows in sizable stands in the Appalachians but is used less than aspen in the North because of competition from other users (Eustis 1980).

Wood Chips

There is a definite trend in fiberboard manufacture away from pulpwood logs and towards sawmill chips and other lumber and plywood wastes. This trend is being dictated by increased competition from paper mills for pulpwood logs.

Figure 34—*The Chipharvestor by Morbark (Morbark Industries).*

Sawmill chips are generally debarked, and they make very satisfactory fiberboard. Other wastes from lumber and plywood mills such as planer shavings, sawdust, sanderdust, and plywood trim are often inferior because of low moisture content, reduced fiber size, cured adhesive, etc.

This trend towards lower valued material continues with the large-scale use of **whole-tree chips** produced from low-quality trees, sawlog tops, etc., by mobile chipping units (fig. 34). These whole-tree chips generally are not debarked and require process modification designed to deal with the high bark content and the presence of grit in the furnish. This important trend is shared by the particle board and the paper industries.

Sawmill chips must be screened to remove the fines content. They should be checked periodically for chip size and bark content. Chips should always be stored and handled in such a way that the greatest possible furnish uniformity is obtained. Long-term storage can result in wood degradation equivalent to partial cooking, which may require adjustments of the pulping conditions.

Bark contained in whole-tree chips (12 to 18 percent in hardwoods) (Einspahr and Harder 1976) not only reduces the quality of the board but also contributes significantly to waste water contamination. The presence of grit in the furnish drastically increases the wear of refiner plates, etc. Efforts are being made by the manufacturers of chipping equipment and others to devise systems that remove undesirable elements like bark, twigs, and grit (figs. 35, 36). These systems may reject a large proportion of the whole-tree chip material, but these rejects have important fuel value, which could reduce overall costs.

Whole-tree chips will not, however, produce the very high quality substrates that are being produced from aspen for high-gloss finishes. Embossed surfaces, on the other hand, allow a great deal more furnish variability and are not as sensitive to surface imperfections caused by bark, shives, etc.

Wood Residues

Utilization of wood residues such as bark and sawdust has been an intriguing challenge for wood technologists because of two attractive attributes: their seemingly low cost and the large total quantities being generated. But the short fibers produced from sawdust and the different fiber morphology and composition of bark cause strength losses in fiberboard, even in small percentages, when compared with boards made entirely from chips (Sinclair and Dymond 1968, Stewart and Butler 1968) (fig. 37, table 11). Compensation by increasing board density may cause total cost to exceed that of board made entirely from chips (fig. 38, table 12) (Nut-

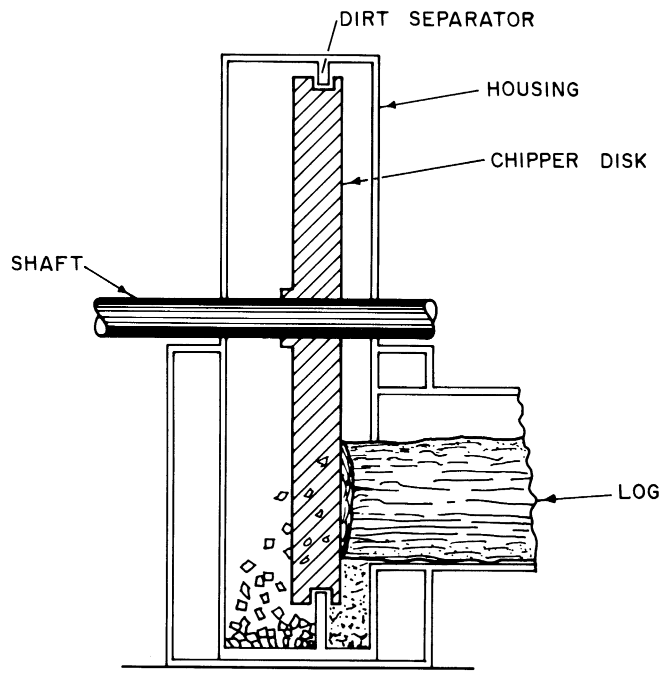


Figure 35—*Principle of dirt separator of Morbark Chipharvestor (Morbark Industries).*

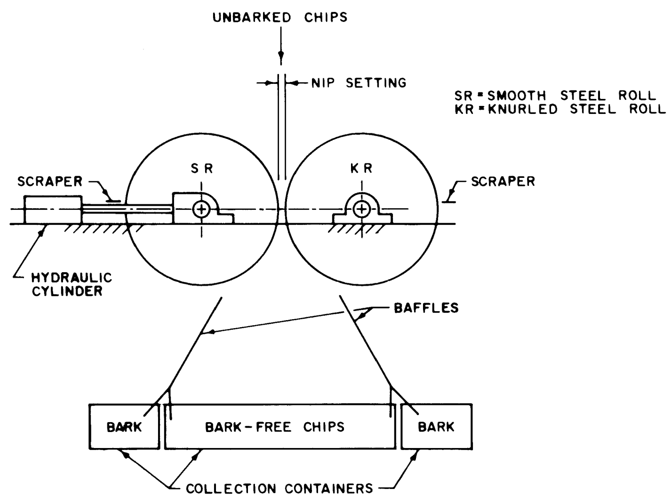


Figure 36—*Schematic diagram of compression chip debarker (Biltonen and others 1979). Operation: Unbarked chips are compressed through the nip. The compression breaks the bark-wood bond, causes the bark to adhere to the rolls, or fragments the bark into finer particles. Bark adhering to the rolls can be scraped from the rolls into the waste area. The fragmented material can be screened out.*

Table 11—*Characteristics of laboratory-processed cedar bark boards, Douglas-fir boards, and commercial hardboard (Stewart and Butler 1968)*

Board type	Specific gravity ovendry	Modulus of rupture (lb/in²)	MOR at 0.896 ovendry[a] (lb/in²)	Internal bond (lb/in²)	Water absorption (%)	Thickness swell (%)	Linear expansion (%)
Laboratory-processed boards[b]							
Cedar bark (36% wood)	0.896	4,500	4,500	102	40	17	30
Douglas-fir chips	.932	7,000	6,200	169	18	11	27
Commercial Douglas-fir fiber	.921	6,000	6,200	102	28	18	27
Commercial hardboard	.894	5,200	5,300	71	18	19	36

[a]Modulus of rupture at 0.896 specific gravity.
[b]Laboratory fiber = presteamed at 160 lb/in² and Sprout-Waldron refined. Laboratory boards = 2.3 percent resin and 1 percent wax; hotpress temperature, 380 °F.

tall). The savings in furnish cost are relatively small, from 1 to 4 percent. A sawdust component above 20 percent of the total furnish would require hardboard densities in excess of 71 lb/ft³, causing major difficulties such as blistering in the press, reducing forming machine speed (resulting in costly production losses), and requiring increased energy for the heavier boards either in the dryer or in the hotpress. This study suggests that unless the sawdust can be refined into fiber of higher quality, it would be used more efficiently as fuel (Nuttall). Standard strength values, of course, are not always fully adequate quality indicators. Boards using considerable percentages of sawdust and/or bark are being made both in the United States and abroad (Alvang and Johanson 1965).

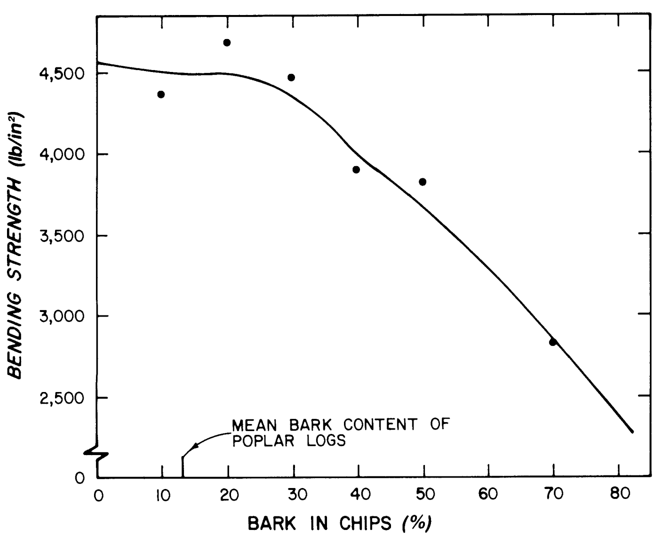


Figure 37 — *Effect of bark content on the flexural strength of hardboards made from poplar wood (Sinclair and Dymond 1968). (© 1968 TAPPI. Reprinted from Tappi Journal, September 1968, with permission.)*

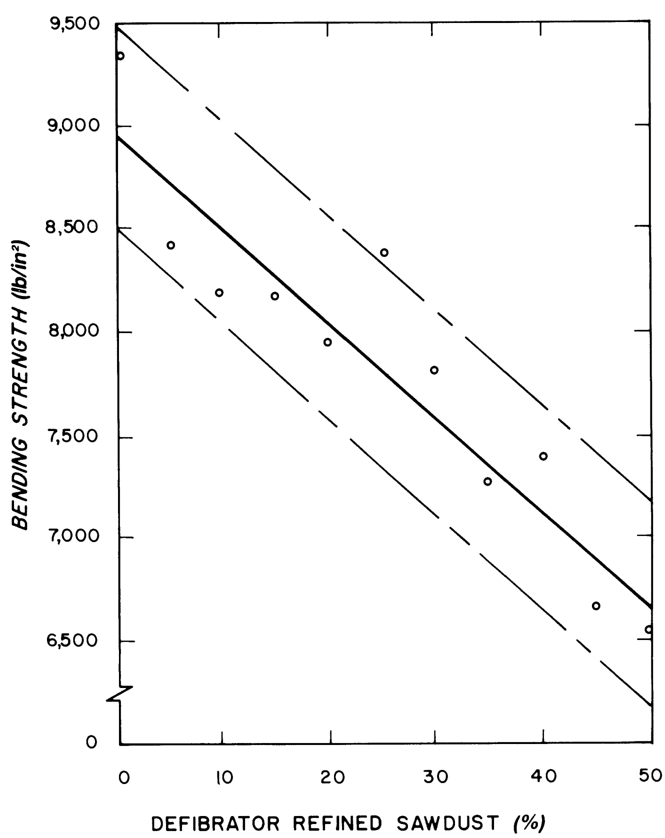


Figure 38—*Effect of sawdust additions on the bending strength of hardboard (Nuttall).*

Table 12—*Effect of adding sawdust to hardboard furnish on the cost of hardboard of equal bending strength (Nuttall)*

Sawdust (%)	Weight (lb/thousand ft²) Total furnish	Pulp from chips	Pulp from sawdust	Cost ($/thousand ft²) Fiber from chips[1]	Fiber from sawdust[2]	Freight penalty[3]	Difference[4]
0	700	700	0	15.75	0	0	0
5	708	673	35	15.14	0.26	0.20	−0.15
10	717	645	72	14.51	.54	.42	− .28
15	725	616	109	13.86	.82	.61	− .46
20	734	587	147	13.21	1.10	.83	− .61

[1]Processed fiber from chips, $0.0225/lb (ovendry).
[2]Processed fiber from sawdust, $0.0075/lb (ovendry).
[3]Freight rate used if sold on a delivered basis, $2.45/cwt.
[4]100 percent chip pulp versus chip and sawdust blend.

Nonwood Raw Materials

Two types of nonwood raw materials are used in the manufacture of fiberboard: biological lignocellulosic fibers (derived from annual plants) and mineral fibers.

Bagasse (sugarcane residue) is one of the oldest raw materials for insulation board and is still being used by the Celotex Corporation in their Marrero, LA, plant. This is the only example of the use of annual plant material for the manufacture of fiberboard today.

Corn stalks, flax shives, and wheat straw have been the subject of considerable study (Lathrop and Naffziger 1948, 1949a, 1949b); all were used in the manufacture of insulation board by the Maizewood Insulation Co. at Dubuque, IA (Porter 1950).

The use of mineral fibers for the manufacture of insulation board is an important development. Mineral fibers do not produce the biodegradable materials that are so expensive to eliminate from waste water. Boards made from mineral fiber also have much higher fire resistance ratings. For these reasons a number of wood based insulation board plants have been converted to the production of mineral fiberboard.

References

Alvang, F.; Johanson, S. Modern developments in Swedish fiberboards. Forest Products Journal. 15(8): 335–340; 1965.

Biltonen, F.E.; Mattson, J.A.; Matson, E.D. The cost of debarked whole-tree chips stump to digester. Res. Paper NC-174. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Experiment Station; 1979. 8 p.

Dadswell, H.E.; Watson, A.J. Influence of the morphology of woodpulp fibers on paper properties. In: Bolam, F., ed. Formation and structure of paper. London: Technical Section of the British Paper and Board Makers' Assocation. 1962: 537–564. Vol. 2.

Einspahr, D.W.; Harder, M. Hardwood bark properties important to the manufacture of fiber products. Forest Products Journal. 26(6): 28–31; 1976.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

Jayme, G. Discussion of paper by Dadswell and Watson. In: Bolam, F., ed. Formation and structure of paper. London: Technical Section of the British Paper and Board Makers' Association, 1962: 568–571. Vol. 2.

Jones, E.J. The relation of fiber and pulp properties to the properties of structural fiberboard products. Tappi. 43(6): 600–602; 1960.

Lathrop, E.C.; Naffziger, T.R. Evaluation of fibrous agricultural residue for structural building board products. I. Methods and equipment. Paper Trade Journal. 127(27): 53–60; 1948.

Lathrop, E.C.; Naffziger, T.R. Evaluation of fibrous agricultural residue for structural building board products. II. Fundamental studies on wheat straw fiber. Tappi. 32(2): 91–96; 1949a.

Lathrop, E.C.; Naffziger, T.R. Evaluation of fibrous agricultural residue for structural building board products. III. A process for the manufacture of high-grade products from wheat straw. Tappi. 32(7): 319–330; 1949b.

Laundrie, J.F.; McNatt, J.D. Dry-formed medium-density hardboards from urban forest material. Res. Paper FPL-254. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1975. 9 p.

Laundrie, J.F.; Fahey, D.J. Kraft pulps from short rotation sycamores. Paper Trade Journal. 157(7): 26–27; 1973.

Little, E.L., Jr. Atlas of United States trees. Misc. Pub. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service; 1975: 327 p. Vol. 1.

Mark, R.E. Cell wall mechanics of tracheids. New Haven: Yale University Press; 1967. 310 p.

McMillin, C.W. Fiberboards from loblolly pine refiner groundwood. Forest Products Journal. 18(8): 51–59; 1968.

Morbark Industries, Inc. Promotional literature. Winn, MI.

Myers, G.C. Hardboards from mixtures of Columbian and Ghanaian hardwoods. AID Report No. 11. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1977. 7 p.

Myers, G.C.; Fahey, D.J. Hardboards from mixtures of Philippine hardwoods. AID Report No. 5. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1976. 9 p.

Nelson, N.D. Effects of wood and pulp properties on medium-density, dry-formed hardboard. Forest Products Journal. 23(9): 72-80; 1973.

Nuttall, H. Commercial fiberboard from hardboard residue. U.S. Gypsum Co. 24 p.

Page, D.H.; Tydeman, P.A.; Hunt, M. Behavior of fibre-to-fibre bonds in sheets under dynamic conditions. In: Bolam, F., ed., Formation and structure of paper. London: Technical Section of the British Paper and Board Makers' Association; 1962: 171-193. Vol. 1.

Porter, R.W. Modernization at Maizewood's insulating-board mill. The Paper Industry. June: 270-274; 1950.

Schwartz, S.L. Insulating board and hardboard from four common hardwoods of northeastern farm woodlots. FPL D1931. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1952. 12 p.

Schwartz, S.L. Preparation of hardboard from white oak. Tappi. 36(10): 445-451; 1953.

Schwartz, S.L. Hardboard from Ohio. FPL 2205. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1960. 4 p.

Schwartz, S.L.; Baird, P.K. Suitability of sand hickory for insulating board and hardboard. Southern Pulp and Paper Manufacture. 15(4): 68, 70, 72-74; 1952.

Sinclair, G.D.; Dymond, D.K. Hardboard from poplar wood. Tappi. 51(9): 108A-111A; 1968.

5. Preparation of Raw Material

General

The pulping operation in refiners or defibrators requires wood raw material input at a continuous, uniform rate and in a homogeneous form that assures easy handling and constant product quality. These requirements are met by the pulp chip (fig. 39). Its manufacture, storage, and handling are described below.

Figure 39—*Hardwood pulp chips.*

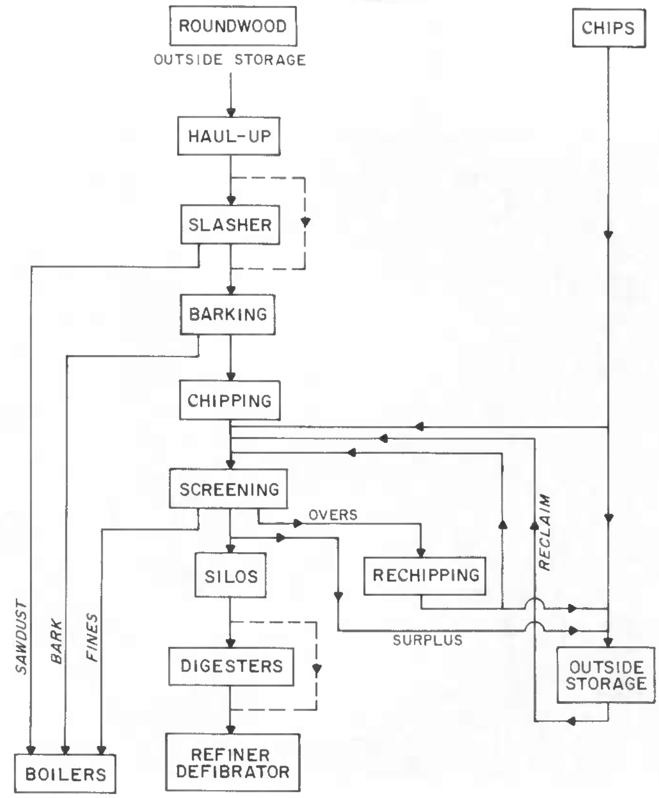


Figure 40—*Diagram of wood-preparing operations (Lamarche 1969).*

Figure 40 (Lamarche 1969) is a diagram of the sequence of steps that are performed in the woodyard or millyard and in the woodroom. Because of the large capacity of most fiberboard mills, the woodyard has to handle and store large quantities of raw material that require considerable land area and materials handling equipment. This makes the woodyard one of the most visible elements of a fiberboard mill, or any pulpmill (fig. 41).

As an example, a hardboard plant may produce 300 million ft^2 per year on a 1/8-in basis. This would be equivalent to about 94,000 tons of board if board density averaged 60 lb/ft^3. At a yield of 90 percent this would require 104,000 tons yearly of dry wood as raw material. A translation of this tonnage into cords of roundwood would have to take into consideration species characteristics such as the wood specific gravity, moisture content, etc. (table 13) (Suchsland 1978). Assuming an average dry weight of 2,000 lb (1 ton) per cord of roundwood, the quantity above would be equivalent to 104,000 cords/year. To cope with seasonal and other supply interruptions, a fiberboard mill may require a raw material inventory of 2 months' production, in this case about 17,000 cords of wood. The largest fiberboard plant in the United States has five times the above capacity, thus requiring the storage of about 90,000 cords of roundwood.

The Millyard

Until recently both paper and fiberboard manufacture were based entirely on 5-ft logs (roundwood), generally delivered by rail. Currently, increasing proportions of the raw material are supplied to mills as multilength stems, tree-length stems, sawmill chips, and whole-tree chips (including bark) (Gilmer 1977). In addition, delivery by truck has increased signficantly.

These changes result from more productive and less labor-intensive harvesting methods, from decreasing timber size, and from greater competition for the raw material. They are reflected in design and equipment of millyards, now accommodating increasing quantities of chips. This increased storage requires close attention to limit the much accelerated deterioration of wood in chip form. Whole-tree chipping reverses the normal barking-

Figure 41—*Partial view of woodyard of a northern fiberboard mill.*

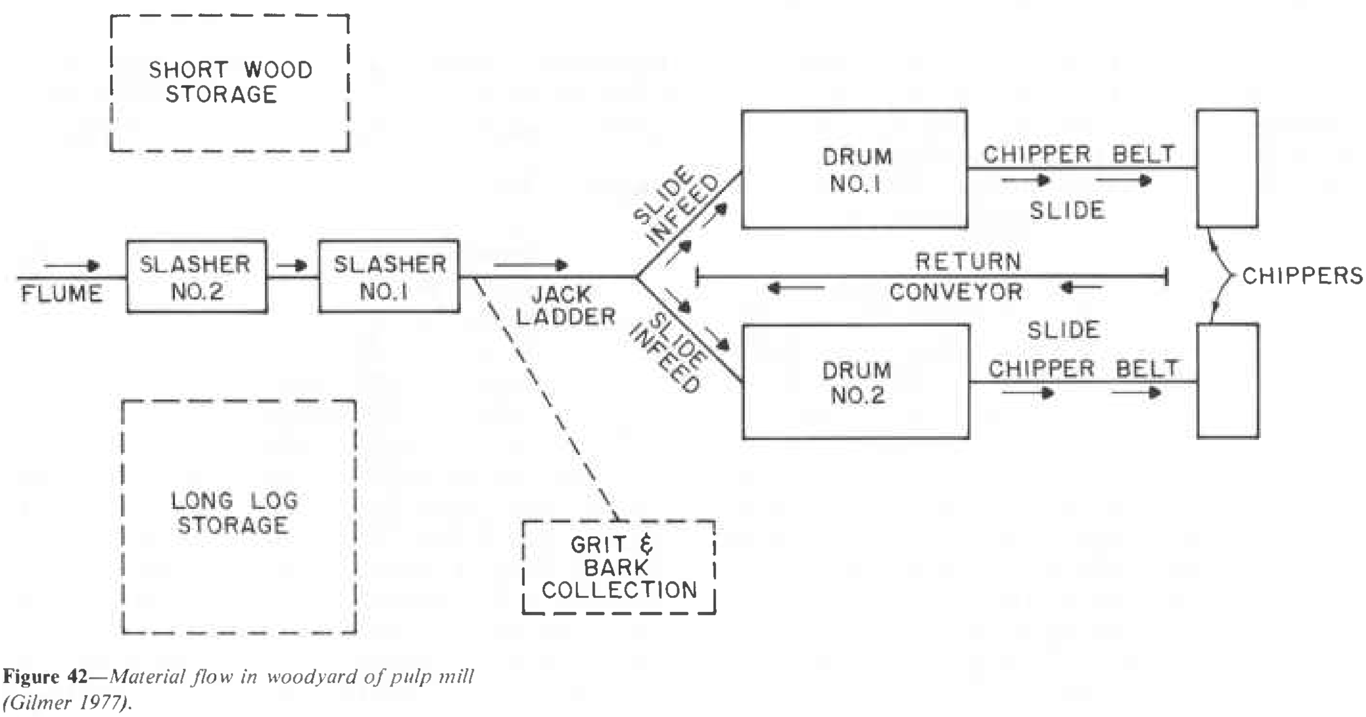


Figure 42—*Material flow in woodyard of pulp mill (Gilmer 1977).*

Table 13—*Weight-volume relationships for pulpwood (roundwood) of various softwood and hardwood species, weights referring to dry wood (Suchsland 1978)*

Species	Specific gravity	Density lb/ft³	Density lb/cord	Cords/100 tons
Aspen	0.35	21.9	1,478	135.3
Cottonwood	.32	20.0	1,350	148.1
Hickory	.64	40.0	2,700	74.1
Southern red oak	.52	32.5	2,194	91.2
White oak	.60	37.5	2,531	79.0
Sweetgum	.46	28.8	1,944	102.9
Yellow-poplar	.40	25.0	1,688	118.5
Pines				
Loblolly	.47	29.4	2,205	90.7
Longleaf	.54	33.8	2,535	78.9
Shortleaf	.46	28.3	2,160	92.6
Slash	.56	35.0	2,625	76.2

chipping sequence and calls for new approaches to bark-wood separation.

A millyard layout indicating material flow is shown in figure 42 (Gilmer 1977). This yard accepts both short and long logs. A chip handling complex is illustrated in figure 43 (Lamarche 1969). Millyard layout obviously depends on the size of the mill, on local factors affecting harvesting and delivery of raw material to the mill, and on special manufacturing considerations that are reflected in special raw material specifications.

Raw Material Measurement

The output of a fiberboard plant is measured in tons. This weight closely approximates the dry fiber content of the product. A close approximation of the dry fiber content of the raw material must therefore be the objective of the raw material measurement. However, there is no simple, direct measurement of the dry fiber content of green wood chips or roundwood.

If the raw material is measured on a volume basis, the dry fiber content per unit volume would depend not only on the wood specific gravity but also on the amount of air space included in the volume unit. If, on the other hand, the raw material is measured on a weight basis, the dry fiber content would depend on the amount of water included. Measurement by weight together with accurate moisture content determination probably comes close to the ideal.

The following standards of volume measurement are commonly used (Wartluft 1976):

- The **standard cord:** a pile of stacked roundwood (or roughly split pieces) occupying 128 ft³ of space; or, generally, sticks 4 ft long stacked in a pile 4 ft high and 8 ft long. This is not a very accurate measure of the solid wood volume because of the variation of the air space with size of logs, crookedness, taper, and the amount of bark present. It is, however, easily determined and is in common use (figs. 44, 45).
- The **long cord:** a pile of stacked roundwood (or roughly split pieces) in 5-ft lengths, occupying approximately 160 ft³ of space. The long cord is thus 1¼ times the standard cord. The long cord is used in the southern United States and is also called a unit.
- The **cunit:** a unit of volume measure containing 100 ft³ of solid wood. A standard cord contains 60 to 80 ft³ of solid wood, depending on species, bark thickness, size, straightness, and wood preparation (table 14) (Wenger 1984).
- The **unit:** a measure of aggregate material (pulp chips, hogged fuel, bark, or sawdust) having a gross cubic content of 200 ft³ uncompacted. It is approximately equivalent to a standard cord of sawmill residues. One standard cord of roundwood yields about 1-1/5 units of chips.

For measurement of pulpwood by weight, the ton (2,000 lb) and the MLB (1,000 lb) are the common units. Both volume and weight measures are used in the industry. Where volume is used, conversion factors must be established in order to determine the dry fiber content by weight.

Purchase by weight eliminates errors due to method of stacking, transportation, and scaling practice, but introduces uncertainty among the haulers regarding the accuracy of conversion factors. It has been reported that settling during transport resulted in a greater weight per

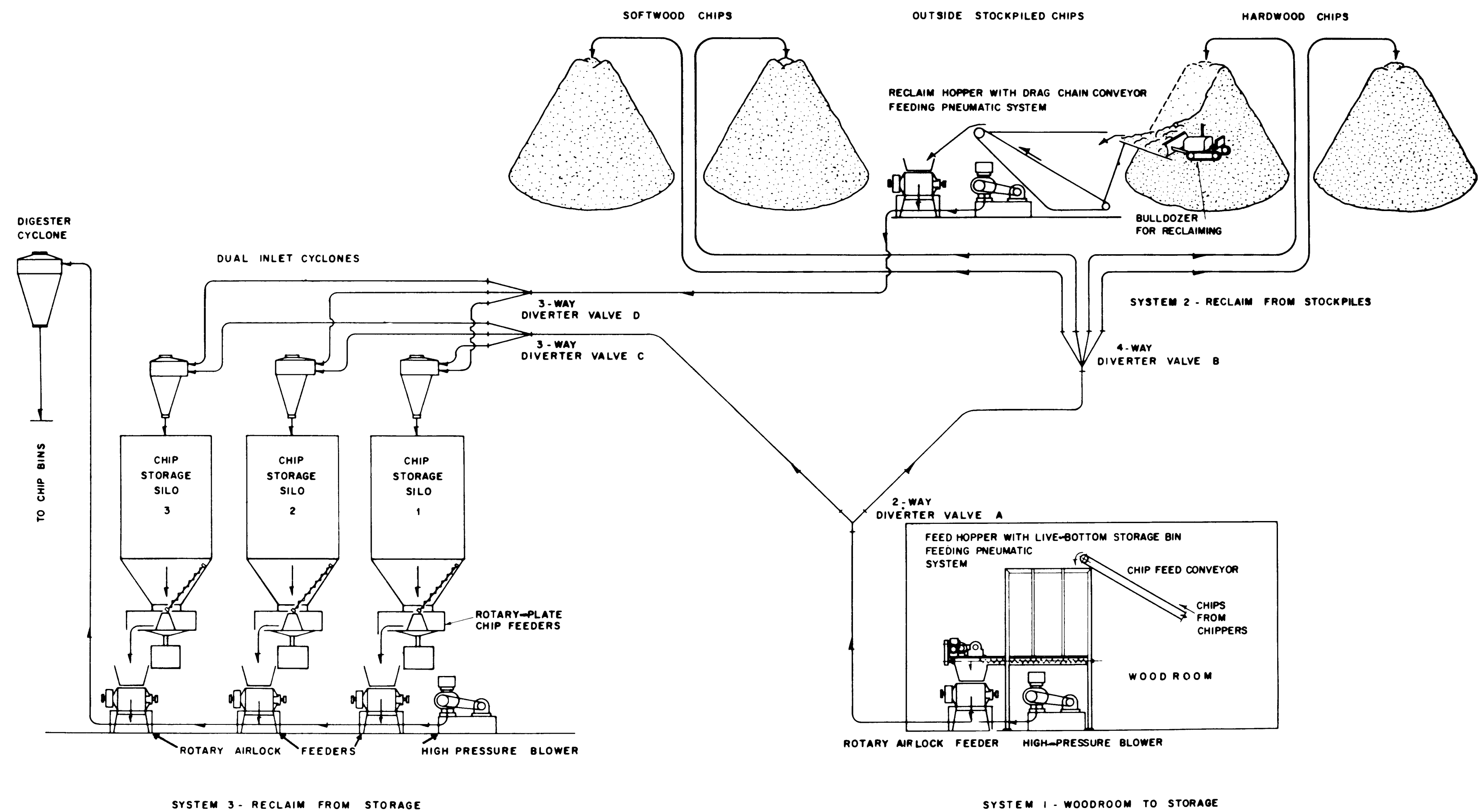


Figure 43—*Diagram of typical chip-handling complex showing flow of chips from woodroom to storage and silos (Lamarche 1969).*

Figure 44—*Scaling truck load of pulpwood.*

Figure 45—*Unloading of truck in woodyard. Total load on truck and trailer approximately 14 cords.*

Table 14—*Solid content of stacked standard cord of unpeeled wood by dimension and condition of bolts—Great Lakes States (Wenger 1984)*[1]

	Solid content (ft³/cord)					
	Less than 6 in m.d. bolts		6 to 12 in m.d. bolts		More than 12 in m.d. bolts	
Condition of bolts	4-ft-long bolts	8-ft-long bolts	4-ft-long bolts	8-ft-long bolts	4-ft-long bolts	8-ft-long bolts
Softwoods						
Straight						
Smooth	90	88	95	93	100	98
Slightly rough	88	85	93	91	98	96
Slightly rough and knotty	84	80	91	88	96	94
Not straight						
Slightly crooked and rough	80	76	88	84	93	91
Considerably crooked	76	72	85	80	90	87
Crooked, rough, and knotty	70	65	79	75	83	80
Tops and branches	67	60	—	—	—	—
Hardwoods						
Straight						
Smooth	85	82	91	88	98	95
Slightly rough	82	78	89	86	96	93
Slightly rough and knotty	78	73	85	82	92	90
Not straight						
Slightly crooked and rough	75	70	82	79	89	86
Considerably crooked	70	65	79	75	85	82
Crooked, rough, and knotty	67	60	75	70	78	75
Tops and branches	58	50	—	—	—	—

[1]A standard cord measures 4 by 4 by 8 ft; m.d. = middle diameter.

cord when pulpwood was rescaled at a receiving point and that railwood settled more than truckwood (Williams and Hopkins 1968).

Aggregate materials such as pulp chips, plywood residues, sawmill residues, and mill residues from secondary manufacturers are usually purchased by weight, generally qualified by moisture content measurements. Volume measurement of these materials is complicated by such factors as compaction and particle size, and therefore is seldom used.

Manufacture of Pulp Chips

Slashing

Tree-length logging considerably reduces labor requirements in the woods and is attractive wherever tree-length road transport is practical and legal. The breakdown into manageable, reasonably straight pieces takes place in the mill on a **slasher**. The tree-length logs are conveyed laterally through a series of staggered circular saws spaced at 6- to 8-ft intervals. Figure 46 shows a large capacity tree-length slasher (120 cords/h) as used in a Canadian paper mill (Martinez and Wolfe 1970). This system handles 48-ft-long logs that are loaded either on the **Starr deck** or on the **breakdown decks**. The Starr deck is a device designed to receive an entire load from a truck. The breakdown decks are conveyors designed to break up these loads and to align the logs perpendicularly to the direction of travel. **Crowding rolls** are power-driven spiral rolls that align or index the ends of the logs. Logs are then fed into the slasher, where they are reduced to 8-ft lengths by a series of circular saws. After going through the slasher, or where slashing is not required, the short logs are loaded on the **"haul up"** or **jack ladder**, which conveys the raw material into the **"woodroom"** for debarking, chipping, and screening (figs. 47, 48).

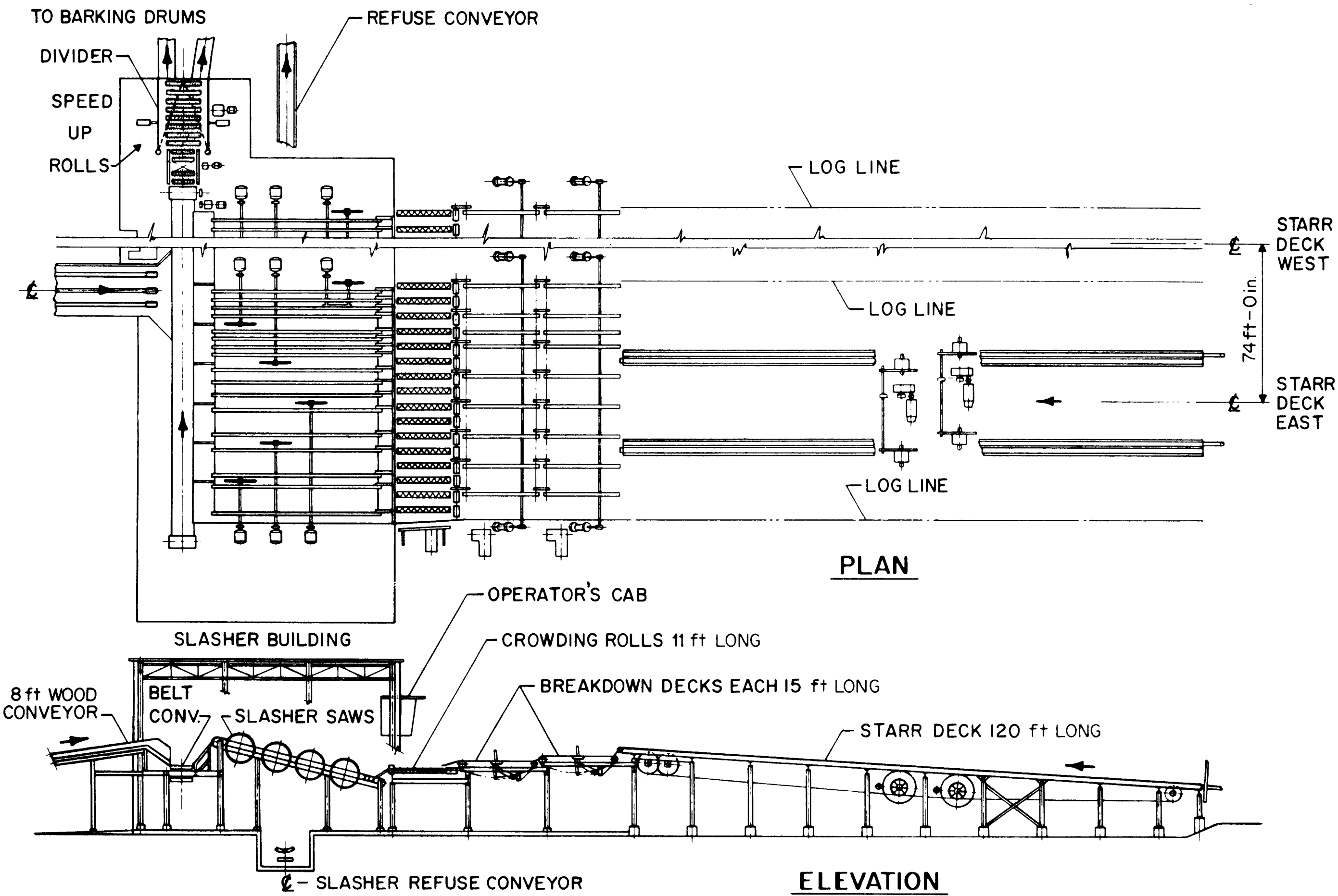


Figure 46— *Tree-length slasher as used in large Canadian pulp mill (Martinez and Wolfe 1970). (© 1970 TAPPI. Reprinted from Tappi Journal, May 1970, pp. 810–814, with permission.)*

Figure 47—*Loading of roundwood on jack ladder for processing in woodroom. Belt conveyor in background delivers screened chips to silos.*

Figure 48—*Jack ladder. Water spray reduces friction, eases handling of logs.*

Debarking

Bark tissue in the living tree serves mainly as a protective shield around the important **cambium**, or tissue-generating layer, which envelops the woody stem. This function is reflected in low specific gravity, short fibers, and low strength, qualities of little value in fiber products. Because bark makes up a relatively small portion of the tree, conversion processes are directed towards the wood portion only, and in most processes bark is removed. Inclusion of bark in fiberboard furnish is generally harmful for several reasons (Eustis 1980):

1. Presence of bark in the wet process plant slows up the drainage rate, i.e., the rate of water removal from the mat on the forming machine, an important productivity parameter. To maintain the production rate the operator will open up the refiner plates somewhat, producing a coarser stock with a better drainage rate but lower board strength. The lower board strength must then be overcome by adding more resins or other additives or by increasing the board density.
2. In the wet process, bark will increase organic raw waste load (BOD) by 10 to 15 percent. Oak bark is one of the worst contributors to raw waste load.
3. The presence of bark produces noticeable reduction in pH at the refiners. Because steamed woodpulp generally has a pH below 4 to begin with, the corrosion of equipment is increased and more chemicals are needed to maintain proper pH control before the introduction of additives.
4. Bark harms hardboard surface quality because many of its components tend to float. Small pieces of corky outer bark may pop up after pressing, particularly in the wet-dry S2S process.

Some barks shrink, leaving a depression in the surface, some turn black in the press, and some stick to the caul plates. No bark will accept paint exactly like wood fiber does; consequently, the most paintable hardboard sheets are made from bark-free wood.

5. Bark carries grit, sand, and other foreign materials. This greatly increases wear on refiner plates, screw conveyors, and in the fiber handling dust pipes in the dry process. If left in the board these materials increase wear of fabricating saws and will cause dielectric arcing when the board is covered with vinyl by dielectric pressing. This last process is used to make door liners in the automotive industry.

The previous discussion has described the detrimental effects of bark and it is reasonable to assume that any modern fiberboard plant would want to remove the bark. At present energy prices, the bark is a valuable fuel, and in a new plant, one would certainly design a powerhouse to utilize this as well as other wood waste. It is one thing to desire bark-free wood but yet another to achieve total bark removal. Plants generally set practical objectives of maximum bark content on the chips. Typically in eastern hardwoods, one would accept a maximum of 1½ percent bark in the summer and 3 percent on frozen wood in the winter (Eustis 1980). Obviously, some products tolerate more bark than others because their end-use requirements are different, but it is generally conceded that bark-free wood is superior, and fiberboard plants would prefer to purchase bark-free chips from their suppliers.

Three types of debarkers are in general use: rosserhead, drum, and ring debarkers.

The **rosserhead**, or Morbark type, debarker utilizes rotating cutters to plane off the bark as the log is moved past the cutter head while rotating about its axis. This type has a low capacity and is best used with short lengths where it does a consistently good bark removal job on mixed species in all sorts of weather. These machines are very good for small sawmills. They are less expensive than other types and cut off knots and other irregularities. Their biggest shortcomings are their limited capacity and the requirement of one operator for each machine.

Conventional **drum debarkers** are generally used in the paper industry and are not used by fiberboard plants except those that are integrated into papermill complexes. Drum debarkers have high initial cost but produce clean logs at a high volume (Mason 1980) and work well with short wood. They are not good, however, on mixed hardwoods. If low- and high-density species are mixed, the softer species get beat up badly, and species that are difficult to debark need to be recirculated several times for an adequate job.

Most popular in the fiberboard industry is the **ring debarker**. In these machines, the debarking tool rotates around the log as one log at a time passes through the ring (figs. 49, 50) (Carthage). The tools are held by springs or air-loaded cylinders and are pressed against the wood, crushing the cambium and peeling off the bark (fig. 51) (Koch 1972). Ring debarkers can handle tree-length wood if it is reasonably straight. Crooked tree-length logs will not stay on the conveyor and must be cut into shorter lengths. Ring debarkers work well on single species and in spring and early summer they do a good job on mixed species.

An important variable of ring debarking is the pneumatic or hydraulic tool pressure. If the pressure is too high, a significant portion of wood will be removed, and if too low, the debarking will be incomplete. Most modern machines are equipped with controls allowing tool pressure adjustment. In general, high-density species and frozen wood require higher tool pressure. Machine capacity with pulpwood logs depends on size of machine and can reach 200 ft of logs/min.

Chipping

The **chipper** reduces the solid wood to small elements of about the size shown in figure 52 (Koch 1972). This size chip produces long, sound fibers, allows quick penetration of steam or cooking liquid, and is easily handled and transported. Only the two ends (A) of a chip are cut by the chipper knives. The length can thus be

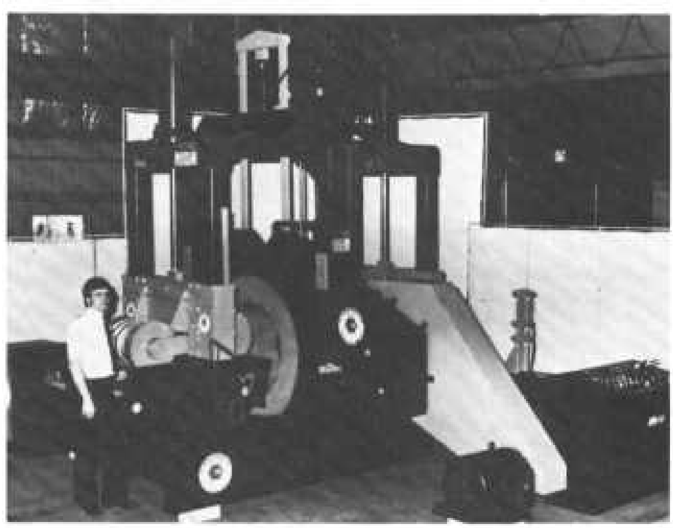


Figure 49—*Carthage-Brunette ring debarker (Carthage).*

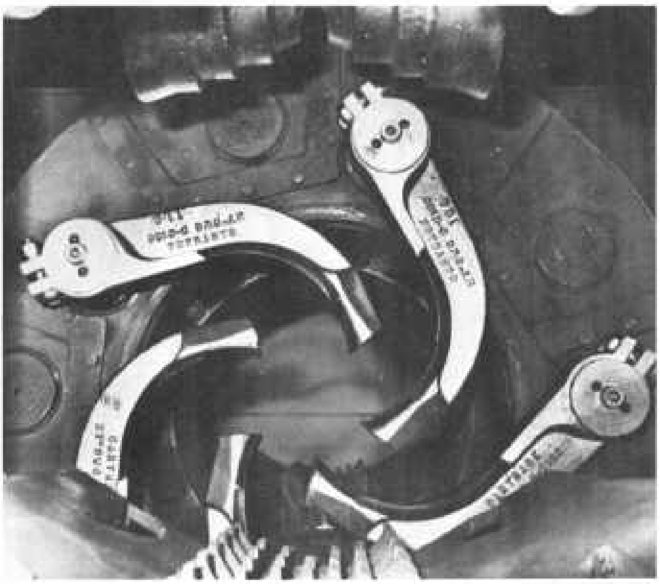


Figure 50—*Carthage-Brunette ring debarker. Close-up of air-operated abrading tools (Carthage).*

directly controlled. Faces B and C are the results of shear failures. Width and thickness can, therefore, be controlled only indirectly.

Most common is the rotating **disk chipper**. The disk revolves in a vertical plane, and is equipped with from 4 to 16 knives, depending on its size. The knives are arranged more or less radially, and their projection through the disk determines the length (dimension parallel to grain direction) of the pulp chip. The logs are either gravity fed through a spout inclined at an angle of 37.5° to the vertical, or the spout is arranged horizontally, requiring power feed. The angle between log axis and disk is the same as in the gravity fed machine.

Gravity feed is limited to short logs and requires space above the machine for log transport to the chipper (fig. 53). Horizontally fed chippers can handle longer logs (Engelgau 1978). Specifications for gravity feed and horizontal feed chippers are shown in tables 15 and 16 (Black Clawson-Sumner). A 116-in gravity feed Carthage chipper carrying 16 knives is shown in figure 54.

The geometrical relationships between the rotating knives and the log are not as simple as might be assumed. To produce chips of uniform length requires multiple helically ground knives and face plates. As the knife advances through the log in a vertical direction, the log moves towards the disk and ideally hits the disk with its upper edge at the moment the next knife engages the log. This would produce chips of equal length. The small angle between the disk and the log face, the **suction angle,**

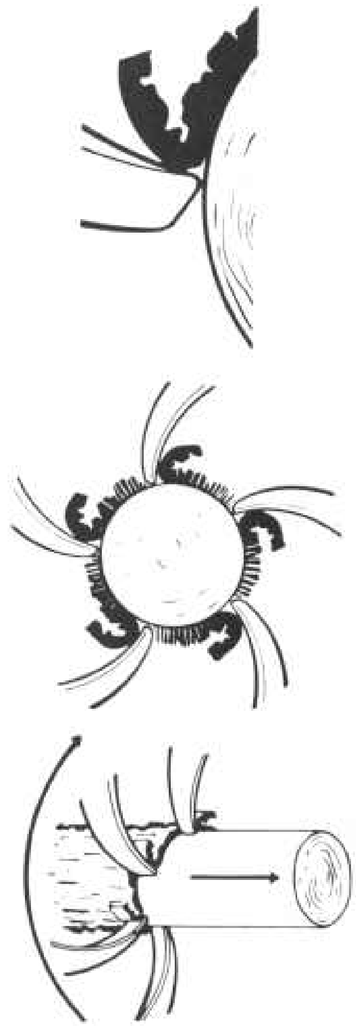


Figure 51—*Illustration of tool action in ring debarker (Koch 1972).*

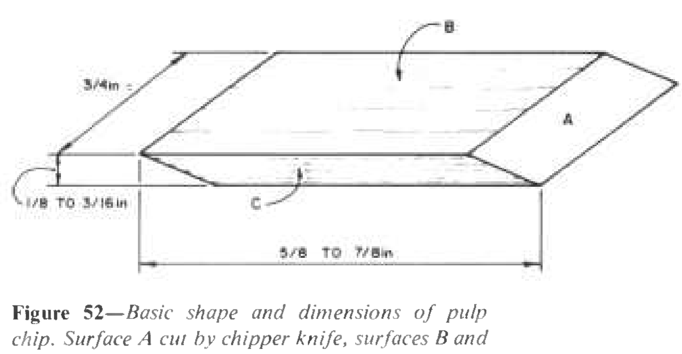
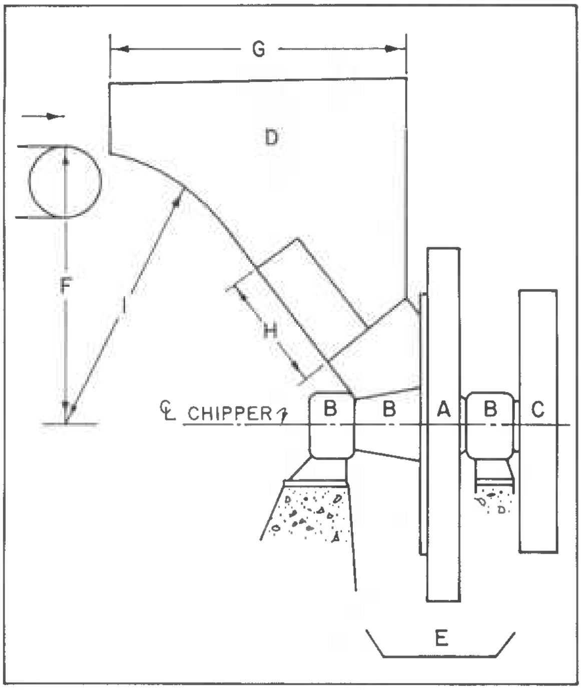


Figure 52—*Basic shape and dimensions of pulp chip. Surface A cut by chipper knife, surfaces B and C split parallel to grain (Koch 1972).*



A = Disk
B = Shaft and bearings
C = Motor
D = Feed chute
E = Chip removal
F = Height required for long logs
G = Horizontal space required for long logs
H = Length of spout extension

Figure 53— *Feed arrangement in gravity feed chipper (Engelgau 1978). (© 1978 TAPPI. Reprinted from Tappi Journal, August 1978, pp. 77–80, with permission.)*

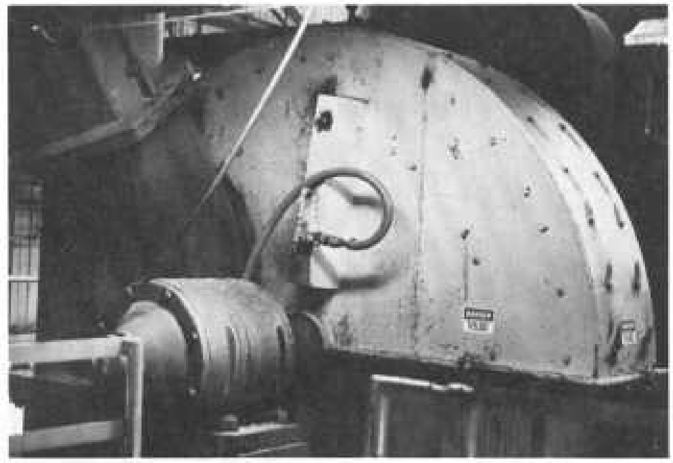


Figure 54—*A 116-inch gravity feed chipper carrying 16 knives, with a 1,000-hp motor.*

is defined by knife projection and distance between adjacent knife edges. It is equal to the knife clearance angle (fig. 55). Closer towards the disk center, the distance between the radially arranged knives is smaller. The top edge of the log would not have traveled far enough to contact the disk surface when the next knife engages, unless the suction angle—clearance angle—was increased. A shorter chip would be produced here. Towards the periphery of the disk the upper end of the log would contact the disk before the next knife engages. This results in increased friction and compression

Table 15—*Specifications for Black Clawson-Sumner gravity feed chipper (Wartluft 1976)*

Chipper model	Spout size (in)	Max. diameter circle (in)	Number of knives[1]	Drive motor[2] (hp)	Max. disk velocity (r/min)
78	15 × 14 × 21	18	6	600	514
		18	8	900	514
90	18½ × 16½ × 27	22	12	1,000	450
		22	15	1,000/1,250	450
106	20½ × 18 × 28	26	10-12-15	1,250/1,750	400
116	21½ × 19 × 36½	28	6-8-10	800/1,500	360
		28	12-15	1,500/2,000	360
125	24 × 21 × 41	32	8-10	1,500/2,000	327
		32	12-15	2,000/3,000	327
153	27 × 26 × 34	34	4-6-8	1,500/2,000	270
175	32 × 32 × 42	42	4-6-8	1,500/2,000	240

[1]Other knife configurations are available to meet specific requirements.
[2]Will vary with conditions.

damage of the chips produced in that region.

These considerations result in a helically twisted knife and a helically ground face plate, which are the features of the so called **Norman chipper**. This design assures full contact between log and disk (Hartler and Stade 1977). Figure 56 shows a cross section through the disk of a Norman type chipper.

Chip thickness is not controlled directly by tool geometry and generally is quite variable (fig. 57) (Hartler and Stade 1977). The average chip thickness is not of as great concern as the quantities of oversized and undersized chips. Chip thickness is related to chip length. A longer chip is thicker because the increased shear area of the longer chip better resists the pushing force of the knife bevel. Chip thickness is also affected by the cutting angle, with larger cutting angles favoring the development of thicker chips.

Chipper drives are usually synchronous motors for high production requirements. If production requirements are low, a wound rotor motor is preferable because, as it slows down under high load, it takes advantage of the energy given up by the disk and flywheel, thus driving the chipper through large logs with considerably less connected horsepower (Crowley and others 1966).

From the chipper the chips are conveyed either pneumatically or mechanically to the screens.

Screening

Of the total chipper output, certain portions are not acceptable as raw material for the pulping process because of size limitations. These portions are removed by screening, which divides the chip flow into three categories: **overs**, **accepts**, and **fines**. Overs are oversize chips containing large slivers and **cards** (chips of correct length but of excessive width). These overs can be rechipped (fig. 58) and returned to the screens. Fines are small particles, generally of less than 1/8 in diameter, consisting of sawdust, small bark particles, and very small chips. The fines are removed and used as fuel.

A typical chip screener is shown in figure 59 (Rotex). The chips are transported and agitated by a low-frequency rotating movement of the screen, which allows the finer fractions to sift to the bottom of the chip blanket without upending some of the chips and allowing them to pass through the screen. **Blinding**, that is, the plugging of the finer screen, is prevented by bouncing

Table 16—*Specification for Black Clawson-Sumner horizontal feed chipper (Black Clawson-Sumner)*

Chipper model	Spout size (in)	Spout diagonal (in)	Max. diameter circle (in)	Number of knives[1]	Drive motor[2] (hp)	Max. disk velocity (r/min)
66	19¼ × 20	27½	15	6-8	400/600	600
78	23 × 26	34	18	6-8-10	800/1,000	514
84	21 × 27	35½	21	6-8-10	800/1,250	514
96	25 × 30½	39	24	6-8	1,000/1,250	450
	25 × 30½	39	22	10-12	1,500/1,750	450
106	29 × 35	45	27	6-8	1,000/1,250	400
	29 × 35	45	27	10-12	1,500/1,750	400
116	33 × 40	52	30	6	1,000	360
	33 × 40	52	30	8	1,250	360
	29 × 35	52	28	12	1,750	360
	29 × 35	52	28	15	2,000	360
135	37 × 45	58	34	6	1,250	300
	37 × 45	58	34	8	1,500	300
153	40 × 50	64	38	6-8	1,500	277
	40 × 50	64	38	10	2,500	277
164	45 × 55	71	42	6-8	1,500/2,000	257
175	50 × 60	78	46	6	1,500	225
	50 × 60	78	46	8	2,000	225

[1]Other knife configurations are available to meet specific requirements.
[2]Will vary with conditions.

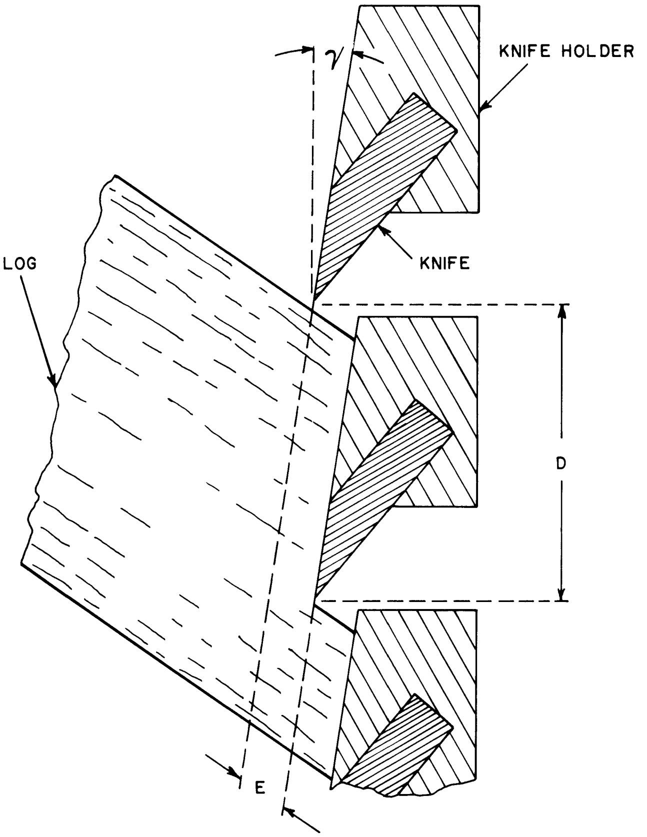


Figure 55—*Section through chipper illustrating relationship between suction angle γ, knife spacing D, and advance of log = chip length E.*

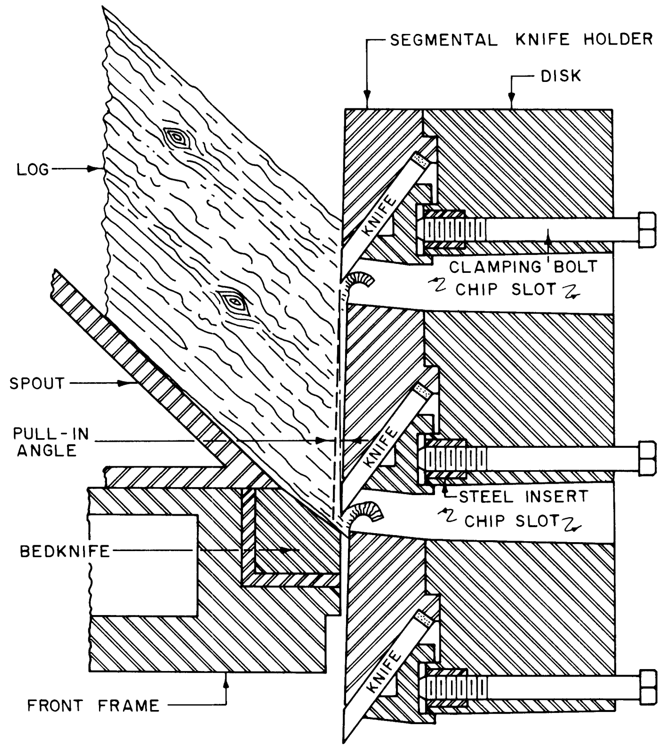


Figure 56—*Section through Carthage Norman type chipper, illustrating cutting action (Lamarche 1969).*

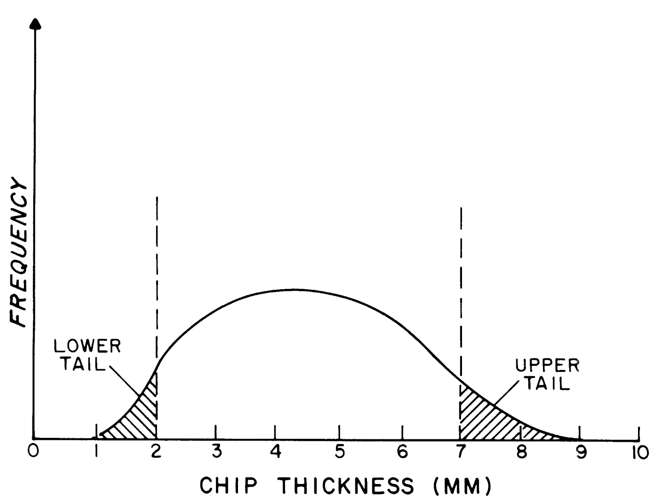


Figure 57 — *Example of chip thickness distribution (after Hartler and Stade 1977).*

rubber balls that continuously tap its underside. Hole sizes of the upper screen vary from 1¼ to 2 in and those of the lower screen from 1/8 to ¼ in.

Other types of screens have high-frequency vertical movements (vibrating screens) that cause a more violent chip action, tending to free the undersized material trapped between larger components by throwing larger chips up into the air. Some of these larger chips may then pass through the upper screen endwise (Barnes and Speyer 1979). Size distribution of chips before or after screening can be monitored by a standard **screen analysis** (Tappi Standard T 16). The size of openings in the various sieves used in the chip analysis varies according to nominal chip size:

Nominal chip size (in)	Opening in screen to be used for classification (in)				
7/8	1-1/4	1	3/4	1/2	1/4
3/4	1-1/8	7/8	5/8	3/8	3/16
5/8	1	3/4	1/2	1/4	1/8

This quality control tool will detect dulling of knives (increase in fines content), wear of chipper bed plate (increase of coarse content), or effect of species and moisture content. Dry and frozen wood increase the fines content (Eustis 1980).

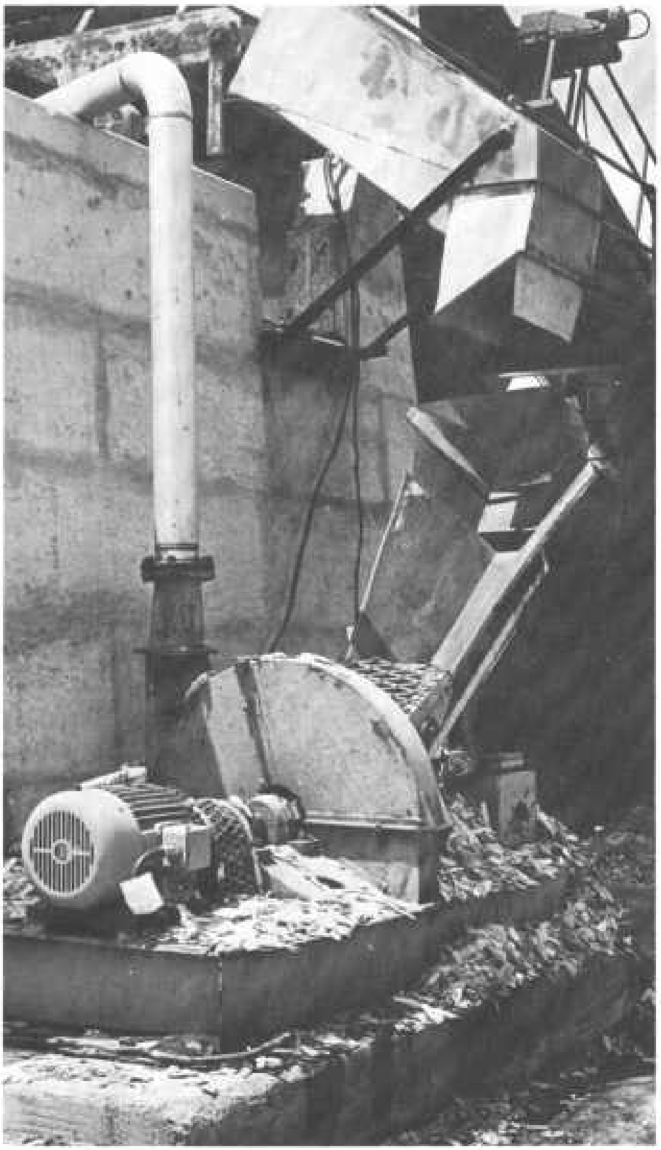


Figure 58—*Rechipper located outside woodroom.*

Well-debarked pulpwood logs chipped on a well-maintained chipper produce chips of fairly high quality that could often be used without screening. The increasing use of whole-tree chips and other sources of low-cost material with relatively large components of bark, twigs, leaves, etc., however, will focus much greater attention on the development of efficient screening systems (Christensen 1976).

Chip moisture content

Because pulpwood is processed green, a substantial portion of the raw material entering the process is water.

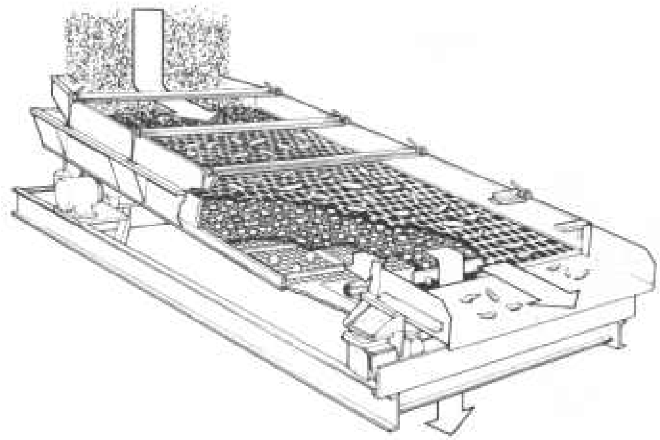


Figure 59—*Rotex chip screener (Rotex).*

Moisture content of green wood varies considerably with species, age of tree, etc., and is affected by storage conditions, duration, and season (table 17) (USDA FS 1974). Monitoring of wood moisture content is necessary for accurate determination of yield, which is based on dry fiber content, and for quality control purposes. Chip moisture contents below 35 percent result in **white wood** (shives in the pulp) (Eustis 1980).

Chip moisture content can be determined by taking periodic "grab samples," but results are not very reliable (Wilhelmsen and others 1976). Application of automatic process control to the pulping process necessitates more reliable and continuous moisture content determination. Such methods are based on resonance and conductivity of the polar water molecule in electric fields of low or high frequencies (figs. 60 and 61) (Lundstrom 1970, Wilhelmsen and others 1976).

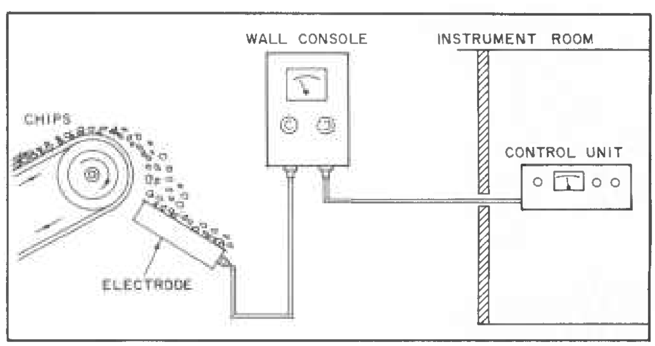


Figure 60—*Schematic of continuous chip moisture content measurement (Lundstrom 1970). (© 1980 TAPPI. Reprinted from Tappi Journal, May 1980, pp. 857–861, with permission.)*

Table 17—*Average moisture content of green wood of North American hardwood and softwood species (U.S. Department of Agriculture Forest Service 1974)*

Species	Percentage moisture content[1]	
	Heartwood	Sapwood
Hardwoods		
Alder, red	—	97
Apple	81	74
Ash		
Black	95	—
Green	—	58
White	46	44
Aspen	95	113
Basswood, American	81	133
Beech, American	55	72
Birch		
Paper	89	72
Sweet	75	70
Yellow	74	72
Cherry, black	58	—
Chestnut, American	120	—
Cottonwood, black	162	146
Elm		
American	95	92
Cedar	66	61
Rock	44	57
Hackberry	61	65
Hickory, pecan		
Bitternut	80	54
Water	97	62
Hickory, true		
Mockernut	70	52
Pignut	71	49
Red	69	52
Sand	68	50
Magnolia	80	104
Maple		
Silver	58	97
Sugar	65	72
Oak		
California black	76	75
Northern red	80	69
Southern red	83	75
Water	81	81
White	64	78
Willow	82	74
Sweetgum	79	137
Sycamore, American	114	130

Species	Percent moisture content[1]	
	Heartwood	Sapwood
Tupelo		
Black	87	115
Swamp	101	108
Water	150	116
Walnut, black	90	73
Yellow-poplar	83	106
Softwoods		
Baldcypress	121	171
Cedar		
Alaska-cedar	32	166
Eastern redcedar	33	—
Incense-cedar	40	213
Port-Orford-cedar	50	98
Western redcedar	58	249
Douglas-fir		
Coast type	37	115
Fir		
Grand	91	136
Noble	34	115
Pacific silver	55	161
White	98	160
Hemlock		
Eastern	97	119
Western	85	170
Larch, western	54	110
Pine		
Loblolly	33	110
Lodgepole	41	120
Longleaf	31	106
Ponderosa	40	148
Red	32	134
Shortleaf	32	122
Sugar	98	219
Western white	62	148
Redwood (old-growth)	86	210
Spruce		
Eastern	34	128
Engelmann	51	173
Sitka	41	142
Tamarack	49	—

[1]Based on ovendry weight.

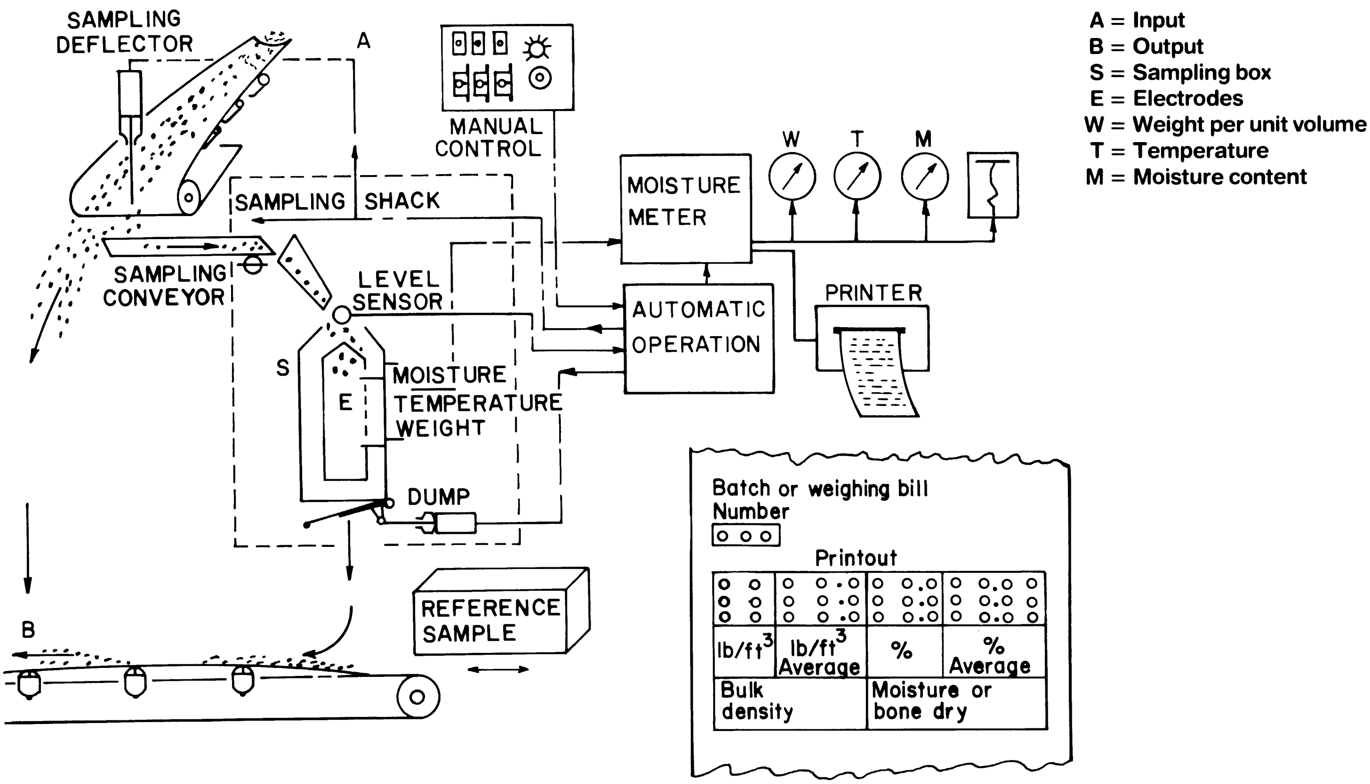


Figure 61 — *Chip moisture meter with automatic sampling configuration and digital averaging and print out circuitry (Wilhelmsen and others 1976). (© 1976 TAPPI. Reprinted from Tappi Journal, August 1976, pp. 56–59, with permission.)*

The Handling of Chips

There is a definite trend in paper, fiberboard, and particle board mills toward using purchased or field-produced chips. These chips come either from sawmills (chipped slabs and edgings—essentially bark-free), from satellite chip mills, which are outlying woodroom operations, and from whole-tree chipping operations, which use the entire tree including bark, twigs, leaves, etc.

The main advantages of this trend are economic. Chip handling can be more readily mechanized and is less costly than handling roundwood. Chips allow denser and, therefore, more efficient storage than roundwood. Some of the disadvantages are loss of direct control over chip quality, less control over species composition of furnish, high bark and dirt content in whole-tree chips, and accelerated deterioration during extended storage.

Chips are delivered by rail car or truck and are unloaded by rail car bottom discharge unloader or dumper, or truck-trailer dumper (figs. 62, 63) (Peerless). Open-top cars may be unloaded with vacuum unloaders (fig. 64) (Rader). Chips are generally stored in open-air piles to which they are transported by either mechanical or pneumatic conveying systems. Long conveying distances favor pneumatic systems (Bryan 1970).

Chips are removed from the storage piles as required by the mill through reclaimer systems, either mechanical or pneumatic. Figures 65 and 66 (K.M.W. Systems) illustrate mechanical reclaimer systems that remove chips on a "first in, first out" principle. The screw reclaimer traverses on fixed parallel rails under the pile. Similar systems are available for circular chip piles and for silo storage (fig. 67) (K.M.W. Systems). Here, the screw reclaimer travels around a fixed center and discharges the chips through a chute in the silo center.

Figure 68 shows a fiberboard plant with belt conveyor leading to the top of storage silos. Surplus chips are dumped and removed to the chip pile. When drawing from this chip pile, chips are fed into a hopper by a front-end loader and then elevated to a conveyor.

Figure 62—*A 300,000-lb-capacity rail car dumper (Peerless).*

Figure 63—*Truck-trailer dumper.*

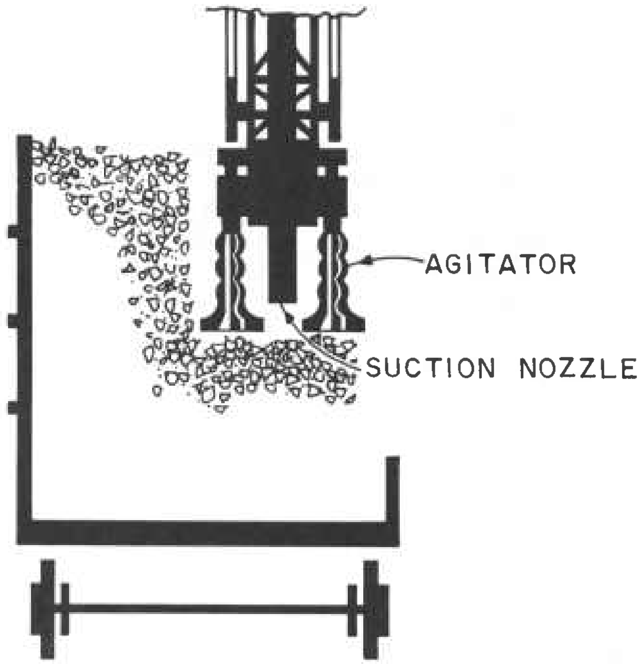


Figure 64—*Principle of open-top car vacuum unloader (Rader).*

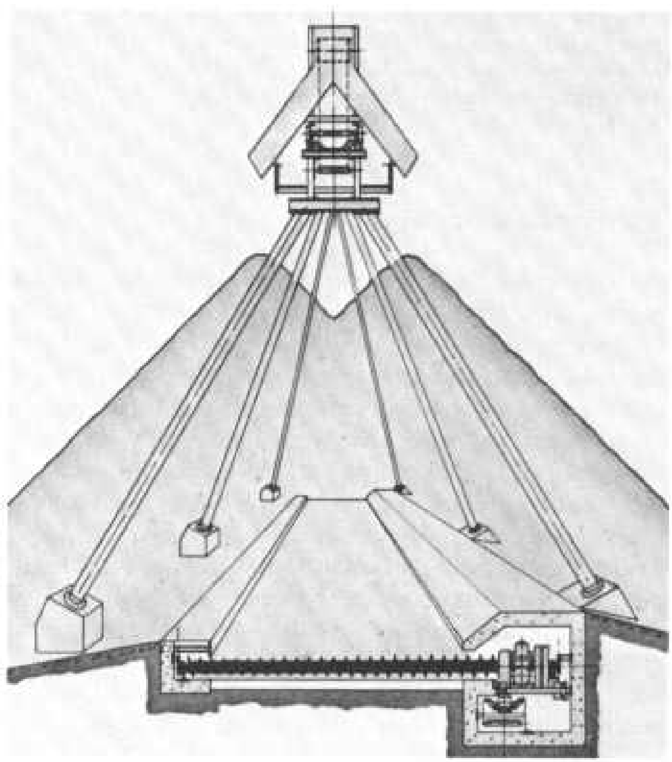


Figure 65—*Mechanical reclaimer system for long chip piles (K.M.W. Systems).*

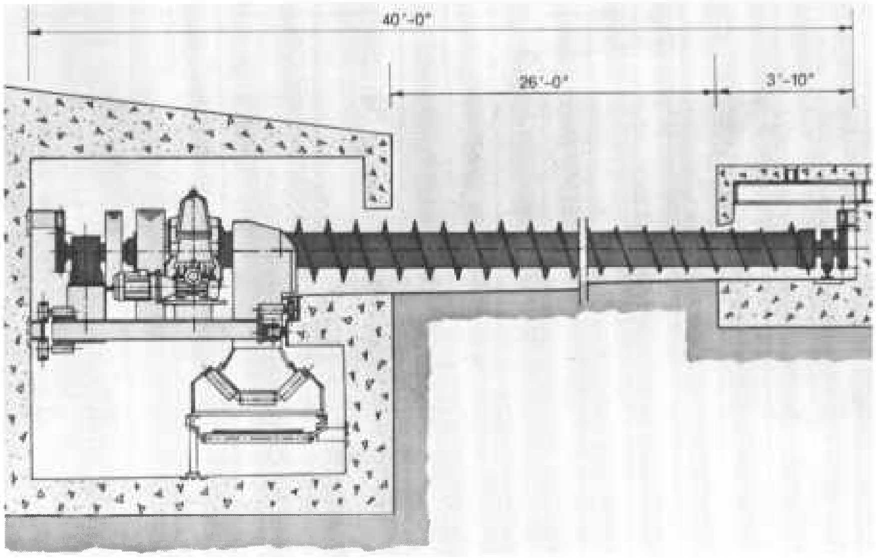


Figure 66—*Traveling reclaimer screw (K.M.W. Systems).*

Deterioration of Wood Chips During Storage

Although pulpwood in all forms is subject to deterioration and yield losses, chips stored outside deteriorate more rapidly than roundwood exposed to similar conditions. Fires due to spontaneous heating in chip piles are rare, but considerable temperature increases do occur in chip piles, indicating biological and chemical oxidation processes (Springer and Hajny 1970). It is believed that the temperature rise in a fresh chip pile is due initially to heat released by respiration of living parenchyma cells. Later, direct chemical oxidation and bacterial action predominate. Figure 69 shows temperature development in tower simulators of piles of aspen chips (Feist and others 1973). Wood losses in chip piles have been reported to average about 1 percent per month of storage time for untreated wood chips (Giffin 1970). There is evidence that unscreened whole-tree chips deteriorate much faster than clean chips (Zoch and others 1976).

Long storage of chips not only reduces yield but also results in precooked chips, particularly with hardwoods. Adjustments in the cook cycle are sometimes required to avoid overcooking chips coming from storage. Chip rotation in fiberboard mills rarely exceeds 10 mo. The following measures can be used to prevent losses: provision of early fire detection and extinguishment, fast turnover of stored chips, and possible chemical treatment of chips to reduce degradation.

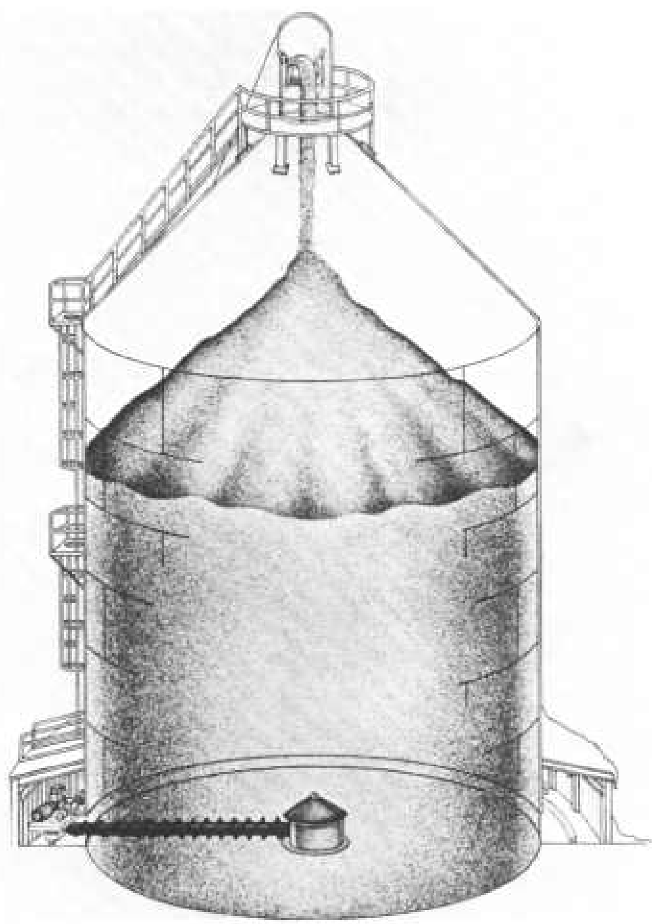


Figure 67—*Mechanical reclaimer system for circular chip piles and silos (K.M.W. Systems).*

Figure 68—*Facility for feeding stored chips into conveyor system, bypassing the woodroom.*

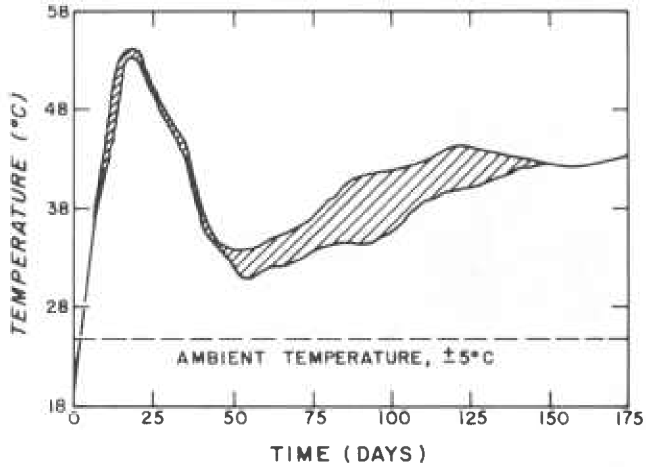


Figure 69—*Temperature development in simulated aspen chip pile (Feist and others 1973).*

The Cleaning of Whole-Tree Chips

Whole-tree chips contain considerable proportions of bark, twigs and foliage, and dirt and grit, generally lodged in the bark. Bark and foliage are detrimental to the development of optimum product properties, and grit and dirt cause serious wear of processing equipment. Rapid wear of refiner plates has been reported as resulting from the use of whole-tree chips (Eustis 1980). The removal of bark, foliage, grit, and dirt is therefore an important prerequisite for the successful use of whole-tree chips.

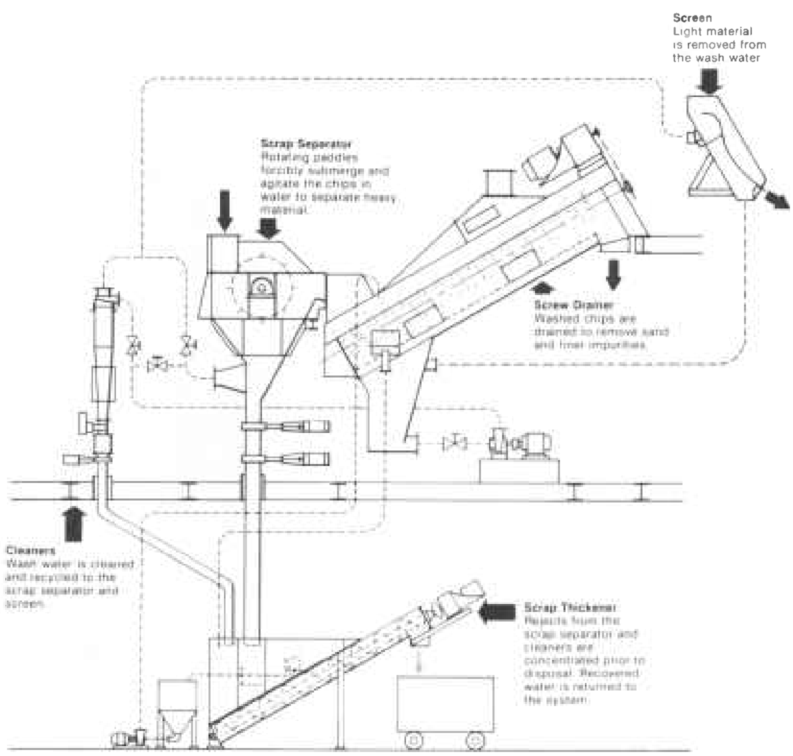


Figure 70—*Defibrator chip washing system (Sunds Defibrator).*

The most practical and only industrially available system at this time for cleaning whole-tree chips is screening and washing. Figure 70 illustrates a **chip washing** system used in several American fiberboard plants (Sunds Defibrator). It is designed to remove magnetic and nonmagnetic tramp metal, stones, and even sand. Both high- and low-density chips can be handled, and the wash water is cleaned and recycled. Rejected material from the scrap separator and cleaners is dumped and thickened in the scrap thickener before disposal.

A Canadian pilot plant system is based on the observation that the bond between bark and wood is weakened during chip storage. After 6 to 12 weeks of such conditioning, vigorous agitation of the chips in water breaks the bark free from wood chips and reduces it to small particles, which are segregated by washing over a screen plate (fig. 71) (Berlyn and others 1979).

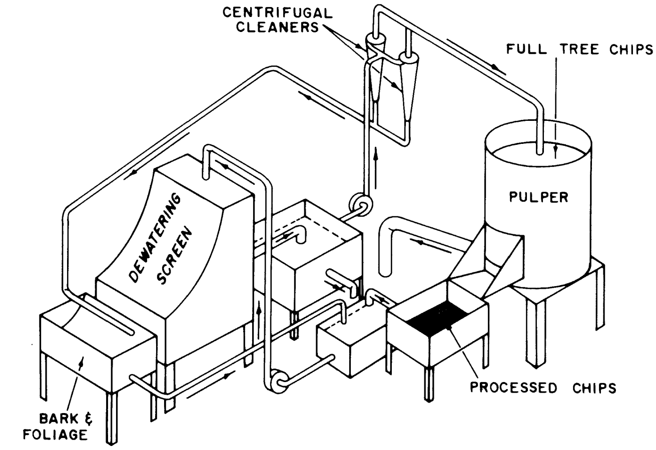


Figure 71 — *Schematic of pilot plant for washing and debarking of conditioned chips (after Berlyn and Gooding 1979).*

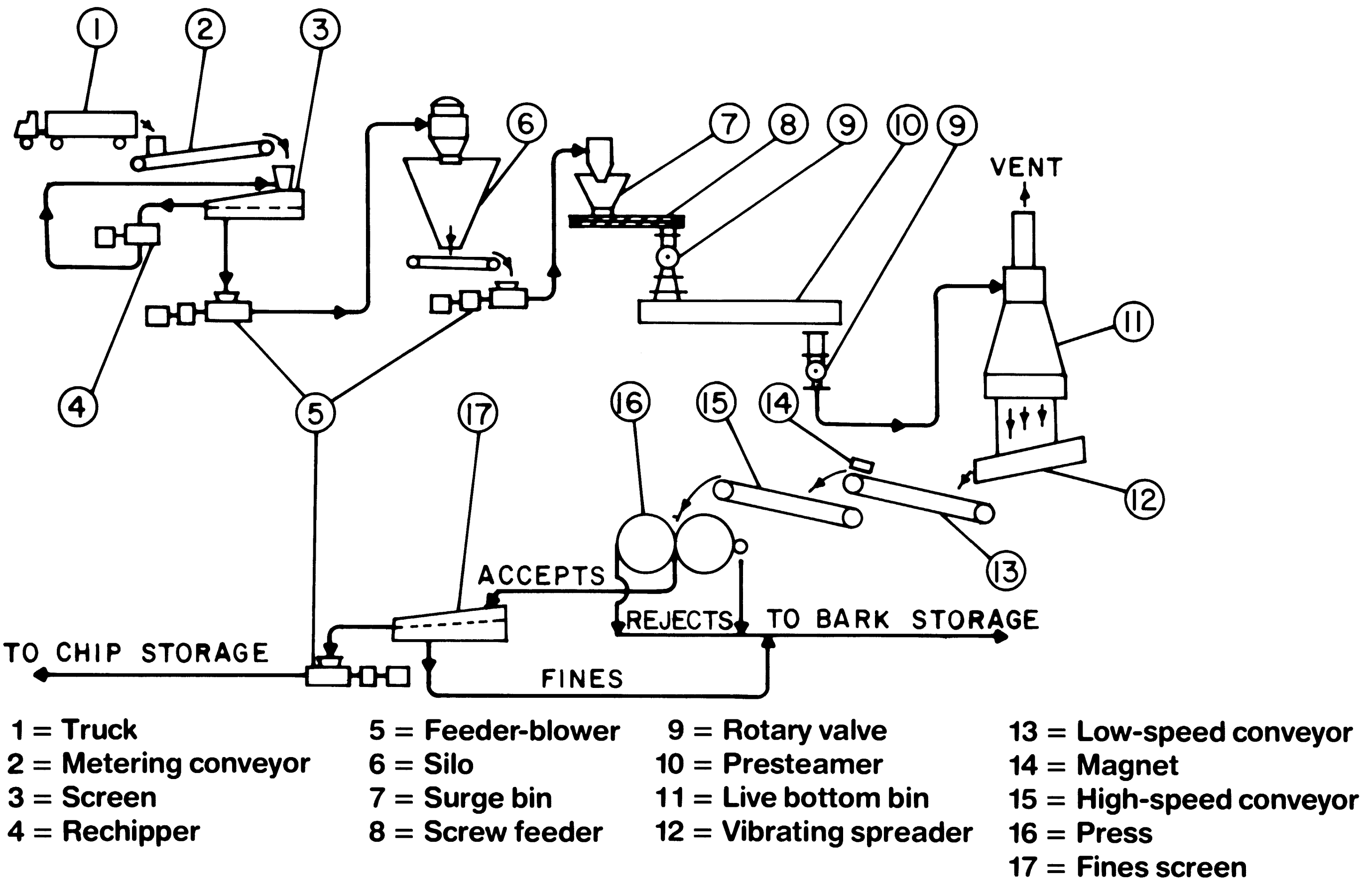


Figure 72 — *Schematic of chip compression debarking plant (after Wawer and Misra 1977).*

Another pilot plant operation, based on the **compression debarking** principle developed by the USDA Forest Service and mentioned in chapter 4, is operating in Canada. Figure 72 shows the material flow of the plant, which includes steam treatment before press debarking. A material balance is shown in figure 73 (Wawer and Misra 1977). The balance shows that 7.5 percent of the wood goes to the boiler together with the bark. At current fuel prices this is hardly a loss. In fact, the fuel value of wood chips is almost as high as their value as raw material for pulp. This is an important factor favoring the use of whole-tree chips.

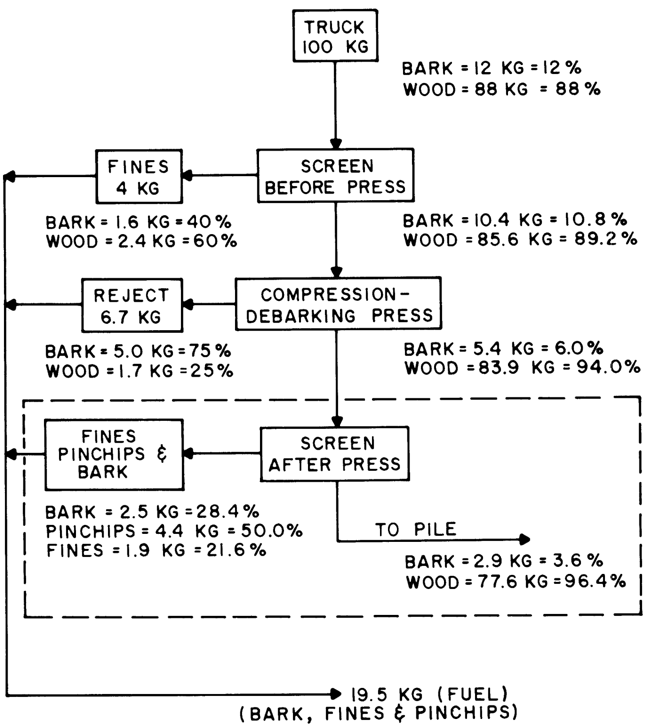


Figure 73 — *Compression debarking pilot plant overall material balance (after Wawer and Misra 1977). Weights in kilograms are based on ovendry material.*

References

Barnes, E.T.; Speyer, J. A new screen for pulpwood chips. Pulp and Paper. 80(9): 105–108; 1979.

Berlyn, R.; Hutchinson, J.; Gooding, R. A method for upgrading chips from full trees. Pulp and Paper. 80(8): 56–60; 1979.

Black Clawson-Sumner, Inc. Promotional literature. Everett, WA.

Bryan, R.W. Celotex chip mill helps to supply board plant. Forest Industries. October: 86–87; 1970.

Carthage Machine Co. Southern, Inc. Promotional literature. Morton, MS.

Christensen, E. Advancing the state-of-the-art in screening bark-free and non-bark-free chips. Tappi. 59(5): 93–95; 1976.

Crowley, E.L.; Zaichowsky, A.; Wardell, N.P.; Rogers, J.R. Large chippers cut costs, up production. Pulp and Paper. November: 37; 1966.

Engelgau, W.G. What is new and old in chipping? Tappi. 61(8): 77–80; 1978.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

Feist, W.C.; Springer, E.L.; Hajny, G.J. Spontaneous heating in piled wood chips—contribution of bacteria. Tappi. 56(4): 148–151; 1973.

Giffin, F.S. Chip storage and handling. Pulp and Paper. 71(7): 66–70; 1970.

Gilmer, W.D. Millyard operations—yesterday and today. Southern Pulp and Paper. January: 17–19; 1977.

Hartler, N.; Stade, Y. Chipper operation for improved chip quality. Svensk Papperstidning. 80(14): 447–453; 1977.

K.M.W. Systems, Inc. Promotional literature. Atlanta, GA.

Koch, P. Utilization of the Southern pines. Agric. Handb. 420. Washington, DC: U.S. Department of Agriculture; 1972. 1663 p. 2 vol.

Lamarche, F.E. Preparation of pulpwood. In: McDonald, R.G., ed. Pulp and paper manufacture, 2d ed., Vol. 1, The pulping of wood. New York: McGraw-Hill; 1969: 73–147.

Lundstrom, J.W. On-line chip moisture measurement. Tappi. 53(5): 857-861; 1970.

Martinez, S.E.; Wolfe, R.B. Tree length slashing at Prince Albert. Tappi. 53(5): 810–814; 1970.

Mason, D. Accurate debarking: the razor-thin edge between profit and loss. Logging Management. April: 30–31; 1980.

Peerless, Lear Siegler, Inc. Promotional literature. Tualatin, OR.

Rader Companies, Inc. Promotional literature. Portland, OR.

Rotex, Inc. Promotional literature. Cincinnati, OH.

Springer, E.L; Hajny, G.J. Spontaneous heating of piled wood chips. Tappi. 53(1): 85–86; 1970.

Suchsland, O. Medium-density fiberboard production possibilities in the Tennessee Valley region. TVA Technical Note B29. Norris, TN: Tennessee Valley Authority, Division of Forestry, Fisheries and Wildlife Development; 1978. 173 p.

Sunds Defibrator. Promotional literature. Minneapolis, MN.

U.S. Department of Agriculture, Forest Service. Wood handbook. Agric. Handb. No. 72: Washington, DC: U.S. Department of Agriculture; 1974. 414 p.

Wartluft, J.L. A suggested glossary of terms and standards for measuring wood and bark mill residues. U.S. Research Note NE-217. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1976. 8 p.

Wawer, A.; Misra, M.N. Compression debarking whole-tree chips. Pulp and Paper Canada. 78(11): T264–T270; 1977.

Wenger, K.F., ed. Forestry handbook. New York: John Wiley & Sons; 1984. 1335 p.

Wilhelmsen, L.A.; Preikschat, E.; Stergion, D.L. Automatic wood chip moisture-bulk density meter. Tappi. 59(8): 56–59; 1976.

Williams, D.L.; Hopkins, W.C. Converting factors for southern pine products. Louisiana State University Agricultural Experiment Station Bull. 626. Baton Rouge: Louisiana State University; 1968. 89 p.

Zoch Jr., L.L.; Springer, E.L.; Hajny, G.J. Storage of aspen whole-tree chips under laboratory conditions. Res. Paper FPL-288, Madison, WI: U.S. Department of Agricuture, Forest Service, Forest Products Laboratory; 1976. 6 p.

6. Pulping Processes

General

The aim of pulping is to convert pulp chips to fibers. In the fiberboard industry this reduction of the chips occurs by mechanical action aided by thermal softening of the lignin-rich middle lamella between wood cells. No chemicals are added to dissolve the lignin or any other wood component. Fiberboard pulping is therefore classified as mechanical pulping, although under the sometimes severe physical conditions chemical changes do occur, and fractions of the wood substance are dissolved.

The defiberizing of the wood chips is not always complete. **Fiber bundles** make up a significant part of fiberboard pulp. In many cases the breakdown goes beyond the fiber element, resulting in broken fibers and fibers with split ends or other damage. These physical characteristics of the pulp are important processing parameters and have significant influences on board properties. They can be controlled to some extent by selection of pulping method and pulping parameters.

Pulping generally occurs in two stages. The major breakdown occurs in the primary stage. The pulp characteristics are finely adjusted and their variations reduced in the secondary stage.

Pulping is energy intensive; it consumes more than half the total energy expended in the fiberboard manufacturing process.

The thermal treatment of chips before or during the defiberizing process causes part of the hemicellulose content to go into solution. The higher the temperature, or the longer the treatment, the more effective is the softening of the fiber bond and the greater the potential of subsequent natural bonding in the consolidation stage. But at the same time the process water becomes loaded with dissolved sugars. The increasing cost of energy and of water treatment will require process modifications and new compromises between process technology and product performance.

The first fiberboard (insulation board) in the United States was made from groundwood, using the standard method for manufacturing newsprint. This method makes a relatively slow-draining pulp, not well suited for hardboard. The groundwood pulping grinder, illustrated in figure 74, is not currently used to make fiberboard in the United States. There are three primary pulping methods used in fiberboard manufacture: the Masonite explosion process, the atmospheric disk refining process, and the pressurized disk refining process.

Figure 75 summarizes the entire fiberboard process range. Theoretically, any of the end-product categories

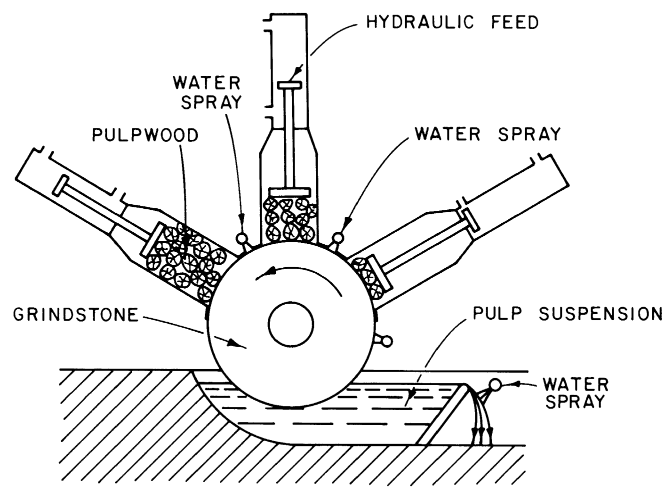


Figure 74—*Multipocket pulpwood grinder (Rydholm 1965).*

could be produced with any of the primary pulping methods. A single fiberboard plant could produce under one roof any or all of the end-product types. In practice, however, a given end product usually requires specific pulp characteristics, and choice of pulping method considers a range of technological requirements, company experience, patent protection, etc. In general, a fiberboard plant is identified by its end product rather than by the pulping method it uses.

The Freeness of Pulp

An important element of the wet fiberboard process is the removal from the pulp of the process water in which it has been conveyed and distributed to form the sheet. Much of this water is removed simply by the force of gravity, draining through a fine screen while the mat is being formed. More water is squeezed out of the mat by roll pressure in the **wet press.** Water that is not drained or squeezed out must be removed as steam in the **hotpress.** A pulp from which the water drains quickly is termed a **free** or **fast** pulp. Conversely, a pulp from which the water drains slowly is said to be a less-free pulp or a **slow** pulp. Fast pulps allow faster line speeds and higher production rates. Slow pulps, on the other hand, permit more intimate interfelting and bonding between fibers. Obviously, pulp **freeness** is related to certain physical characteristics of the fiber and does influence product properties as well as productivity.

The freeness test is a simulation of the wet-sheet forming process. It assigns numerical values to pulps,

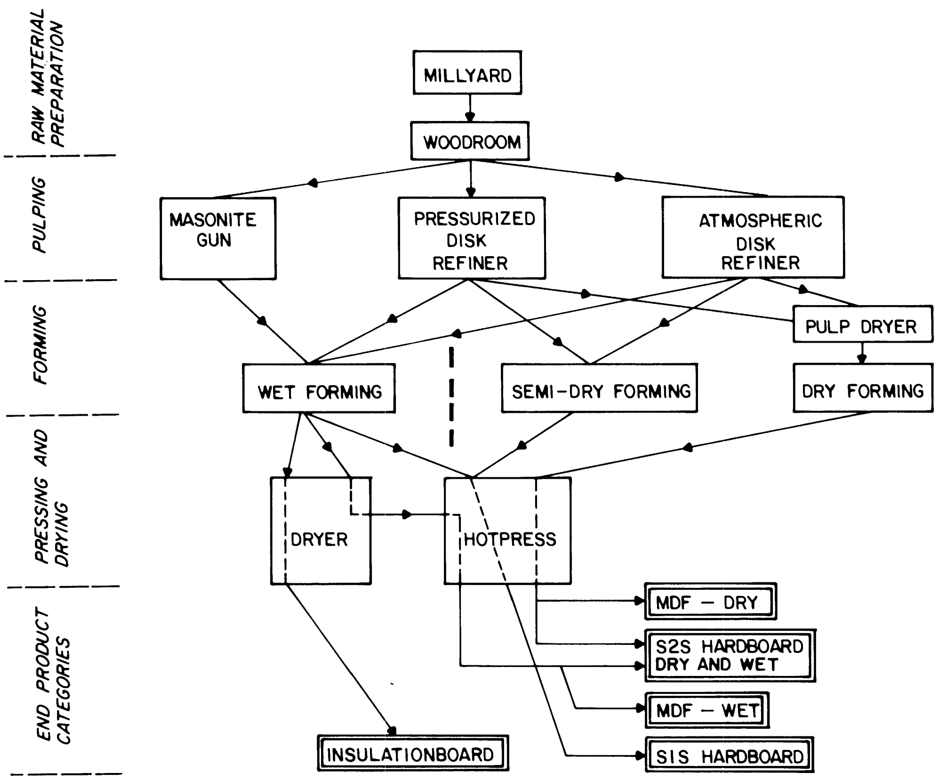


Figure 75—*Summary schematic of fiberboard processing.*

allowing their actual performance on the forming machine to be estimated.

Freeness testers are of two types:

a) those producing numerical values that increase with the freeness (the freer the pulp the higher the numerical result).

b) those producing numerical values that decrease with the freeness (the freer the pulp the lower the numerical result).

The official standard in North America for paper pulp freeness measurement is the Canadian Standard freeness (CSf) tester, described in Tappi Standard T-227. The testing device consists of a drainage cylinder and a drainage cone (fig. 76). The drainage cylinder receives the pulp sample—3 g ovendry pulp in 1,000 ml of water. When the bottom cover and a petcock in the top cover are opened, the water drains through a screen plate at the bottom of the cylinder and is collected in the drainage cone. The drainage cone has two orifices. If the water drains from the pulp faster than it can pass through the bottom orifice, it will rise in the cone and discharge through the side orifice. The faster the pulp, the more water will pass through the side orifice. This quantity is measured and recorded as the Canadian Standard freeness. It ranges from 0 to 1,000 ml. The Canadian Standard freeness tester is thus of the first type—the higher the number, the faster the pulp.

Fiberboard pulp, including insulation board pulp, is much faster than most paper pulps. A tester like the Canadian Standard is not sensitive enough for the relatively narrow range of fiberboard pulp freeness values.

Developed for evaluation of insulation board pulp, the Tappi Standard SFMC drainage tester is in general use in most fiberboard mills in the United States (insulation board and hardboard). It is actually a "slowness" tester, and measures the time required for a given pulp sample to drain its water through a 40-mesh screen (fig. 77) (Tappi).

A glass cylinder receives the sample (10.6 g ovendry pulp in 1,000 ml of water). When the drain valve is opened, the water drains through the screen while the fibers are deposited on it. The time required for the stock level to drop from the upper to the lower mark on the glass cylinder is determined by a stopwatch and recorded as the drainage time. This tester is therefore of type

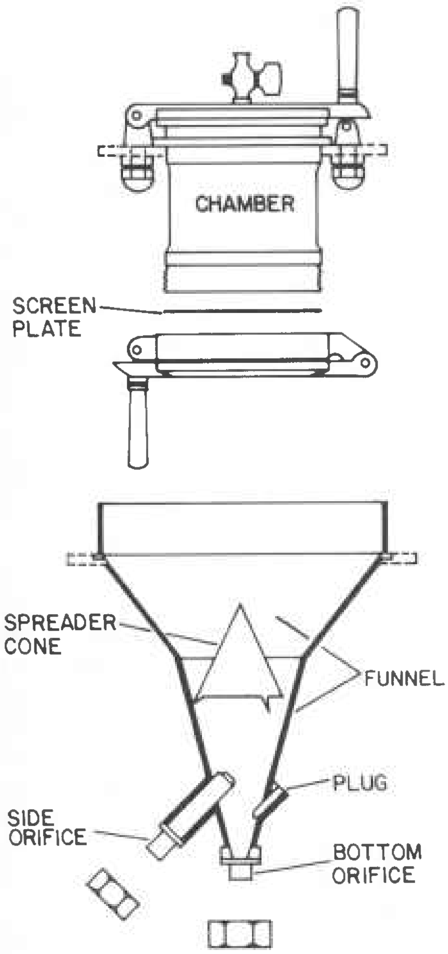


Figure 76—*The Canadian Standard freeness tester (Tasman 1969) (exploded view).*

b—the higher the number, the slower the pulp. Drainage time for water is 1.5 s; for S1S hardboard pulp, 15 to 20 s; and for insulation board pulp, about 50 to 60 s. A critical examination of this instrument was made by Graham (1955).

The Defibrator pulp freeness tester is also designed for the fiberboard pulp range. Its principle is similar to that of the Tappi tester (fig. 78). Its range is from 9.6 (water alone) to 110 s.

Several other devices are used for the evaluation of paper pulps, both of the drainage time type (b) and of the freeness type (a). But the Tappi and Defibrator instruments are the only ones used in the fiberboard industry in the United States.

The freeness or the drainage time of a pulp does not completely identify its characteristics. Two pulps may have the same freeness but may have totally different

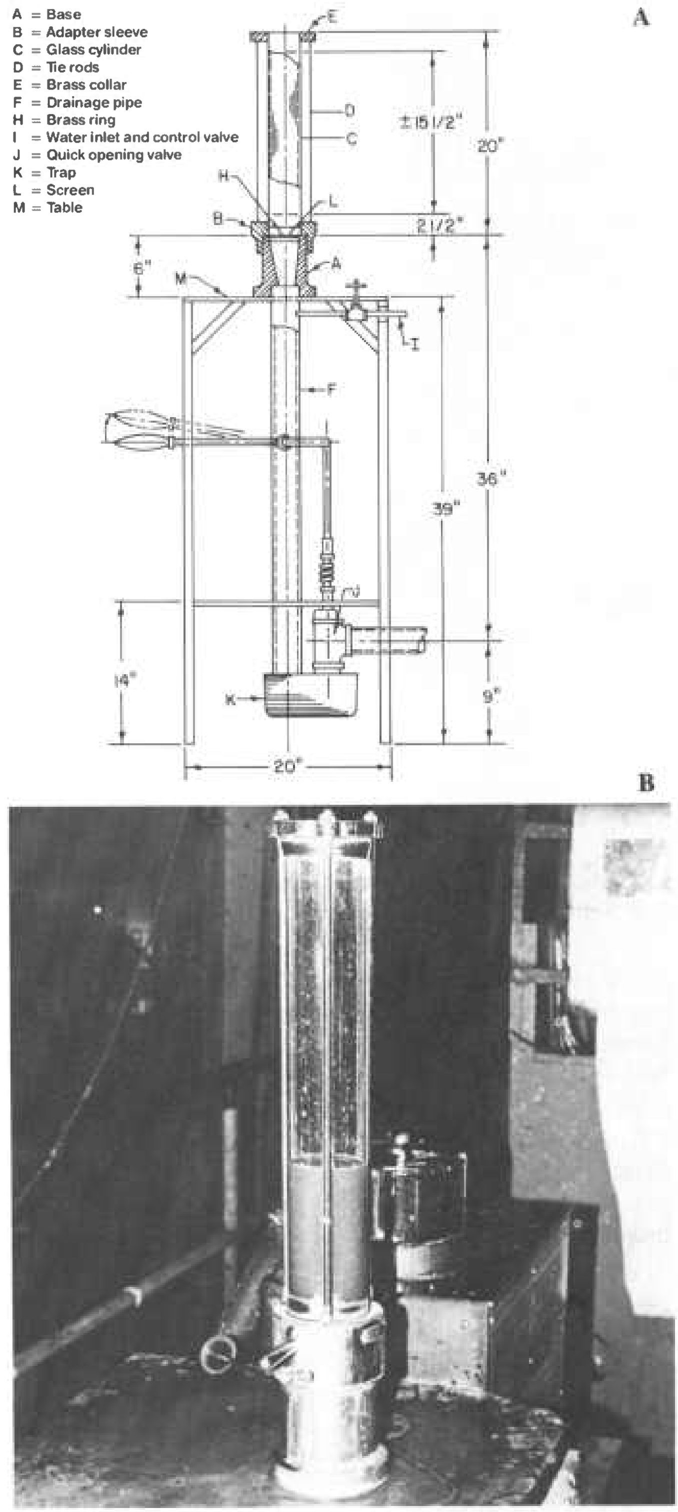


Figure 77A — *Tappi Standard SFMC Drainage Tester (TAPPI 1951). (© 1960 TAPPI. Reprinted from TAPPI Useful Method 1006 Sm-60, with permission.)* **B** — *Tappi Standard SFMC Drainage Tester.*

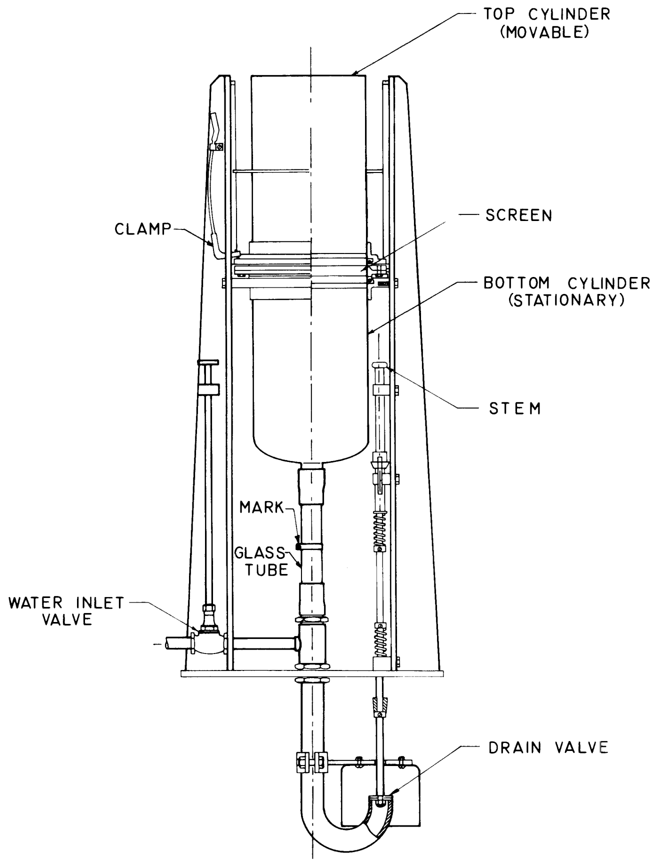


Figure 78—*Defibrator pulp freeness tester (Sunds Defibrator).*

processing characteristics. Freeness cannot always be correlated with actual water drainage characteristics on the forming machine (D'A Clark 1970). Rather, relationships between measured freeness and processing characteristics must be determined in each case in the mill. Then the freeness measurement is an important quality control device.

In general, the larger the total surface area of a quantity of pulp, the slower the pulp will be. The pulp surface area can be increased by more extensive refining (more energy per ton of pulp) causing a squeezing, crushing, and **fibrillation** (broomlike appearance of fiber ends) of the fibers. This fibrillation is important for the promotion of hydrogen bonding in paper. Most fiberboards do not rely on hydrogen bonding for their strength, but, because of their much thicker mats, they require fast draining stock. A high degree of freeness is therefore one of the most important characteristics of fiberboard pulp. Insulation boards do rely on hydrogen bonding and require slower pulps. In dry fiberboard processes, freeness is meaningless and is not measured.

The Masonite Pulping Process

General

In the Masonite pulping process, steam provides both the conditions under which the natural fiber bond is softened and the force that finally breaks that bond. In all other mechanical pulping processes, fibers are separated by the action of abrading or cutting tools.

The Masonite gun and its operation

The Masonite gun—so called because of the explosive nature of the defiberizing phase—is shown in cross section in figure 79. This drawing is taken from Mason's article on pulp and paper from steam-exploded wood, written in 1927 (Mason 1927). The appearance and size of the gun have not changed much over the years, although its operation today is automated (figs. 80, 81). The Masonite gun is used exclusively by the Masonite Corporation.

The gun is a pressure vessel with an inside diameter of about 20 in, a height of about 5 ft, and a capacity of about 10 ft^3, (about 0.1 ton) of green wood chips. At the tapered bottom end, the vessel is equipped with a slotted port and a quick-opening hydraulic valve. An inlet valve at the top is designed to receive the chips from a hopper. Steam is admitted through a high-pressure steam valve. The sequence of operation is as follows (Boehm 1930):

1) Gun is loaded with green chips through the port on the top.
2) Chip inlet valve is tightly closed.
3) Low-pressure steam (350 lb/in^2—just over 430 °F) is admitted immediately. This brings the chips to a temperature of about 375 °F.
4) The chips remain at 375 °F for 30 to 40 s.
5) High-pressure steam is admitted and the gun pressure is elevated within about 2 to 3 s to 1,000 lb/in^2, equivalent to a temperature of about 540 °F.
6) The chips remain at this pressure for about 5 s.
7) The hydraulic discharge valve is opened.
8) The chips explode due to the pressure differential and at the same time are forced by the expanding steam through the slotted bottom port plate where they are shredded into a mass of fiber bundles.
9) Steam and fibers are separated in a cyclone.

A typical time-pressure diagram for the Masonite gun operation is illustrated in figure 82.

The program of steam pressurization may vary (Spalt 1977):

Steam pressure may be raised steadily until discharge

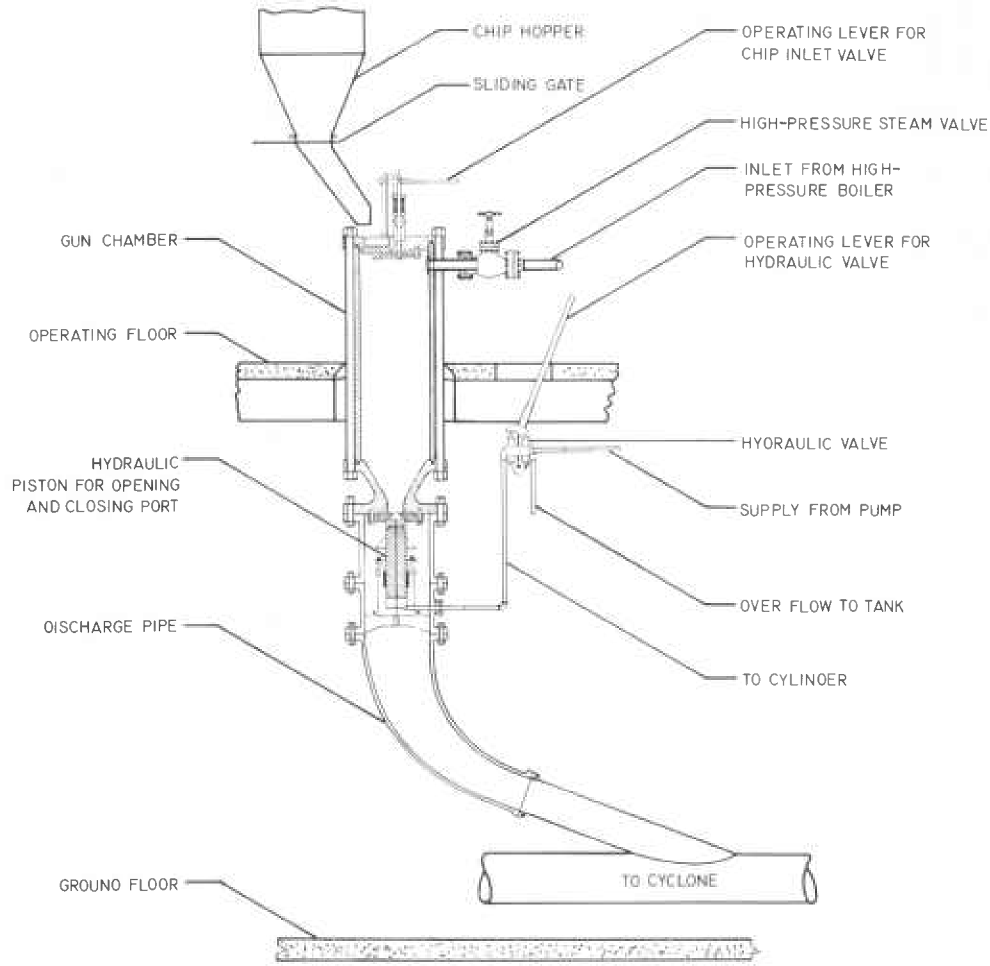


Figure 79—*Cross section of Masonite gun (Mason 1927).*

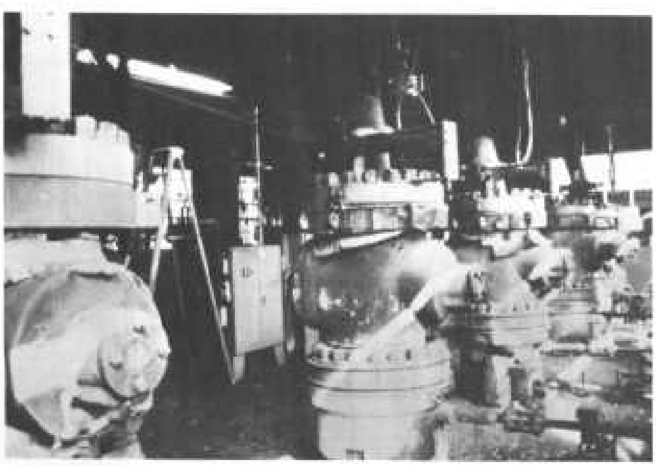


Figure 80—*Series of Masonite guns (Masonite Corp.).*

Figure 81—*Discharge tubes of Masonite guns (Masonite Corp.).*

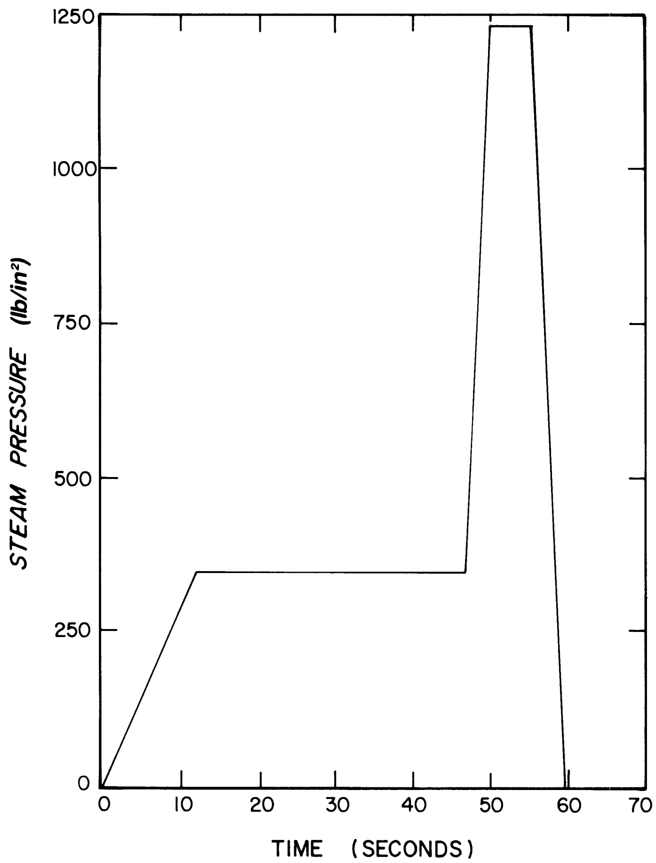


Figure 82—*Typical Masonite gun cycle.*

sure may be admitted at a prescribed rate until a target pressure is attained, held for a prescribed time, and discharged. Another version uses controlled rate of steam pressurization to target pressure, hold at pressure up to 90 seconds, and raise rapidly to a higher pressure (shooting pressure) and discharge. After separation in cyclone, pulp is diluted and conveyed to secondary refiners.

Effect of gun cycle on wood chip

During the severe treatment of the wood chips, important structural and chemical changes occur:

1) Part of the wood substance is dissolved.
2) The lignin bond is chemically and physically weakened, thus allowing relatively easy separation of fibers upon decompression.

The dissolution of part of the wood substance is due to hydrolysis of the hemicellulose under the catalytic action of acetic acid. The hemicellulose breaks down to sugars (hexoses and pentoses), which are water soluble and are removed from the pulp by washing. The degree of hydrolysis and the extent of wood losses can be controlled by modifying the gun cycle (Boehm 1944). The catalyzing effect of acetic acid, which is believed to be generated by cleavage of acetyl groups of hemicellulose at steam pressures between 300 and 400 lb/in^2 is illustrated as a sudden rise in the hot water extractability (fig. 83). The effect of preheating time on pulp yield is shown for various temperatures in figure 84.

Pulp yields of the Masonite process have been reported as low as 65 to 70 percent, and more recently as between 80 and 90 percent. Very early Masonite yields were less than 50 percent. Yield figures are influenced not only by the temperature–time gun cycle, but also by such variables as species, specific gravity, growth factors, moisture content, etc. The Masonite process, originally based on southern pine, is now applied mainly to hardwoods in the Masonite plant at Laurel, MS. Masonite's other wet hardboard plant in Ukiah, CA, is based on softwoods. Because softwoods and hardwoods require different gun cycles, when both woods are used in the same mill they are pulped separately and then mixed.

Masonite pulp characteristics

Masonite pulp is dark in color due to thermal degradation. Jack pine pulp (Masonite) studied by Koran (1970) consisted of 60 percent fiber bundles and 40 percent individual fibers and fiber fragments. The fibers appeared relatively stiff and showed little collapse. Their surfaces were very smooth and were enveloped by a continuous primary wall network, heavily encrusted with lignin and in many areas covered by thick layers of middle lamella substance (Koran 1970). This indicates that the fiber separation occurred in the lignin-rich middle lamella or in the primary wall rather than in the lignin-poor and cellulose-rich secondary wall. Early investigators of the Masonite process recognized an "activation" of the lignin, a condition suitable for reexerting its bonding power in the hotpress (Boehm 1944).

Masonite fibers are not "fibrillated," that is, they do not have the ribbonlike appendages that give the fiber the broomlike ends essential for the development of hydrogen bonding in paper. Masonite pulp will not produce this fibrillation even with further refining and is therefore unsuited for paper manufacture. It is, however, for the same reason a very free pulp that drains water fast, an important characteristic in the manufacture of wet-formed hardboard.

Because of the presence in the pulp of acetic and formic acids, the pH of Masonite stock is low, between 3.0 and 4.0.

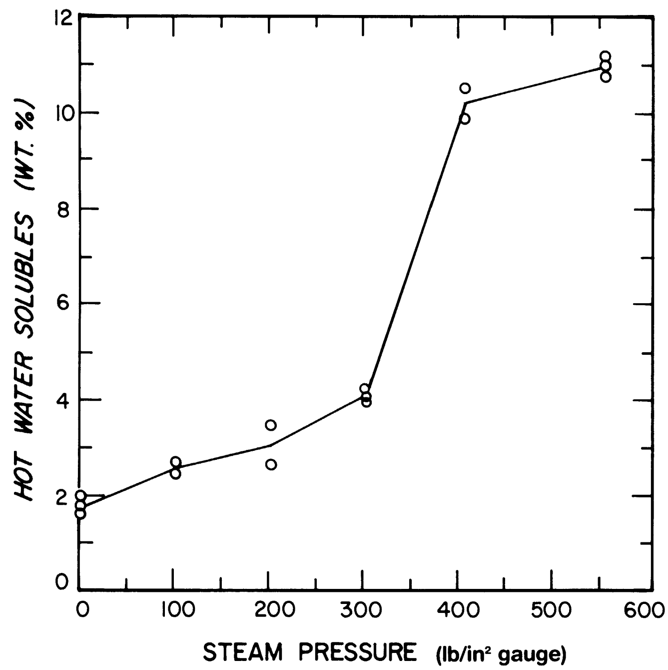


Figure 83—*Hot-water extractability of wood chips as a function of saturated steam pressure used in the preheat segment of the digesting operation (Spalt 1977).*

The Masonite pulping method, in terms of the pulp quantity it produces, is still—at least in the United States—a major pulping method. However, it is doubtful that any more Masonite guns will be installed in the future. Low yield and relatively high energy requirements will cause their gradual replacement by disk refiners.

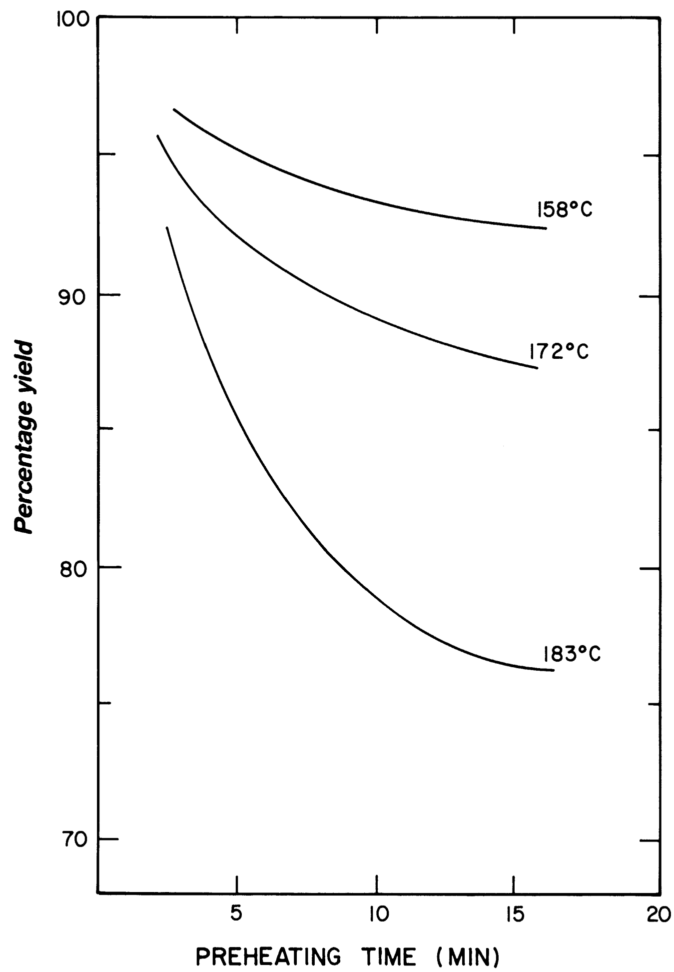


Figure 84—*Effect of preheating time and temperature on pulp yield (EPA 1973).*

Disk Refining

General

The significant feature of the disk refining process is the mechanical shearing, cutting, squeezing, and abrading action to which the pulp chips are exposed as they are being forced through the narrow gap between two profiled disks.

Disk refining was introduced in the paper industry as a substitute for stone grinding in the 1920's. It has obvious advantages over stone grinding, such as the possibility of using wood chips and wastes rather than just roundwood, the possibility of using hardwoods, and generally easier raw material handling. Disk refining allows a variety of controlled pretreatments such as water soaking, steam cooking, and chemical treatments. Disk-refined pulp is generally of higher quality than groundwood.

In the fiberboard industry, disk refiners were first introduced by the U.S. Gypsum Company at Greenville, MS, when it became desirable to utilize hardwoods that could not be ground on stone grinders. Today, most fiberboard pulp is produced by disk refiners.

Types of disk refiners

There are two different dynamic principles in disk refiner design: the single disk and the double disk. Actually, both have two disks, but in the **single-disk** machine only one revolves, the other is stationary (fig. 85). In the **double-disk** machine both disks revolve at the same speed but in opposite directions (fig. 86). The actual profiled cutting elements (plates) are ring segments bolted to a disk or housing, each constituting a third or a sixth of the full circle. These plates are made of wear- and corrosion-resistant alloyed steel castings and are supplied in various profiles, depending on the application. A selection of plate profiles as used in the fiberboard industry is shown in figure 87 (Bauer).

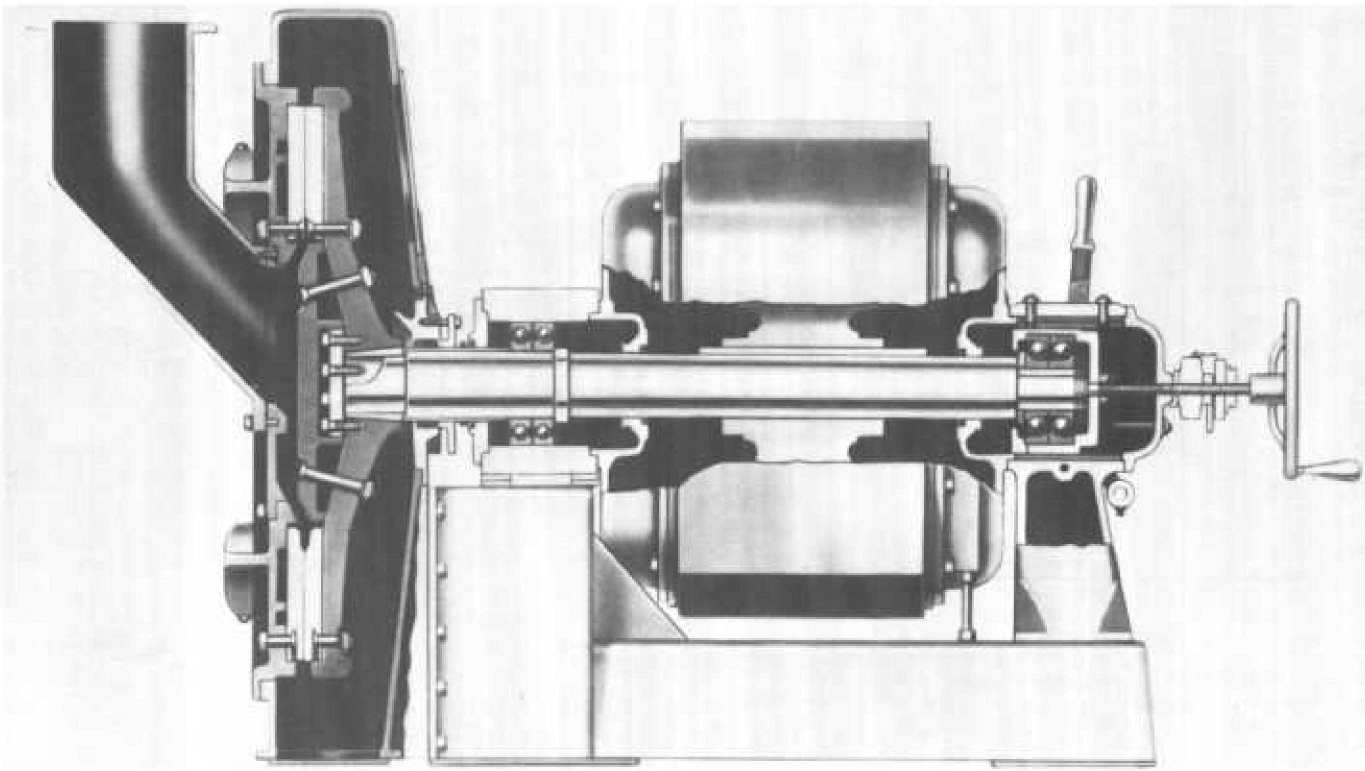


Figure 85—*Cutaway view of a single-revolving-disk mill (Bauer).*

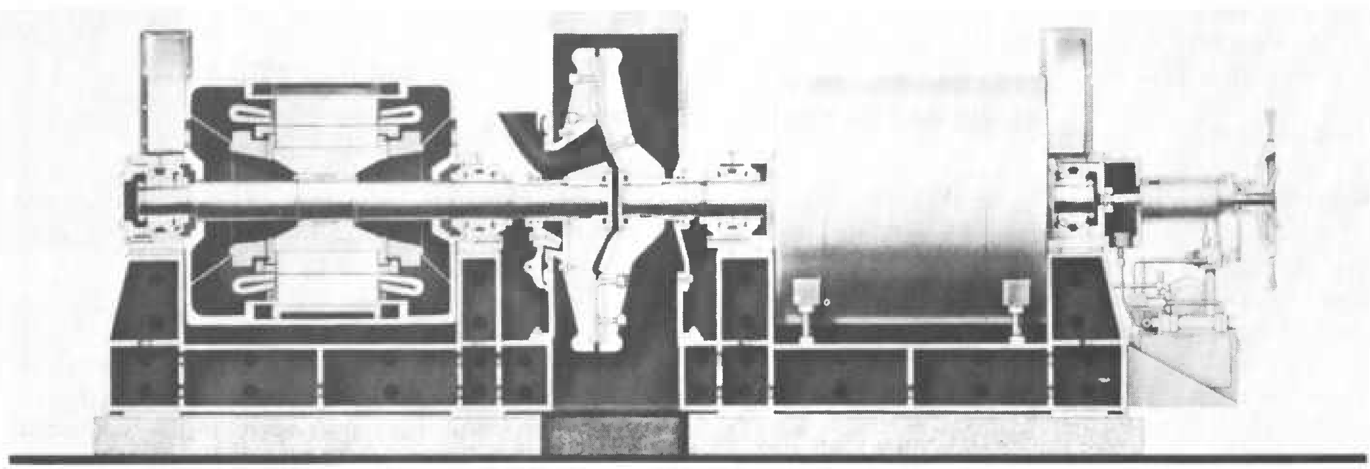


Figure 86—*Cutaway view of a double-revolving-disk mill (Bauer).*

Both single-disk and double-disk mills are used in the primary pulping of chips for fiberboard manufacture. While there are distinct differences in the dynamics of the mill action on the chips, one cannot find clear and consistent separation of pulp properties from single- and double-disk refiners.

The choice of refiner type must be based on experience in commercial operation or on tests made with full-size equipment (Textor 1948). In this reference the difference between the two mill types is described as follows (Textor 1948):

A ball in contact with both plates of a single disk

CLASSIFICATION OF PLATES

C-E Bauer supplies three basic classes of plates. These are:

(a) Flat Plates (Fine, Medium, and Coarse)
(b) Waveline Plates
(c) Devil Tooth Plates

A brief description of each classification is shown below, along with a few examples of applications. It should be noted that these examples are very general.

Class 1 and 2—Flat Fine Plates. These plates have more than 3½ teeth per inch at periphery. Applications include Refiner Mechanical and Thermo-Mechanical Pulps, chemical and groundwood rejects, milling of peanut butter and other comparable food products.

Class 3 and 4—Flat Medium Plates. These have between 3½ and 2 teeth per inch at periphery. These are excellent fiberizing plates, and are used in double disc refiners for chip refining in insulating board mills and hardboard mills; for fluffing certain cellulosic materials in single or double disc mills. They are also used in Pump-Through Refiners for stock preparation in paper mills. In dry applications these plates are used in many general fine grinding operations, such as woodflour, nutshell grinding, asbestos, etc.

Class 5 and 6—Flat Coarse Plates. These plates have less than 2 teeth per inch at periphery. Recommended for use in refining chips in dry process hardboard mills, preparing asbestos, grinding mica, ferrous and non-ferrous alloys, dewatered material such as press cake, meal for feed and fertilizer, etc.

Class 7—Waveline Plates. Matching plates, the surface of which forms a series of intermeshing concentric hills and valleys in the radial direction. These convolutions cause material to be thrown from one plate to another while moving outward in a radial direction. This type plate is normally used in low power input applications. In dry grinding, fiberizing, hulling, cracking, coarse granulation, fluffing of alpha cellulose pulp. Widely used in wet processes, such as pulp industry where very low freeness drop is desired and where main objective is to disperse stock, pre-refine, coarse breakdown of fiber bundles, processing of screen rejects, etc.

Class 8—Devil Tooth Plates. Intermeshing plates easily identified because teeth are coarse, unconnected individual units arranged in concentric rings. Designed for coarse size reduction, granulating, shredding and mixing. Rough breakdown of wood chips, fluffing certain pulps, degermination for starch, feather curling, etc.

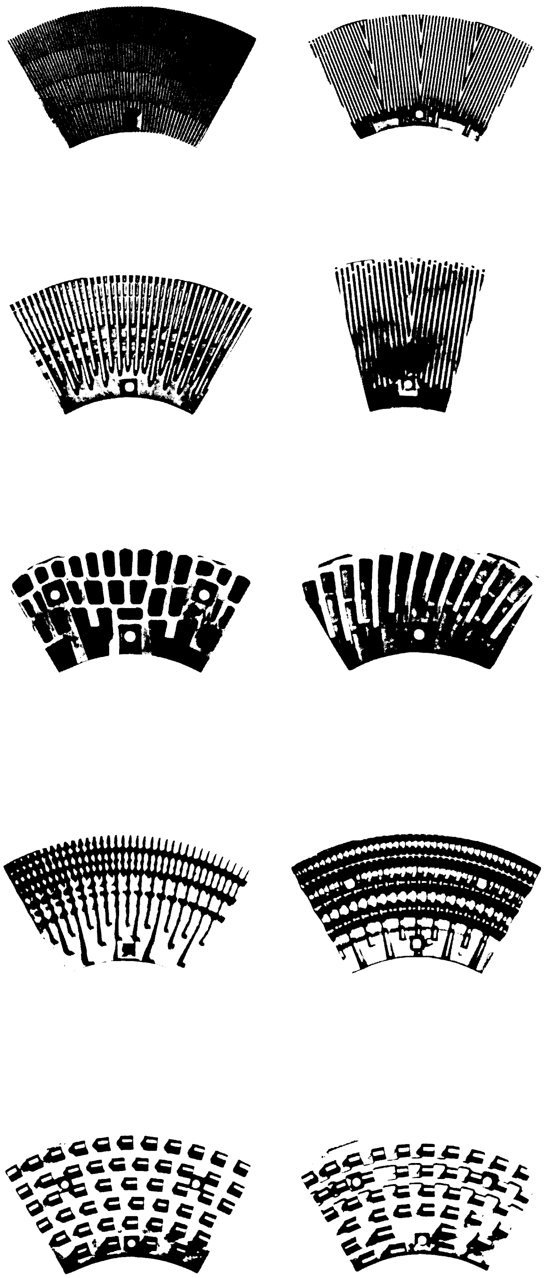


Figure 87—*General classification of Bauer refining plates (Bauer).*

unit will be set in motion by the revolving disk, will roll on the stationary plate, and will travel in a spiral path from the center to the periphery. It will be subject to two centrifugal forces; the rapid rolling will tend to "explode" the ball, while the spiral travel will work to accelerate discharge of the ball from the machine. On the other hand, a ball similarly placed between the plates of a double revolving disk unit, will receive the same but opposite impetus from each plate; it will roll rapidly but will not travel outwardly as long as it is in contact with both plates, except for other forces such as gravity, or the feeding of additional material. The only centrifugal force acting on a ball under such conditions is that tending to explode it.

Disk refiners are also classed as either primary or secondary refiners. Most of the breakdown of the chip occurs in the **primary refiner**, requiring high energy input. Secondary refining requires only about one-tenth or less of the total pulping energy. Primary refiners are thus high-powered machines, whereas **secondary refiners** are smaller, with lower power. They are sometimes called "pump through" machines.

Finally, there is the important distinction between atmospheric and pressurized refiners. **Pressurized refiners** are capable of maintaining, in the refiner housing and particularly at the refining zone, a steam atmosphere at elevated pressure levels. This has important technological consequences, to be discussed later in this chapter. **Atmospheric refiners** have no such capabilities, but, when handling liquid stock, may develop hydraulic pressures as high as 100 lb/in^2.

Atmospheric disk refining

Most atmospheric refining takes advantage of the beneficial effects of thermal treatments of the pulp chips on pulp properties. These treatments are applied to the chips in either batch type or continuous digesters.

Textor (1948) lists the following treatment categories:

a) No treatment—green chips
b) Steaming or water soaking—atmospheric pressure, temperature.
c) Steaming or water cooking—elevated pressure, temperature.

No treatment produces a pulp that is very similar to groundwood. The middle lamella is not the usual plane of failure, and the method produces a relatively slow pulp with a large portion of broken fibers and fiber bundles. It is used in dry processes not greatly dependent on the lignin bond, where freeness is not a problem, and in wet processes where surface quality requirements are not very critical. The pulping of untreated chips is energy intensive. The advantage of untreated chips is that they produce maximal yield and minimal biochemical oxygen demand (BOD) loading of process water (wet process). The second type of pretreatment produces slight improvements in the pulp. The fibers are more pliable, fewer are broken, and better felting and a stronger mat result.

The third pretreatment—steaming or water cooking—produces important changes in the wood structure. Depending on the severity of the treatment, hydrolytic breakdown of hemicellulose and lignin reduces yield and increases the BOD loading of the process water **(white water)**. The color of the chips changes to brown. Power consumption in the refining process is reduced, and the pulp is strong and pliable, improving the quality of wet formed S1S and S2S fiberboard.

Figure 88 (Textor 1958) shows an automatic Bauer rapid cycle digester for steam pretreatment of pulp chips at elevated pressures. The digester is a pressure vessel made of corrosion-resistant material, about 3 ft in diameter and about 20 ft tall, holding about 120 ft^3 of chips, designed for pressures up to 300 lb/in^2. Chip input at the top and discharge at the bottom are controlled by large-diameter hydraulically operated valves. The sequence of operation follows:

1) With bottom valve closed and top valve open the digester is filled with green chips.
2) With both top and bottom valves closed, bottom steam valve and vent valve are opened. (This fills the digester with steam and removes the air.)
3) Vent valve is closed and steam pressure built up to desired level.
4) After maintaining steam pressure for desired time, pressure is reduced by opening vent valve.
5) When pressure has dropped to about 25 to 50 lb/in^2, chips are blown into the chip bin by opening bottom valve.
6) Steam escapes into atmosphere through large-diameter blow stacks.
7) Cooked chips are conveyed to primary refiners.

A continuous digester is shown in figure 89. The horizontal pressure cylinder, made in various sizes up to a 40-in diameter and 40-ft length, is equipped with a screw conveyer. The **dwell time** (cycle time) can be controlled by a variable speed drive that adjusts the rate at which the chips are moved laterally. The cylinder is sealed at both ends by rotary valves that charge and discharge chips into and from the digester at a constant rate. Steam is admitted to the cylinder, and the cooking conditions are maintained continuously. (See also Atchison and Agronin 1958.)

Cooking conditions depend greatly on wood species. Softwoods require longer cycles than hardwoods. The more severe the cooking conditions, the greater are the hydrolytic loses, the lower the yield, and the greater the contamination of white water with biodegradable materials. On the other hand, more severe cooking conditions result in cleaner fiber separation and availability of more lignin for bonding. The tendency in the industry is to reduce steam pressures in the interest of greater yields and lower white water BOD levels.

A northern wet-process hardboard mill reports the following practical cooking cycles in rapid cycle digesters (Eustis 1980):

Product type	Species	Cooking cycle
S2S	Poplar	180 lb/in² steam pressure; 2-min treating time
S1S	50:50 oak-birch	150 lb/in² steam pressure; 30-s treating time

Should the species composition of the S1S furnish change so that the oak component exceeds 60 percent of the total, then the cooking cycle must be shortened. Should the oak component drop to less than 40 percent, the cooking cycle must be lengthened. With straight pine, the cook would have to exceed 2 min.

A southern insulation board mill reports a cooking cycle of 6 min at 190 lb/in² steam pressure for pine chips.

In winter, allowances must be made in the cooking cycle for frozen wood. This is done by increasing the vent cycle from 15 s in the summertime to at least 1 min in the winter. This allows the ice to melt before steam pressure is applied (Eustis 1980).

A northern hardboard siding mill produces most of its furnish on atmospheric refiners without cooking.

Feeding of refiners. For consistency in output quality, refiners should be charged to run at full load. This can best be accomplished with single- or twin-screw feeders or coaxial feeders that force-feed the treated chips into the refiners at a constant and controllable rate (figs. 90, 91). Such feed systems require an oversupply of chips at the refiners in order to avoid the possibility of shortfalls. Surplus chips are returned to the chip bins (fig. 92).

Refiner variables. The goal of the refiner operation is the production of a pulp ideally suited for the manufacture of a particular board product. This desired pulp quality is difficult to define in simple terms. It includes freeness, fiber length distribution, springiness, and other quality elements that may only be expressed in terms of final product properties. Neither are these quality elements controlled entirely by refining variables. They are also influenced and limited by raw material qualities such as species and by the cooking conditions.

The dominating operation variable is the throughput rate, which influences the specific energy, i.e., the energy required per unit weight of pulp produced. Figure 93 illustrates the interrelationship between this operation variable and various pulp and sheet properties, of which the freeness or drainage time is the most important for fiberboard manufacture.

In practical operations—given a certain raw material and a certain pretreatment—the freeness of the stock on the forming machine is used as the primary indicator for controlling refiner operation. These freeness re-

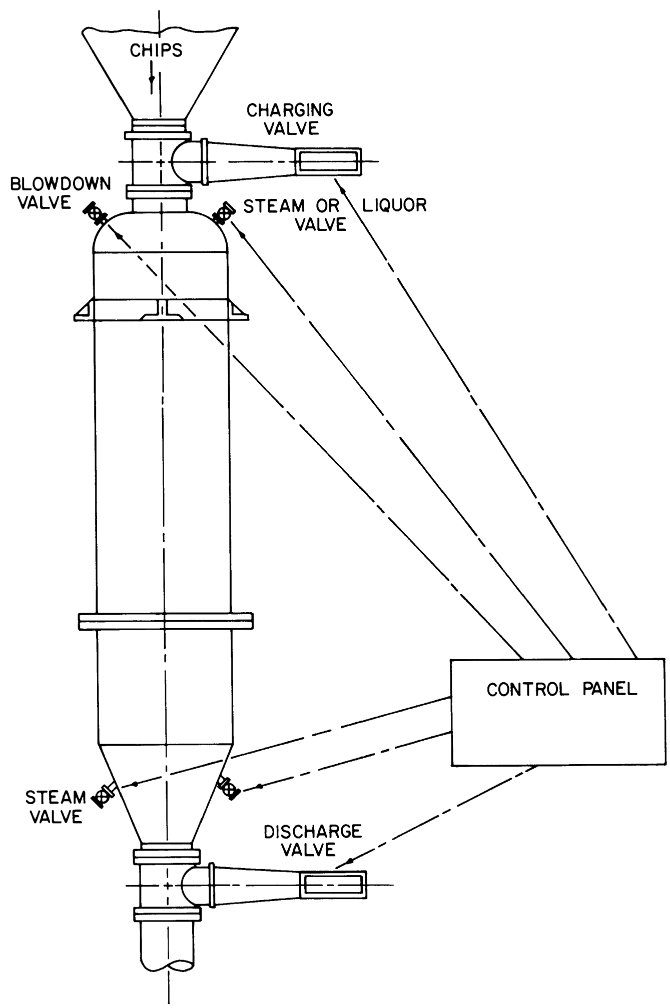


Figure 88—*Automatic Bauer rapid cycle digester (Textor 1958).*

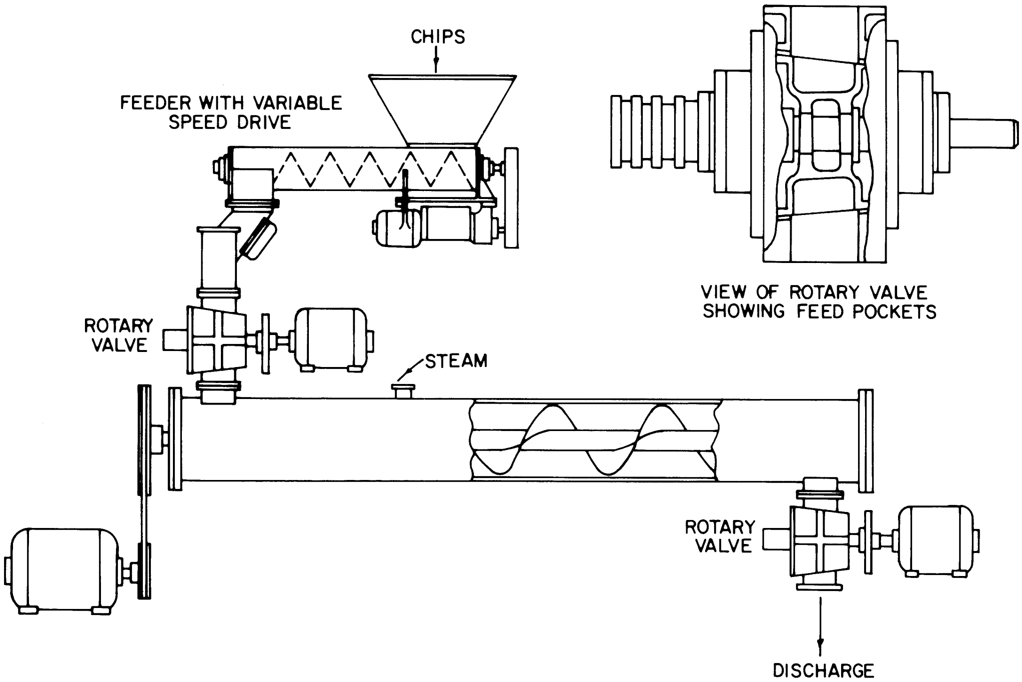


Figure 89—*Grenco continuous digester (Atchison and Agronin 1958).*

quirements vary from process to process and from plant to plant. If the stock is not free enough, for instance, the plate gap would be opened. This increases the freeness of the stock and—running the refiner at capacity—also increases the throughput rate. The energy input per ton of stock produced (specific energy) would decrease.

Average specific energy levels required for various product categories are listed below:

Product	Specific energy level
Dry-formed fiberboard	10–11 hp · d/ton
Insulation board	20–30 hp · d/ton
S1S and S2S wet-formed hardboard	20-30 hp · d/ton

The effects of consistency changes and plate wear on pulp freeness are shown in figures 94 and 95. With relatively new plates, increasing consistency initially slows the pulp slightly (reduction of CSf), and then at higher consistencies the CSf increases rapidly (pulp becomes faster). Worn plates produce a much slower pulp at low consistency, but at higher consistency produce faster pulps than new plates. Thus, consistency could be varied in an effort to counteract the effect of plate wear on pulp freeness. Plate design itself is, of course, a major variable. Some aspects of it are discussed in a Tappi report on refiner variables (Anon. 1971) and in an article on the hydraulic behavior of the refiner (Leider and Rihs 1977).

Selection of refiners. Primary refiners are selected on the basis of their capacity. The specific energy levels for various product categories listed above may serve as guidelines. Most of this energy is applied in the primary pulping stage. Secondary refiners apply approximately 1 to 2 hp · d/ton. As an example, a 100-ton-per-day insulation board plant would require as a refining capacity:

$$25 \text{ hp} \cdot \text{days/ton} \times 110 \text{ tons/day} = 2{,}500 \text{ hp}.$$

This could be handled by one Bauer 412 double-disk refiner (2,500 hp) or by three Bauer 411 double-disk refiners (1,000 hp each) (figs. 96, 97). The three 411's would be the better choice, because interruptions such as plate changes or other down times would not affect the total refiner capacity of the mill. Also, the three 411 machines would provide the needed extra capacity to make up for losses in the system. Secondary refining in the above example would only require 200 hp (1 to 2 hp · days/ton), which could be handled by a 32-in Bauer 442, for instance (figs. 98, 99). The secondary refiner operates at a much lower consistency than the primary. Its purpose is to fine-adjust the freeness just ahead of the forming machine. In some mills, control of the secondary refiner is assigned to the forming machine operator. It is also often located in the machine white water cycle

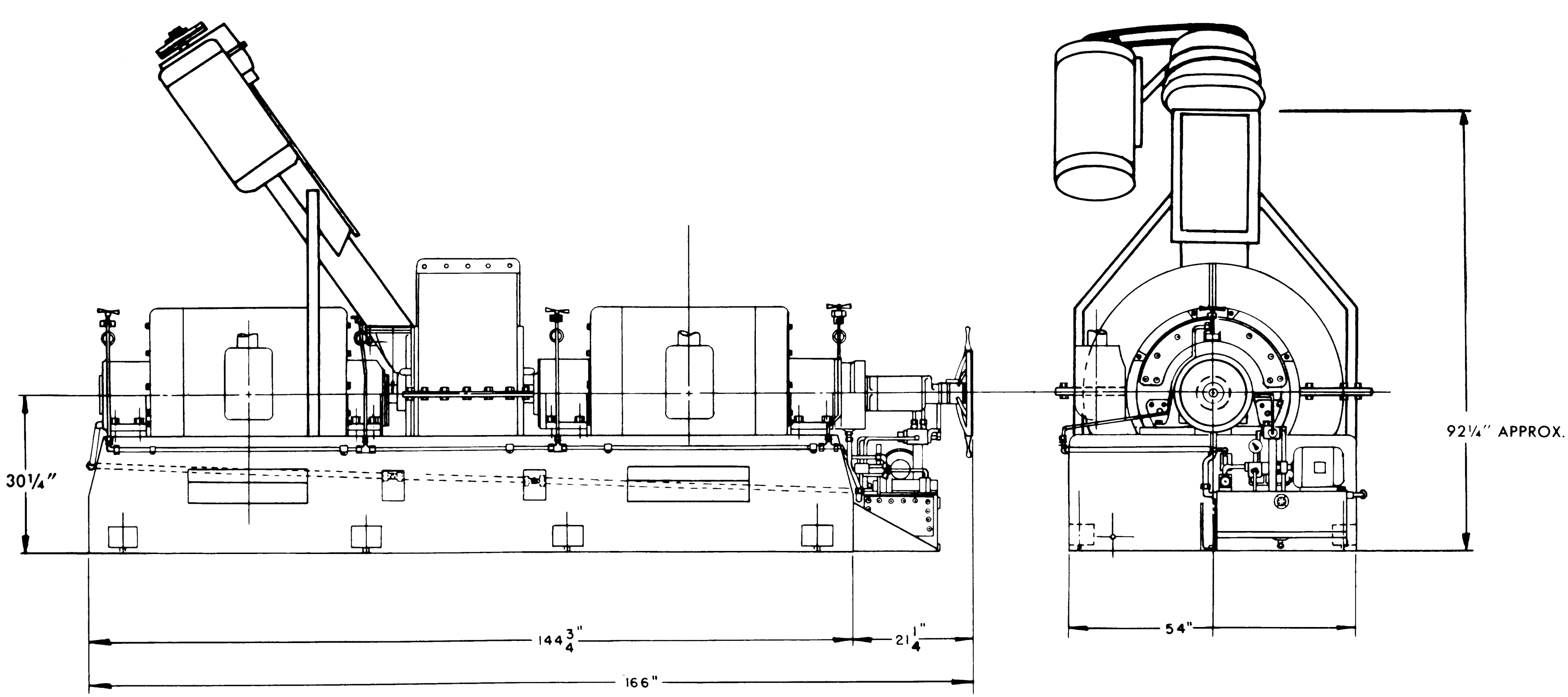


Figure 90—*Bauer refiner with twin-screw feeder (Bauer).*

discussed later (fig. 114). Secondary refiners are not an absolute necessity, and some mills operate without them. Figure 100 shows equivalent single-disk refining equipment offered by Sprout-Waldron.

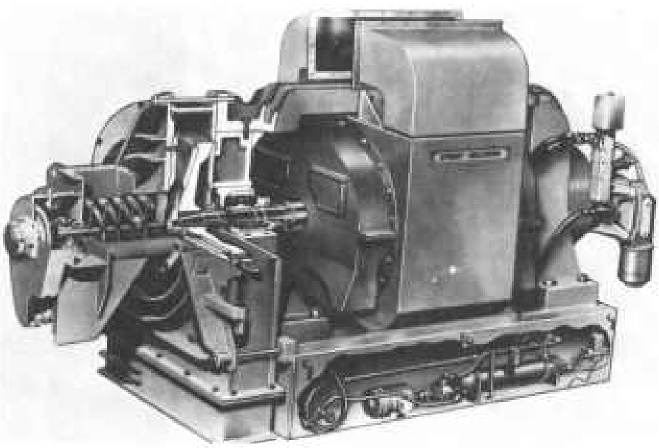


Figure 91—*Sprout-Waldron refiner with coaxial feeder (Sprout-Waldron).*

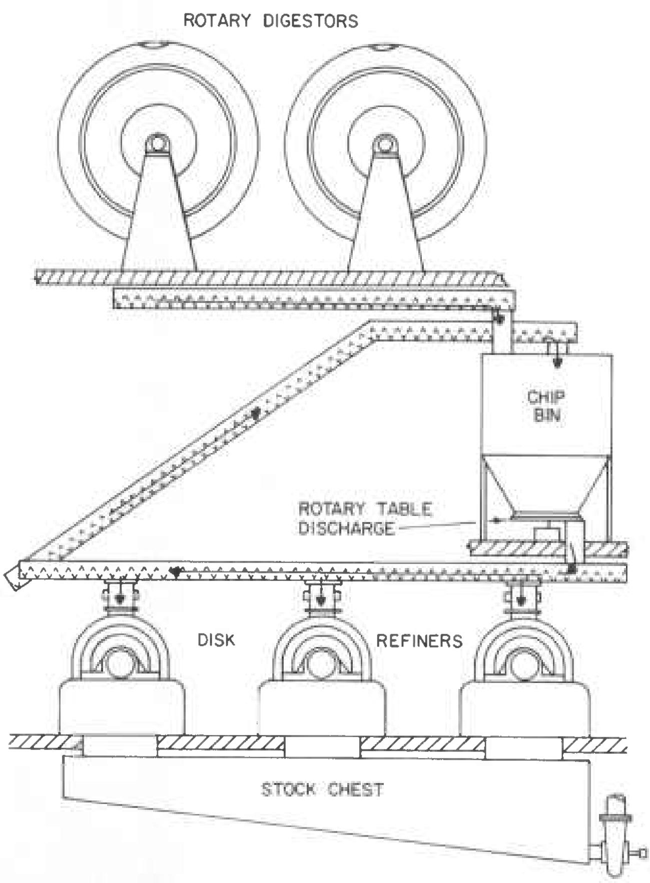


Figure 92—*Flow sheet of system for pretreating and refining wood chips (Textor 1948).*

Pressurized disk refining

General. Pressurized refiners, of which the Asplund defibrator is the prototype, are disk grinders in which chips are defibrated in an atmosphere of pressurized, saturated steam. They consist of a preheater, a disk mill, and infeed and outfeed devices that maintain the internal steam pressure.

Figure 101 (Sunds Defibrator) is based on investigations by Asplund. It shows the significant drop in the power required to fiberize softwood and hardwood chips when the refiner temperature exceeds 300 °F. This reduction of power required is attributed to the thermal softening of the lignin, allowing relatively easy mechanical

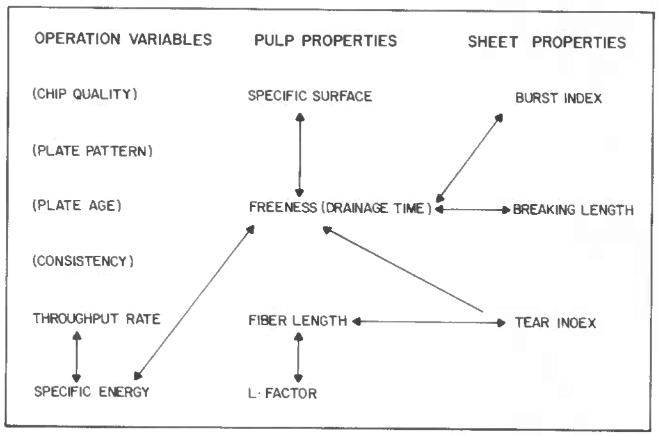


Figure 93—*Schematic illustration of interrelationships between specific pulping energy and various pulp and sheet properties (Johnson and El-Hosseiny 1978). (© 1978 TAPPI. Reprinted from Tappi Journal, December 1978, with permission.)*

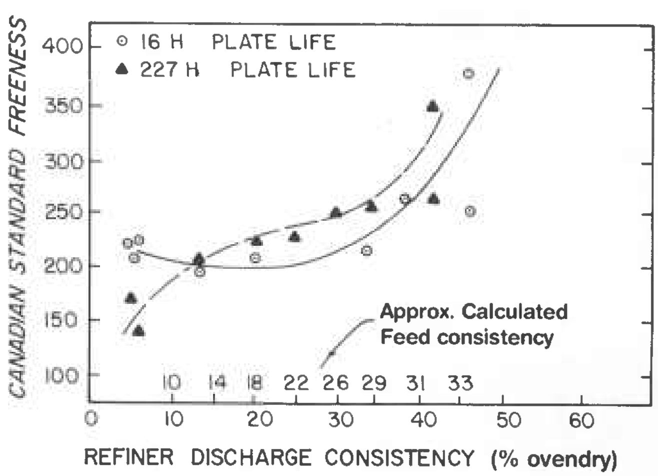


Figure 94—*Effect of refining consistency on freeness of unscreened pulp (after Mihelich 1972). OD = ovendry.*

separation of fibers along the middle lamella, and is the technological base for the pressurized refining process.

The Asplund defibrator and its operation. An overall view of an Asplund defibrator is provided in figure 102. It consists of these main components: the chip feeder, the preheater, the defibrator disk mill, and the pulp discharge (not shown). Because the entire machine is pressurized and throughput is continuous, the infeed and the outfeed ends of the machine are sealed against the internal steam pressure, while the chips are continuously fed into the preheater and the pulp is continuously discharged to atmospheric pressure.

The process sequence, shown in figure 102, follows:

a) From the chip chute (1) the green chips are fed (2) into the screw feeder (3), which features a conical horizontal feed screw rotating in a conical feed pipe and enforcing a considerable compaction of the pulp chips. Compression ratios are variable, but they are high enough so that the moving densified chip plug (4) blocks the escape of steam from the preheater. Splines in the plug pipe prevent the plug from rotating and pressed-out water is removed through drainage holes.

b) As the compressed chip plug enters the preheater (6) it falls apart in the steam atmosphere (5). The preheater is a vertical cylinder of about 2 ft in-

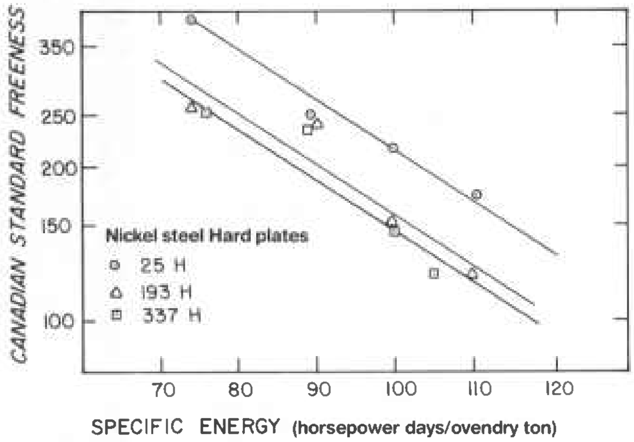


Figure 95 — *Effect of plate wear on freeness (after Mihelich 1972).*

Figure 96—*Bauer 412 double-disk refiner (Bauer).*

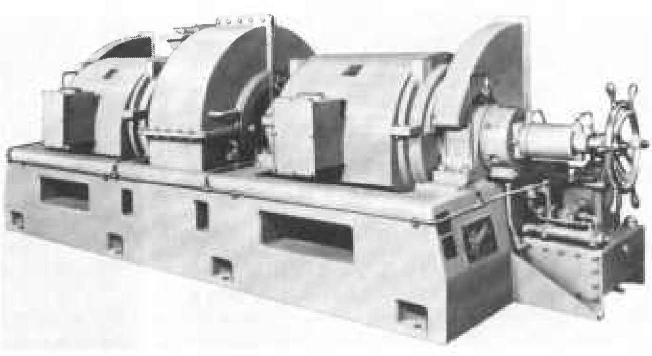


Figure 97—*Bauer 411 double-disk refiner (Bauer).*

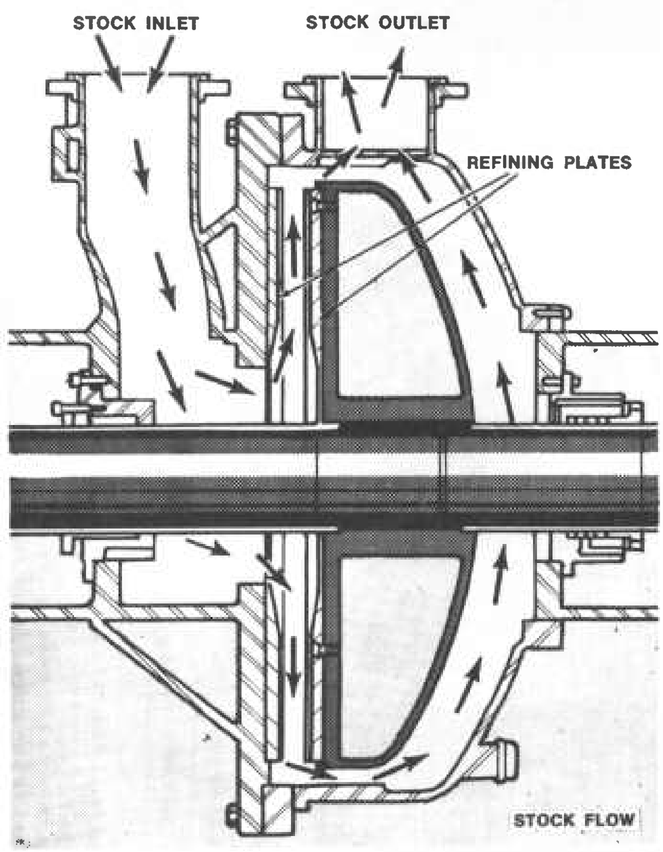


Figure 98—*Bauer pump-through refiner (Bauer).*

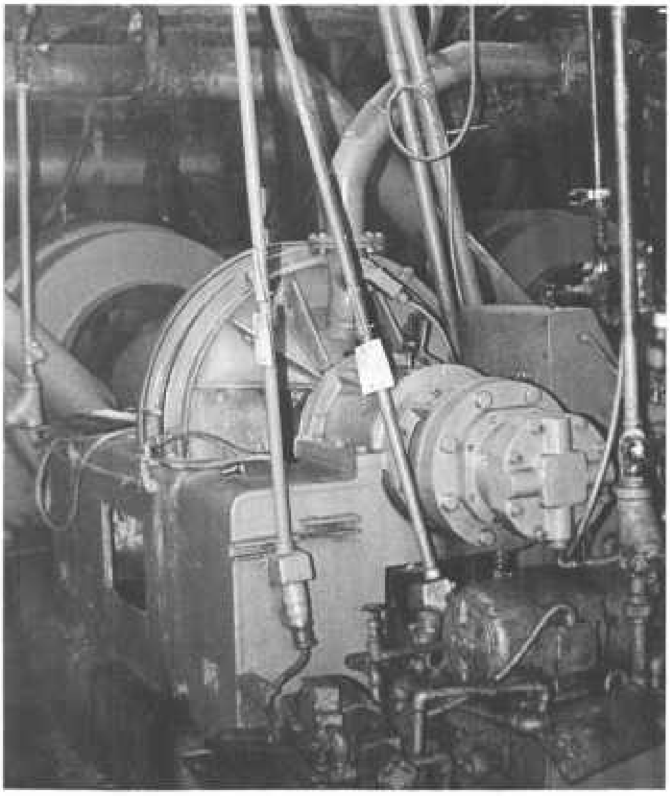
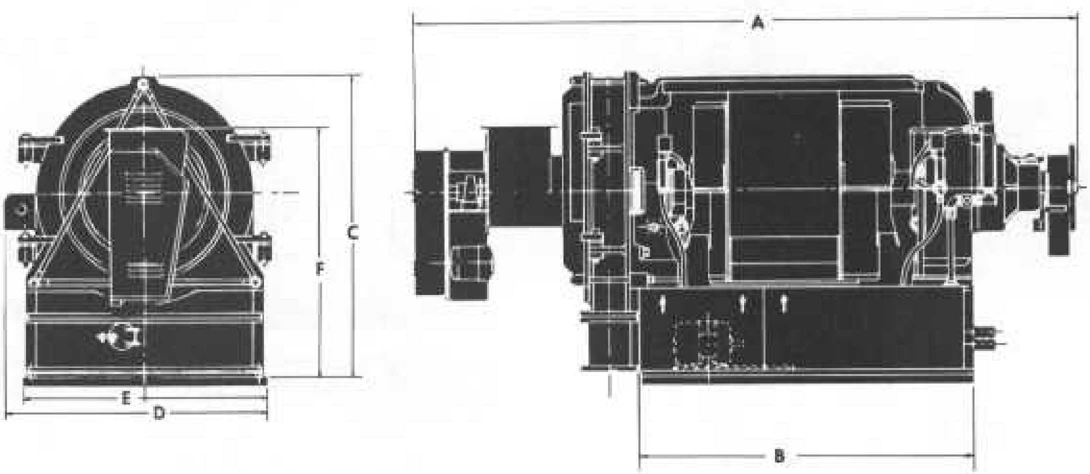


Figure 99—*Bauer 442 refiner.*

side diameter and 10 ft or more height, depending on capacity required and on the necessary heating time. At a given rate of chip removal from the bottom, the preheating time is controlled by the level of the chips in the preheater. This is accomplished by means of a gamma ray level controller (7), mounted outside the preheater, that senses the fill level and maintains it by regulating the speed of the feeder screw. A higher fill level increases the preheating time.

c) A conveyor screw (8) at the bottom of the preheater feeds the softened chips into the center of the defibrator mill (9). This consists of two grinding disks, a stationary one mounted to the housing and a rotating one mounted on the main shaft rotor. Each grinding disk carries six steel alloy grinding segments, profiled for a shearing action to defiberize the chips. As they are ground, the chips are forced outward from the center through the gap between the disks to their periphery. The 0.008- to 0.016-in gap between the disks is controlled by adjusting the pressure differential on both sides of an oil-hydraulic piston.

d) The pulp is discharged to atmospheric pressure through a reciprocating valve discharge chamber



Model	Drive	Speed	A	B	C	D	E	F	Approx. Shipping Weights Domestic	Export
36-1B	300-1000 hp	1500/1B00 rpm	12'-11"	6'-B"	6'	5'-4"	5'	5'	26,500 lbs.	27,500 lbs.
42-1B	1250-2500 hp	1500/1800 rpm	13'-4"	6'-B"	6'	5'-4"	5'	5'	29,000 lbs.	30,000 lbs.

Figure 100—*Sprout-Waldron primary single-disk refiners (Sprout-Waldron).*

to a cyclone that separates pulp from steam. Another version uses a blow pipe that blows the pulp through an orifice with minimal steam losses to the system.

The total dwell time of the chips in the defibrator, including preheater, is about 1 min for fiberboard pulp.

Table 18 shows specifications and capacities for various models of defibrators. Figure 103 shows a Type 42 defibrator in a Swedish fiberboard mill.

Defibrator pulp is of light color, just slightly darker than the color of the original wood (Lowgren 1948). Under the microscope, defibrator pulp looks very much like sulfate pulp. It consists of individual fibers with undamaged walls, providing good drainage properties. It is considered to be a springy, bulky pulp. Like Masonite pulp, defibrator pulp cannot be fibrillated and is, therefore, unsuited for paper manufacture; but in conjunction with chemical treatments to remove some or all of the lignin, the pulp develops characteristics similar to those of other semi- or full-chemical pulps and is suitable for paper.

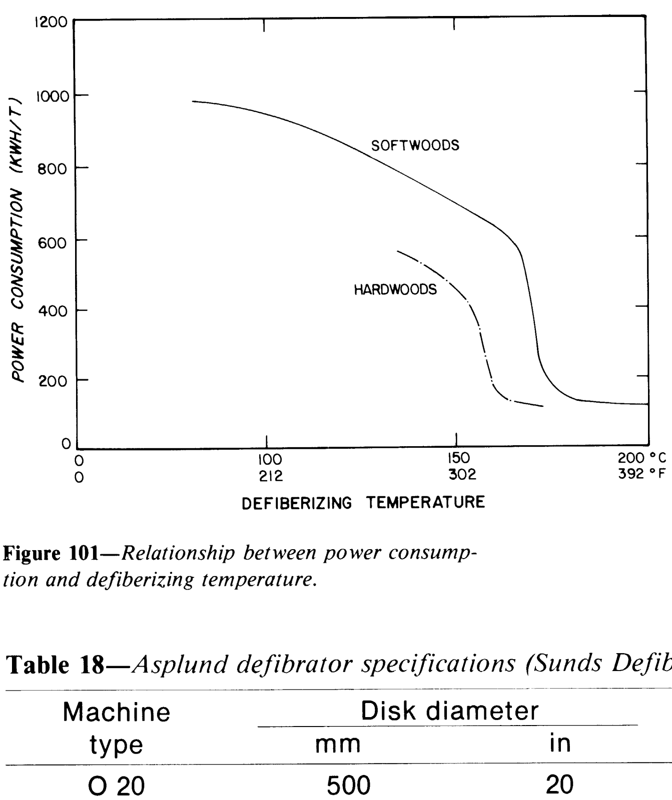


Figure 101—*Relationship between power consumption and defiberizing temperature.*

Asplund defibrators are used for both wet- and dry-formed hardboard and medium-density fiberboard.

The Sprout-Waldron pressurized refiner. This pressurized refiner system is very similar to the Asplund defibrator. Figure 104 (Sprout-Waldron) shows the system components. The disk mill is a single revolving disk type machine like the defibrator. Specifications are listed in Table 19. Capacities are given as up to 200 tons/d for the 36-in unit and up to 400 tons/d for the 42-in unit. A 42-in Sprout-Waldron pressurized refiner in a hardboard plant is shown in figure 105. This machine has a horizontal preheater in which a conveyor screw transports the chips. A disk segment is shown in figure 106.

Sprout-Waldron pulp characteristics are very similar to those of defibrator furnish. The pressurized refined fiber is used for both wet- and dry-formed hardboard and for medium-density fiberboard.

The Bauer pressurized refiner. An overall view of the Bauer pressurized refining system is provided in figure 107 (Bauer). The Bauer 418, like the 420, is a double-disk refiner (both disks revolving). The infeed end is sealed by a rotary valve (fig. 108). The preheater is the horizontal type; heating time is determined by the speed of the conveyor screw. A cross section of the disk refiner

Table 18—*Asplund defibrator specifications (Sunds Defibrator)*

Machine type	Disk diameter mm	Disk diameter in	Max. motor size kW	Max. motor size hp	Capacity (ton/day)
O 20	500	20	200	270	10-15
O 24	600	24	300	400	15-20
L 32	800	32	800	1,100	20-70
L 36	900	36	1,200	1,600	50-100
L 42	1,070	42	2,500	3,400	75-200

Table 19—*Sprout-Waldron pressurized refiner specifications (Sprout-Waldron)*[1]

Model	Disk diameter (in)	Max. hp	r/min (60 Hz)	Length (ft)	Width (ft)	Height (ft)	Weight (lb)
36-1CP	36	1,000	1,800	8 3/4	4	4 3/4	12,000
42-1CP	42	3,000	1,800	8	4 1/2	5	13,500

[1]Data are approximate.

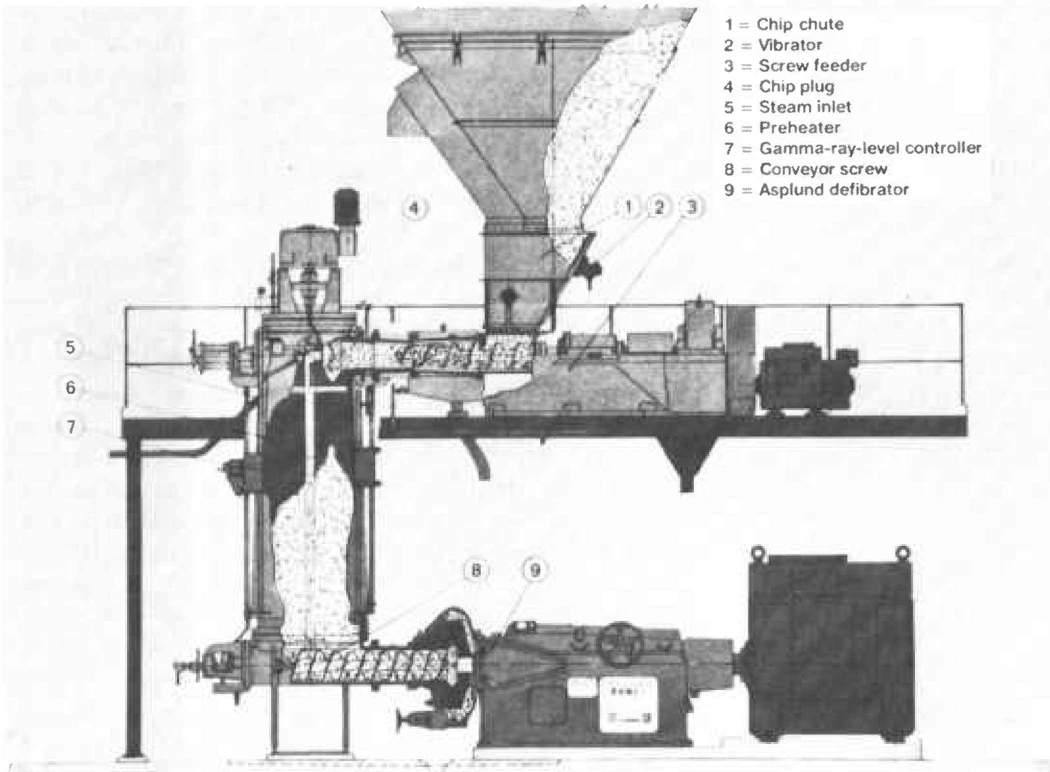
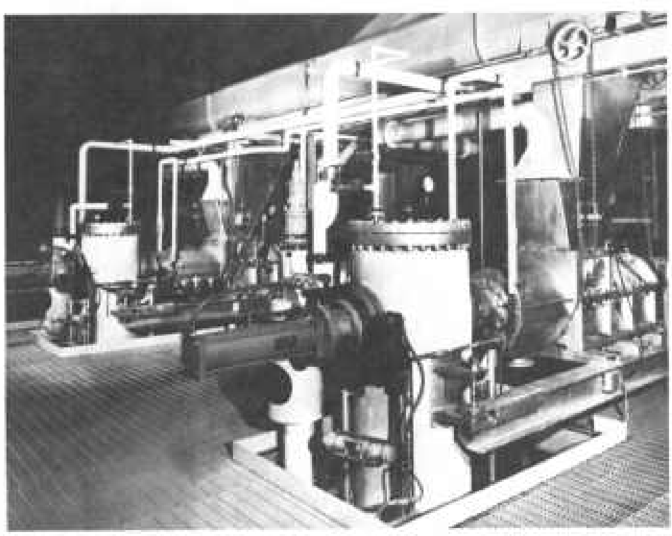


Figure 102—*Asplund defibrator pulping plant (Sunds Defibrator).*

A



B

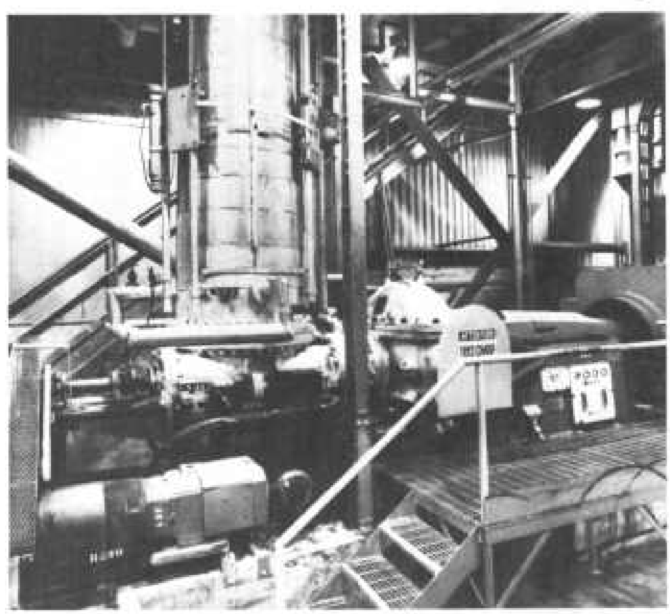


Figure 103—*Installation of Type 42 defibrator in fiberboard mill (Sunds Defibrator).* **A**—*Chip chute and top of preheater.* **B**—*Lower part of preheater feed screw drive and defibrator.*

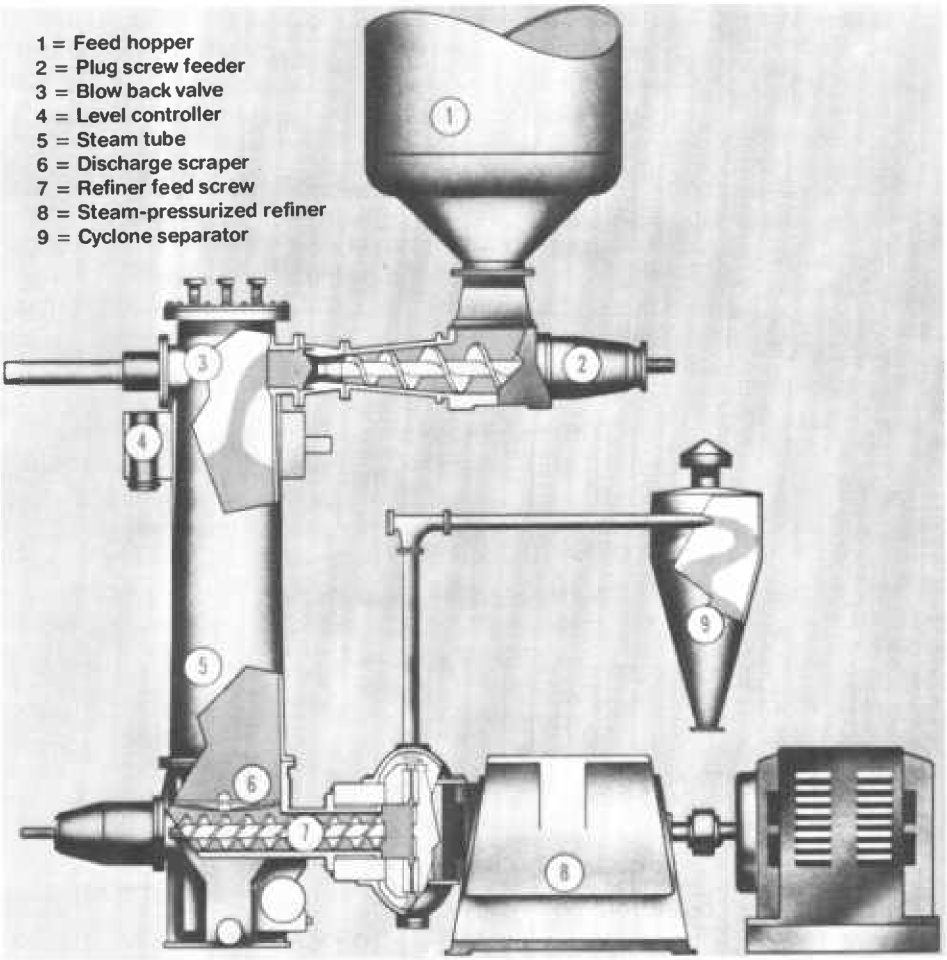


Figure 104—*Sprout-Waldron pressurized refining system (Sprout-Waldron).*

A

B

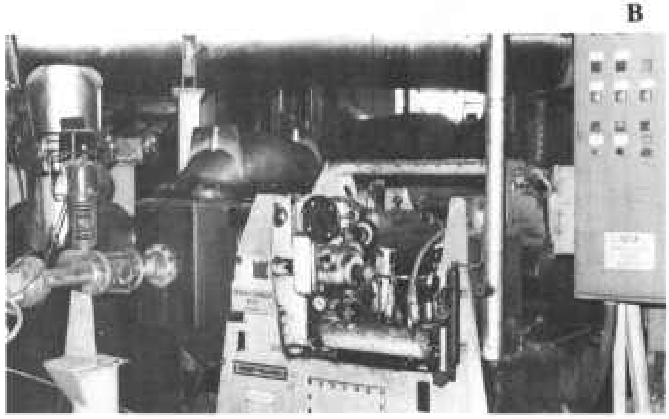


Figure 105A—*Sprout-Waldron pressurized refiner with housing opened to show disk pattern.* **B**—*Sprout-Waldron 42-in pressurized refiner in hardboard mill.*

Figure 106—*Plate segment of Sprout-Waldron 42-in pressurized refiner.*

showing the twin disks and the stock flow is illustrated in figure 109. Figure 110 shows a selection of refiner disk segments used on the 418 (36-in diameter) and the 420 (40-in diameter). The medium-type plate profile is used in the fiberboard industry.

The 418 pressurized refiner was an important element in the development of the dry-formed medium-density fiberboard process in the 1960's. It produces a fluffy, bulky pulp that requires considerable compression—a prerequisite for the development of favorable gluing conditions—when densified to moderate board densities. This kind of fiber would be too fluffy to make good wet-formed fiberboard.

The described refiners are also used in the manufacture of pulp for dry process board of high- and medium-density. But special considerations must be made when manufacturing pulp for dry process boards.

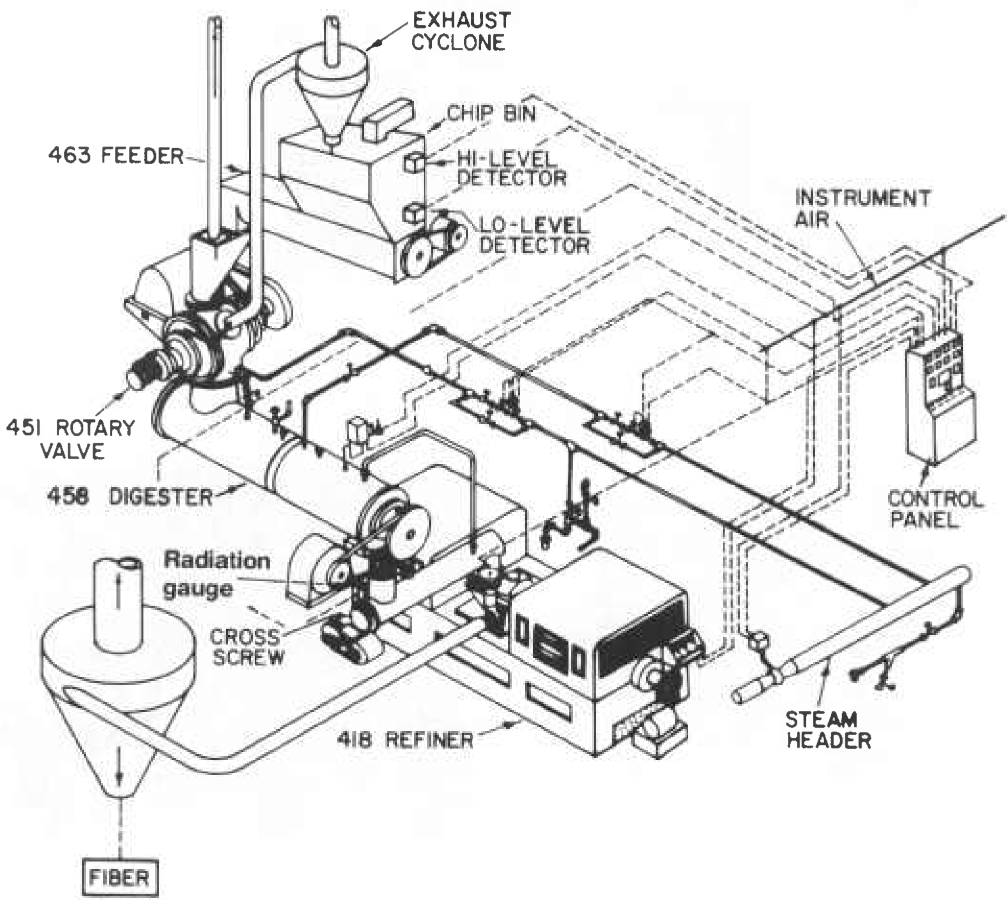


Figure 107—*Bauer 418 pressurized refining system (Bauer).*

In producing dry pulp, one important pulp characteristic—freeness—can be disregarded. Strength-developing characteristics such as fines content, particle size distribution, and bullk density are of primary importance.

Large fractions of fines tend to attract excessive resin binders without contributing significantly to board strength. Particle size distribution is strongly affected by pretreatment and has important consequences with regard to board surface quality and strength.

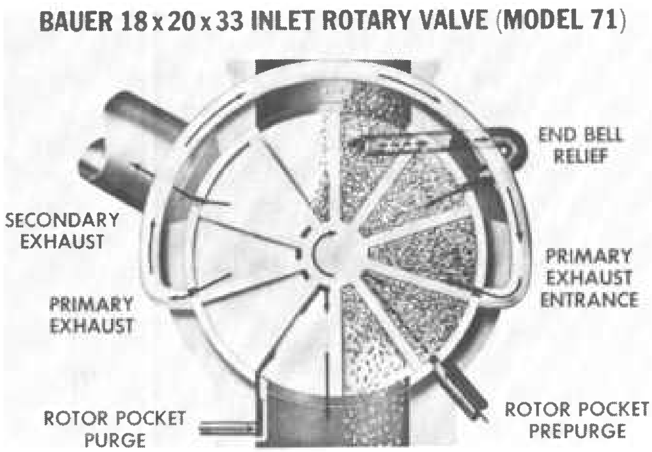


Figure 108—*Bauer inlet rotary valve model 71 (Bauer).*

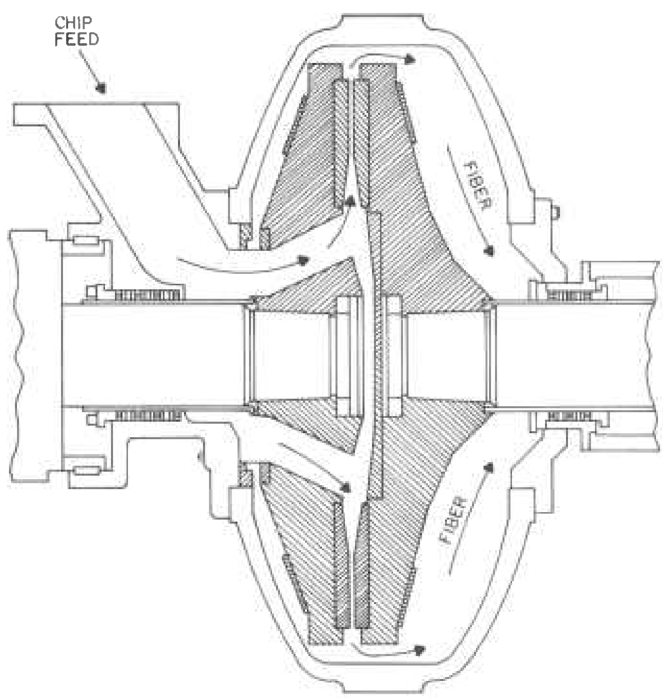


Figure 109—*Cross section of Bauer pressurized refiner showing stock flow (Bauer).*

Reasonably low bulk density is particularly important for the manufacture of medium-density dry process fiberboard. Dry fiber furnishes of bulk densities below 2 lb/ft^3 are considered superior.

High consistency refining

In most wet-process atmospheric refiners, water is added to the chip feed to reduce consistency to about 12 to 14 percent of dry wood content. More water may be added after the refined fiber leaves the refiner disks to make the furnish pumpable (1 to 2 percent consistency). (High-density pumps can handle pulp consistency of up to 10 to 12 percent.)

High-consistency refining refers to the refining without adding water to the refiner. Vacuum is applied to remove the furnish from the refiner case. The resulting pulp is finer and freer. This allows higher machine speeds, and, because the mat is fluffier, more water can be squeezed out in the first phase of the press cycle. Forming machine consistency is, of course, the same as with conventional pulping, about 1 to 2 percent. The result is a shorter press cycle, or improved fiber.

The reduced density of the mat is a disadvantage in the wet S2S process because it is more fragile, breaks easily, and burns more readily. Here, high consistency refining may be applied to only part of the furnish to free up the stock and to speed up the machine.

Increasing the consistency in single disk refiners and opening the plate gap forms a pad of pulp between the

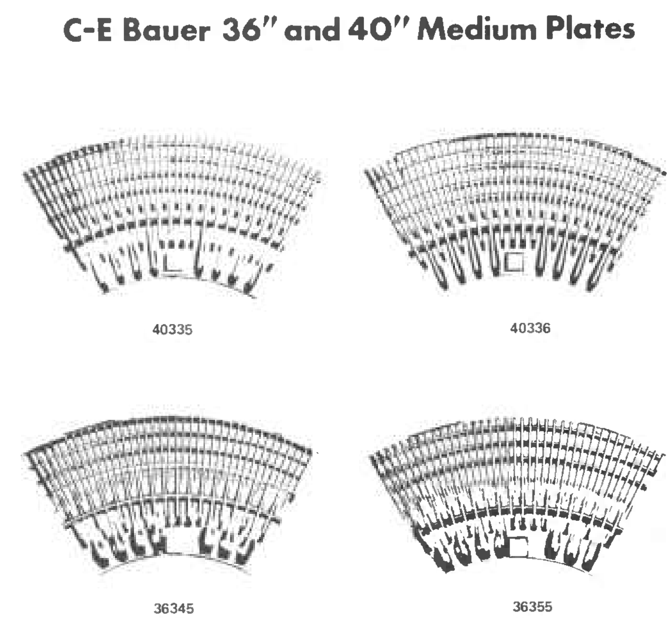


Figure 110—*Medium-type plate segments as used in Bauer 418 pressurized refiner (Bauer).*

plates, which produces a highly satisfactory furnish at lower power consumption. It is claimed that in this case the wood is defiberized by wood-to-wood contact. If consistencies are too high, steam will develop and rupture the pad between the plates, allowing chips and shives to leave the refiner, which ruins the pulp (Eustis 1980). Special attention should be given to the safety aspects of this practice. Pressurized refiners are essentially high-consistency refiners. Dry process refining is always high-consistency refining (no water added).

Pulp Washers and Screw Presses

Pulp washers and pulp presses are used only in the wet process. Their purpose is to remove dissolved solids—hemicelluloses—from the pulp. These substances, if retained, can cause the board to stick to the press platens and generally impair board quality. The principle of screw presses and pulp washers is to remove the "contaminated" water and replace it with fresh water. The dissolved solids are, however, the primary water pollutants generated in wet-process fiberboard plants. Their removal and subsequent treatment is a significant cost factor and requires careful analysis.

The trend is to either produce a salable product from the dissolved solids or to recycle as much of the process water as possible and to allow the dissolved solids to build up to the maximum tolerable level.

A vacuum **pulp washer** is shown in figure 111 (Dorr-Oliver). A wire-mesh-covered cylinder revolves in a vat to which the diluted pulp is supplied. A water leg[1] applies vaccum to the interior of the cylinder, causing water from the vat to flow through the wire mesh, depositing the thickened pulp on it. A stream of fresh water supplied by shower pipes to the outside of the revolving pulp mat and drawn through it by the vacuum completes the washing process. Elevated temperatures and a pH of around 5 improve its efficiency.

A series-combination of vacuum washers is shown in figure 112. The filtrate from each succeeding stage is returned as wash water and dilution water for the previous stage.

This results in a concentrated filtrate discharge. Since the wash water runs in the opposite direction of the pulp, these are called **countercurrent washers.**

Figure 113 (Bauer) shows a continuous rotary **pulp press** designed to dewater refined pulp. The dewatering occurs as the pulp is forced into a conical cage by the feed screw. Pressures of several thousand lb/in^2 are developed, forcing the water through screens into the machine housing. The water removal in percentage of total water content is much greater in screw presses than in vacuum washers. Discharge consistencies of vacuum washers are about 12 to 14 percent, those of screw presses up to 75 percent.

A pulping system, including screw presses, is charted in figure 114 (Superwood). The process water system is divided into a primary and a secondary white water cycle. The screw presses keep practically all of the dissolved solids out of the machine white water system (secondary cycle), allowing recycling of the machine water. The primary white water cycle is also recycled from the screw press to the cyclone. This system reduces the white water discharge to a very low level, which in this particular installation is being handled by the municipal treatment plant. Fresh water demands are similarly reduced.

The Pulping of Bagasse

Although the use of bagasse is limited to the manufacture of insulation board at the Celotex plant in Marrero, LA, it has historical significance and has played an important part in the development of the fiberboard industry.

Bagasse fibers are very similar to wood fibers in size and structure (fig. 3), and the equipment used for pulping bagasse is the same as that used in pulping wood chips.

Before and during the mechanical extraction of the sugar juices, the cane stalks are chopped and crushed. This residue, at a moisture content of about 100 percent, is stored and aged at the board plant in large piles for about a year. During this period, pasteurization of the bagasse brings about a retting and softening without loss of strength and springiness of fibers.

Formerly, at the Marrero plant, the aged bagasse was steam cooked in batch digesters, then reduced in hammermill-type shredders and refined in Claflin refiners. Today, the aged material is refined directly without cooking in Sprout-Waldron atmospheric refiners. Single-step refining is used for insulation board; secondary refining is added to make ceiling tile. Small portions of recycled paper stock are added to the furnish.

In all other respects the manufacture of bagasse boards is practically identical to that of boards made from wood fiber furnish.

[1]A water leg, measured in feet, indicates the vertical distance between two water levels. Water falling through a vertical pipe from the higher to the lower level creates a suction force proportional to the water leg.

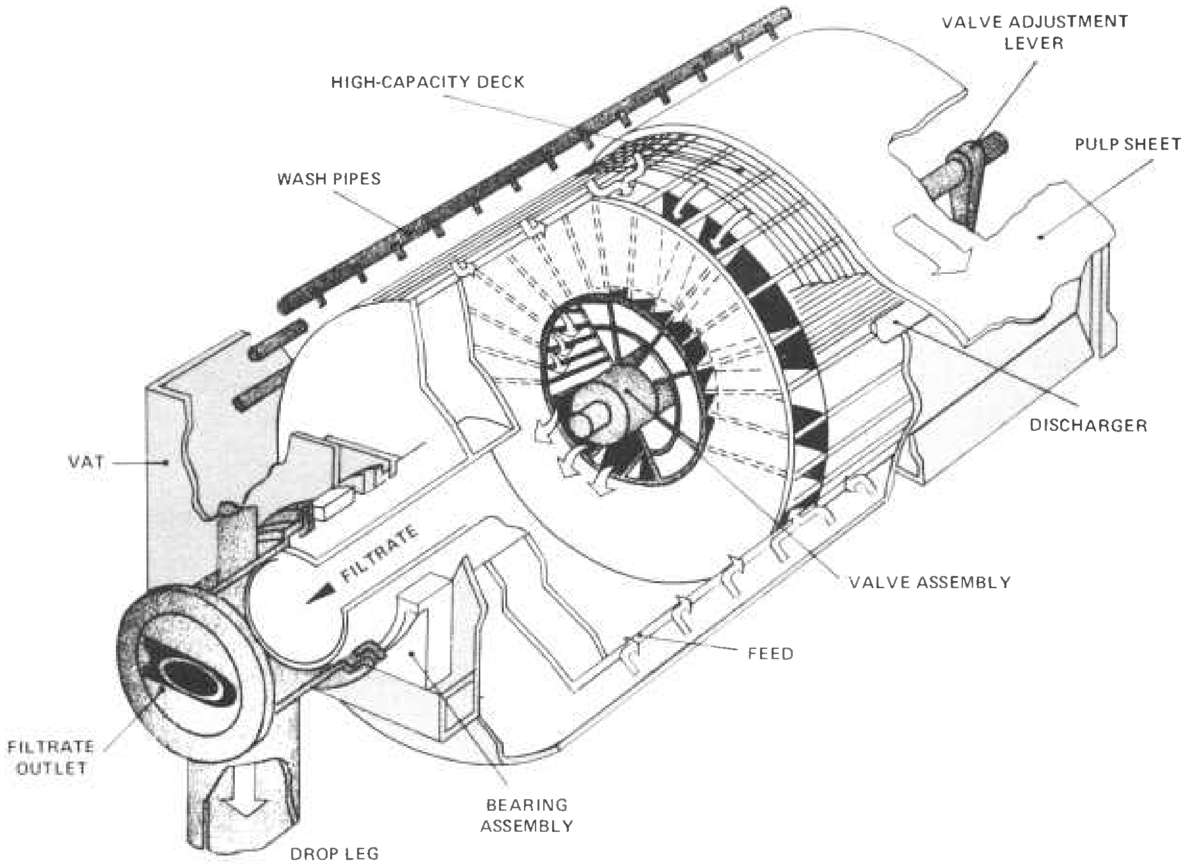


Figure 111—*Principle of vacuum pulp washer (Dorr-Oliver).*

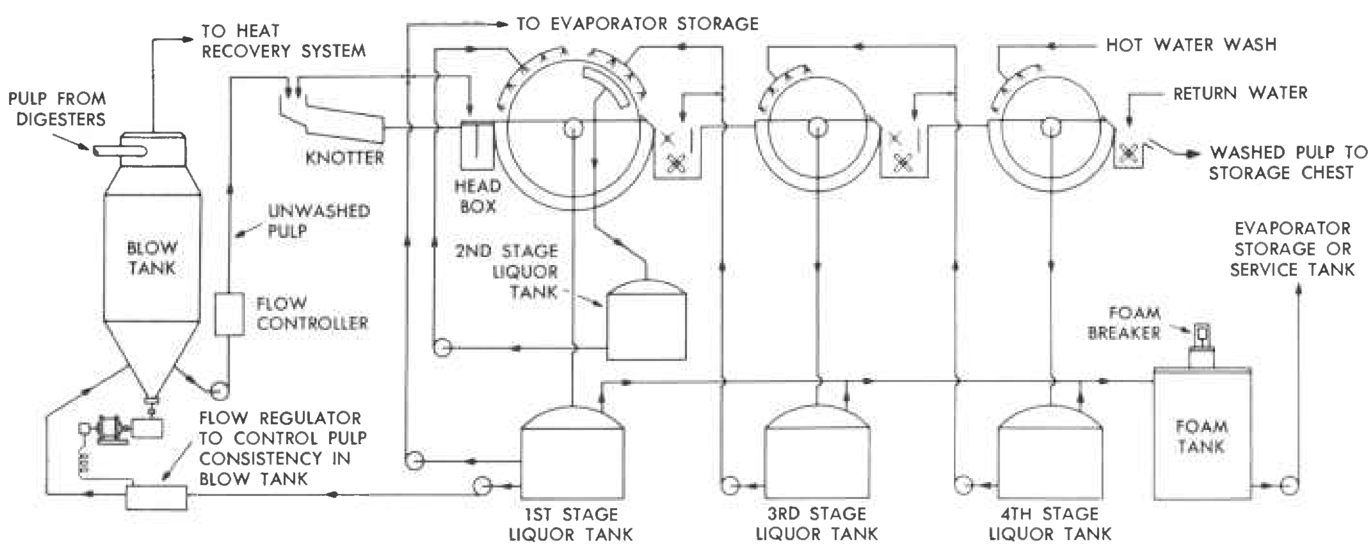


Figure 112—*Principle of four-stage Oliver washing system with three washers (Dorr-Oliver).*

Process Control

General

Essential to the production of high-quality fiberboard is consistency in the performance of every processing unit. Such consistency can only be maintained by frequent or continuous measurement of accessible in-process material characteristics, and the appropriate adjustment of processing equipment to counteract the effect of disturbances. This requires, of course, knowledge of the relationship between processing equipment parameters and in-process material characteristics.

In a pulping operation, disturbances can be generated by variation in the raw material composition, by wear of refiner plates, by the general variability of the performance of equipment, and by many other known and unknown causes.

In its simplest form, process control consists of measurement of a process characteristic (liquid level in a storage tank) and the manual adjustment of an appropriate process element (liquid inlet valve) when a disturbance occurs. This process of responding in a predetermined fashion to a measured disturbance can readily be automated.

Computer control

The computer adds the capability of mathematical treatment of measured data and tremendous data storage capacity. It allows much faster scanning of process signals; storage of such signals; calculation of derived measurements such as yield data, energy input per ton of product, etc.; and even the subsequent control of such derived measurements. The computer extends automated instrument process control to very complex systems where large numbers of variables interact. In addition, it provides recall of stored process records for the purpose of further analysis.

Computer control of pulping process

The building blocks of the control system are the control loops. Each loop consists of a transducer that measures the quantity to be controlled and transmits the results of the measurement to the computer and an actuating process element that either stabilizes the con-

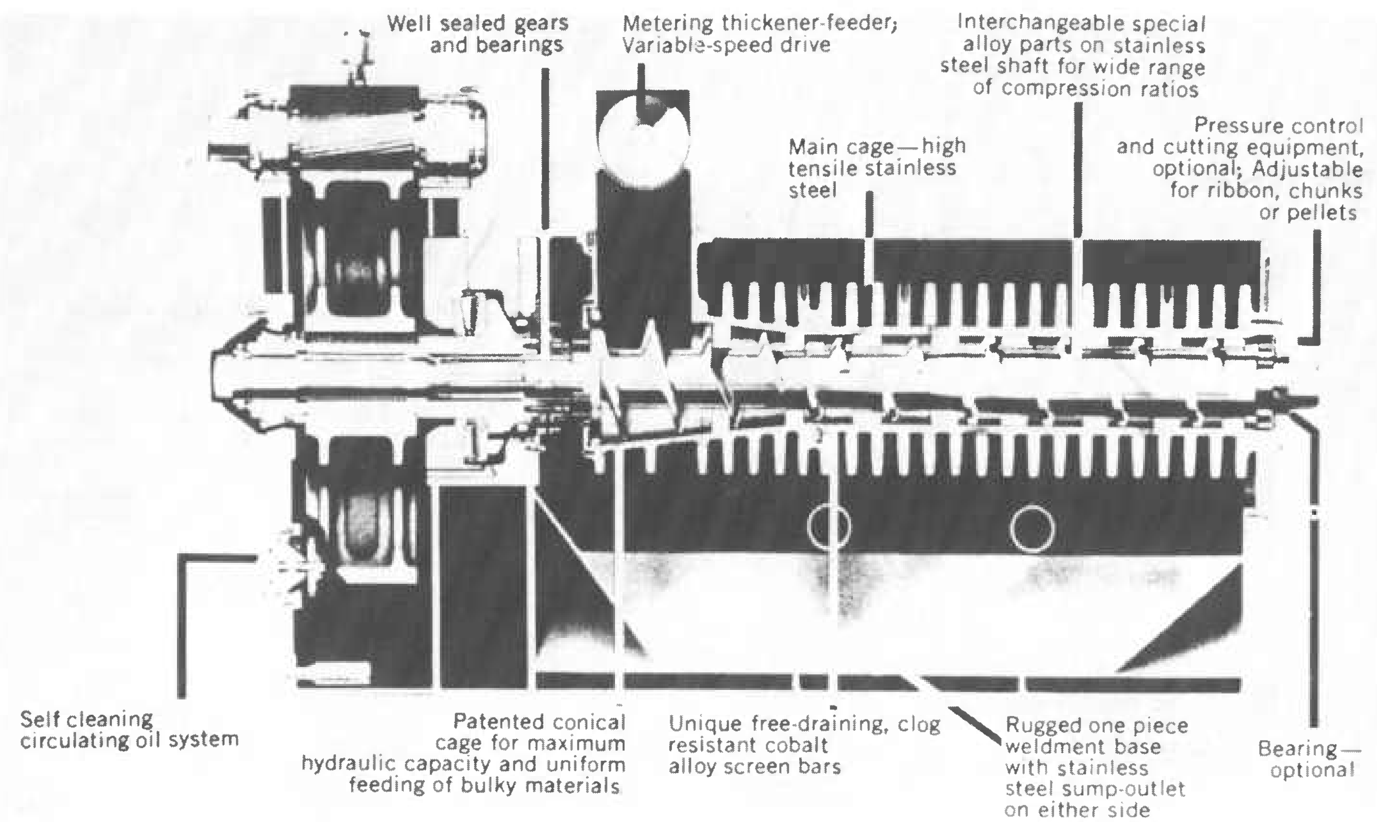


Figure 113—*Cross section of pulp dewatering press (Bauer pressafiner) (Bauer).*

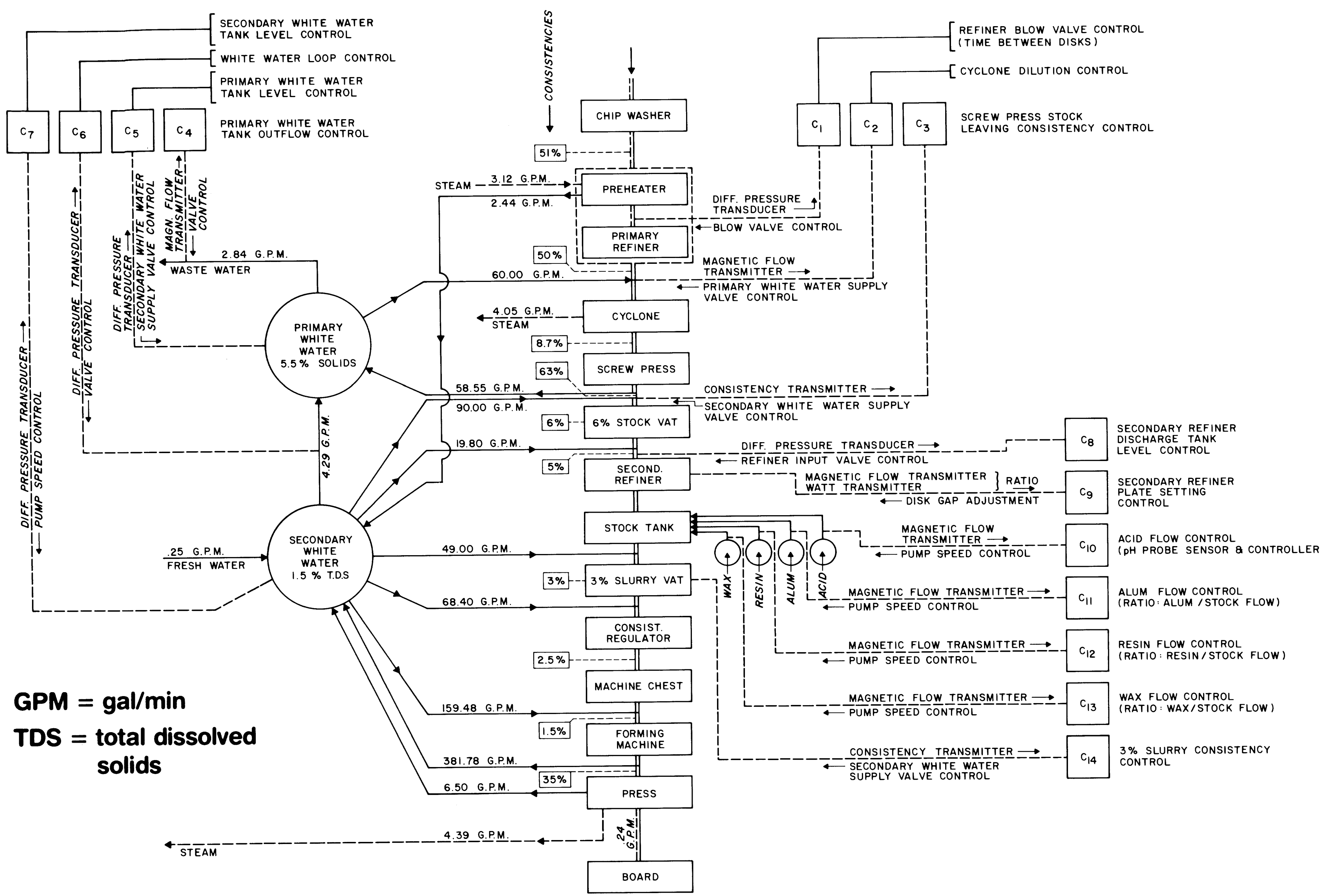


Figure 114—*Schematic presentation of production sequence in Superwood hardboard plant emphasizing control of pulping operation and process water handling. Designed according to data provided by Superwood Inc.*

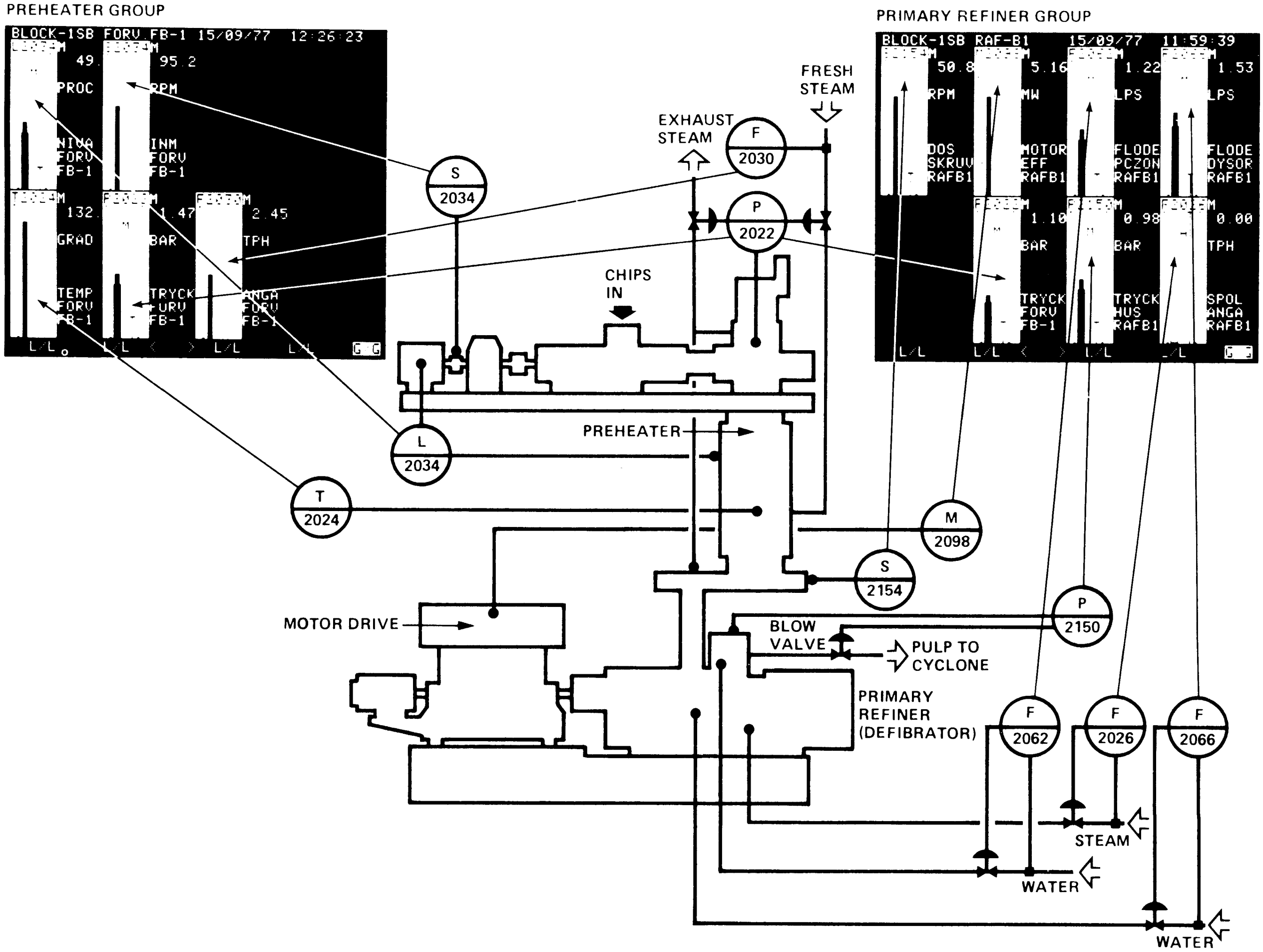


Figure 115—*Control system for Asplund defibrator (Foxboro).*

trolled quantity or adjusts it to a different level as directed by the computer. Figure 115 shows the control loops for an Asplund defibrator with preheater (Foxboro). The preheater control loop consists of the following elements:

1) the speed of the screw conveyor controlling the amount of chips going into the preheater; this speed is adjusted to keep the level in the preheater constant, based on a gamma gauge measurement of the chip level.
2) the pressure in the preheater; this is kept between two limit values by adjusting the fresh steam flow to the preheater.
3) the temperature in the preheater; measured only.
4) the flow of fresh steam; measured only.

Loops in the refiner section are:

1) speed of the preheater discharge screw that controls refiner production.
2) refiner motor power; this controls the amount of refining and is adjusted by changing the gap between disks.
3) flow of dilution water to the screw conveyor feeding the refiner.
4) flow of dilution water to the refining zone.
5) pressure in the preheater.
6) refiner housing pressure, maintained to give good pulp flow through the refiner.
7) steam flow to the refiner, controlled to ensure good pulp flow through the blow valve.

Figure 115 also shows the displays of the two groups of control loops as they appear on a video screen (fig. 116). This control loop design allows the operator to easily control the refiner from his console to produce the best possible pulp. The freeness of the pulp, which appears on another graphic display, is used as a guide.

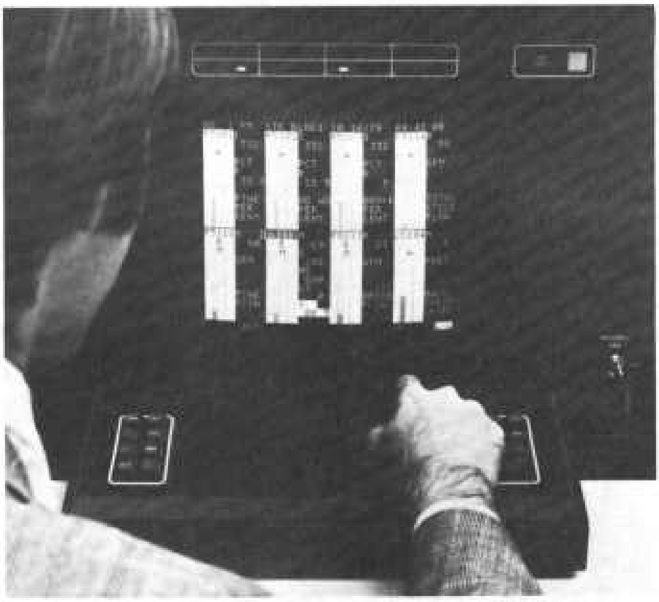


Figure 116—*Control loop display on video screen (Foxboro).*

Figure 118—*Plant area overview on video screen (Foxboro).*

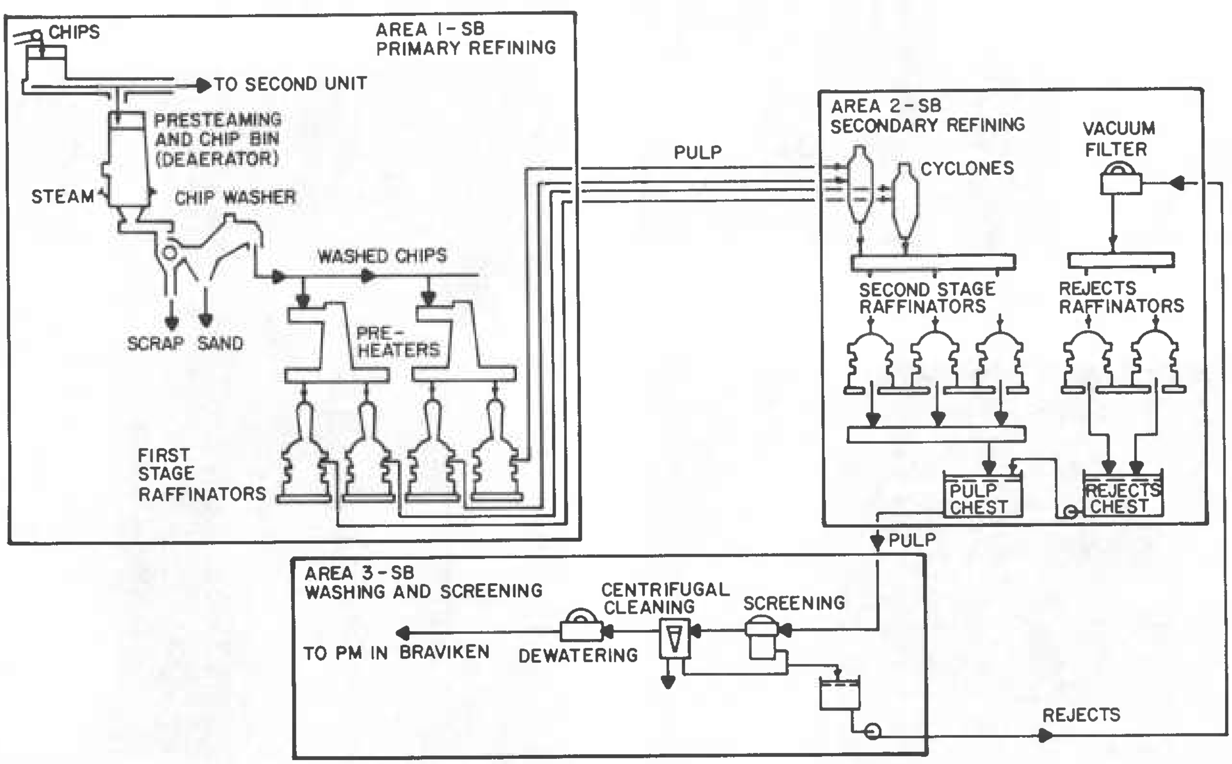


Figure 117—*Process diagram for entire pulp plant [Braviken, Sweden] (Foxboro Co.). Note: Raffinator is the equivalent of refiner. "PM in Braviken" refers to pulpmill in town of Braviken.*

The entire pulping operation contains many groups of control loops that may be combined into plant areas (fig. 117). Displays of plant area and an entire plant overview can also be selected to appear on the video screen (fig. 118). An alarm situation in a given loop will cause a special light signal to appear on the screen. Switching from plant overview to plant area and finally to the specific loop group will readily locate the trouble spot. Corrective action can be taken right at the console (Foxboro).

The chart in figure 114 is a simplified schematic illustration of the computer control system of the pulping section of a wet-process hardboard plant (Superwood). Individual control loops are indicated in terms of the type of transducer and actuator used; see also figures 119 through 124. Computerized process control has also been applied to the forming and pressing operations, particularly in the case of dry-formed hardboards. Reference to these systems will be made in later chapters.

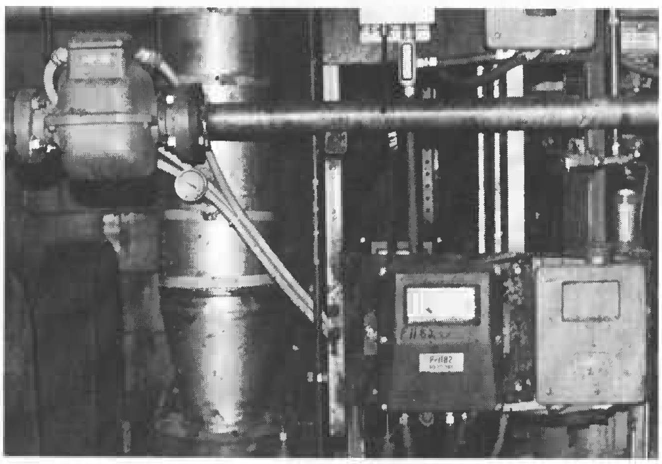


Figure 119—*Magnetic flow meter with transmitter.*

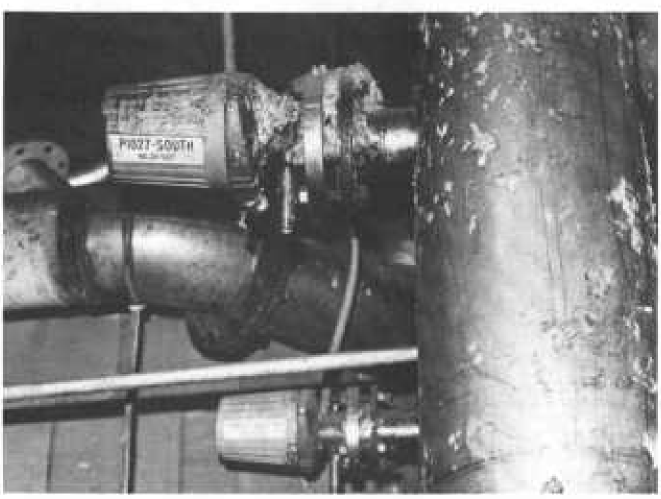


Figure 120—*Pressure transmitter.*

Figure 121—*Temperature transmitter.*

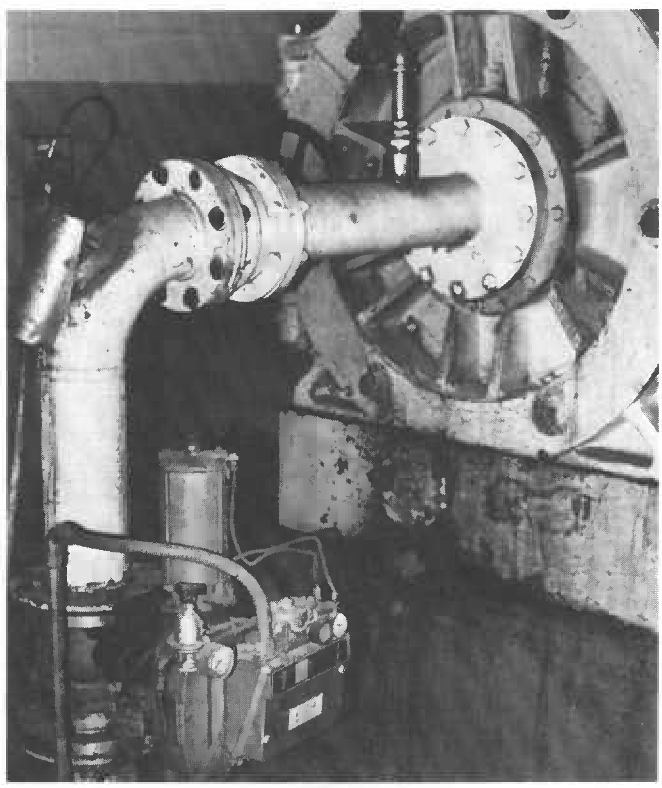


Figure 122—*Secondary refiner inlet control valve.*

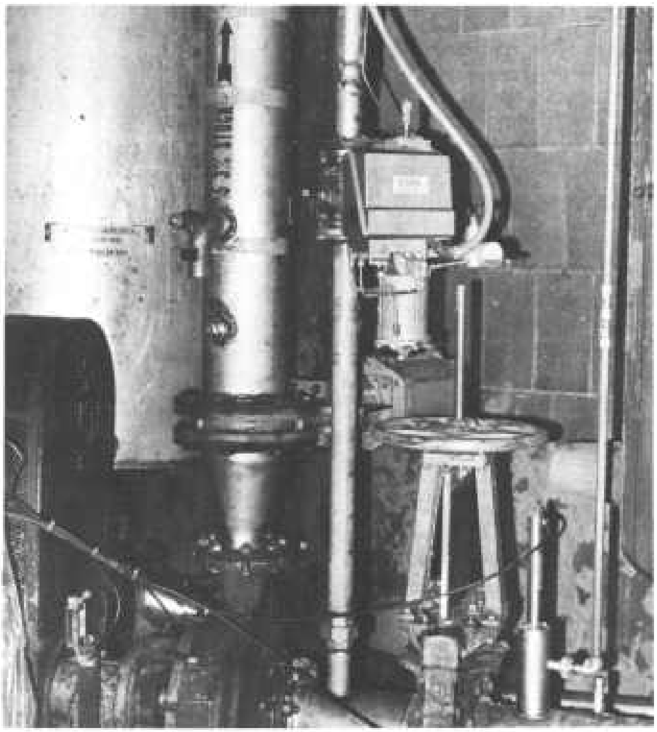


Figure 123—*Dilution pump control.*

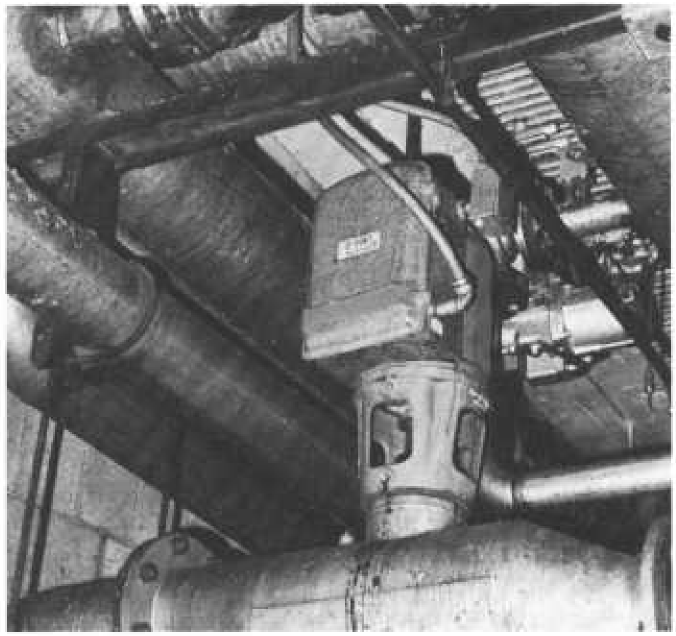


Figure 124—*Consistency transmitter.*

References

Anon. An introduction to refining variables. Tappi. 54(10): 1738-1741; 1971.

Atchinson, J.E.; Agronin, T. The Black-Clawson (Pandia) continuous method of preparing pulp for insulation board and hardboard. In: Fiberboard and particleboard. Proceedings of the international consultation on insulation board, hardboard, and particleboard; 1957; Vol. III; Paper 5.4. Rome: FAO; 1958. 300 p.

C.E. Bauer, Combustion Engineering, Inc. Promotional literature. Springfield, OH.

Boehm, R.M. The Masonite process. Industrial and Engineering Chemistry. 22(5): 493-497; 1930.

Boehm, R.M. Developments in the manufacture of structural products from hydrolyzed wood. Paper Trade Journal. 118(13): 247-258; 1944.

D'A Clark, J. Freeness fallacies and facts. Tappi. 53(1): 103-113; 1970.

Dorr-Oliver, Inc. Promotional literature. Stamford, CT.

Environmental Protection Agency. Development document for proposed effluent limitations guidelines and new source performance standards for the plywood, hardboard and wood preserving segment of the timber products processing point source category. EPA 440/1-73/023. Washington, DC; 1973. 317 p.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

The Foxboro Co. Promotional literature. Foxboro, MA.

Graham, W.H. Evaluation of the Tappi-SFMC drainage time tester for mill control of insulating board pulp. Tappi. 38(4): 252-255, 1955.

Johnson, F.Y.; El-Hosseiny, F. Kinetics of chip refining and pulp characterization. Tappi. 61(12): 51-52; 1978.

Koran, Z. Surface structure of thermo mechanical pulp fibers studied by electron microscopy. Wood and Fiber. 2(3): 247-258; 1970.

Leider, P.J.; Rihs, J. Understanding the disk refiner. I. The hydraulic behavior. Tappi. 60(9): 98-102; 1977.

Lowgren, U. Wood pulping by the Asplund defibrator. Paper Trade Journal. September: 41-43; 1948.

Mason, W.H. Pulp and paper from steam exploded wood. Paper Trade Journal. 84(8): 131-136; 1927.

The Masonite Corporation. Promotional literature. Chicago, IL.

Mihelich, W.G. Single stage chip refining—some major operating parameters and their effects on pulp quality. Pulp and Paper. 73(5): 78-82; 1972.

Rydholm, S.A. Pulping processes. New York: Interscience Publishers; 1965. 1269 p.

Spalt, H.A. Chemical changes in wood associated with wood fiberboard manufacture. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, DC: American Chemical Society; 1977: 193-219.

Sprout-Waldron, Division of Koppers Co. Promotional literature, Muncy, PA.

Sunds Defibrator. Promotional literature. Minneapolis, MN.

Superwood Corporation. Personal communication. Duluth, MN.

Tasman, J.E. Analysis and testing. In: McDonald, R.G. (ed.). Pulp and paper manufacture: control, secondary fiber, structural board, coating. 2d ed. New York: McGraw-Hill; 1969. Vol. 2; 132-186.

Technical Association of the Pulp and Paper Industry. Drainage time of pulp for insulating board: suggested method T 1006 sm-60. New York; 1951. 3 p.

Textor, C.K. Wood fiber production with revolving disk mills. Forest Products Research Society Proceedings. 2: 89-98; 1948.

Textor, C.K. The Bauer method of preparing furnishes for the manufacture of insulation board and hardboard. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard and particleboard; 1957; Vol. III; Paper 5.3. Rome: FAO; 1958. 300 p.

General

Chemicals are added to fiberboard furnishes for several reasons:

- acidity control
- improvement of water resistance (sizing)
- enhancement or establishment of fiber bond
- process control (defoamers, release agents)
- protection of fiber from decay and insect attack
- fire protection
- coloration

The first four are common to most fiberboard processes. Chemical additives are added in relatively small quantities, not only because of cost but also because their presence, while enhancing one desirable property, can be detrimental to another. Chemicals that improve product water resistance, for instance, often interfere with the development of fiber bonding.

Not all fiberboard processes have the same requirements for chemical treatments of furnish. This depends primarily on technological demands made on the product in service and on basic process technology.

The Sizing of Fiberboard

General

Sizing is the process wherein suitable chemicals are added to the stock (papermaking, board making) and precipitated upon the fibers for the purpose of controlling the penetration of liquids into the final dry paper or board (Cobb and Swanson 1971).

Control of liquid penetration is very important in papermaking, because it governs the absorption of inks in printing and writing. Fiberboard-sizing is clearly an adaptation of paper-sizing technology to reduce water absorption of the finished product and to control linear expansion, thickness swelling, surface deterioration, and strength loss caused by the swelling of the wood fiber.

The principal goal of paper and board sizing is to cover the surfaces of the individual fibers with an agent that will reduce the surface energy of the fiber, and thus of the paper or board, and render it hydrophobic.

The application of the sizing agent occurs in two steps in all wet processes. The water is used as a medium to assure thorough mixing of size and fiber in the first step. In the second step, the size is forced to precipitate out of the watery suspension and is fixed by chemical means to the fiber surface, where it remains to develop its hydrophobic qualities in subsequent processing. In the dry process, the size is applied directly to either the chips or the fibers, generally together with the resin binder required in all dry-process fiberboard.

As in paper manufacturing, the size in wet-process fiberboard is precipitated by adjusting the pH. The size is added to stock having a pH adjusted to a level that allows the mixing of the size emulsion with the water. Adding the precipitant lowers the pH, causing the size to **floc**. The precipitant also provides the mechanism for fixing the size to the fiber surface.

Rosin size

The most common size in paper, and one that is used to some extent in insulation board, is rosin. Rosin is a naturally occurring, solid, resinous material obtained from pine trees (Watkins 1971). It can be obtained from the living tree and distilled **(gum rosin)** or it may be extracted from pine stumps and refined **(wood rosin)** or obtained by fractional distillation of tall oil, a byproduct of sulfate-pulping of softwood **(tall oil rosin)**.

Rosin size is prepared by saponifying the molten rosin (a hydrolytic process) through adding sodium hydroxide or sodium carbonate. The size is emulsified or added directly to the stock. Dilute emulsions have a pH of 9 to 10.

The precipitant, i.e., the agent that causes precipitation of the rosin size and of most other sizes and additives in fiberboard, is aluminum sulfate, $Al_2(SO_4)_3$, or alum. It is added in diluted form (1 to 2 lb of dry alum per gallon) in a quantity sufficient to reduce the pH to about 4.5 after the size has been thoroughly mixed with the stock (Lull 1971). This causes the size to precipitate.

The aluminum gives a positive charge to the size, causing the size particles to be attracted by the negatively charged fiber surfaces. The aluminum is also involved in developing the low-energy (water-repelling) surface of the final product (Swanson and others 1971). Rosin size is generally added in amounts of less than 3-percent solids as based on dry fiber weight. The degree of water resistance imparted to the product increases uniformly with increasing size addition up to about 2 percent. Above 2 percent the curve becomes less steep and is nearly horizontal with the addition of 3 percent rosin (Swanson and others 1971).

Wax size

Waxes are hydrocarbons of relatively high molecular weights (300 to 700) derived from crude oil, either as residuals or as distillates. Their melting points range from 120 to 200 °F. They are insoluble in water and are chemically inert (Porter 1971). Wax sizes are prepared by melting the wax and then emulsifying it in the water phase. Table 20 lists some physical and chemical properties of wax sizes (Porter 1971).

In the paper industry, wax sizes are generally used in combination with rosin, replacing 20 to 40 percent of the dry rosin size. This combination not only improves water resistance but also enhances other properties such as printability, pliability, folding endurance, etc.

In fiberboard, wax sizes are used only to improve water resistance. The emulsified and homogenized sizes are added to the stock at a temperature below the melting point of the wax. The precipitating agent is alum. The theories for the mechanism of rosin-sizing also apply to wax-sizing. Besides electrostatic forces, entrapment of wax particles by the alum floc also plays a role. The sizing effect in the finished product is increased with drying temperature (fig. 125) (Cobb and Swanson 1971).

Wax sizes are also used in dry fiberboard processes. In these, wax is added in molten form or as an emulsion directly to the chips or fibers; distribution is mechanical. In some cases, the wax is added together with the liquid resin solutions.

Wax sizes tend to lower strength properties to a greater extent than does rosin size, particularly when used in excess of 0.5 percent solids as based on dry fiber. Between wax contents of 0.2 and 0.5 percent, however, the effect on board strength is small.

Asphalt size

The American Society for Testing and Materials (ASTM) defines asphalt as:

> black to dark brown solid or semisolid cementitious material which gradually liquifies when heated, in which the predominating constituents are bitumen, all of which occur in the solid or semisolid form in nature, or are obtained by refining petroleum, or which are combinations of the bitumens mentioned, with each other or with petroleum or derivatives thereof (ASTM 1980).

Asphalts vary in composition, properties, and application. Paving asphalts have a higher oil content and

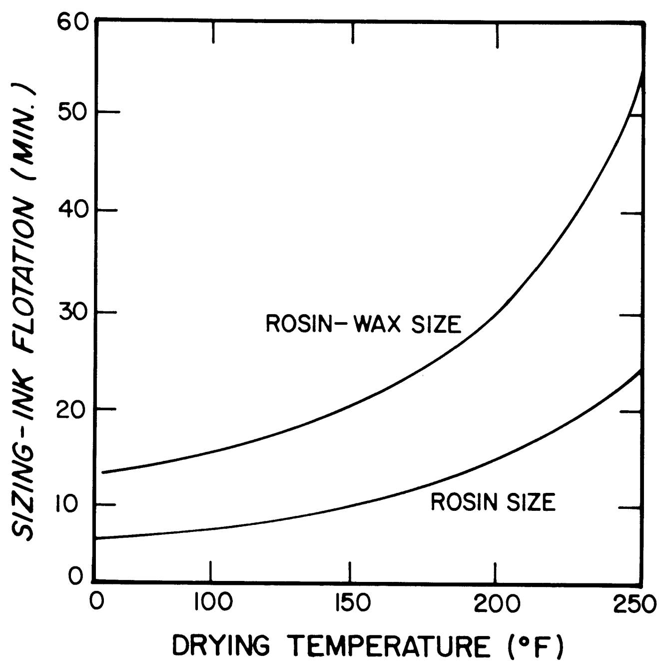


Figure 125— *Effect of drying temperature on the effectiveness of sizing as measured by the ink flotation test (longer time = better sizing) (Cobb and Swanson 1971). (© 1971 TAPPI. Swanson, T. W. Internal Sizing of Paper and Paperboard.)*

Table 20—*Physical and chemical properties of wax sizes (Porter 1971)*

Measurement or property	Acid-stable type	Non-acid-stable type
Total solids (% by weight)	40-55	40-65
Density (lb/gal)	7.6-8.1	7.6-8.1
pH	5-8	8-11
Particle size, average (μm)	1	0.5
Color	White, off-white	White, off-white
Stability		
Alum	Stable	Unstable
Alkali	Stable	Moderately stable
Mechanical	Good	Good
Temperature		
Above 32 °F	Stable	Stable
Below 32 °F	Unstable	May be stable
Storage	3-6 mon	3-6 mon

molecular weight and lower resin content than do the asphalts used for sizing.

Asphalt size is used in emulsion form and is precipitated by adding alum. Stock and forming machine temperatures should not exceed 135 °F. Mechanical entrapment in the alum floc and electrostatic forces between size and fiber surface cause fixation on the fiber. After adding alum, sufficient time should be allowed for the above processes to take place at furnish consistencies maintained in intermediate mixing tanks (chests). For best retention, pH should be adjusted to 4.5 to 5.0 at the **headbox**. Table 21 shows specifications for an asphalt emulsion size (Lorenzini 1971).

Asphalt sizes do not reduce bond strength. In fact, they increase tensile and bending strength of insulation board as a result of smooth sheet formation and improved drainage in comparison to other types of conventional sizing (Lorenzini 1971).

Because of its dark color, asphalt size in fiberboard manufacturing is limited to structural insulation board. Some naturally occurring asphalts are also used in binders for fiberboard siding and other fiberboard products.

Fiberboard Binders

Lignin is the potentially most important binder in fiberboard manufacture. If it is exposed in the pulping process and "activated" in the hotpress, additional binding agents may not be necessary. Masonite is still making wet-formed fiberboard without additional binders. Most other processes, however, use added binders, either to enhance the lignin bond or to establish artificial fiber bonds in the absence of lignin bonding. Table 22 is a simplified schematic of fiberboard bond types. Table 23 lists additives used as binders in the manufacture of fiberboard. The establishment of S1S hardboard mills in the West in the 1940's was substantially aided by the availability of water-soluble, highly condensed phenolic resins of high pH that could be precipitated on the fiber surface, had a high degree of retention, and could form a satisfactory fiber bond in the hotpress (Keaton 1950).

Dry-formed hardboard and dry medium-density fiberboards must, of course, rely entirely on added adhesives because these processes do not provide conditions under which the lignin bond can be utilized.

Wet-formed S2S boards cannot use thermosetting adhesives such as phenolic resins because the mat goes through a severe drying cycle before hotpressing. Phenolic resins would cure in the dryer and could not contribute to fiber bonding after densification in the press. Thermoplastic resins such as those derived from pine rosin (Vinsol) and from naturally occurring asphalt (Gilsonite) are used as binders in these cases. **Drying oils** such as linseed oil, tung oil, or tall oil are also used in the wet S2S process, either alone or in combination with thermoplastic resins.

Many other binders have been tried as adhesives in fiberboard or are mentioned in various patents as suitable additives promoting fiber bonding (Wilke 1942); among them are starch, casein, animal glue, latex, tannins, etc. Of these, only starch has industrial importance today. It is added as a secondary binder to insulation board stock (table 22).

Resin binders and drying oils not only bond fibers but also have a sizing effect. This sizing effect is due not only to fiber surface modification but also, in the case of phenolic resins, to swelling restraint affected by improved bonding. This effect can be enhanced by treating fibers with penetrating resins, which impregnate the

Table 21—*Typical specifications for anionic asphalt emulsion size (Lorenzini 1971)*

Measurement or property	Range
Asphalt content (% by weight)	57- 60
Emulsion pH	9- 11
Particle size (μm)	1- 5
Viscosity, Saybolt-Furol (ASTM D #244) (s)	20-100
Asphalt softening point, R&B (ASTM D #2398) (°F)	185-210
Asphalt penetration at 77 °F (ASTM D #5) (mm)	0- 10

R&B = ring and ball.

Table 22—*Bond types in fiberboard (simplified)*

Process	Primary bond	Secondary bond
Wet		
Insulation board	Hydrogen	Starch, asphalt
S1S Masonite	Lignin	—
S1S	Lignin	Phenol, drying oils
S2S, MDF	Lignin	Thermoplastics, drying oils
Dry		
S2S	Phenol	—
MDF	Urea	—

MDF = medium density fiberboard

Table 23—*Additives used as binders in fiberboard manufacture*

Binder type	Examples	Source
Starch	Cornstarch Rye flour Potato flour	
Drying oils	Linseed oil	Flax seed
	Tung oil	Seed of tung tree
	Tall oil	Byproduct of sulfate pulping of softwoods
	Soybean oil	Soybean
Thermoplastic resins	Vinsol	Pine rosin
	Gilsonite	Naturally occurring asphalt
Thermosetting resins	Phenol-formaldehyde Urea-formaldehyde	

fiber, as well as with a bonding resin (Brown and others 1966, Fahey and Pierce 1973) (fig. 126). Almost complete restraint of thickness swelling can be obtained in this fashion, but only at resin levels that would be uneconomical for standard hardboard manufacture. Normal phenolic resin addition levels are about 1 to 2 percent in wet-formed hardboard and up to 5 to 6 percent in dry-formed hardboard. Most strength properties and sorption characteristics show little further improvement beyond resin content of 3 percent (American Marietta). Urea-bonded medium-density fiberboard (dry process), however, requires rather high bonding resin levels (8 to 11 percent).

Fire Retardant and Preservative Treatments

Fire retardants

Wood and wood products such as fiberboard are combustible materials. When subjected to high temperatures they develop combustible gases that contribute not only to fire destruction but also to smoke, which obscures vision, hinders escape, and irritates the respiratory system (Holmes 1977).

Though fire endurance (resistance to fire penetration) is of importance in the case of columns, beams, floors, etc., **flame spread**, fuel contribution, and smoke development are of great importance with materials such as plywood, particle board, and fiberboard panels.

Standardized tests for these characteristics are described in ASTM Standard E 84 (ASTM 1980). The results are expressed in relative values against an arbitrary scale on which asbestos-cement board defines the zero point and untreated red oak rates 100. For instance, on materials with a flame-spread index of 200, the flame would, under the standard test conditions, advance a given distance on the surface in half the time required on red oak.

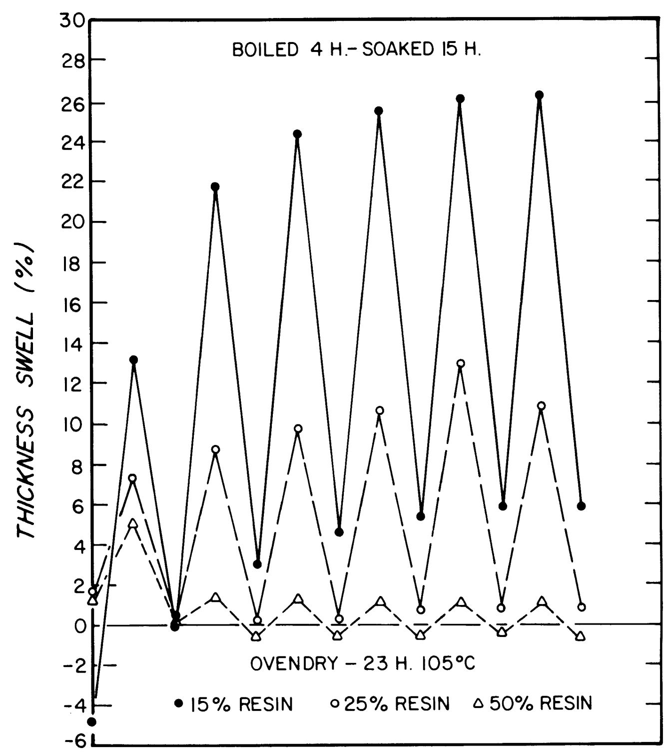


Figure 126—*Dimensional stabilization of dry-formed hardboard as a result of treatment with three levels of impregnating resins (Brown and others 1966).*

Materials are generally classified into groups as based on their flame-spread index values (USDA FS 1974).

Class A	0- 25
Class B	26- 75
Class C	76-200
Class D	201-500
Class E	500

Class A would be prescribed for exitways of buildings with no sprinkler systems that are intended for large assembly and institutional purposes. Class B would be prescribed for schools, hotels, etc.

Most untreated wood species and untreated wood products have flame-spread indices exceeding 100. They either cannot be used where codes require class A or class B performance or they must be treated to reduce their ratings to the appropriate levels.

Many chemicals have been used as fire retardants for wood and wood products (Goldstein 1973). All are thermally stable inorganic salts. The most widely accepted theory of their mechanism in reducing flaming combustion of wood is that the chemicals alter the pyrolysis reaction so that less flammable gases and tars and more char and water are formed. (Goldstein 1973).

In the case of aluminum trihydrate, the mechanism also involves a heat sink cooling effect resulting from moisture loss, as well as the replacing of wood with nonburning inorganic chemicals.

The only commercial treatment of fiberboard with fire retardant chemicals is one patented by the Masonite Corportaion (Short and Rayfield 1978). It is a two-step treatment: one component is added to the furnish; the other is applied to the surface of the finished board. The pressed boards containing 45 to 60 percent aluminum trihydrate are coated with preheated borate ester resin. After a short penetration period, the boards are heat-treated at 150 °C to 165 °C for 1.5 to 2 hours. This treatment is followed by humidification at 90 °C and 90 percent relative humidity. This treatment qualifies these boards for a Class I(A) fire rating when subjected to the E 84 flame test of the Underwriters Laboratory. The substantial quantities of chemicals required make such boards very expensive, however. Their application is therefore limited.

The Forest Products Laboratory has, on an experimental basis, treated dry-formed hardboard with various fire retardant chemicals. Class B level protection could be achieved with 20 percent retention as based on dry fiber (Myers and Holmes 1975, 1977).

Preservative treatments

Wood fiberboard, like other wood products, is subject to decay and insect attack when exposed to conditions favorable to these agents. Under those conditions, fungicidal and insecticidal treatment of the product is in order. This generally is the case when boards are shipped to tropical areas or are used in some applications in the Southern United States.

Sodium pentachlorophenate (Mitrol G); a water-soluble sodium salt of pentachlorophenol, is commonly used to protect paper and fiberboard against mildew, rot, and termites (Chapman Chemical Co.). It is added to the furnish in sufficient quantities to provide a retention in the product of 0.5 percent, based on dry fiber, for protection against rot and mildew and a retention of 0.75 percent for protection against termites. Addition of sodium pentachlorophenate does, however, interfere with the sizing of boards (Eustis 1980).

When sodium pentachlorophenate is added, the pH of the furnish should be 8.5 or higher, which requires the addition of alkali. The preservative is precipitated along with size and other additives with alum or acid. The pentachlorophenate is converted to the highly insoluble free pentachlorophenol and fixed on the fiber surface. Solubility and volatilization, however, can cause losses as high as 25 to 60 percent. In closed water systems, losses are smaller.

Pentachlorophenol is a toxic substance that continues to undergo review by the U.S. Environmental Protection Agency (EPA). Pentachlorophenol-treated products that have the potential to come into frequent contact with human skin should be protected by two coats sealant. In addition, pentacholorophenol should not be used where it could contaminate food, feed, or potable water or where treated products could be chewed by domestic animals.

In the future, manufactured products containing pentachlorophenol may be required to bear cautionary labels. EPA will advise both manufacturers and users when a decision is reached on this issue.

Because pentachlorophenol is toxic, it requires special considerations in water treatment efforts and appropriate precautions for worker safety during manufacture.

Industrial Practices

Figure 127 is a simplified schematic of the stock flow in a wet-process fiberboard plant, from the primary refiner to the Fourdrinier sheet-forming machine, showing introduction of chemical additives, pH change, and

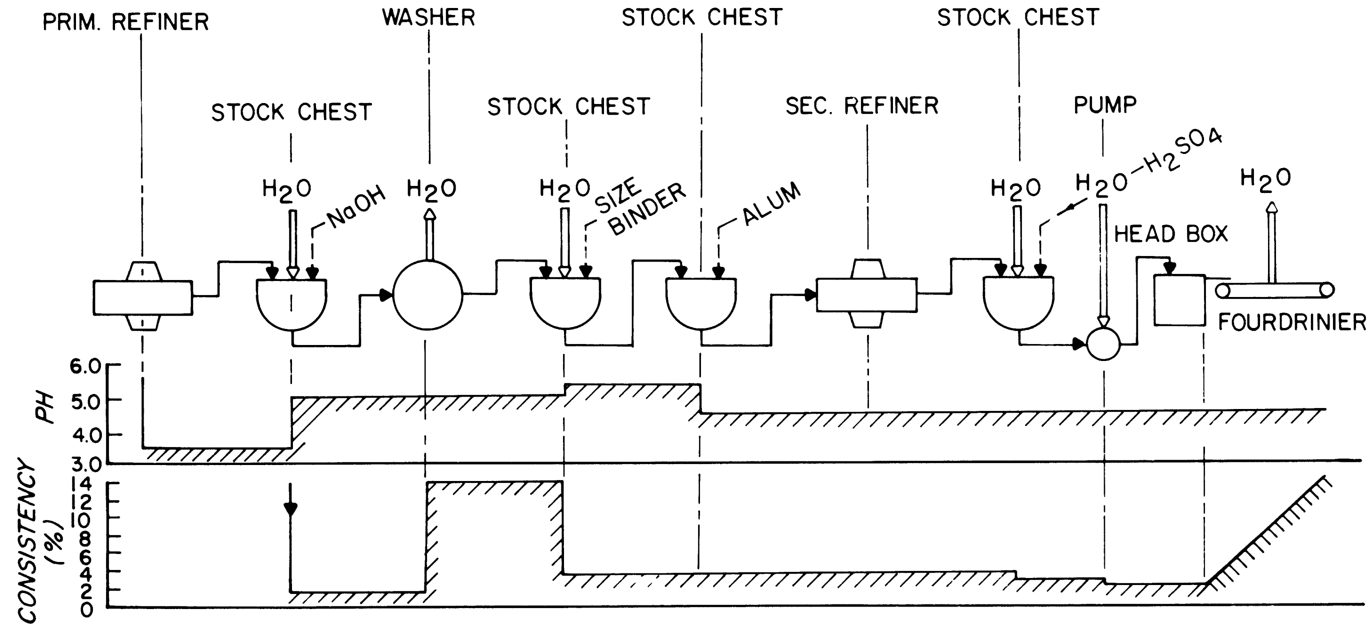


Figure 127—*Schematic of stock flow in wet-process fiberboard plant, showing pH, stock consistency, and introduction of additives.*

stock consistency. It applies equally to the manufacture of insulation board and S1S and S2S wet-formed fiberboard (hardboard and medium-density).

Following the primary breakdown, the stock is diluted to make it pumpable and to reduce its acidity. Caustic soda is also used at this point to raise the pH value of the raw stock from below 4.0 to 5.0 or greater. The higher pH value helps reduce corrosion and makes it easier to wash out the dissolved sugars in the pulp washer. On the other hand, addition of caustic soda reduces hydrophobicity. Much of the water added is removed in the washer and now carries biodegradable materials, which could be recirculated or which must be removed before the water can be discharged.

In the next stock chest, the consistency is reduced to about 3.5 percent. The diluting water could be fresh but generally is **machine white water,** which is the water that is removed from the stock in the sheet forming stage on the Fourdrinier machine. Recirculation of machine white water reduces water treatment requirements and recovers and reintroduces chemical additives not retained in the mat.

Size, binder, and other chemical additives are added at this point and thoroughly mixed with the stock. The pH is reduced in the next stock chest to about 4.5 by the addition of alum. This causes the chemical additives to precipitate. Secondary refining occurs next, followed by further dilution of the stock to forming machine consistency (2 percent). Final adjustment of the pH may be made in the last stock chest before the forming machine by the addition of sulfuric acid.

In dry fiberboard processes, wax and binder are introduced either before (phenolic resins) or after (urea resins) the fiber dryer. Figure 128 illustrates an option found in dry hardboard operations. Although the dryer temperatures are high, the phenolic resin will survive because drying times are very short, only a few seconds. Figure 129 shows an arrangement that may be found in a dry medium-density fiberboard plant. Here, a urea-formaldehyde resin is applied to the dried fiber furnish in a **short-retention blender** with axial agitators like those used in the particle board industry (Maloney 1977).

Ratios of additive quantities to dry fiber can be automatically controlled at a given set point. The computer control system outlined in figure 114 constantly monitors and controls these ratios and allows adjustment of the set point from the control console. Figure 130 shows a control system as it may be used in a dry process plant (Ballard and Schlavin 1969).

Insulation board

Although wax has been used in molten state in the manufacture of insulation board, added to cookers or refiners, it is more often used as an emulsion. Molten wax

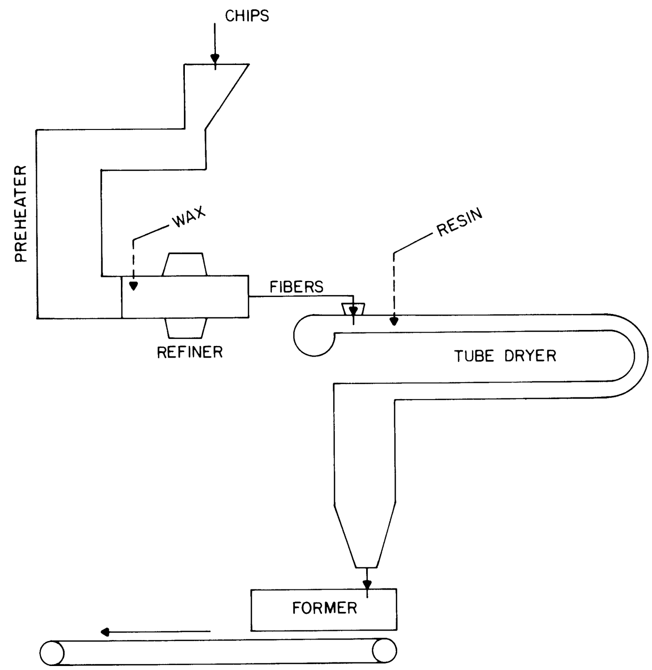


Figure 128—*Schematic of furnish preparation in dry-process hardboard plant, showing addition of phenolic resin prior to drying of fiber in tube dryer.*

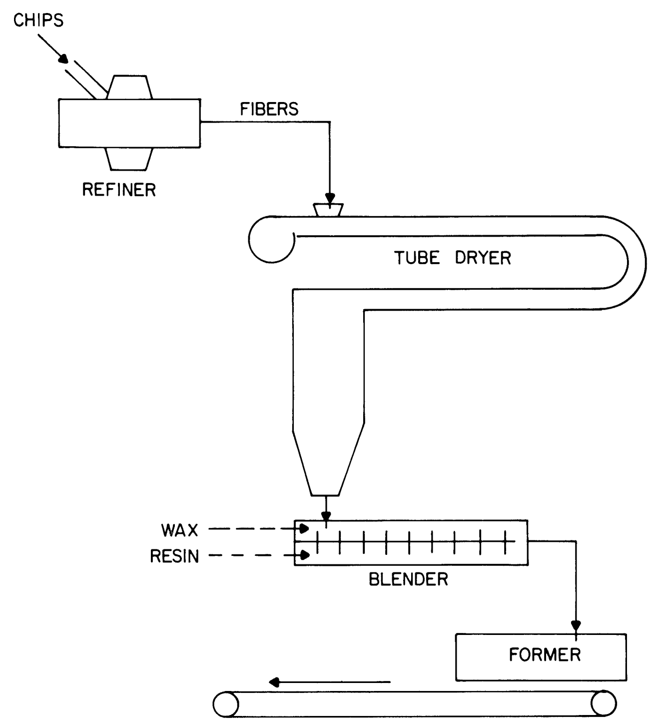


Figure 129—*Schematic of furnish preparation in dry medium-density fiberboard plant, showing addition of urea resin in short retention blender after drying of fiber in tube dryer.*

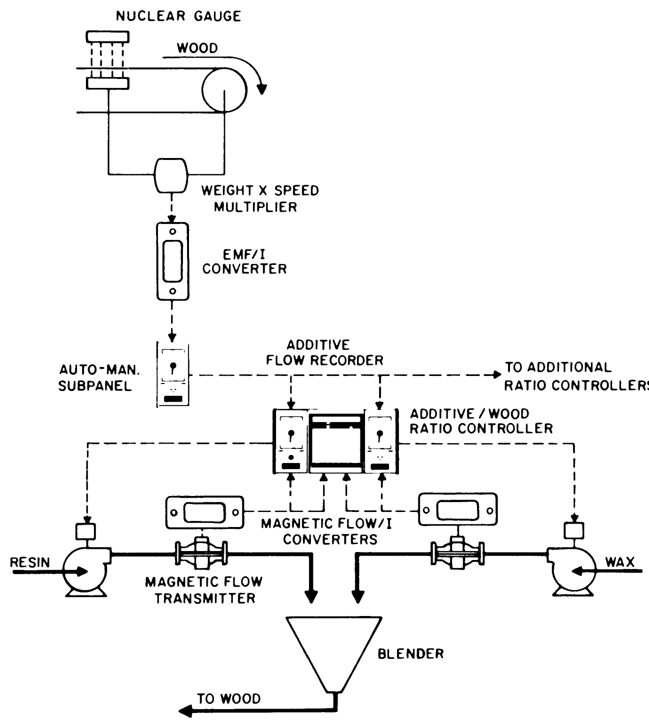


Figure 130—*Electronic wood/resin/wax ratio control system in dry-process fiberboard plant (Ballard and Schlavin 1969).*

reduces strength properties more than does emulsified wax (Eustis 1980). Some mills use rosin size or a combination of rosin and wax emulsions. Rosin size affects strength less than does wax but, because it has a higher melting point, requires higher dryer temperatures. Size must be melted to be effective.

Higher dryer temperatures improve the sizing process, which means that a reduction in size can be compensated for by higher dryer temperatures. Present energy costs, however, will probably favor compensation in the reverse direction: higher wax content and lower dryer temperature. Wax size is effective even when the boards are not completely dried (Eustis 1980).

Part of the wax evaporates in the dryer and condenses, presenting a fire hazard. Rosin size does not distill to that extent. Figure 131 (Porter 1971) shows the variation of water absorption with drying time for wax-sized insulation board. Most insulation board mills use an addition of between 0.75 and 1.25 percent dry wax as based on the dry fiber.

Asphalt is the largest volume sizing agent in insulation board. It is used in all wall sheathing and roof insulation. Asphalt is added in emulsion form in quantities of 10 to 15 percent emulsified solids based on dry fiber weight. Asphalt was first used in insulation board by the

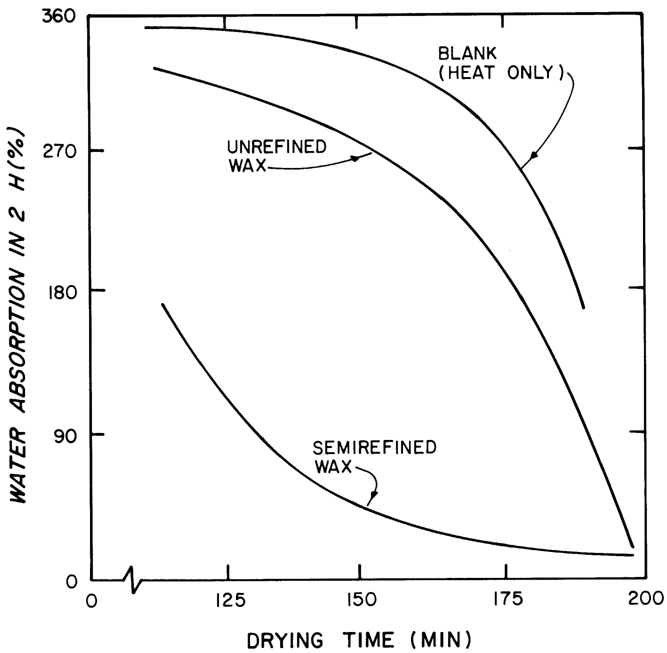


Figure 131 — *Effect of drying time on water absorption by insulation board (Porter 1971). (© 1971 TAPPI. Swanson, T.W. Internal Sizing of Paper and Paperboard.)*

Insulite Corporation of International Falls, MN. They simply ground up high-melting-point asphalt and added the powder to the pulp. The asphalt melted and flowed slightly in the dryer (Eustis 1980).

Starch adds strength to insulation board. Any kind of starch can be used. It is stirred up with water, and the slurry is pumped into the pulp just ahead of the forming machine. Starch is added in quantities of 1 to 2 percent. The more starch used, however, the more attractive the board becomes to rodents and insects (Eustis 1980).

S1S board

The standard additives in the manufacture of S1S board are phenolic resins and wax. Resin is added in quantities of 0.5 to 1 percent, in some cases up to 2 percent. The quantity of resin used has an important effect on the press cycle (Eustis 1980). At minimum press cycles, the resin is not completely cured. The cure can be completed during subsequent heat treatment. However, the board will suffer substantial **springback** (immediate expansion of thickness upon removal from press), particularly along the board edges, which do not reach the same temperature in the press as does the board center. This can be compensated for by increasing the resin content. Thus, there exists a trade-off between resin content and press time or between resin cost and productive capacity. The compromise is, of course, affected by resin costs. When resin costs are high, S1S boards will remain in the press longer to minimize springback by lowering the resin content.

Selective application of resin binder reduces springback. Abitibi uses a patented system of extra resin application in which resin is injected into a strip along the edges of the mat while it is on the forming machine (Eustis 1980). Resin concentration in these strips can be as high as 5 percent. This technique maximizes resin efficiency and allows minimal press cycles. The extra resin holds down edges and corners. Adding extra resin to the surface of the wet mat has been shown to improve dimensional stability of experimental board (Steinmetz and Fahey 1968). Effective resin levels, however, are very high.

Wax emulsion for improving water resistance is added to S1S furnish in very small quantities, from 0.1 to 0.5 percent as based on dry fiber. Wax emulsion may also be added in diluted form by spraying it on the surface of the mat on the forming machine. The emulsion spray acts as a defoamer as it breaks surface bubbles and is then sucked into the mat by vacuum (Eustis 1980). In still other cases, molten wax is added to very hot stock (180 °F) or applied to the chips. However, this may cause the formation of wax drops, which form surface spots that interfere with finishing operations.

The Oregon Lumber Company hardboard plant at Dee, OR, operates without adding size. The board derives its water resistance principally from the inclusion of Douglas-fir bark (25 percent of the total furnish). The bark is reported not to have any detrimental effect on process or product (Runckel 1953).

Instead of using alum as precipitant, Abitibi at its Alpena, MI, plant uses ferric sulfate. This works as well as alum in reducing the stock pH and produces a dark gray board, which is a desirable background for the printed paper overlay that is applied directly to the wet mat in their wall panel manufacturing line (Eustis 1980). Ferric sulfate, however, is more corrosive than alum. Air entrapped in the furnish sometimes causes the stock to foam, particularly at higher temperatures. Tiny air bubbles, beaten into the stock in refiners and mixers, can reduce freeness by 10 to 15 percent, cause tanks to overflow, and interfere with the forming process.

In insulation board and wet S2S plants—where efficient water removal on the forming machine is very critical because of the high energy cost of removing the remaining water in the dryers—the **air** is removed from the stock in **deculators**, vacuum tanks in which the air is boiled off and removed. This improves the freeness of the pulp going to the forming machine. S1S lines do not normally use deculators because water removal is not as critical, because much of the water remaining in the mat after forming can be squeezed out mechanically in the first part of the press cycle. Instead, these plants use defoamers, added just ahead of the forming machine, to break up air bubbles in the stock. In the past, kerosene was used. Today, special defoamers are available that reduce the surface tension of the water and cause the air bubbles to break. Too much defoamer, however, interferes with the sizing of the sheet (Eustis 1980).

Wet-formed S2S board

As mentioned earlier, wet-formed S2S boards cannot be bonded with phenolic resin binders, because during the drying of the mat before hotpressing, phenolic adhesives (which are thermosetting resins) would cure.

Bonding of fibers in these boards must therefore rely on the formation of lignin bonds in the hotpress, which may be enhanced and reinforced by the addition of drying oils or thermoplastic resins to the furnish. The choice depends to some extent on the final use of the product.

Masonite, for instance, makes wet-formed S2S boards with the addition of wax size only. The board is used for interior applications. Masonite siding is made by the S1S process and uses phenolic resin. Other interior wet S2S boards (Abitibi, U.S. Gypsum) are made with the addition of drying oils (linseed oil, tung oil, or soybean oil), linseed oil being the most commonly used. These oils are emulsified by stirring them up with caustic soda and are added to the stock at rates ranging from 0.5 to 1.5 percent. The lower the board density, the more oil is added (Eustis 1980): for 65 to 70 lb/ft^3, 0.75 percent oil; for 50 to 55 lb/ft^3, 1.5 to 2.0 percent oil. Both U.S. Gypsum and Abitibi use ferric sulfate to precipitate the oil emulsions. This produces a characteristic gray color of the pulp, which turns to a grayish brown in the hotpress. It also results in a strength increase (bending strength) of at least 10 percent over boards in which the oils are precipitated with alum (Eustis 1980). The fixation of the oils on the fiber seems to be purely mechanical. Losses are therefore great, and closed water systems (recirculation of machine white water) become imperative.

Much higher oil quantities are used in so-called **slush overlays**. These overlays are thin layers of highly refined pulp that are applied on top of the regular mat by means of a secondary headbox. Oil contents can go as high as 6 percent, but only about 1.5 percent is retained. The rest is sucked away by the vacuum system and is removed with the white water. In a closed white water system, the lost additives build up to a constant level and circulate. Only the quantities that are retained would have to be added.

Temple East-Tex produces wet S2S siding with only linseed oil and size; no resin is added.

Boise Cascade (Insulite) at International Falls, MN, produces wet S2S siding using a high melting point thermoplastic resin derived from naturally occurring asphalt (Gilsonite). Wax is used as a sizing agent, and alum is the precipitant. Gilsonite is used at the rate of 5 percent.

A thermoplastic resin derived from pine rosin (Vinsol) is used in Abitibi's siding, which is made by the S1S process.

These thermoplastic resins require a releasing agent that is applied to the mat to prevent the board from sticking to the hotpress. Various materials are used, such as diesel fuel, kerosene, silicones, and urea.

Dry-formed hardboard and medium-density fiberboard

The standard adhesive for dry-formed hardboard is phenol–formaldehyde resin. Resin content is, of course, higher in dry-formed hardboard than in wet-formed hardboard, where phenol or other binders play a secondary role. These binders also vary in contents, depending on the application of the product. Wax is generally added as a sizing agent.

Weyerhaeuser at Klamath Falls, OR, for instance, produces a dry-formed siding by using a phenolic resin content of 6 percent and a wax (as size) content of 0.5 percent. The additives are applied as indicated in figure 129.

In other cases, the liquid resin is introduced through the hollow shaft of the refiner, so that it contacts the chips as they are being fiberized between the plates.

One of the main problems in adding binder to dry furnish is that the binder often has enough tack to cause the dry fiber to lump together as soon as the binder is applied. This condition makes uniform distribution and deposition of the furnish in the forming machine difficult, if not impossible.

The development of the dry medium-density fiberboard process in the 1960's was based in part on a so-called ***in situ* resin**, a combination melamine–urea–formaldehyde resin of low molecular weight, low tackiness, and low viscosity. Later, standard urea resins with low tack were used as well. These resin binders are applied in short retention blenders like the Grenco continuous blender illustrated in figure 132 (Suchsland 1978). The retention time in this blender is between 1 and 3 s. The resin is injected into the fiber mass through radially arranged injection tubes. Solid resin contents

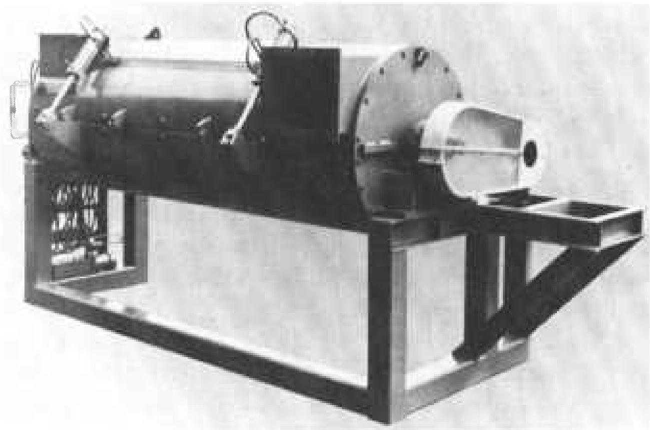


Figure 132—*Grenco short retention blender for dry furnish (Suchsland 1978).*

commonly range from 8 to 10 percent based on dry fiber weight.

The pH of the dry fiber furnish is generally not controlled. However, pH of the furnish is taken into consideration in binder formulation, since it affects curing rates. Experiments conducted at the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory have shown that modification of the pH of dry fiber furnish, by spraying it either with a 1 to 2 percent solution of sulfuric acid for downward adjustment or with a 5 to 10 percent solution of sodium bicarbonate for upward adjustment, had significant effects on mechanical and physical properties. Such treatments could counteract the refractory gluing properties of species such as oak (Myers 1977).

References

American Marietta Co. The effect of process variables on the physical properties and manufacture of S2S dry process hardboard. S/S Bulletin 701-2-1a. Seattle, WA: American Marietta Co. 14 p.

American Society for Testing and Materials. Annual book of ASTM Standards, part 18. Philadelphia, PA; 1980: 795-808.

Ballard, G.A.; Schlavin, L.E. Instrumentation for the particle board industry specific gravity. In: Maloney, T.M., ed. Proceedings of 3d Particleboard Symposium; 1969 March; Pullman, WA. Pullman: Washington State University; 1969: 33-43.

Brown, F.L.; Kenaga, D.L.; Gooch, R.M. Impregnation to control dimensional stability of particle board and fiberboard. Forest Products Journal. 16(11): 45-53; 1966.

Cobb, R.M.K.; Swanson, J.W. Introduction. In: Swanson, J.W., ed. Internal sizing of paper and paperboard. TAPPI Monograph Series No. 33. New York: Technical Association of the Pulp and Paper Industry; 1971: 1-4.

Dow Chemical Co. Promotional literature. Midland, MI.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

Fahey, D.J.; Pierce, D.S. Role of phenolic resins in imparting properties to dry-formed hardboard. Tappi. 56(3): 53-56; 1973.

Goldstein, I.S. Degradation and protection of wood from thermal attack. In: Nicholas, D.D., ed. Wood deterioration and its prevention by preservative treatment, Vol. 1. Syracuse, NY: Syracuse University Press; 1973: 307-339.

Holmes, C.A. Effect of fire-retardant treatments on performance properties of wood. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, DC: American Chemical Society; 1977: 82-106.

Keaton, C.M. Phenolic resins in hardboard. The Lumberman. 77(3): 90; 1950.

Lorenzini, E.M. Internal sizing with asphalt emulsions. In: Swanson, J.W., ed. Internal sizing of paper and paperboard. TAPPI Monograph Series 33. New York: Technical Association of the Pulp and Paper Industry; 1971: 150-157.

Lull, R.W. Alum. In: Swanson, J.W., ed. Internal sizing of paper and paperboard. TAPPI Monograph Series 33. New York: Technical Association of the Pulp and Paper Industry; 1971: 38-47.

Maloney, T.M. Modern particle board and dry-process fiberboard manufacturing. San Francisco: Miller Freeman Publications; 1977. 673 p.

Myers, G.C. How fiber acidity affected functional properties of dry-formed hardboards. Res. Pap. FPL-282; Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1977. 8 p.

Myers, G.C.; Holmes, C.A. Fire retardant treatments of dry-formed hardboard. Forest Products Journal. 25(1): 20-28; 1975.

Myers, G.C.; Holmes, C.A. A commercial application of fire retardants to dry-formed hardboards. Res. Rap. FPL-298; Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1977. 8 p.

Porter, R.B. Internal sizing with wax series. In: Swanson, J.W., ed. Internal sizing of paper and paperboard. TAPPI Monograph Series 33. New York: Technical Association of the Pulp and Paper Industry; 1971: 127-146.

Runckel, W.J. Douglas-fir slabs, edgings and bark: wet continuous process hardboard. Journal of the Forest Products Research Society. 3(5): 148; 1953.

Short, M.B.; Rayfield, J.W. Methods of impregnating wood with boric acid. U.S. patent 4,076,871. 1978 February 28. 3 p.

Steinmetz, P.E.; Fahey, D.J. Resin treatments for improving dimensional stability of structural fiberboard. Forest Products Journal. 18(9): 71-75; 1968.

Swanson, J.W.; Kumler, R.W.; Misplay, R.G. The process of sizing. In: Swanson, J.W., ed. Internal sizing of paper and paperboard. TAPPI Monograph Series 33. New York: Technical Association of the Pulp and Paper Industry; 1971: 54-96.

Suchsland, O. Medium-density fiberboard production possibilities in the Tennessee Valley region. TVA Technical Note B29. Norris, TN: Tennessee Valley Authority, Division of Forestry, Fisheries and Wildlife Development; 1978. 173 p.

U.S. Department of Agriculture, Forest Service. Wood handbook. Agric. Handb. No. 72: Washington, DC: U.S. Department of Agriculture; 1974. 414 p.

Watkins, S.H. Rosin, and rosin sizes. In: Swanson, J.W., ed. Internal sizing of paper and paperboard. TAPPI Monograph Series No. 33. New York: Technical Association of the Pulp and Paper Industry; 1971: 5-36.

Wilke, A. Das Bindemittel in der Faserplattenfertigung. Holz als Roh- und Werkstoff. 5(2): 78-81; 1942.

8. Wet-Process Fiberboard Manufacture

General

Wet- and dry-formed fiberboard processes differ drastically from one another, although many of the initial processing steps previously discussed are common to both. Figure 75 may suggest that in a fiberboard plant the furnish produced by any of the three principle pulping methods can be supplied to any of the several product manufacturing lines—wet or dry—according to market demand. This is not the case. A fiberboard plant is designed to produce either wet- or dry-formed board, and is generally limited to one or two different endproduct categories.

Although there are significant differences between wet and dry fiberboard processing in practically all steps, beginning with cooking and refining, a more visible and fundamental differentiation begins with the forming and carries through the pressing operation. Wet fiberboard processing from forming through drying and pressing is discussed in this chapter, dry forming and pressing in the chapter following. Subsequent steps such as humidifying and board fabrication are similar in both and are discussed together in subsequent chapters. Through part of the wet process the fibers are suspended in water. The furnish **consistency**, i.e., the relative quantity by weight (dry) of the fiber component, varies considerably, as illustrated in figures 114 and 127. Most of this water is removed from the furnish on the forming machine.

Consistency values alone, however, do not directly reflect the enormous quantities of water consumed, handled, and/or recirculated. It must be remembered that a reduction of the consistency from 2.0 to 1.0 percent requires doubling of the amount of water.

Figure 133 is a schematic illustration of an S1S fiberboard process, indicating both furnish consistency and actual quantities of water and fiber, based on a daily board production of 100 tons. The central part of the diagram shows the consistency variation in percent. The incoming raw material has an assumed moisture content of 100 percent (based on dry weight), which translates into a consistency value of 50 percent. To produce 100 tons of board in 24 h requires a constant rate of dry fiber flow from one end of the process to the other of 0.069 tons/min.

At 100 percent moisture content (50 percent consistency), the raw material introduces into the process 18 gallons of water/min. As water is being added and removed, the consistency of the furnish changes. The absolute quantity of dry wood fiber passing through each step of the operation, however, remains the same at 0.069 tons/min. To reduce the consistency from 50 percent to 12 percent requires the addition of only 116 gal/min. To further reduce the consistency from 12 percent to 1 percent requires the enormous quantity of 1,671 gal of water/min. All of this water is removed in the washer and much of it is replaced subsequently. After the washer, the consistency is gradually reduced to the forming consistency of about 2 percent. On the forming machine the mat is formed by drawing the water from the slurry. Some more water is removed in the wet press, and the rest is squeezed out or evaporated in the hotpress.

Water consumption and discharge problems can be greatly reduced by partial or total recirculation as indicated by the dotted lines in figure 133. Two water cycles are apparent. The primary water cycle recirculates the washer discharge, which is contaminated with sugars. The secondary cycle (machine white water) is kept separate from the first. It carries washed out chemical additives that build up to a constant level so that chemicals have to be added only at the rate at which they are actually retained in the board.

Similar diagrams could be drawn for the other two options of the wet process: insulation board and wet-formed S2S board. In the case of insulation board, the hotpress would be replaced by the continuous dryer, and in the case of wet-formed S2S board, the dryer would be inserted onto the line, directly preceding the hotpress.

Although the amount of water removed in the hotpress or dryer is relatively small, these two steps impose important limitations on the wet process: only one smooth side in the S1S process and considerable energy requirements for water evaporation in continuous dryers (insulation board and S2S board).

A schematic of the wet-formed fiberboard process is shown in figure 134 (Watts 1958).

Forming Machines

General

Wet-forming machines utilize water as a distributing medium for the fine pulp fibers. The forming of the sheet occurs when the watery pulp suspension flows onto a wire screen that allows the water to drain while retaining the fibers.

The uniformity of the result depends to a large extent on the furnish concentration at which the forming process takes place. Pulp fibers in suspension have a tendency to form lumps at higher concentrations, when their free movement is restricted by a high frequency of fiber collisions (Mason 1950). This "mechanical entanglement" of fibers can lead to uneven fiber deposition and density variation in the final product. Below a certain

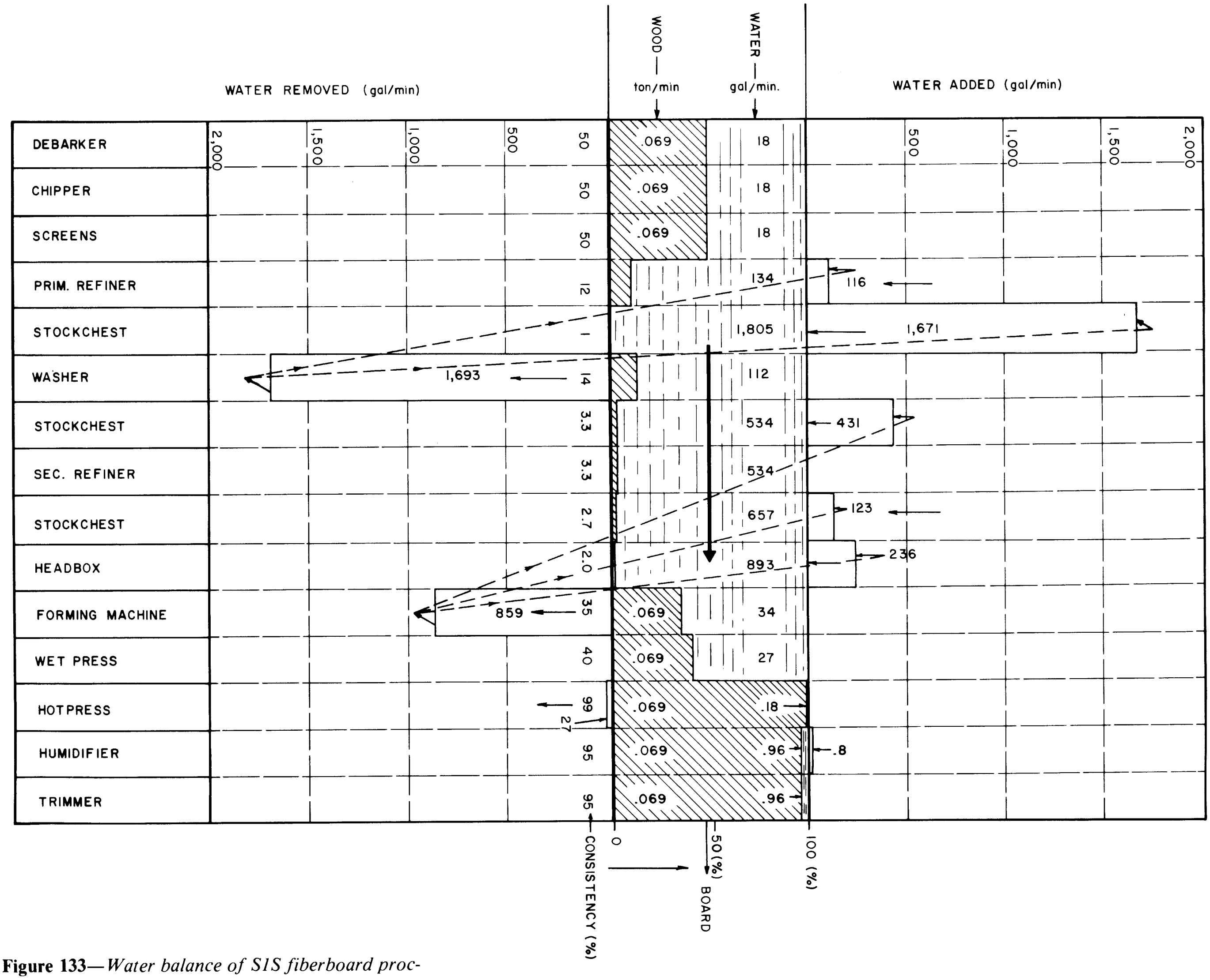


Figure 133—*Water balance of S1S fiberboard process. Central portion of chart shows changing consistency of furnish quantity necessary to produce 100 tons of board in 24 hours. Horizontal columns to the left and right indicate quantities of water removed or added as furnish moves through sequence of operations. For instance: as furnish is diluted from 12 to 1 percent consistency in stockchest, 1,671 gal/min of water must be added.*

critical concentration, fiber movement is generally unimpeded. Upon removal of the water, however, fibers have a tendency to settle independently and without the interweaving that is necessary to develop maximum sheet strength. Figure 135 shows the effect of furnish concentration on the bending strength of the board. At the concentration where maximum bending strength develops, the forming of lumps (flocculation) is just avoided, but there occurs a "collective sedimentation" of fibers, that is, physical interference at the moment of sedimentation, which results in a more three-dimensional fiber network. Optimal furnish concentration would also be influenced by the type of raw material, fiber length, cooking conditions, and other factors.

Of great importance for productivity and economy of the process is the rate at which water can be removed from the furnish. The dominant factor is the drainage characteristic of the furnish itself as expressed by its

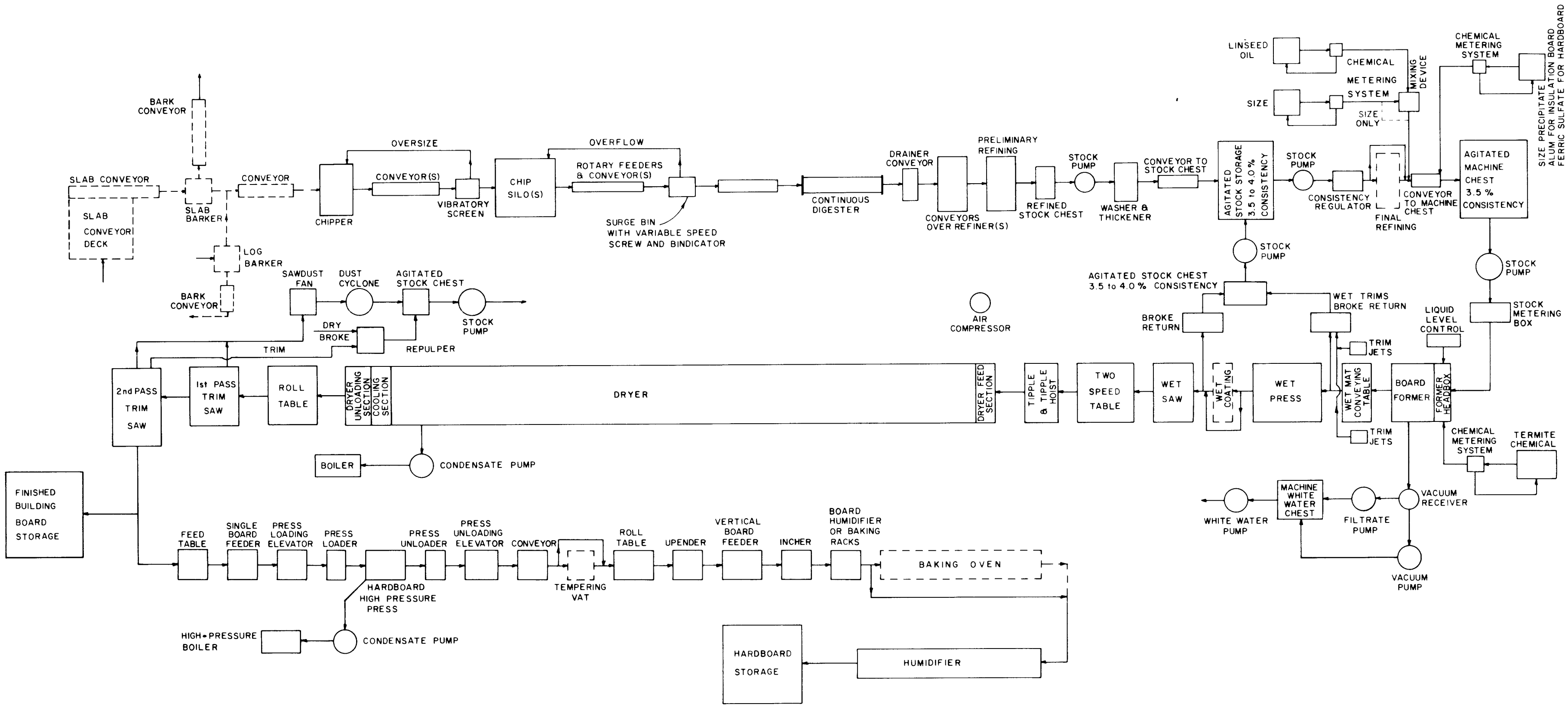


Figure 134—*Schematic of wet-formed fiberboard process (Watts 1958).*

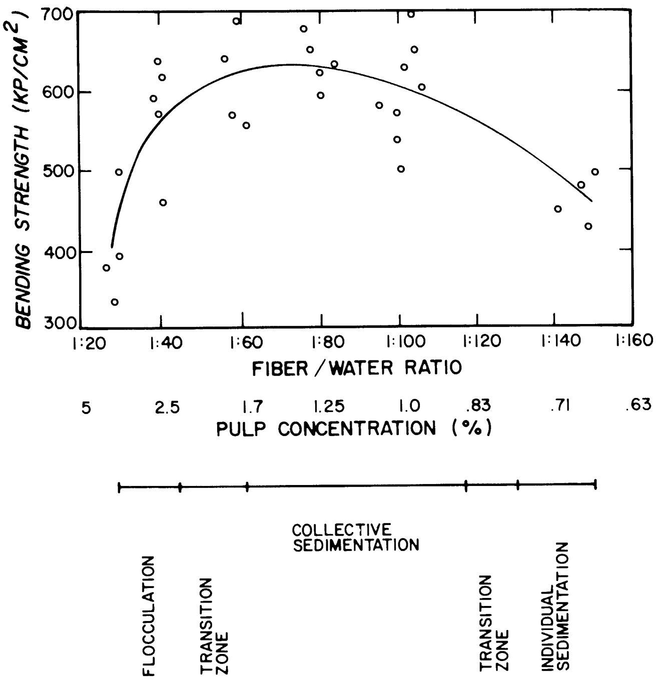


Figure 135—*Effect of furnish concentration in head box on bending strength of fiberboard (Lampert 1967). Note: 1 kp/cm² (kilopond/square centimeter) is equivalent to 14.223 lb/in².*

freeness. Another important factor is the furnish temperature (more precisely the water temperature). The viscosity of water is significantly reduced by only moderate increases in its temperature (fig. 136). Limitations here are the adverse effects of higher temperatures on chemical additives. Three different wet forming machines are used in the industry:

- batch-type sheet mold
- continuous cylinder machine
- Fourdrinier machine

Of these, the Fourdrinier machine is the most important and is used exclusively in new installations.

Batch-type sheet mold

The discontinuous, or batch-type, wet-forming process was developed by Ralph Chapman of Corvallis, OR (see chapter 1) in an effort to produce fiberboard economically on a small scale. The principle of this forming system is illustrated in figure 137 (Lyall 1969). It is described in an article by Stordalen and Bollerslev (1952):

> The forming equipment consists of a 4 by 8 ft deckle box. The upper part is lowered or raised by air cylinders. The upper part is forced down pneumatically on an endless screen, which also passes between the platens of the cold press. In the lower part of the box, vacuum is applied to suck the water out of the stock, forming a thick mat.
>
> To form a mat, the box is lowered onto the screen and stock from the chest is pumped at a continuous rate of flow through four "swing spouts," into the forming box. The spouts pass over the box at a predetermined speed, depending upon the desired thickness of the finished board, and then return to the discharge side. The spouts, when not over the deckle box, discharge back into the chest, keeping the stock constantly agitated. When the spouts return to the discharge side they activate a switch, which in turn activates valves, and vacuum is pulled on the mat from underneath the screen. On a predetermined time cycle, depending upon the thickness of the board, the air cylinders on the forming box are activated, the top section of the forming box raises, a chain drive carries the screen and the

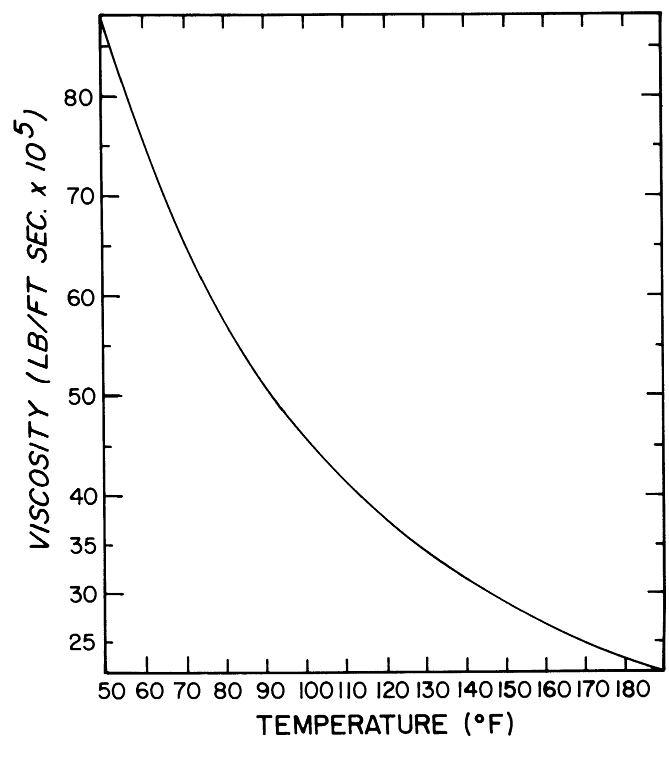


Figure 136—*Relationship between temperature and viscosity of water.*

formed mat into the cold press or prepress. Another cycle is now ready to begin. The closing of the prepress and the lowering of the forming box are simultaneous.

Excess water is removed in the prepress. On leaving the prepress, the mat has a moisture content of approximately 170 to 200 percent (equivalent to a consistency of 33 to 37 percent or a water content of 63 to 67 percent). From here, the mat is carried by belts on a tipple into loading racks where the mat is supported on rollers alone.

When the loading rack is full, the forming operation is stopped; the mats are then carried onto screens that are fixed to the lower platen of the press and the pressing cycle begins.

One noteworthy part of this process is that the complete felting and loading operation can be stopped and started by one button on the press control panel without affecting the operations before or after the forming section.

The important advantages of this forming system are simplicity, low capital investment, and ease of control and operation. Limited capacity, however, and variability of the forming process have stood in the way of general acceptance of this idea. Nevertheless, two plants in the United States (Corvallis, OR, and Duluth, MN) are still operating the original Chapman machines (fig 138) although additional capacity is being formed on Fourdrinier machines (Superwood). A third Chapman plant in New Westminster, BC, has replaced the Chapman former with a Fourdrinier machine.

Cylinder forming machines

Cylinder machines are continuous formers, very similar in design to vacuum pulp washers discussed briefly in chapter 6. Compared with the Fourdrinier forming machine, cylinder machines are simple, relatively inexpensive, and rugged.

A **single-cylinder** machine is illustrated schematically in figure 139 (Lyall 1969). These machines are built with

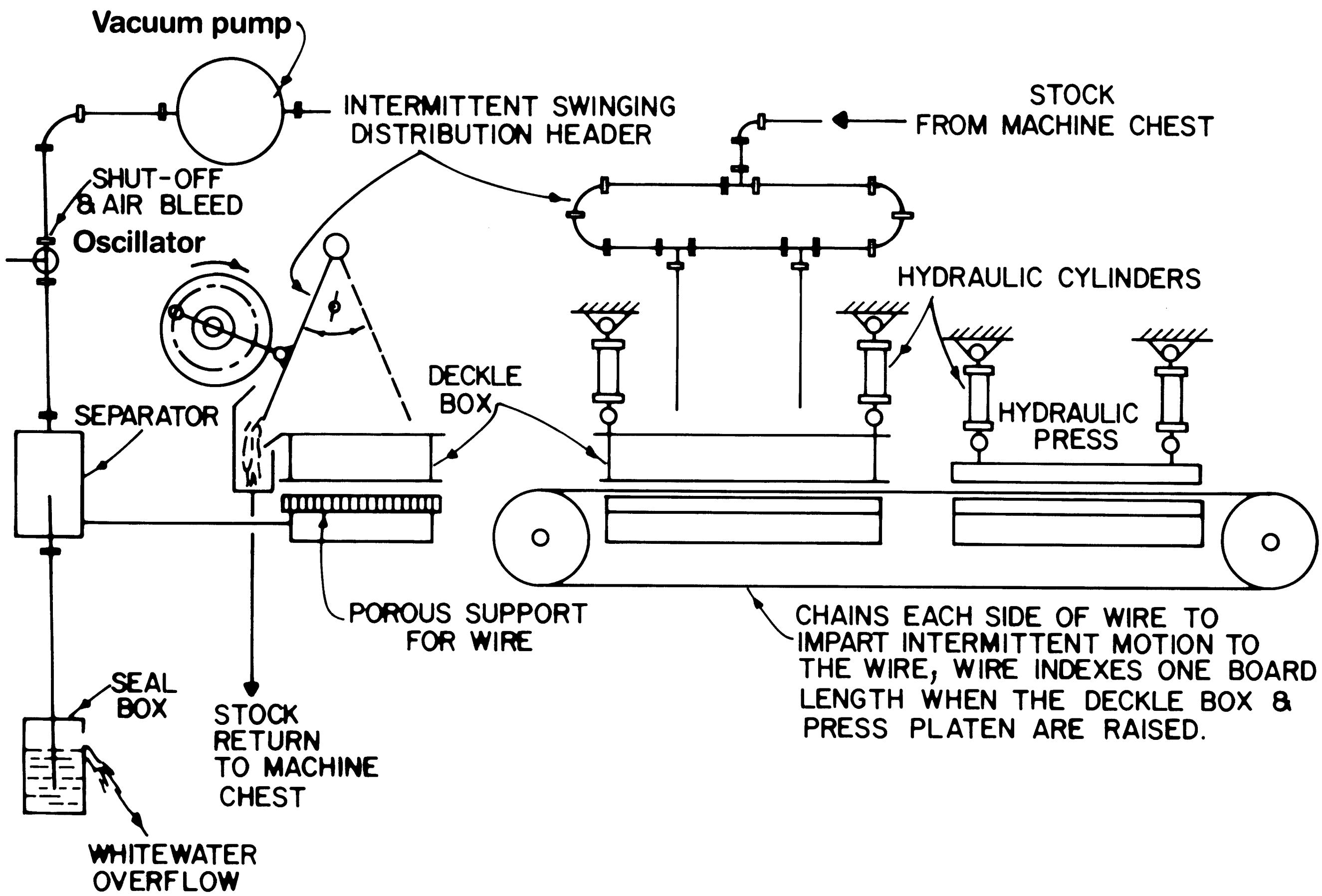


Figure 137—*Sheet mold type forming machines (Chapman process) (Lyall 1969).*

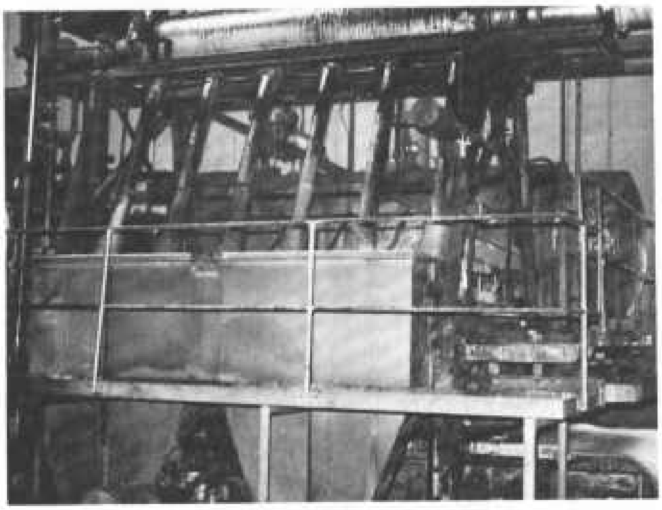


Figure 138—*Chapman forming machine showing swing spouts and stock return boxes.*

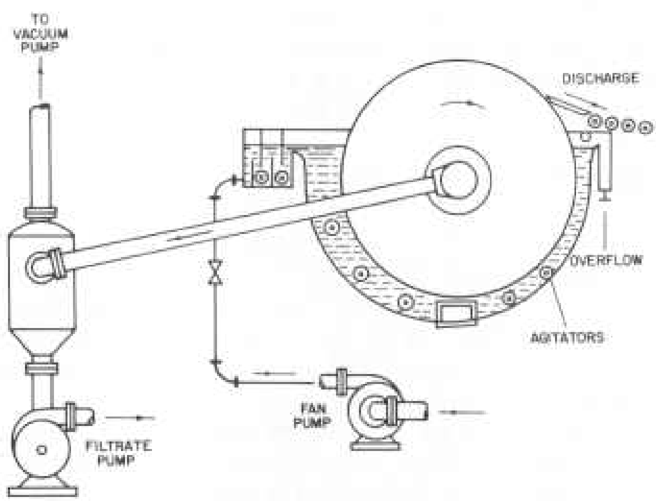


Figure 139—*Single-cylinder vacuum forming machine (Lyall 1969). The diluted pulp slurry is supplied to the stock chest by the fan pump. From the stock chest the furnish flows into the trough in which the cylinder slowly rotates against the stock flow. Water is sucked by vacuum through the wire surface of the cylinder, while the fiber mat is being built up on the wire. On emerging from the trough, the mat is transferred to roller conveyor.*

diameters ranging from 8 to 14 ft and are from 9 to 15 ft long.The revolving cylinder is partially submerged in a vat continuously supplied with furnish from the stock chest by means of the so-called **fan pump**. Uniformity of the furnish is assured by continuous agitation and by maintaining a constant furnish level in the stock chest. The **mantle** of the cylinder is formed by a wire screen supported by radial partitions of the cylinder, which in turn form the compartmentalized drainage deck. These compartments are connected through a system of hollow spokes and trunnion valves to a vacuum pump. The pressure differential between the interior of the cylinder and the furnish vat causes the water to pass through the screen, depositing the fibers on it. White water (water drained from furnish) and air are conducted to a vacuum separator and are removed by vacuum and filtrate pump respectively.

At the point where the mantle of the cylinder emerges from the vat, the forming is completed. The built-up mat is compressed by press rolls equipped with press wire or press felt. These rolls simply force more water through the mat and the screen into the interior of the cylinder. No water is removed from the top of the mat.

The interior of the cylinder is so subdivided that the vacuum applied to longitudinal sections of the forming surface can be independently controlled. As the forming surface enters the pulp mixture, vacuum is applied slowly, then is gradually increased as the mat builds up on the revolving screen surface, reaching its maximum as the mat emerges from the pulp slurry. The vacuum is held at maximum value until the mat reaches the point where it is lifted off the screen surface by a so-called **doctor** and delivered to the wet press by roller conveyors. At this point the vacuum is cut off to facilitate the removal of the mat. The normal vacuum level maintained in the cylinder ranges from 15 to 24 in of Hg.

A **double-cylinder** forming machine is illustrated in figure 140 (Lyall 1969). The principle of the forming process is the same as for the single-cylinder machine. A pressure differential forces water through the screen surfaces of the cylinders revolving in the pulp vat. In the case of the double-cylinder machine the pressure differential is created by a water leg of around 10 ft, depending on the freeness of the stock, its consistency, temperature, and other characteristics affecting drainage.

The two cylinders are geared together and run at the same speed in opposite directions. Each cylinder forms half of the total mat thickness, the two halves being merged and "laminated" in the nip between the cylinders, where hydraulic pressure forces them together and helps dewater the mat. The doubling of the drainage area contributes to the higher productivity of the double-cylinder machine. Because no vacuum system is required, the construction of the cylinders is greatly simplified. The positive water pressure requires sealing of the vat along lines where the two cylinders enter the pulp and around

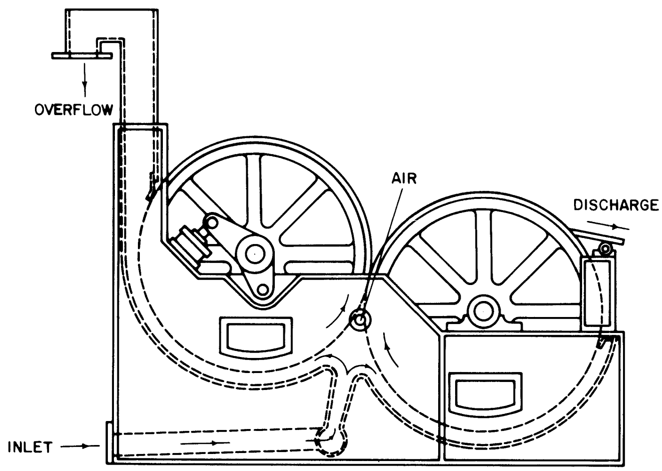


Figure 140—*Double-cylinder gravity forming machine (Lyall 1969). Similar to a single-cylinder machine, mat is formed on wire screen surface as water is sucked through it. At the nip the two mats are joined and are discharged on right as one mat.*

the ends of the cylinders. In addition, air is blown into the nip to keep the water in the vat away from the outgoing nip.

The double-cylinder machine has an important advantage over all other forming machines: it produces a mat of symmetrical fiber structure. All of the wet-forming machines have the tendency to deposit the coarser fraction of the stock first and the finest fraction last. The two surfaces of the board will therefore have different appearance and different properties. This condition can be somewhat alleviated by agitating the stock in the vat immediately prior to the deposition of the fibers. "Laminating" the two halves of the mat combines the top surfaces from each cylinder and presents the identical bottom surfaces of the individual mats as outside surfaces. The quality of the bond depends on the fiber characteristics, wood species, and freeness. If the surface fibers are too fine or too coarse, the sheet may delaminate either in drying or after drying.

The caliper of the laminated mat, besides being a function of the thickness of the two halves, is controlled by the hydraulic pressure applied to the mat in the nip. Pressures of 400 lb/in are not uncommon.

Double-cylinder machines produce boards of exceptionally uniform caliper and density.

Cylinder machines are capable of handling slower stock than the Fourdrinier-type forming machine at the same forming speed and on the same forming surface area, but they are not suitable for very free draining stock. They also produce a mat of relatively low water content (less than 80 percent).

Cylinder machines have a tendency to orient fibers in the machine direction (direction of rotation). Eustis (1980) estimates this bias as 60:40; i.e., the value of most properties like bending strength, linear expansion, and others measured in the machine direction will exceed values at right angles in a 60 to 40 ratio; those like linear expansion will be less in a 40 to 60 ratio.

Production rates of cylinder forming machines depend mainly on stock freeness and on the required thickness and density of the mat. For a given pulp the build-up of the mat is determined by the peripheral speed of the cylinder or cylinders. The slower the speed, the thicker will be the mat on the screen. The relationship between mat thickness and forming speed is not linear, however, because, as the mat builds up, the vacuum or the pressure differential becomes less effective in forcing water through the screens. The forming speed for very thick mats is thus greatly reduced.

Tables 24 (Lyall 1969) and 25 (Fuhrmeister 1958) give some examples of practical forming speeds on single cylinders producing insulation board mats; table 24 also shows data for double cylinders.

The Fourdrinier forming machine

The Fourdrinier fiberboard forming machine is a modification of the Fourdrinier paper machine named after the inventor Henry Fourdrinier of England. It forms the sheet continuously on a wire screen traveling in a horizontal plane. Water is removed by a combination of gravity and vacuum and in the press section of the machine by hydraulic pressure.

Fourdrinier-type forming machines can handle a wide range of pulp freeness and are used for the manufacture of hardboard as well as insulation board.

Figure 141 (Lyall 1969) is a simplified drawing of the important elements of a Fourdrinier machine. The main element is the endless wire screen, usually called "the wire." It is driven by a **couch roll,** the last bottom roll of the machine, and serves as both the forming surface and conveyor that carries the mat through the continuous **wet press,** the final section of the machine.

The **wire** is a metal weave of from 14 to 32 mesh in which the warp wires (running along the machine direction) are phosphor bronze; the shute wires (across the machine direction) are brass. Newer machine suse plastic wires (Edge Wallboard).

The wire is joined together to form a loop either by a seam produced at the factory or by a pin seam that can be fitted on the machine. The seamed wire requires a can-

Table 24—*Speed of single- and double-cylinder forming machines producing insulation board (Lyall 1969)*

Cylinder diameter (ft)	Speed			
	1/2-in board		1-in board	
	Line (ft/min)	Cylinder (r/min)	Line (ft/min)	Cylinder (r/min)
Single				
14	50–60	1.1–1.4	20–24	0.45–0.55
Double				
4	6–25	0.5–2.0	—	—
8	40	1.6	—	—
12	60	1.6	—	—

Table 25—*Production capacities of single-cylinder forming machines producing insulation board (Fuhrmeister 1958)*

Cylinder size (ft)		Area	Nominal production[1]	
Diam.	Face	(ft^2)	(ft^2/day)	Nominal tonnage/day
8	9	225	200,000	70
11.5	10	350	300,000	100
14	9	396	350,000	120
14	13.3	572	600,000	200
14	15	660	700,000	250

[1]1/2-in insulation board.

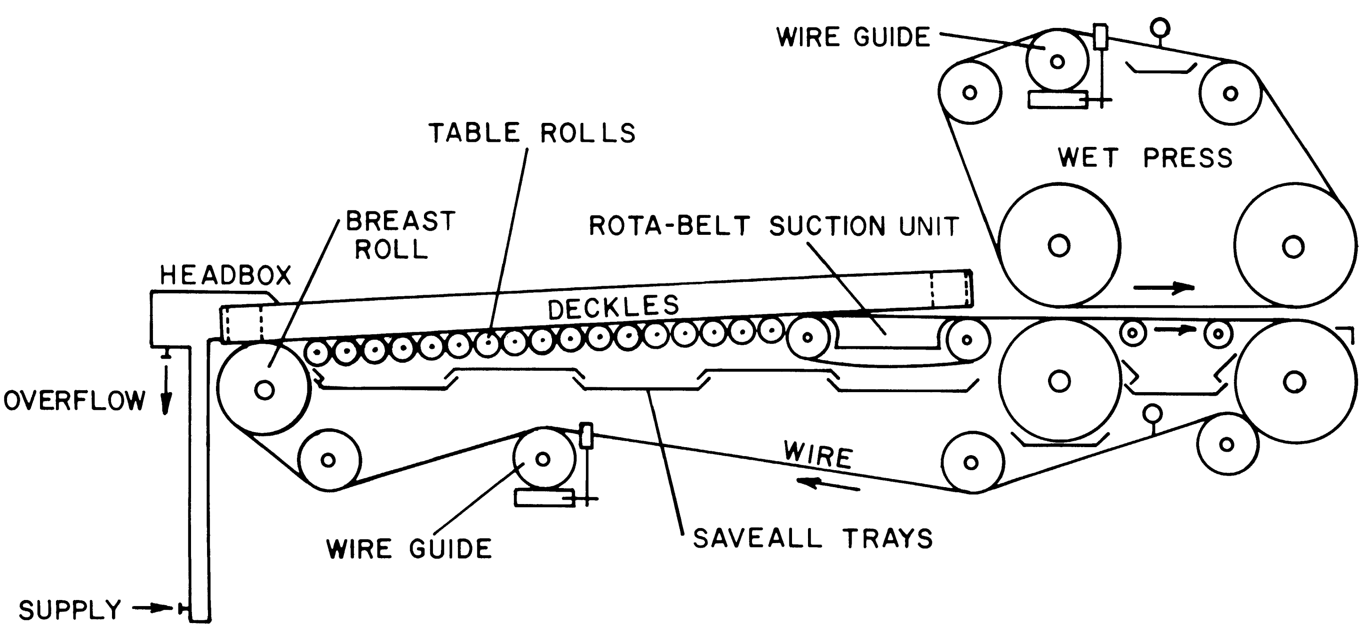


Figure 141—*Fourdrinier board forming machine with wet press (Lyall 1969). This is the most common former in wet-process fiberboard industry.*

tilever frame for installation to permit the loop to be slipped over the rolls from one side of the machine. The pin seam can be used on any machine but leaves an impression on the backside of the board. Pin seams on plastic wires, however, leave virtually no marks and have made the cantilever design unnecessary (Edge Wallboard).

The pulp is supplied at the appropriate consistency (1 to 2 percent) to the **headbox** which is preceded by some type of manifold assuring uniform distribution of the pulp over the width of the machine (fig. 142) (Edge Wallboard). From the headbox the pulp flows down an apron of plastic-covered cloth onto the **forming table.** A fence (**deckle**) on each side of the wire confines the stock to the screen and establishes the board edges.

The forming table consists of supportive framework, screen supports, and dewatering devices. The sheet is formed on this table and then is transformed from the very dilute pulp slurry in which each fiber is freely movable into a sheet in which all fibers are in permanently fixed positions relative to one another. Many of the qualities of the finished board are established here. Care must be taken that this original sheet structure is not disturbed in subsequent steps.

The forming table slopes upward from the headbox towards the wet press. This slope is adjustable and helps match the speed of the outflowing stock to the speed of the wire. Any speed differential will cause a drag on the fibers and a bias on their orientation resulting in directional mechanical and physical properties. Changes in the drainage characteristics of the stock would require slope adjustments. The Fourdrinier's slope has gone from fixed tilt to a parabolic curve to a double adjustable tilt. The double adjustable tilt currently used permits a steeper slope near the headbox, then a more gentle slope to the press section (Edge Wallboard).

On the machine shown in figure 141 the screen is supported by a series of closely spaced idling steel **table rolls,** 4 to 5 in in diameter. These rolls are designed to carry the considerable load of the stock and also contribute to the dewatering. Figure 143 shows the development of the vacuum in the outgoing nip of a table roll running at peripheral speeds of 2,000 and 2,500 ft/min. The vacuum, which is considerable, is caused by the surface tension of the water (Strauss 1970). Only paper machines run at such speeds. A fiberboard machine might reach speeds of up to 100 ft/min and the vacuum created is much smaller.

At a certain point on the forming table the stock will change from a watery suspension of fibers to a fiber mat. This point is called the **wet line** and can be recognized by the disappearance of the light reflection from the liquid water surface. Past the wet line the surface has a dull appearance (see figure 144). The rota-belt suction unit in figure 141 is located past the wet line. This type of **suction box** is equipped with a slotted rubber belt that travels with the screen to reduce friction and wear. These boxes are connected to vacuum pumps and apply vacuum of up to 10 in Hg.

One of the biggest changes made to Fourdrinier machines in recent years is the elimination of table rolls

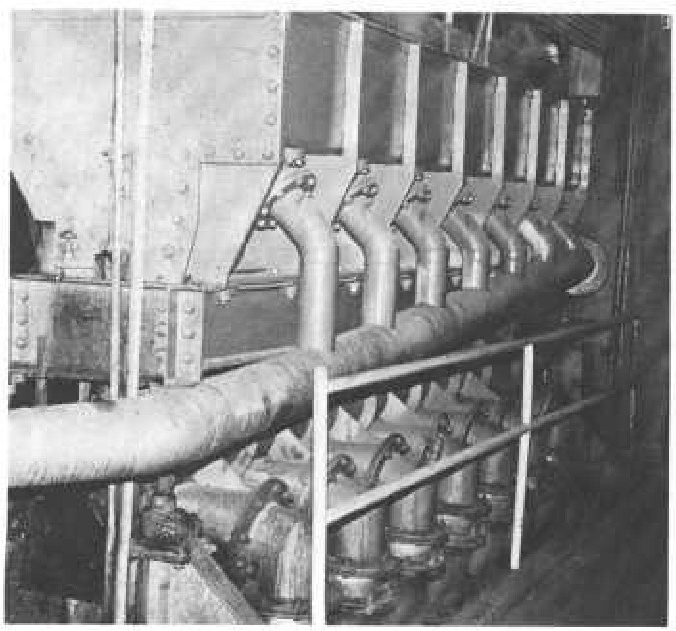


Figure 142—*Headbox with manifold.*

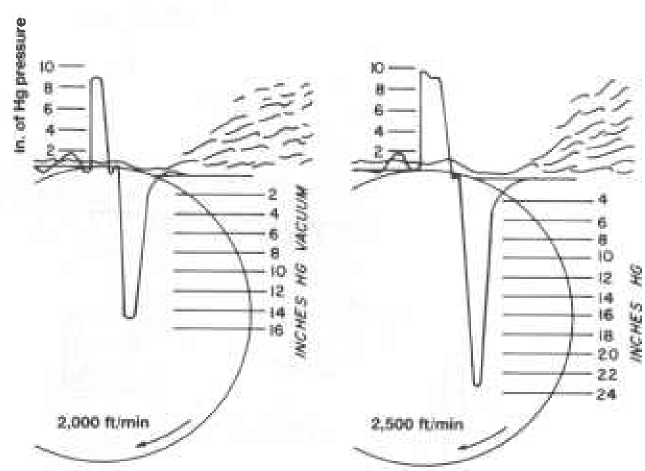


Figure 143 — *Dewatering action of Fourdrinier table roll on paper machine (Strauss 1970). Action on fiberboard former is similar, but due to lower speeds (100 ft/min) vacuum is much smaller. (© 1960 TAPPI. Reprinted from TAPPI Useful Method 1006 Sm-60, with permission.)*

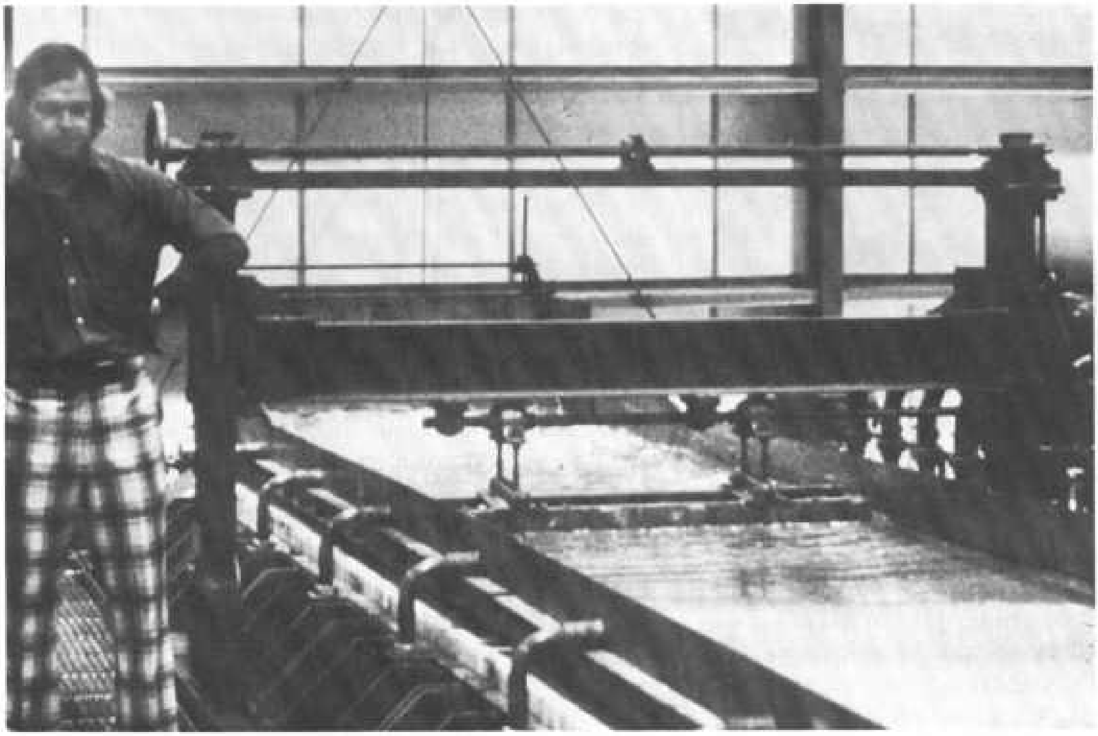


Figure 144—*Wet line on Fourdrinier forming machine (Edge Wallboard).*

and the acceptance of suction drainage boxes topped by ultra-high-molecular-weight polyethylene. Because these boxes are structurally more rigid than table rolls, they provide a flat surface for formation. **Pond depths,** i.e., the depth of the liquid flowing onto the forming machines, of 20 in are not uncommon, and it has been determined that under such conditions a normal table roll will deflect as much as 0.200 in while the suction box will deflect less than 0.040 in (Edge Wallboard).

It is important that vacuum be applied gradually. Too rapid drainage early in the forming process might tighten up the sheet, making it more difficult for water to pass through it. Springy stock resists compaction better and can tolerate more suction. Past the wet line the vacuum can be increased. Even then, vacuum increased too abruptly will suck the sheet down so forcefully that the surface may crack. A new Fourdrinier, without table rolls, normally has 20 suction boxes, each box 3 ft long (in direction of screen travel). The first three boxes after the headbox are operated through the drop leg to a seal box, 6 or 7 ft below the wire. The next four boses are piped to a deeper seal pit and a low-vacuum manifold (3 to 5 in Hg). Then, by valving, the vacuum level on these boses is graduated to control the rate of dewatering. The eighth box is piped through a triple compartment separator to a high-vacuum manifold (15 in Hg). The last two boxes are piped to individual separators and the high-vacuum manifold. The polyethylene-topped suction box has replaced the rota-belt on modern machines (Edge Wallboard). Figure 145 shows the vacuum manifold for the suction boxes of the forming table.

The amount of water that can be extracted from an uncompressed mat is limited. At a certain point (about 80 percent water content) the vacuum will suck air and very little water. To extract any more water requires compression to keep the mat saturated. This takes place in the wet press.

All modern machines are equipped with a **puddler**. This is a flat, vertically oscillating board oriented across the machine, just dipping into the top layer of the stock. This puddling action brings water and fines to the surface and develops a superior surface finish. As can be seen in figure 144, the puddler is located before the wet line. Most hardboard siding machines and some hardboard machines are equipped with a **secondary headbox**, which applies a surface layer of fine pulp on top of the main sheet. The overlay is generally a much slower stock, and the purpose is to upgrade the surface quality of an other-

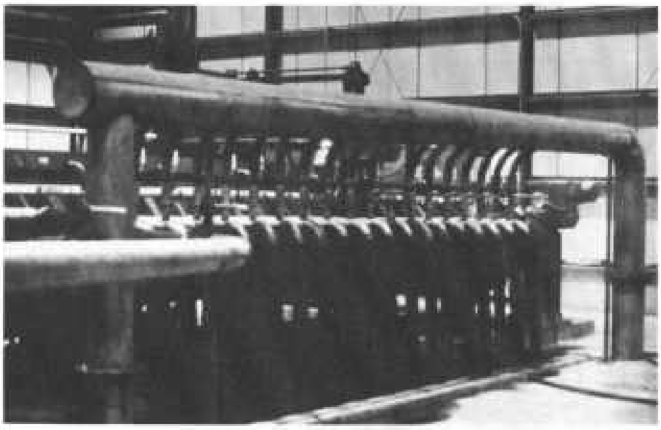


Figure 145—*Vacuum manifold for suction boxes on Fourdrinier forming machine (Edge Wallboard).*

wise fast and relatively coarse stock. Secondary headboxes apply up to 10 percent overlay based on the weight of the substrate. The drainage time of the overlay may be twice as long as that of the substrate. For instance, an 18-to 20-s stock (Tappi Standard) may receive an overlay of 50-s stock. If the overlay stock is too slow, not enough water can be removed from it before it reaches the wet press, where it would be "crushed" (Eustis 1980).

Secondary headboxes are located past the wet line. The overlay stock is released onto an apron, which drags on the substrate and from which the stock flows on top of the substrate. Figure 146 shows a secondary headbox shrouded by rising steam. Overlaying is normally not practiced in the manufacture of insulation board.

Fourdrinier formers for S1S hardboard differ in design from those for insulation board and S2S hardboard. An S1S hardboard or medium-density board forming line is normally coupled directly to the hotpress; that is, a forming line feeds one hotpress, requiring synchronization of press cycle and forming speed for continuous operation. The width of the hotpress is either 4 or 5 ft. Wider presses would be expensive because increased bending stresses would require much stronger platens and other structural members. Hardboard forming lines are therefore 4 or 5 ft wide, generally, although some are 8 ft wide.

In the manufacture of insulation board and S2S wet-formed hardboard, the forming line is coupled to a dryer rather than to a press. Drying a 12-ft-wide mat, for instance, is much more efficient than drying three 4-ft-wide mats, and no disproportionate design costs are involved. The width of insulation board and S2S hardboard forming machines is therefore a multiple of one standard panel module: 8, 12, and also 15 ft. The dried mat, which can be handled much more easily than the wet mat, is then cut to standard width before fabrication or pressing.

The Wet Press

The **wet press** is any device that further reduces the water content of the wet mat after extraction from the uncompressed mat by gravity, and vacuum has reached a practical limit. This limit is 20 to 30 percent solid fiber content in the case of the Fourdrinier forming machine and somewhat higher for cylinder forming machines.

Most wet presses are continuous roller presses; they are independent units for cylinder forming and they become an integral part of the forming machine in the case of the Fourdrinier. The discontinuous Chapman process uses a cold platen press as a wet press (fig. 137).

We shall consider in the following the principle and operation of the wet press as it is found on Fourdrinier machines. Wet presses used in the cylinder forming process are very similar if somewhat simpler because of the higher solid fiber content entering the press.

It should be pointed out here that there is a basic difference between hardboard and insulation board (and S2S) in terms of the critical need for further dewatering in the wet press. In both cases the final product is practically dry, i.e., all of the water must be removed. Some of the water is removed in the wet press in both cases and the rest in the hotpress or dryer, respectively. Figure 147 shows schematically the water removal from the wet mat in insulation board and S2S manufacture, and in the manufacture of S1S. In the wet press, water is removed in liquid form at relatively little energy cost. Water remaining in the insulation board and S2S mats must be converted into steam in the dryer at very high energy cost.

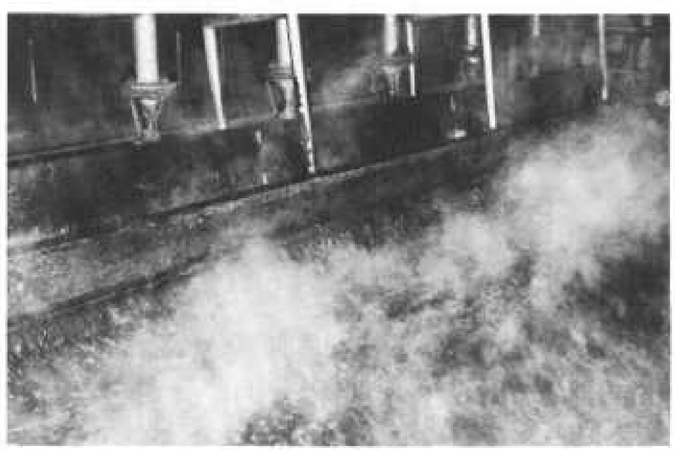


Figure 146—*Slush overlay being applied to S1S mat.*

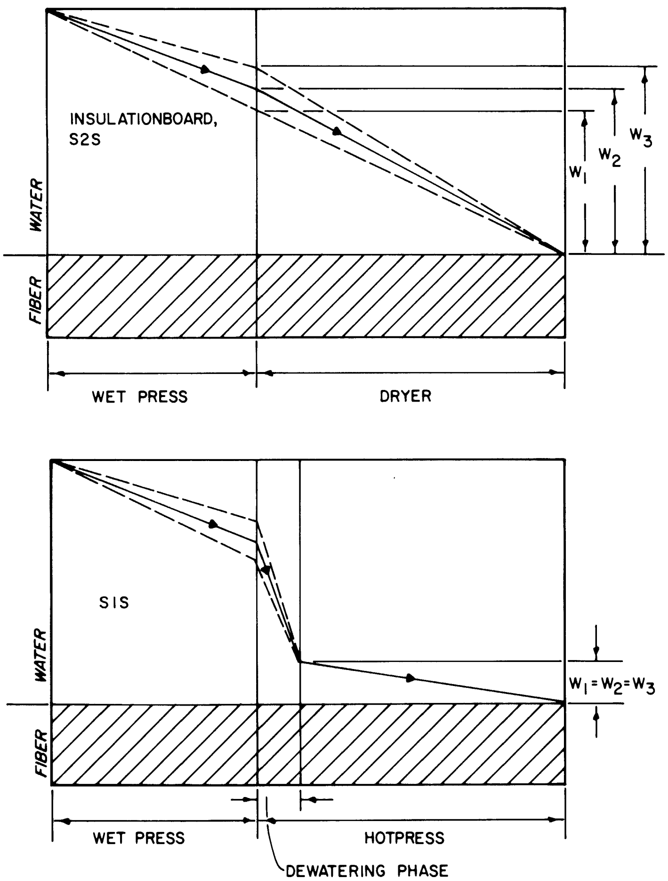


Figure 147—*Illustration of the relative sensitivity to wet press efficiency of the dryer and the relative insensitivity of the hotpress. W = water quantity to be removed.*

The cost of manufacturing insulation board and S2S hardboard is therefore sensitive to the moisture content of the mat at the dryer entrance (tipple moisture[2]). If we assume a dryer efficiency of 65 percent, it would take 1,800 Btu to evaporate 1 pound of water. Using a rate of $2.50/1,000,000 Btu, a reduction in tipple moisture of 3 percent on a 350 tons/day machine would yield a corresponding reduction in yearly energy cost of over $165,000 (Edge Wallboard). In the manufacture of S1S the hotpress removes most of the water remaining after wet pressing during the initial dewatering phase of the press cycle. A very high pressure is applied during this phase to squeeze out as much liquid water as possible, before heat transferred from the platens converts it to steam. The relatively small amount of water remaining in the mat after this initial phase of the press cycle is essentially independent of the water content of the mat leaving the west press. Wet press efficiency is, therefore, much less critical.

Figures 148 ad 149 show wet press sections of an insulation board machine and a hardboard machine, respectively. The numbered rolls are the **press rolls,** the main elements in the wet press. In both machines, at each pair of press rolls—starting from the infeed end—the gap between the Fourdrinier wire and the top wire is reduced by forcing the top rolls down against adjustable stops with hydraulic cylinders. This reduces the air volume in the mat until the mat is saturated with water at a mat den-

[2] This term derives from the mechanical loading device, the tipple, which feeds the mat into the various decks of the continuous multideck dryer.

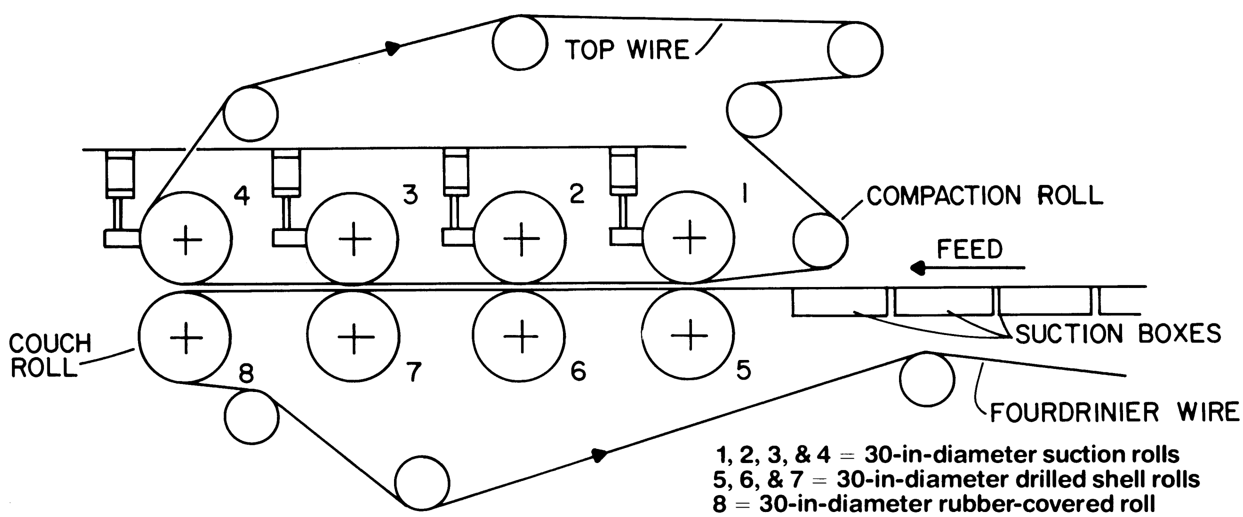


Figure 148—*Wet-press section of insulation board machine.*

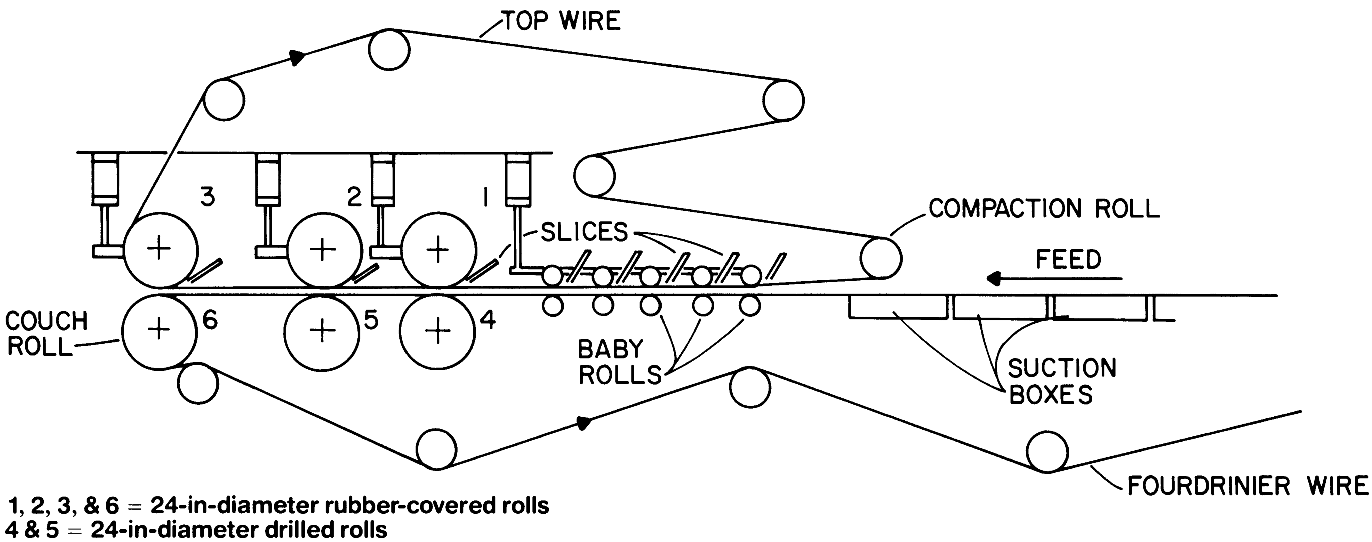


Figure 149—*Wet-press section of hardboard machine.*

sity of 62.5 lb/ft^3 . At this point hydraulic pressure inside the mat builds up and forces water to flow from the mat. The water flow can be approximated by the following equation:

$$\text{Water removed} = \frac{\text{press loading} \times \text{temperature}}{\text{speed} \times \text{basis weight}} \times K$$

where K = constant.

Figure 150 illustrates this situation in the nip between two press rolls. The total nip pressure is equal to the sum of the two internal pressure components, namely the hydraulic pressure and the resistive pressure of the mat.

According to the above equation, the water flow could be increased by increasing the press loading. However, excessive nip pressures will raise the hydraulic pressure above the resistive pressure of the mat, at which point fibers will be dislocated and the mat structure destroyed. This condition is known as **crush** and is evidenced by the appearance of wrinkles in the sheet. Modern machines are run "crush limited," i.e., the pressure is increased until crush occurs and then the rolls are backed off. Even then, fiber dislocation can occur in the center of the sheet, because there the hydraulic pressure is higher than in the outside layers (fig. 151).

Perforated rolls or **suction rolls** (fig. 152) reduce the pressure gradient, allow higher press loading and produce stronger boards, raising the possibility of reducing the basis weight (Edge Wallboard). Higher stock temperatures, because of their effect on water viscosity and thus on stock drainage, increase the water flow according to the equation above. However, depending on stock consistency, some or all of the energy saved in the dryer must be expended to heat the stock going into the headbox. Thus, higher consistencies favor net energy savings (Edge Wallboard).

As mentioned above, all these considerations are much more important in the manufacture of insulation board and S2S hardboard. The wet press illustrated in figure 148 uses four suction rolls on top and three perforated rolls on the bottom. The fourth bottom roll is the main wire drive roll and is rubber covered to increase traction. Perforated bottom rolls have proven as effective

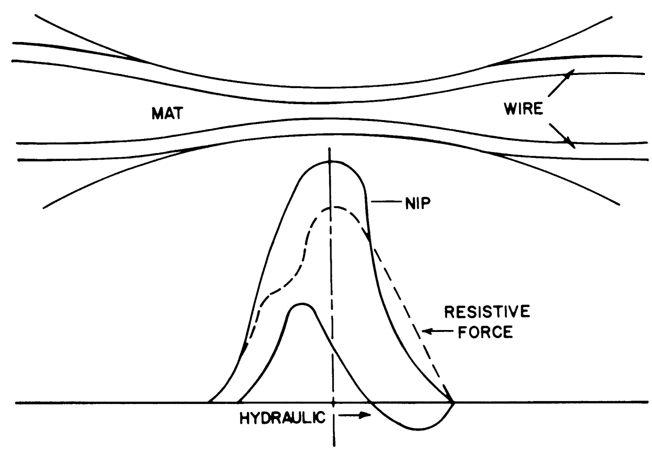


Figure 150—*Internal mat pressure in press roll nip (Edge Wallboard).*

as suction rolls, yet do not require the maintenance and the vacuum and separation system demanded by suction rolls. Insulation board may be dewatered down to 45 to 65 percent water content.

The insulation board wet press not only dewaters the mat but also presses the mat to a thickness that must be equal to the final board thickness plus an allowance for the shrinkage occuring in the tunnel dryer. Difficulties in thickness control sometimes arise from the deflection of the press rolls under load. This not only results in thickness variations but also in moisture content differences. Often, the moisture content will be lower along the edges of the mat than in the center, causing problems in the dryer. Increasing the stiffness of the rolls by using stainless steel shells, or the precise use of crowned rolls are measures to combat roll deflection. Crowned rolls have the disadvantage of developing peripheral speed differences that can distort the wire.

In the hardboard machine (fig. 149) solid rolls are used instead of the expensive suction rolls. The squeezed-out water is removed from the nip by **suction slices**, which are vacuum devices with narrow slots extending across the width of the machine and located as close to the nip as possible. The initial compaction is accomplished by a series of so-called **baby rolls**, also equipped with slices. Dewatering is not as efficient here as in insulation board machines. Water content at the output end of the hardboard wet press ranges from 65 to 75 percent. Figure 153 shows the infeed end of an S1S wet press.

Modern board machines are driven by sophisticated DC or variable-frequency AC drive systems. These sectionalized systems provide individual motors for each press roll and various auxiliary drive points. These machines run at speeds of 20 to 100 ft/min, 60 ft/min being a good average. Figure 154 shows part of the drive for press rolls of a hardboard machine.

Both S1S and insulation board machines are around 60 ft long, including the forming section (27 to 30 ft) and wet press. S1S machines are generally 5 ft wide; insulation board and S2S machines are 165 in wide, which would be called a 12-ft machine.

Trimming of Wet Fiber Mat

All forming machines, with the exception of the Chapman process, produce a continuous mat, which has to be subdivided into individual sheets that conform in their dimensions to press size or multiple final board sizes.

This trimming is accomplished by rotating steel disks while the mat is traveling on roller conveyors (fig. 155). Simultaneously the edges of the mat are also trimmed by either steel disks or water jets. The trim waste from the edges as well as entire defective mats can be detoured and returned to the process via a **repulper** in which the waste is broken down and diluted.

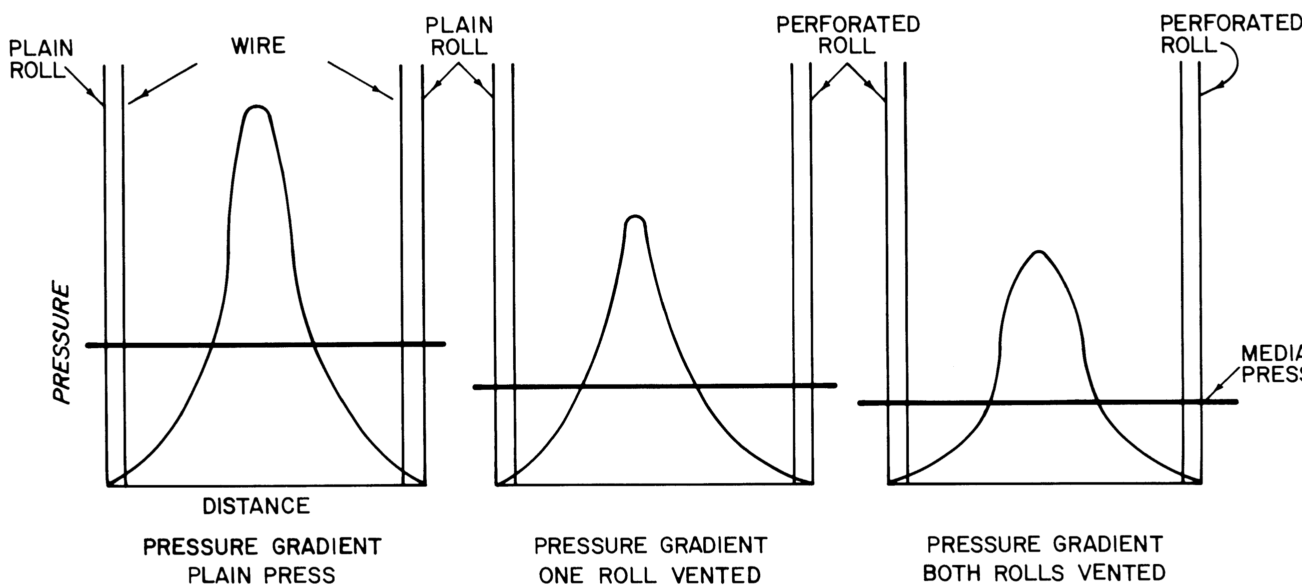


Figure 151—*Mat pressure distribution between press rolls of various designs (Edge Wallboard).*

Hotpressing and Drying

General

Although hardboard and insulation board processes differ considerably in many details of processing equipment and furnish preparation, until the mats emerge from the wet press the technology of manufacture is almost identical for all wet lines. The processing of the wet mat from that point on, however, is unique for each line. The distinguishing process element in the S1S hardboard line is the hotpress, in the insulation board line the dryer, and in the S2S line a dryer and hotpress combination (fig. 156).

The important technological functions of these elements are:

a) To provide conditions under which the various types of fiber bond can develop.

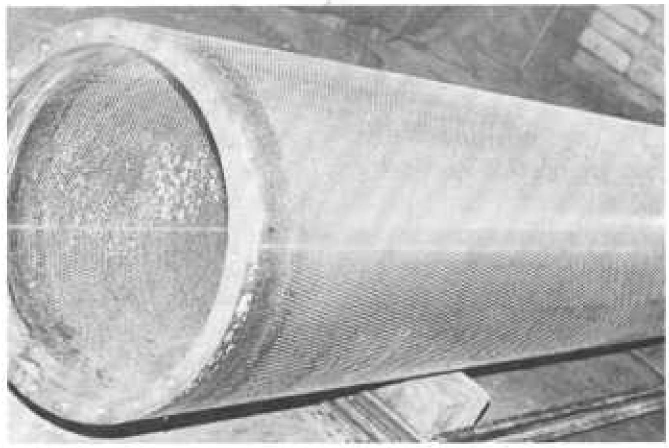


Figure 152—*Perforated roll from S2S wet press.*

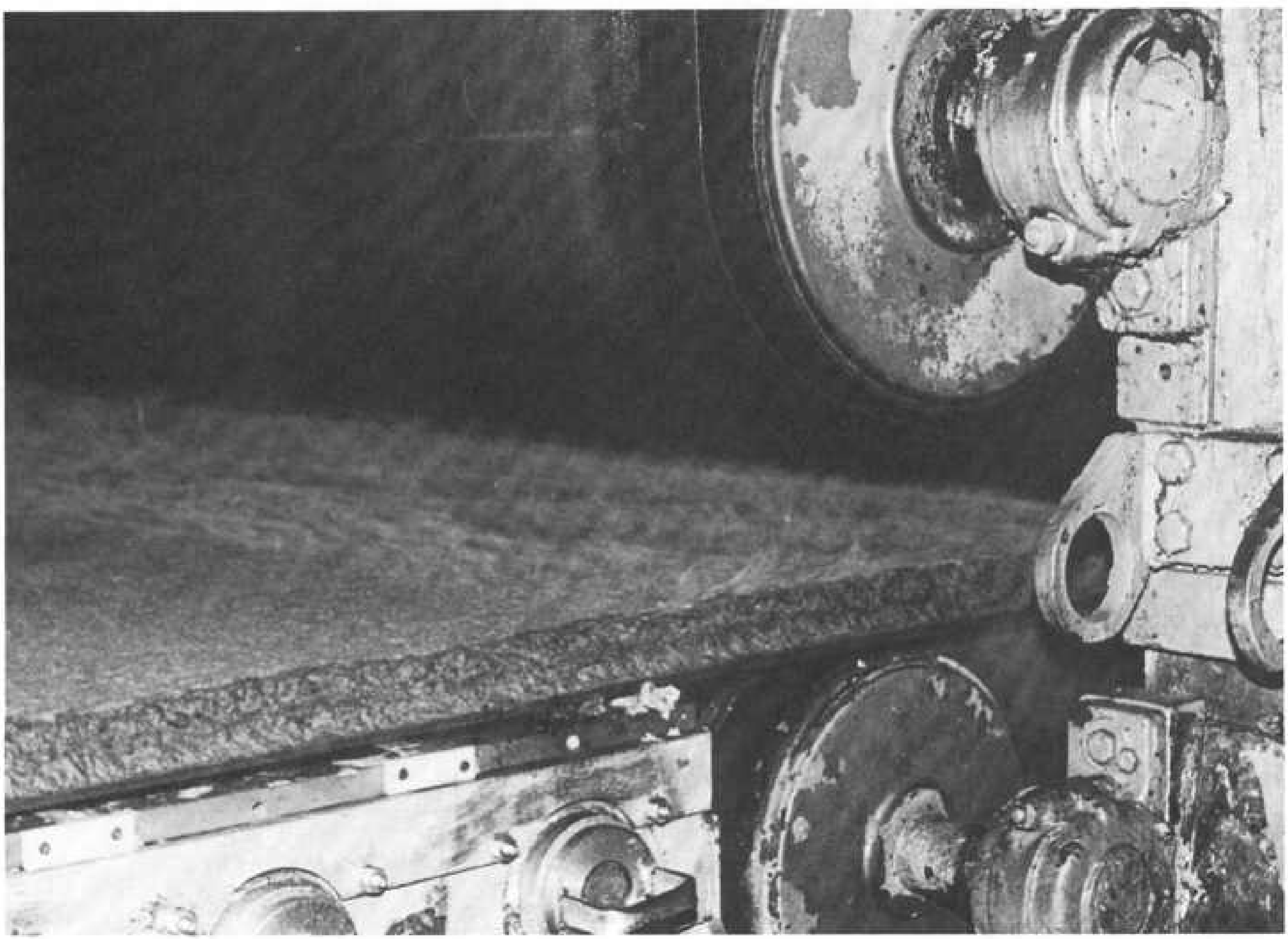


Figure 153—*Infeed end of S1S wet press.*

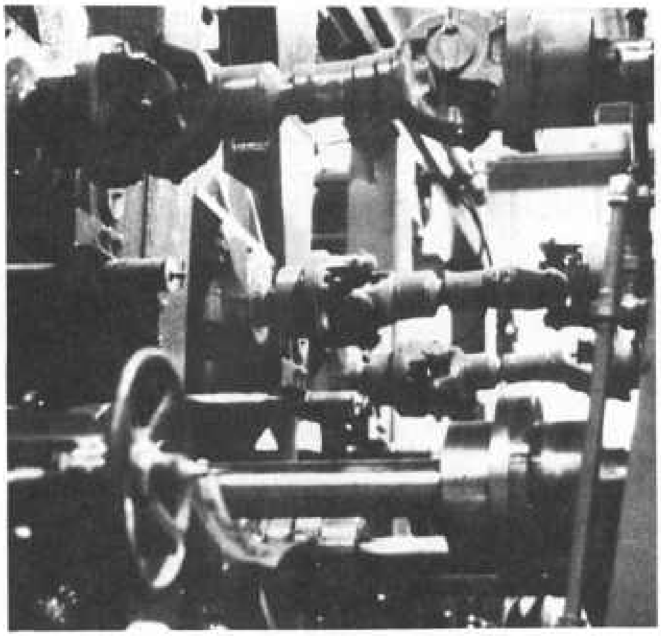


Figure 154—*Part of press roll drive of hardboard machine (Edge Wallboard).*

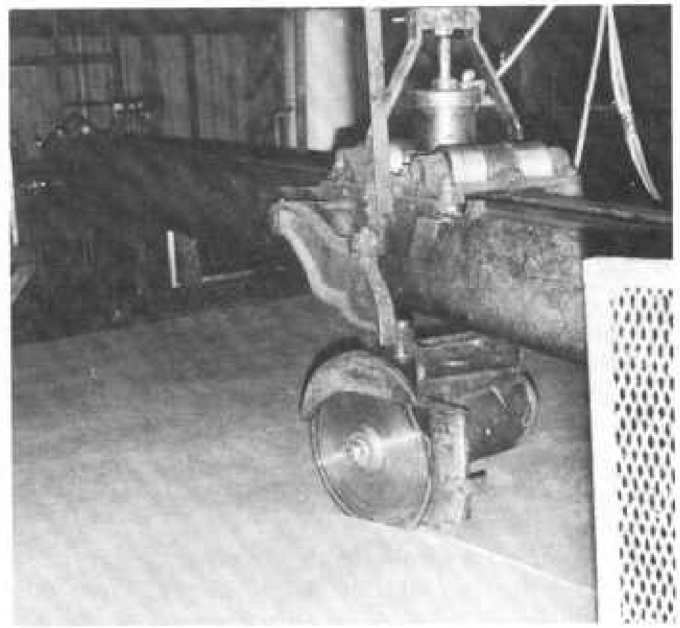


Figure 155—*Disk trimmer cutting traveling mat to length. Mat travel is from left to right. Overhead beam travels at same speed and in same direction as mat, while saw travels along beam across mat. When cut is completed the saw lifts up, and beam and saw return to initial position.*

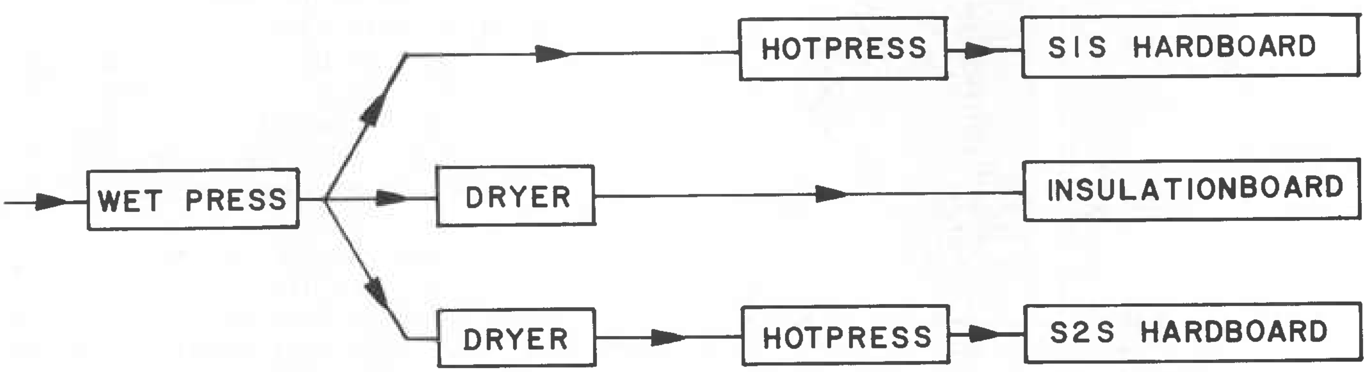


Figure 156—*Schematic of processing of wet fiberboard mats.*

b) To reduce the moisture content of the mat to a level that is in equilibrium (or nearly so) with the atmosphere.
c) To provide a degree of densification (hardboard) that is consistent with the development of adequate mechanical and physical properties for various applications.

Presses—types and construction

Because of the large forces involved, the difficult problems associated with the rapid transfer of large quantities of heat to the mat, and because of the need to precisely adjust and modify press cycles, continuous hotpresses are not practical.

The hotpress is thus a batch operation in an otherwise continuous process. Since the pressing time is generally a constant for a given board type and board thickness, the press capacity, and, therefore, the capacity of the entire line, is a function of platen size and number of press openings. The multi-opening press used throughout the fiberboard industry permits stacking mats and press platens to compress many boards with the same total force (fig. 157). The important relationship between forming line speed, press time, and press size is illustrated in the nomograph in figure 158. An 18-ft-long, 20-opening hotpress, for example, with a total press time, including loading and unloading, of 6 min, could thus accommodate a forming line speed of 60 ft/min. If this same line were used for the manufacture of a thicker board, requiring a press time of 8 min, the line speed would have to be reduced to 45 ft/min. Given the width of forming line and press, the line capacity in square feet per minute can readily be calculated.

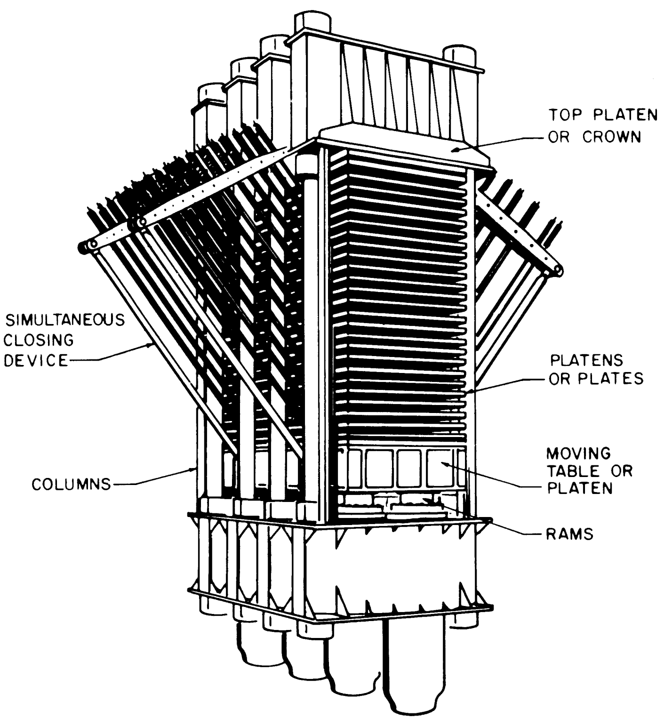


Figure 157—*Multi-opening board press (Morse 1967). System of rods on each side of press is designed to lift all platens simultaneously as press table is being pushed up by rams. All openings thus close at the same rate.*

Almost every part of a press is subjected to very large forces, generated by the hydraulic rams compressing the boards between platens. Given a specific pressure on a fiberboard mat of 1,000 lb/in^2, for example, the total force on a 5- by 18-ft press platen would be 6,480 tons, or almost 13 million pounds. This total force is resisted by the structural members of the press where it will cause normal stresses and bending moments. No reaction forces other than the press weight are transmitted to the foundation (fig. 159).

The frame members of the press may consist of press crown and base bolted together on each side by a series of cylindrical columns. This type of press is called a **column press** (fig. 160). In the **frame press,** on the other hand, the structural members consist of solid steel frames, each cut from a single piece of steel plate. Crown and base are mounted inside of the frames (fig. 161). Both types are found in the fiberboard industry. Newer presses seem to favor the frame design.

Press platens provide the plane, smooth surfaces against which the fiberboard surfaces are pressed and molded, and they carry the heating medium, either saturated steam or hot water. A system of interior channels provides for the passage and distribution within the platens of a sufficient quantity of heating medium to assure quick and uniform heating of the mat over its entire area.

Most fiberboard presses in the United States are heated by saturated steam. The European industry has turned almost exclusively to hot water systems. Greater uniformity, lower accumulator pressure, less heating medium leakage, and possible pH control are cited as advantages of the high-pressure hot water system. On the other hand, hot water requires forced circulation, and in most mills steam generation is also required for the operation of digesters, pressurized refiners, dryers, etc. (Kielland 1958).

Press temperatures vary from mill to mill, but average about 400 °F. Press platens are about 2½ in thick with heating channels of 1-1/8 in diameter. Platens must be plane and their surfaces parallel within tolerances of 0.005 in. The pressure is applied to the press platens by a series of cylinders and rams, so dimensioned that they will be able to provide the required specific pressure on the fiberboard mat with a reasonable hydraulic working pressure. Larger and fewer cylinders are the trend because they reduce maintenance costs. Hydraulic working pressures are between 3,000 and 5,000 lb/in^2. To provide a specific pressure of 1,000 lb/in^2 would require a ratio of platen area to total ram area of from 3:1 to 5:1.

The hydraulic medium in fiberboard presses is generally water, to which lubricants and other additives have been added. While pure oil hydraulic systems afford better protection of the equipment from wear and more economic pumping, in wet fiberboard pressing the hydraulic oil is easily contaminated by water squeezed from the mat early in the press cycle. For this reason water is preferred.

The demand for fast closing and pressure buildup requires hydraulic pressure fluid at very high rates of speed, which may exceed the capacity of the pumps. Either so-called **jack rams** or low-pressure **accumulators** are used to overcome this difficulty. Jack rams are small-diameter rams that can close the press quickly with a relatively small quantity of hydraulic fluid. The larger main

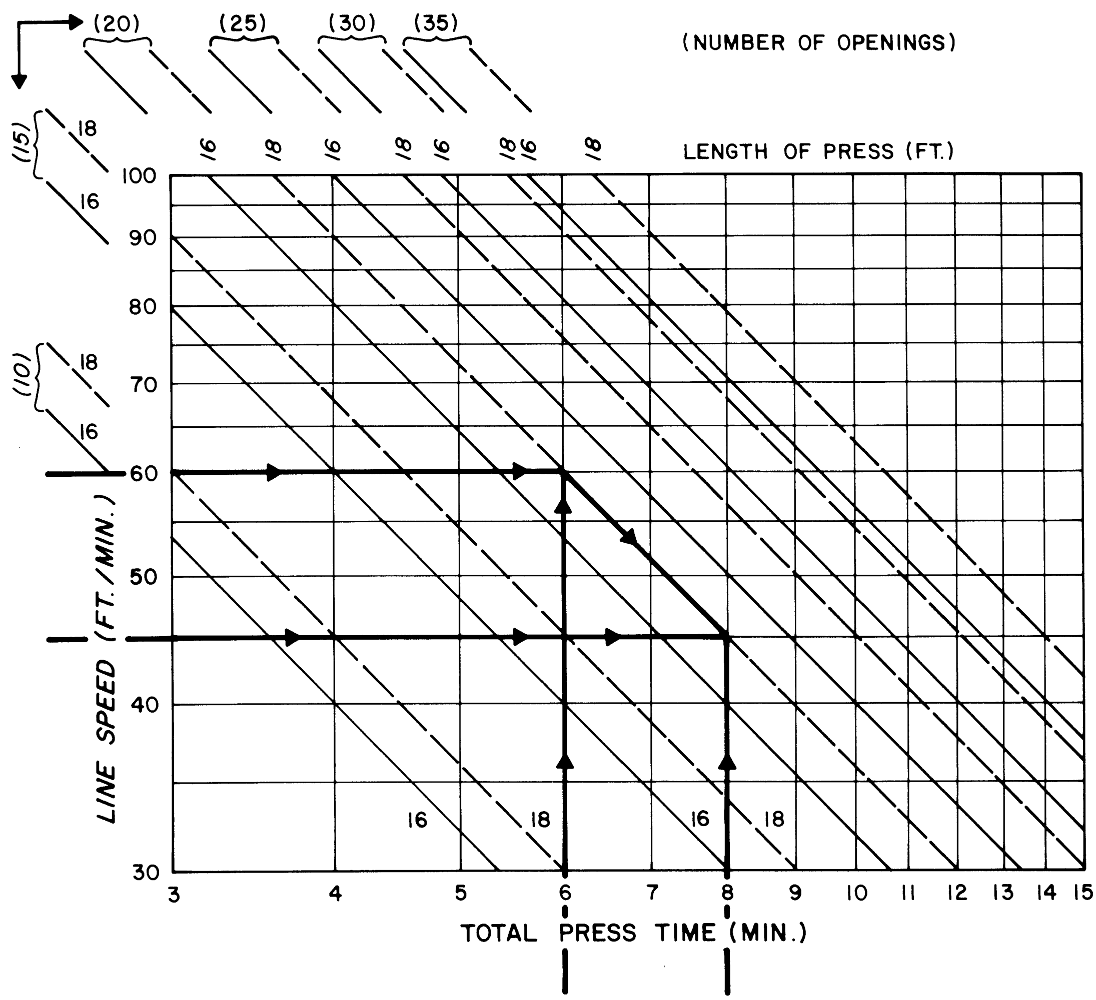


Figure 158—*Illustration of relationship between line speed, press time, and press size. Example: The production given by a line speed of 60 ft/min (left scale) and press time of 6 min (bottom scale) requires 20 press openings, 18 ft long (top scale). If the press cycle were increased to 8 min, the line speed would have to be reduced to 45 ft/min.*

cylinders are filled without pumping by the force of gravity (fig. 162) (Morse 1957). An accumulator is a low-pressure storage device that can deliver to the press large quantities of hydraulic fluid in a very short time (fig. 163) (Maloney 1977). During periods of low fluid demand (after press has closed) the pumps recharge the accumulator against a cushion of air or nitrogen. The accumulated fluid is discharged to close the press quickly during the next cycle.

It is advantageous to close all openings simultaneously rather than successively as the rams rise, pushing the platens upwards. **Simultaneous closing** provides more uniform heat transfer on both surfaces of each board and assures that the boards in all openings are subjected to identical pressing and heating conditions. However, the closing speed of the individual openings is then only a fraction of the ram speed (van Hüllen 1966):

$$V_o = V_r/n$$

where V_o = closing speed of individual opening (inches/minutes),

V_r = ram speed, and

n = number of openings.

Simultaneous closing therefore requires high ram speeds.

Figure 164 (van Hüllen 1966) shows a board press with simultaneous closing arrangement. This equipment consists of swinging arms to which the individual platens are connected by means of tie rods. As the press table moves upward at speed V_r, the tie rods lift all platens simultaneously at speed V_0. Compensating cylinders are installed at the ends of the rods. Their purpose is to compensate for the weight of the platens and allow individual adjustment between each pair of platens, in order to press all boards to uniform density.

The press shown in figure 164 represents one of several available simultaneous press closing designs.

S1S pressing

Press lines. Since the pressing is a batch process, provisions must be made in the press line design to match the continuous output of the wet press to the cyclic nature of the press operation.

The coupling of line to press can be accomplished simply by loading a number of mats into a series of movable press loaders that when full are removed to one of several available hotpresses. Each press loader holds a number of mats equal to the number of openings per

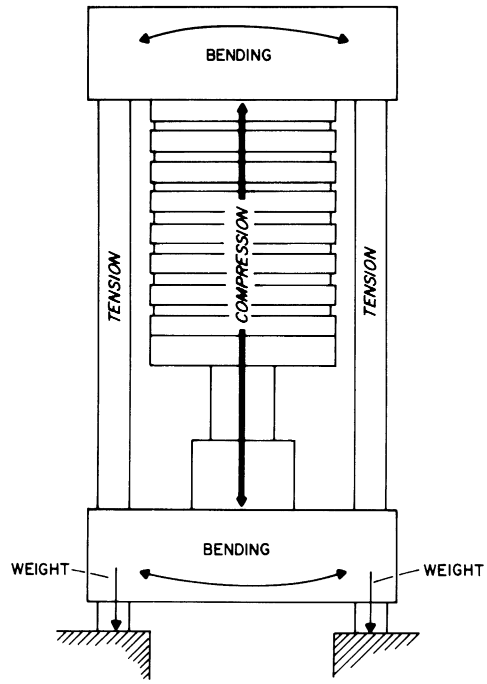


Figure 159—*Forces and bending moments in hydraulic press.*

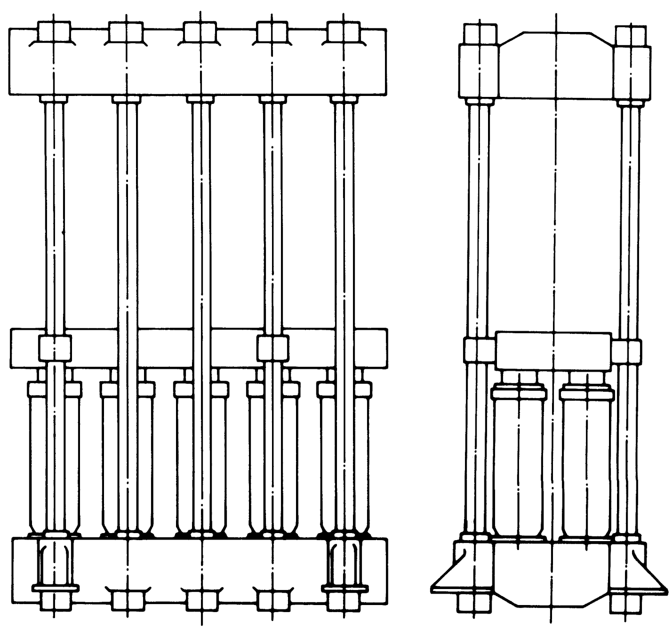


Figure 160—*Column-type hydraulic press (Hedin 1970).*

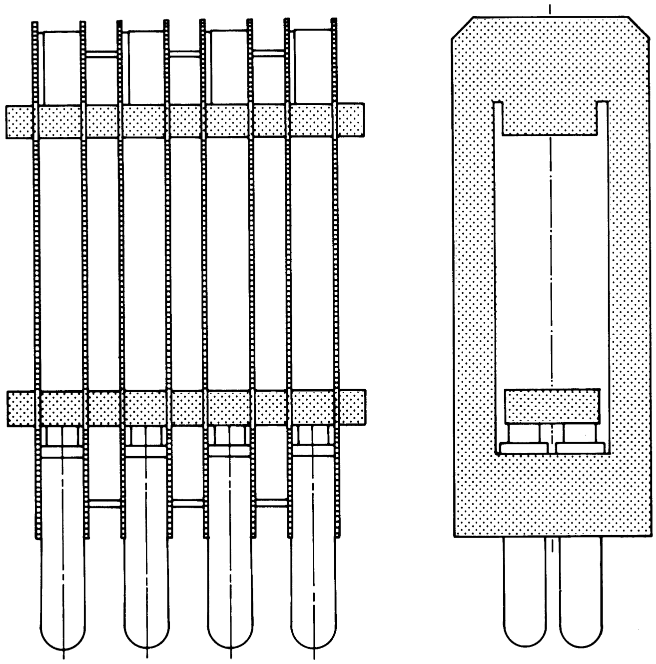


Figure 161—*Frame-type hydraulic press (Hedin 1970).*

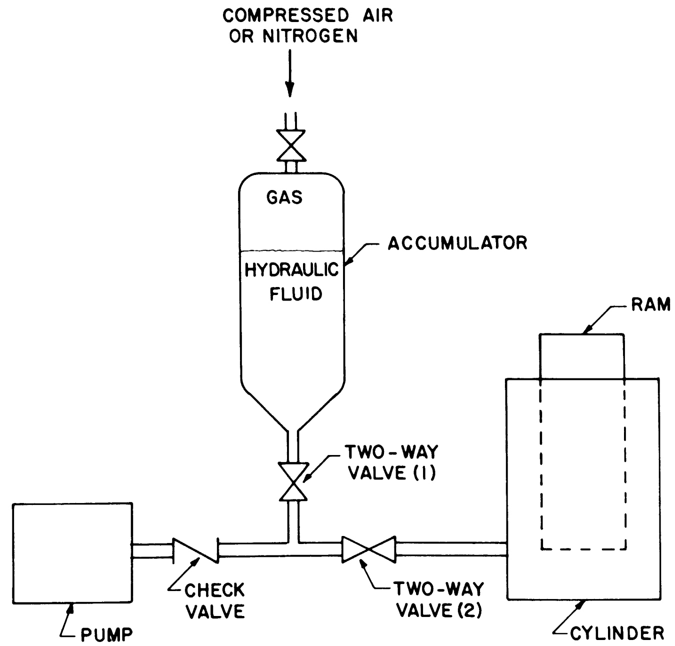


Figure 163—*Bottle-type hydraulic fluid accumulator for rapid closing of board press (Maloney 1977).*

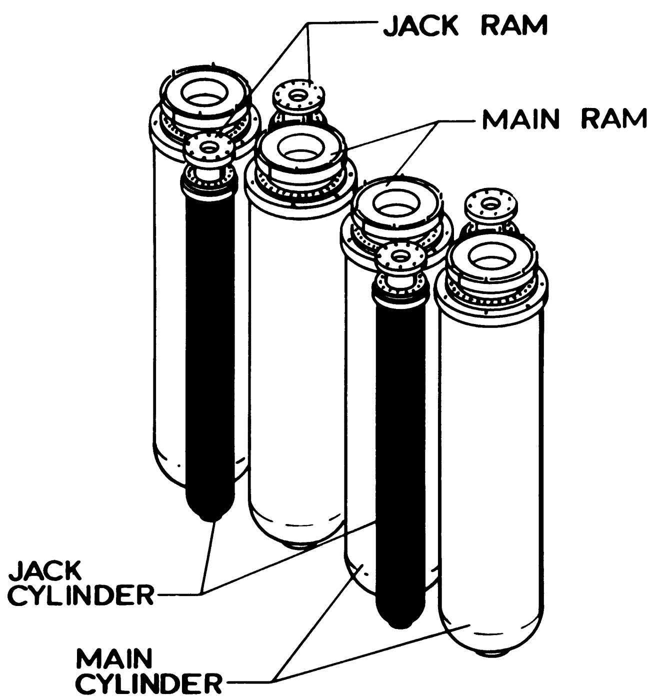


Figure 162—*Arrangement of jack and main rams in hydraulic press (Morse 1967). Small-diameter jack rams provide enough force to close press quickly without requiring large pump capacity. After press is closed, main rams apply high pressure with small travel without requiring large pump capacity.*

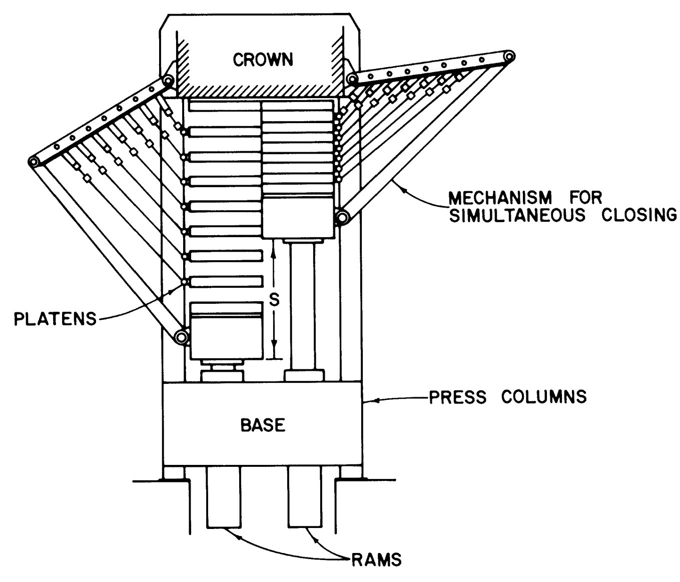


Figure 164—*Board press with simultaneous closing arrangement (van Hüllen 1966).*

press. This is practiced by the Masonite Corporation in its Laurel, MS plant.

Most other fiberboard plants have a direct coupling between wet press and hotpress. Described below is such a system, as designed and installed in a number of fiberboard plants in the United States by the Siempelkamp Corporation.

The main features of this system are a simultaneously closing, 24-opening, 4- by 16-ft press and a vertical wire screen orbit, which returns the carrier screens under the press to the mat conveyor. Here, each mat is placed on a wire screen, which in the hotpress will allow water and steam to escape from the densified mat and which gives one side of the board the characteristic "screen back" appearance.

Visible in the foreground of figure 165 (Siempelkamp) are part of the Fourdrinier forming machine and the wet press. The short overhead beam bridging the conveyor right behind the wet press supports a traveling water jet cutter that trims the wet mat lengthwise to the width of the press platens. Edges are trimmed by disk cutters. The mats are then ready to be mated with the screens, which are returning from the floor below.

Figure 166 (Siempelkamp 1980) illustrates the operation of the press line:

> The screens are returned under the press on a belt conveyor (1) and are then lifted by a lift chain conveyor (2) into the screen storage magazine. The screens are removed one by one from the screen magazine by cams on a lift mechanism (3), which engage a steel towbar at the leading end of each screen. This brings the screen into a horizontal position. Screen and mat are traveling now at the same speed, which allows the deposition of the wet mat on the screen.
>
> The following elements of the press line: the tipple conveyor (4), the storage conveyor (5), the preloader (6), and the loader (7) serve as buffers between the continuous mat conveyor and the discontinuous press operation (fig. 167) (Siempelkamp 1980). The objective is to load the press loader during the time period the previous charge is held in the press (8), so that when the press is opened and the

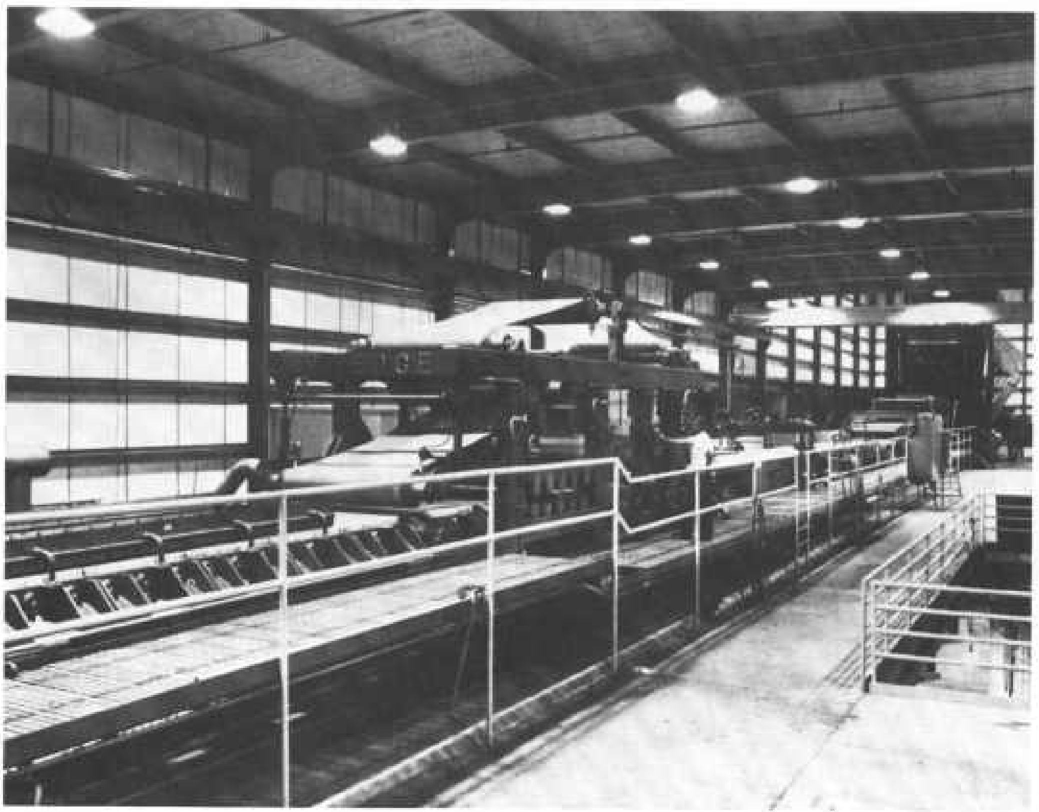


Figure 165—*Siempelkamp wet-process hardboard press line in western S1S fiberboard plant (Siempelkamp 1980).*

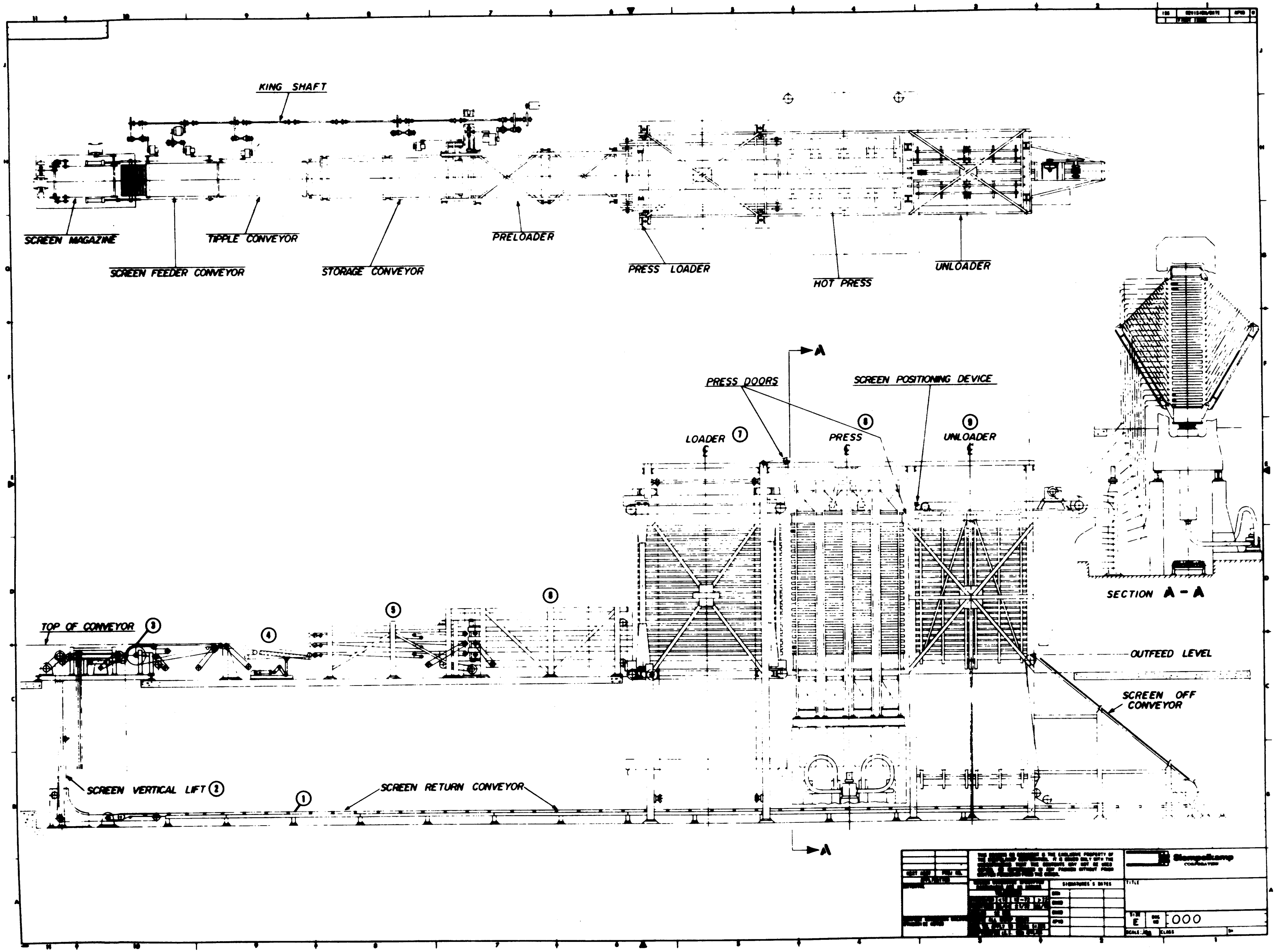


Figure 166—*Layout of Siempelkamp S1S hardboard press line (Siempelkamp 1980).*

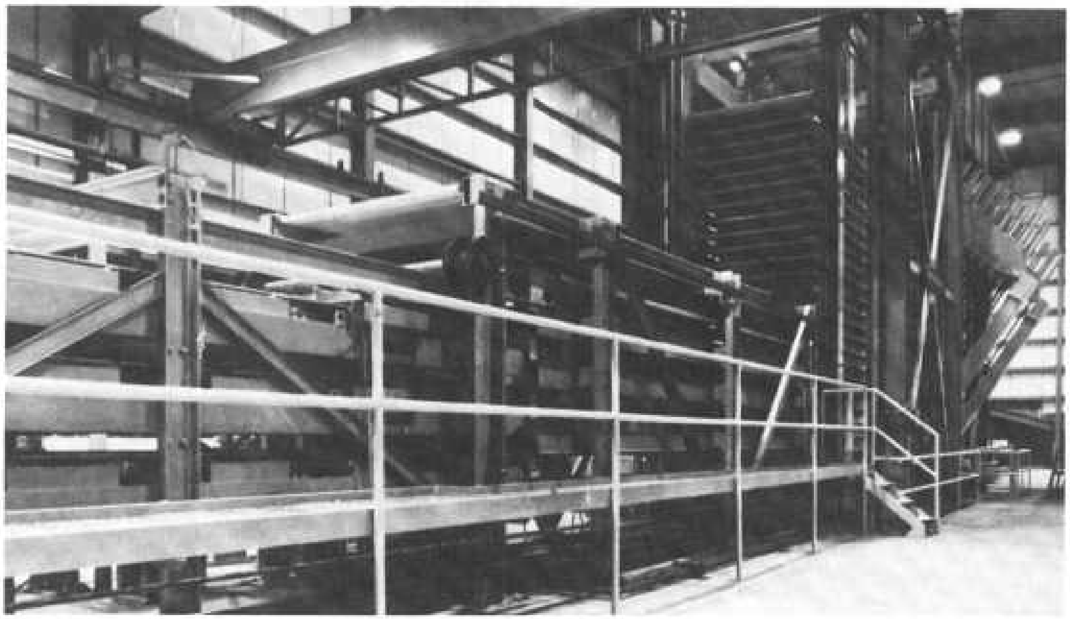


Figure 167—*Siempelkamp S1S hardboard press line, showing storage conveyor, preloader, loader, and press (Siempelkamp 1980).*

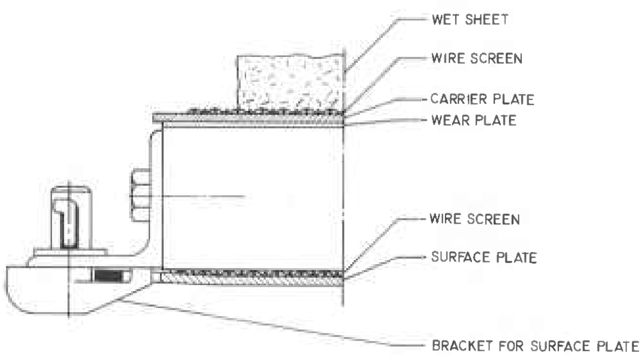


Figure 168—*Arrangement of mat, screen, and caul plates in S1S hotpress (Hedin 1957).*

pressed boards are removed into the unloader (9), the mats accumulated in the loader can be simultaneously transferred into the press. This accumulation occurs in three steps. First, the mats are accelerated on the tipple conveyor (4), which charges the storage conveyor (5), capable of holding three mats for the time interval required by the preloader (6) to charge three mats simultaneously into three separate levels of the press loader. It is the separation of the mats in the tipple accelerator that allows the system to absorb the holding time in the storage conveyor.

The press loader (7) contains hardboard trays, onto which screen and mat are placed and which serve as conveying supports for the transfer into the press. The press loader cage is lowered and raised during the loading cycle so that half of the mats are loaded onto the tray shelves on the way down, the other half on the way up. As the press opens, frame arms to which the trays are attached, are driven forward by hydraulic motors, positioning trays with screens and mats in the press openings. Mechanical arms engage the screen towbars at the far end of the press, position them properly, and hold them in position while the trays are retracted into the press loader. This deposits the screens on the press platens.

When the press opens at the end of the press cycle, "tee"-tongues located at the center of each screen towbar are engaged by a clamp mechanism on a traveling boom on the discharge end of the press. The boom pulls the screens and pressed boards out of the press into an elevator-type unloading cage (9). The screens and boards are removed from the cage, one at a time, as the cage descends. Chain lugs engage both ends of the towbar and direct the screens downward onto the screen conveyor (10). The boards continue to travel horizontally in line with the discharge level of the unloader by means of roller or belt conveyors.

Other press lines use steel **cauls** (rigid steel sheets) as screen and mat support. These cauls carry screen and

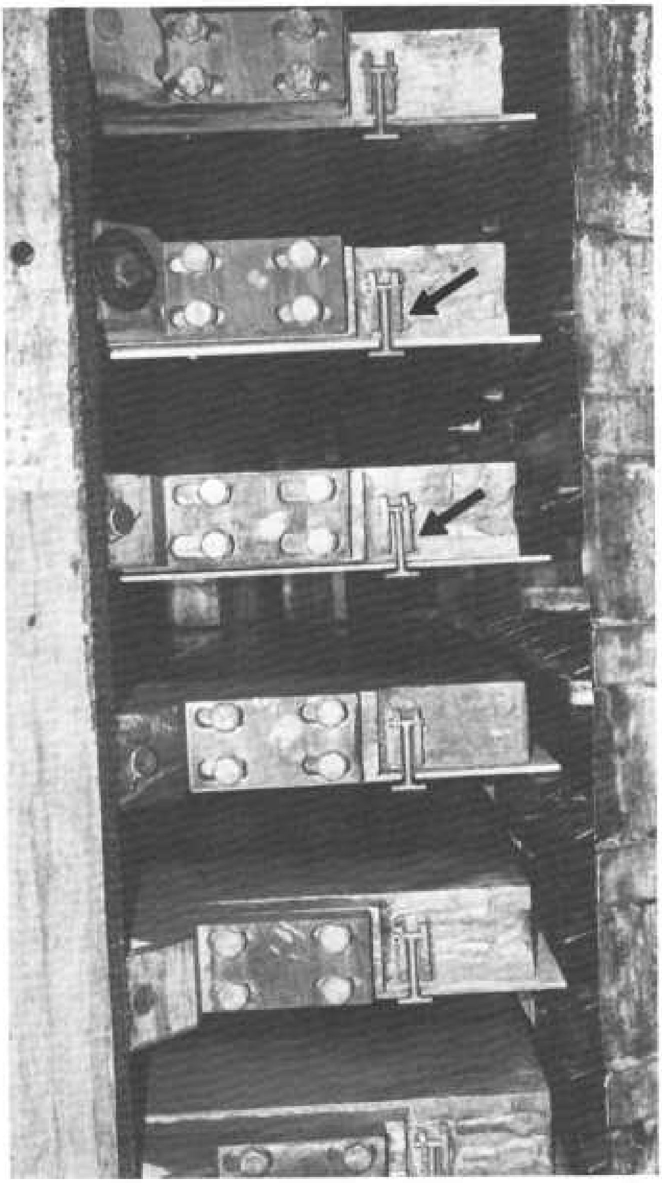


Figure 169—*Quick release T-shaped fasteners for top caul in hotpress (S2S).*

mat, and the entire assembly proceeds through the press. Cauls and screens are returned on a horizontal conveyor system.

The arrangement of this assembly in the press is shown in figure 168 (Hedin 1958). The caul or carrier plate rests on top of the platen, which is protected by a thin wear plate. The wire screen rests on top of the carrier plate and separates the wet mat from it. A surface caul is mounted on the underside of the press platen, separated from it by another wire screen, which has the purpose of providing the same heat transfer resistance as is offered by the screen wire on which the mat rests. The surface caul must be clean and smooth because it generates the board surface characteristics. It is held in place by clamps, which allow quick removal and replacement (fig. 169).

In time, carbon deposits appear on caul plates and wire screens and must be removed occasionally by cleaning in sodium hydroxide solution. Failure to remove such deposits will eventually cause carbon particles to appear on the board surfaces.

Press cycle. The water content of the mat entering the hotpress is about 65 to 75 percent, a ratio of water to dry fiber of about 2:1. The **press cycle,** i.e., the functional relationships between platen temperature, pressure, and time, must be so adjusted that the water is removed from the mat at minimal cost while at the same time optimal physical and mechanical properties are developed in the board.

Theoretically, at least, press cycles are infinitely variable and press cycle manipulation is a powerful tool in adjusting and modifying board properties. Wilcox (1953) and Norberg and Back (1968) supply good examples of the interrelationship of these variables.

Most practical press cycles used in the manufacture of SIS hardboard, however, more or less follow the pressure-time pattern illustrated in figure 170. The platen temperature is maintained at a constant level. This pressure-time function clearly divides the press cycle into three phases:

Phase I: High-pressure squeeze or inversion phase.

Phase II: Low-pressure drying or dwell phase.

Phase III: Consolidation phase.

The first phase is designed to remove as much water as possible from the mat as quickly as possible without transferring unnecessary heat to the water. The high-pressure level, which normally varies between 800 and 1,000 lb/in^2, is therefore established as rapidly as the hydraulic system of the press allows. Some lower density boards may be squeezed at pressures as low as 400 lb/in^2. Pressure levels in excess of 1,000 lb/in^2 do not result in appreciable improvements.

Application of this pressure forces the water downward through the mat to escape laterally through the voids of the wire screen. The process is aided by a rapid rise of the water temperature, which reduces its vicosity.

The high temperature differential between mat and press platen and the great heat capacity of the wet mat cause large quantities of heat to be transferred from the platen to the mat, quickly condensing the steam within the platens. This places an enormous burden on the boiler. Steam demand of a 20-opening press may jump to

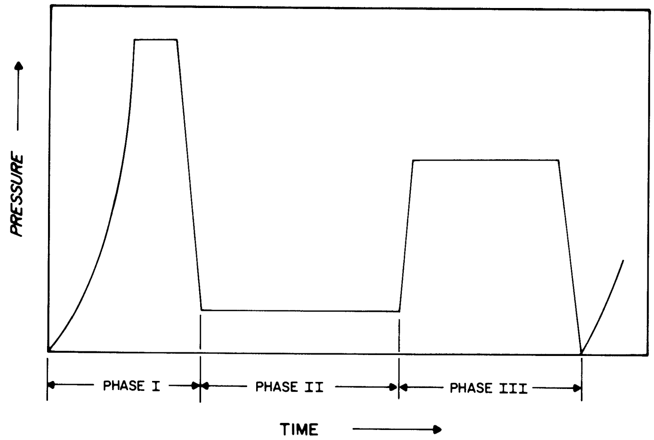


Figure 170—*Typical S1S hardboard press cycle.*

20,000 to 30,000 lb/hr for a short time when the press is first closed. Steam accumulators are used to ease this burden.

Ideally, phase I ends when all the squeezable water has been removed and the remaining water has reached a temperature of 212 °F. At this point the pressure is quickly reduced to a level below the pressure of saturated steam at platen temperature.

Phase I takes about 1.5 min, 40 to 45 s of which are required for the initial pressure build-up. About 50 percent of the water present in the wet mat is removed during this phase, bringing the ratio of water to fiber to about 1:1.

Phase II is the drying phase. Most of the remaining water is removed in the form of steam. Practical pressure levels are between 80 to 100 lb/in^2, or about one-tenth of the initial high pressure. If pressures during this phase are too low, however, steep steam pressure gradients may develop, which could damage the mat structure. The second phase ends when steam ceases to exit visibly but before the board has dried to a moisture content of less than 8 percent. This requires about 3 to 4 min.

In phase III the pressure is raised again to achieve final densification to desired thickness and to develop fiber bonding. Pressure levels are between 400 and 500 lb/in^2. The consolidation of the mat takes advantage of the plasticity afforded by the combination of mat temperature and sufficient fiber moisture content. The compression deformation that takes place under these conditions is essentially permanent. If the third phase is initiated too late, that is, when the moisture content has fallen below 8 percent, then the compression of the mat is much more elastic and is recovered to a much larger degree upon release of pressure. If phase III is started too early, the higher moisture content causes staining of the board surfaces.

Phase III ends with the opening of the press when the moisture content has been reduced to about 0.5 to 1.0 percent. This requires about 2 to 3 min. Terminating the press cycle at higher moisture contents may result in incomplete fiber bonding, splits along the center plane of the board and in boards sticking to the top caul plates. Final moisture content in excess of 3 percent reduces the rigidity of the board which may cause permanent distortions (sagging) during subsequent handling and transportation. Such distortions lead to misalignment of saw cuts relative to embossed plank scores, for instance (Eustis 1980).

When pressing low density boards, below 55 lb/ft^3, phase III may be eliminated without harming the board. Phase II would simply be extended to assure adequate drying. At board densities of 60 lb/ft^3 and up, however, the consolidation phase is necessary for final thickness adjustment.

The total press cycle as described above would require about 6 to 8 min for a 1/8-in-thick hardboard. A 6-min cycle would allow the pressing of eight press loads/hr, assuming 1½ min/cycle for loading and unloading. The platen temperature is maintained at a constant level. Although figure 171 (Steinmetz 1970) ap-

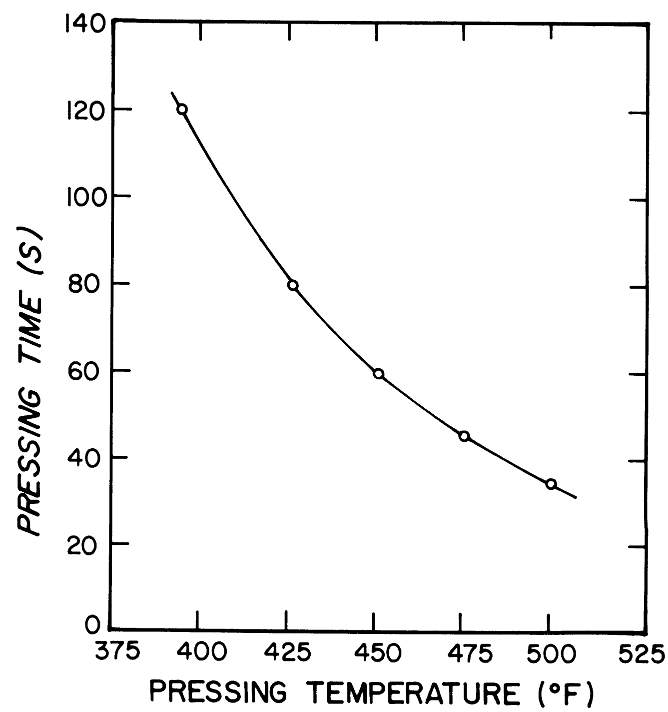


Figure 171—*Effect of press temperature on press time for dry-formed hardboard (Steinmetz 1970).*

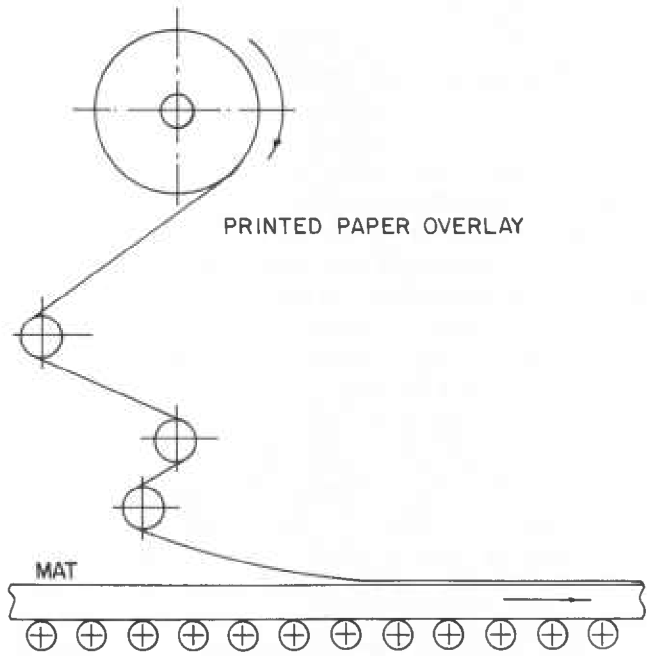


Figure 172—*Application of printed overlay to wet mat prior to hotpressing.*

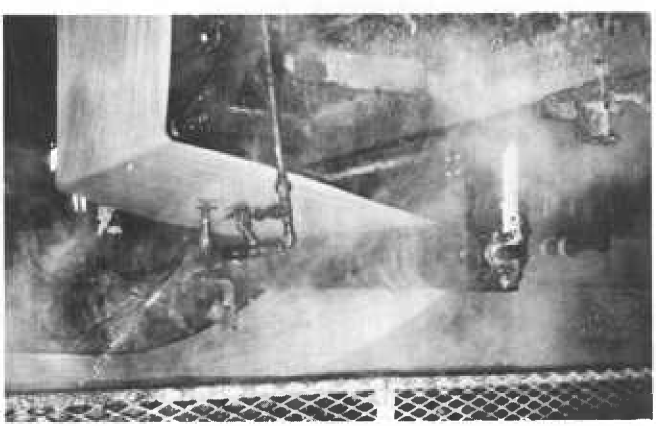


Figure 173—*Paper overlay being applied to wet mat.*

plies to dry-formed hardboard, it clearly demonstrates the important effect of press temperature on press time and therefore on productivity. However, there are several practical limits to increasing the press temperature in fiberboard manufacture:

- too rapid steam generation and subsequent blow-out danger, particularly in high density board;
- beginning deterioration of wood at temperatures in excess of 420 °F; and
- limited heat resistance of printing ink on overlay papers applied to the mat prior to hotpressing.

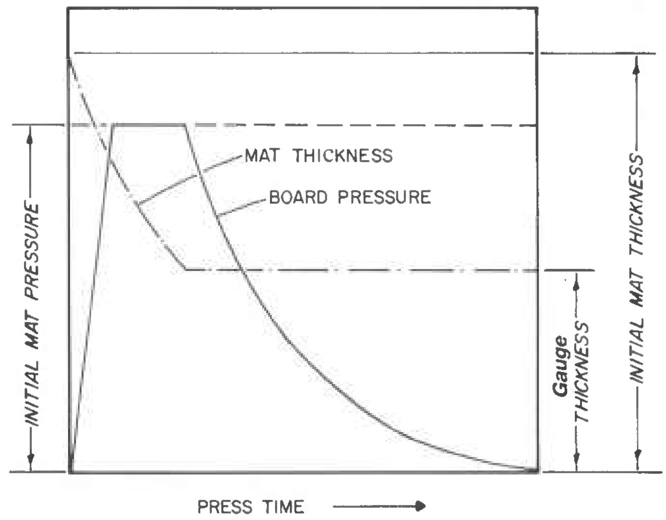


Figure 174—*Pressing to stops: board pressure and mat thickness as functions of press time.*

This method is used by Abitibi and limits platen temperature to 380 °F (figs. 172, 173).

Pressing to stops. Most fiberboards are pressed without stops. Final board thickness is determined by the total accumulative response of the mat to the press cycle. Pressure is varied during the cycle according to the requirements of efficient water removal, while the compressibility of the mat varies with changing mat temperature and moisture content. A given cycle will compress identical mats to identical final thickness. The uniformity of mat characteristics is, therefore, an essential prerequisite for small thickness tolerances.

Thickness control by gauge bar or **pressing to stops** is used in the manufacture of some relatively thick, low-density siding products. This method is also standard procedure in the manufacture of particle board and MDF. Metal strips of a thickness equal to the final board thickness are inserted between press platens alongside the mat and limit the compression of the mat. The pressure on the mat is determinate only until the spacers are reached, when part of the total load is carried by the spacers. As the mat dries and shrinks, the mat pressure might actually drop to zero, and the total press load is carried by the spacers (fig. 174).

In practice the press load is reduced constantly to the level required to just keep the press closed. In such an operation the boards may be removed when the mat pressure approaches zero, regardless of the moisture content, because beyond this point, the press is simply used as a dryer. Final moisture reduction could be accomplished in heat treating ovens, if available. Gauge bars are often replaced by electronic control devices.

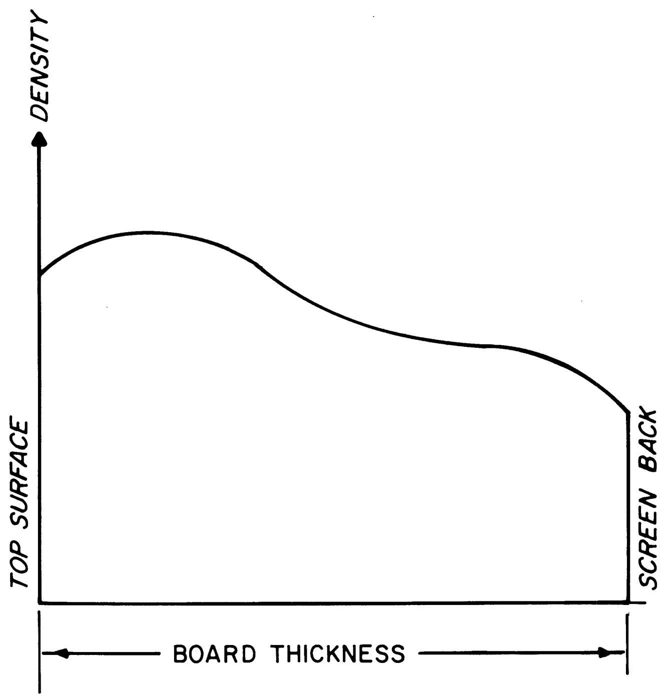


Figure 175—*Density profile of S1S hardboard (Spalt 1977).*

Thickness tolerances. Final board thickness is affected by springback, which is an instantaneous recovery of compression deformation upon release of pressure. This occurs more along the board edges than in the center and is ascribed to lower platen edge temperatures due to water flowing out of the mat. Prior injection of additional resin into the wet mat center along the edges reduced this springback and shortened the press cycle (Biltonen 1975).

Density profile. Mat densification is the response of the mat to the applied pressure. Mat response is affected by its temperature, moisture content, and other characteristics. These mat conditions vary as a function of the distance from the press platen. This gives rise to an unequal response of the various layers of the mat and results in a density variation over the board cross section. Some board properties such as surface hardness, bending stiffness, and internal bond (tensile strength perpendicular to board plane) are very sensitive to such density variation. In thicker MDF and particle board this density variation can be controlled to some extent by changes in the press cycle. In S1S hardboards the density variation follows a profile as shown in figure 175 (Spalt 1977). The asymmetrical shape of this distribution is due to the one-directional water flow and to the embossed screen pattern.

Drying of the mat

The fiberboard dryer is one of the most important elements in the insulation board and S2S hardboard process lines in terms of both space requirements and cost.

In both lines the function of the dryer is to reduce the water content of the mat by evaporation from 65 or 75 percent to an almost totally dry condition. Two tons of water are removed per ton of dry board. The technological benefit of this costly effort is the development of hydrogen bonding in the case of insulation board and the possibility of making high-density hardboard without wire screens in the case of S2S hardboard.

Fiberboard dryers are continuous machines. Their dimensions are therefore determined by line speed and drying time. Such dryers could be and actually were, in some early installations, coupled directly to the output of the wet press. However, this requires considerable floor space. At a line speed of 35 ft/min, for example, a drying cycle of 2 h would require a dryer length of 4,200 ft. To reduce dryer length, modern dryers are built as multideck, typically 8-deck dryers. In such a dryer the above drying cycle would require a length of 525 ft.

Dryer construction. A fiberboard dryer is basically an enclosed, usually 8-tiered roller conveyor that exposes the wet mat to the drying medium (hot air) while transporting it at a speed that allows the continuous and uninterrupted transfer into the dryer of wet mats from the wet press.

The desirability of high temperature gradients for efficient drying and the limitations placed on dryer temperatures by the sensitivity to scorching of the drying board have resulted in a dryer design that exposes the drying board to gradually decreasing temperatures. This is accomplished by dividing the dryer into **zones**, each zone equipped with its own heating and circulating units (fig. 176) (McMahon), (fig. 177) (Lyall 1969). Figure 176 shows the theoretical temperature curve of the air, i.e., the temperature that affords the most efficient drying without harming the board, and the temperature actually provided by the dryer. In the example shown the dryer temperature rises to the maximum level of 800 °F in the first zone in which the drying air moves in the direction opposite to the wet mat travel (counter flow). In zones 2, 3, and 4, air moves parallel with the boards. Counter flow is used in the first zone to minimize leakage of hot air from the dryer through the dryer entrance.

After leaving the last zone the board passes through a cooling section. Dryer entrance and exit are protected from leakage by seal sections in which unheated air is circulated and a negative air pressure maintained equal to the negative pressure in the dryer itself (fig. 178).

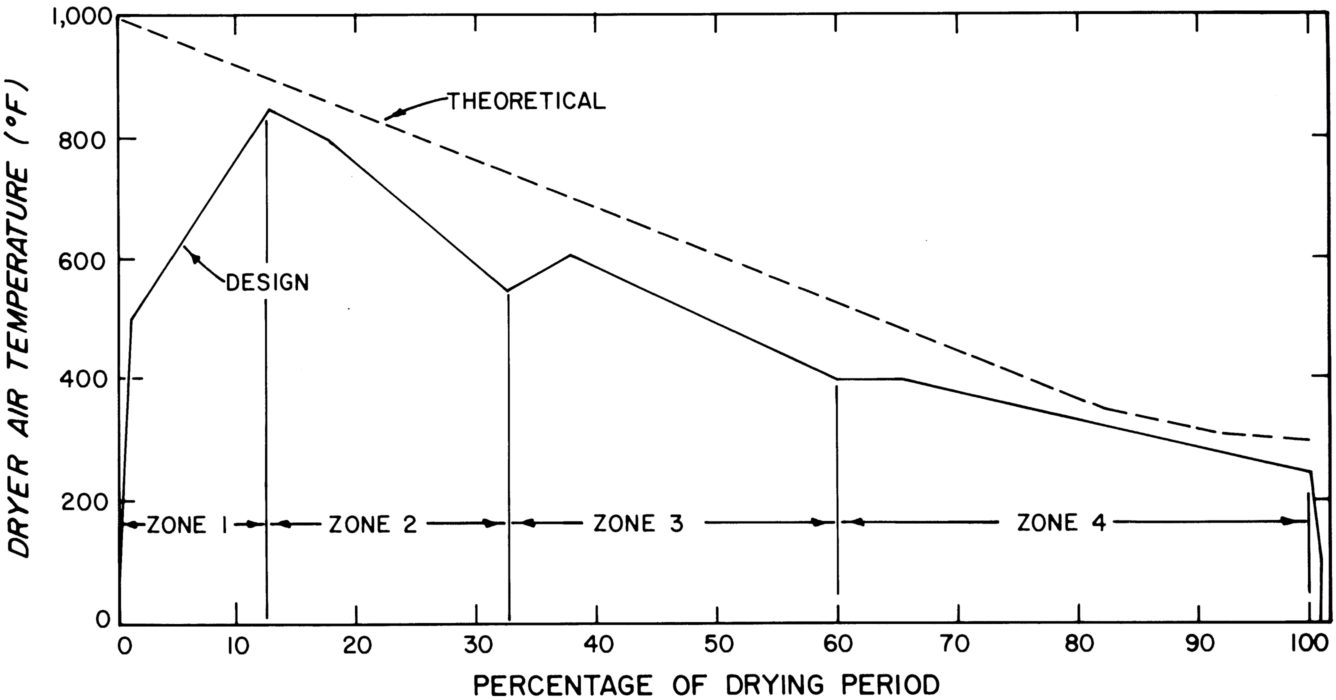


Figure 176—*Ideal (theoretical) and actual (design) temperature distribution in four-zone board dryer (McMahon).*

Heating and circulation. The drying medium is hot air at temperatures above the boiling point of water. The air can be heated by either steam, oil, or gas; the typical fiberboard dryer is gas heated. The gas or oil burners are located on top of the dryer in combustion chambers through which the drying air is recirculated. In steam-heated dryers the heating coils are located inside the dryer between the decks, transferring heat to the board by radiation as well as convection. Gas- or oil-heated dryers operate at higher air temperatures, and installation is less costly than for steam-heated dryers. Maintenance costs of direct fired dryers may be higher, however, due to the higher temperatures, and they present a greater fire hazard.

Gas burners are capable of delivering 26 million Btu/h to each zone. Combustion air is supplied by separate air blowers with combined capacity for each zone of 4,000 ft^3/min (Lyall 1969).

Heating air is circulated for each zone by two fans located above the dryer. The two fans are connected by a common shaft driven by 125-hp motors and capable of circulating 165,000 ft^3/min of air (Lyall 1969).

Feeding and transporting. The drying mats are transported by closely spaced chain-driven rollers on each of eight separate decks. The speed of the rollers is adjustable and is matched to the line speed so that there are no unnecessary gaps between individual boards. Standard roller diameter is 3 in with a roller spacing of 4 in at the wet end and up to 2 ft at the dry end. A 250-ft, eight-deck dryer contains approximately 8,100 rolls and 16,200 bearings. In order to keep all eight decks completely loaded, the continuous supply of cut-to-length mats coming from the wet press must be divided into eight channels. This is done by the so-called tipple, a belt conveyor hinged at one end at the line conveyor level while the other end can be raised or lowered to match up with any of the eight dryer decks.

The operation of the tipple loading mechanism is illustrated in figure 179 and is explained below:

It is assumed here that the line operates at a speed of 40 ft/min. The tipple runs at the same uniform speed as the line conveyor. As soon as the tipple has discharged one mat into the speed-up section of the dryer, its position will be changed to another dryer deck. The changing of position takes time and requires some spacing between mats entering the tipple. This spacing is provided by another speed-up section (not shown) on the line conveyor.

The eight-deck dryer speed-up section consists of roller conveyors that can be driven at one of two speeds:

the line speed (in this case 40 ft/min) or the dryer speed (1/8 of line speed = 5 ft/min). In the drawing, the tipple is ready to charge deck 5. The previous mat in deck 5 is just leaving the speed-up section at 5 ft/min. At the moment the new mat enters deck 5 of the speed-up section, this particular conveyor will shift to the speed of the tipple (40 ft/min) and will run at this speed until the mat has left the tipple and has caught up close to the previous mat. In the meantime the next mat has entered the tipple and will reach the end of the tipple conveyor by the time it has been repositioned to charge deck 7. At this point the previous mat in deck 7 has reached the same position that was held by the mat in deck 5 at the beginning of the loading cycle. The loading sequence indicated reduces the maximum travel of the tipple to the distance between two decks. The entire loading cycle is automatic, controlled by limit switches.

The discharge mechanism at the dryer output end provides similar features (figs. 180, 181).

Dryer performance. Water is removed from the mat by supplying heat to evaporate the water into an unsaturated atmosphere, where it will be removed by sufficient air circulation.

The rate at which water is removed depends on the drying conditions provided and on the mode in which water is leaving the mat. Three phases of drying can be distinguished. In the first phase, water evaporates from the wet surface of the mat and is resupplied by capillary action from its interior. Under constant drying conditions the drying during this phase proceeds at a high but

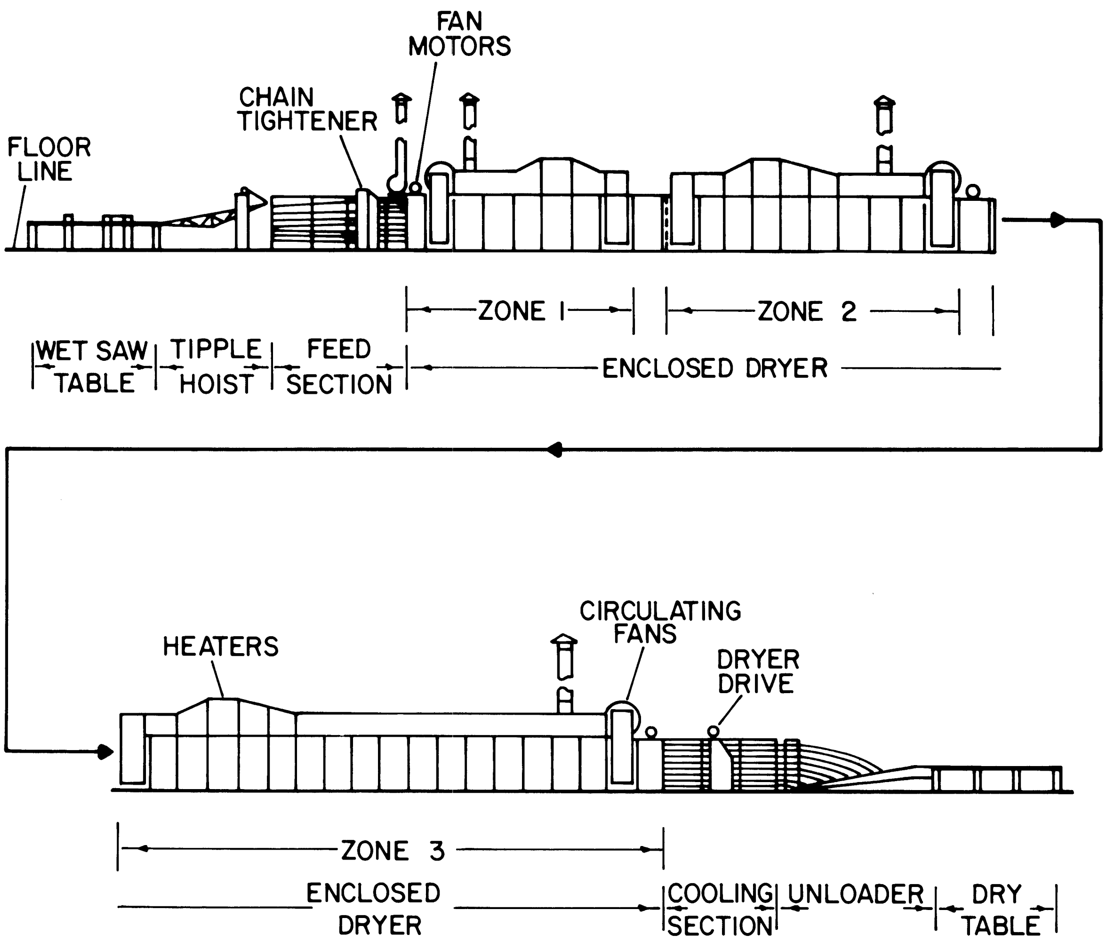


Figure 177—*Gas-fired board dryer (Lyall 1969). Mats enter dryer at top left. Heaters and circulating fans are mounted on top of drying chambers. First zone is a high-temperature zone with countercurrent flow. In zones 2 and 3, air flows in direction of mat travel.*

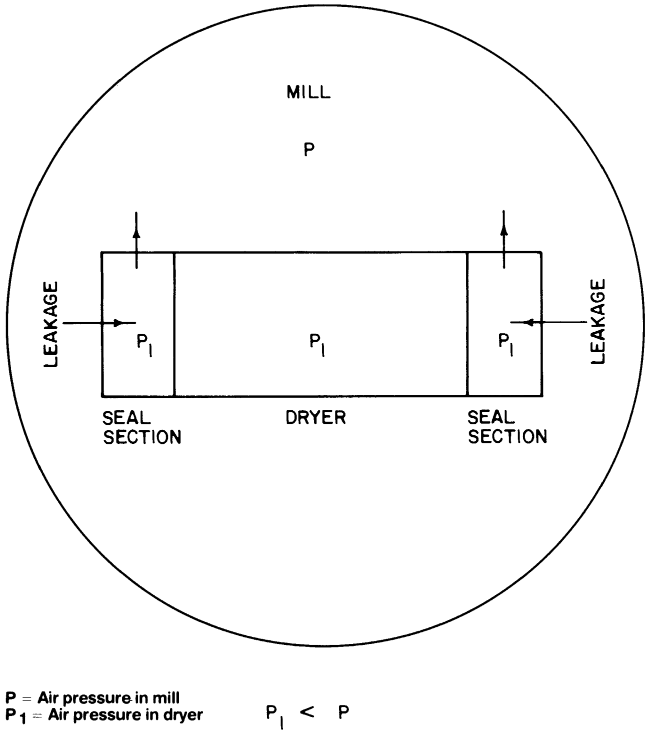


Figure 178—*Seal sections, where air is unheated, but maintained at dryer pressure, minimize loss of heat from section of fiberboard dryer.*

constant rate. The first phase ends when the surface of the mat begins to dry because water from the interior of the mat does not rise to the surface as fast as it is being removed. The temperature of the mat rises during this second phase and the rate of drying decreases. During the third stage, water from the interior does not move to the surface in liquid form but only by diffusion as water vapor. This is the slowest form of drying (fig. 182).

The amount of heat supplied and, therefore, the rate of drying, is controlled by the air temperature. High air temperatures increase drying if sufficient circulation is provided and if the air is dry enough to absorb the water vapor emanating from the drying mat.

Care must be taken to control the drying enough to prevent the surfaces from drying out too fast. This would create an insulating barrier and would severely retard the removal of water from the interior of the mat during the later drying phases. Also, excessively high surface temperatures as well as overdrying must be avoided to prevent discoloration of the surface and to reduce the fire hazard.

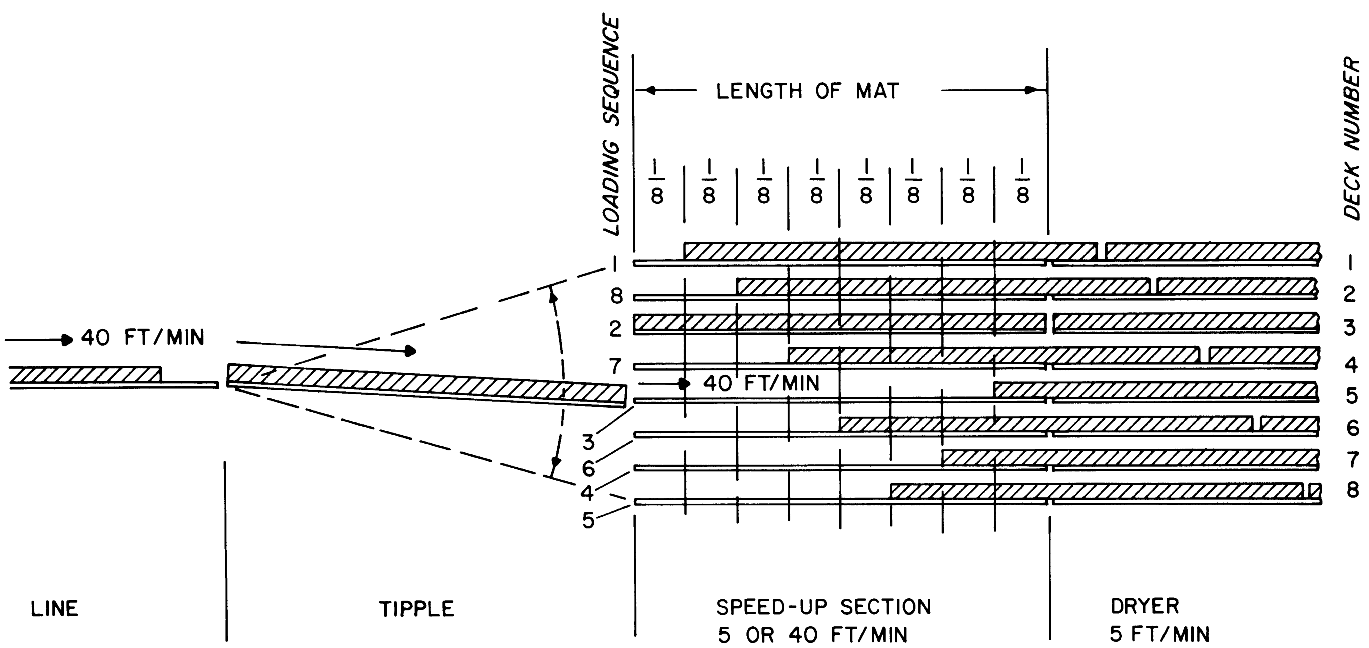


Figure 179—*System of loading 8-deck dryer reduces mat speed from 40 to 5 ft/min without causing gaps between individual mats.*

The heat energy required per hour can be calculated following equation (Jessen 1952):

$$K = A \cdot \left[\left(t_\ell - t_e\right) \cdot \left(c + \frac{b}{100 + b}\right) + \left(\frac{a}{100 - a} - \frac{b}{100 - b}\right) \cdot \left(1182 - t_e\right)\right]$$

where K = total heat required for drying (British thermal units per hour),
A = moisture-free material handled by dryer (dryer capacity) (pounds per hour),
a = moisture content of material entering dryer (percent),
b = moisture content of material leaving dryer (percent),
t_e = temperature of material entering dryer (°F),
t_ℓ = temperature of material leaving dryer (°F), and
c = specific heat of material (British thermal units per °F per pound).

Normally, roller dryers perform at 50 to 75 percent efficiency, so that the total heat required is given by:

$$H = (100/E)\ K$$

where H = total heat energy supplied to dryer (British thermal units per hour),
K = total heat energy required for drying (British thermal units per hour), and
E = dryer efficiency (percent).

Safety. Danger of explosion and fire is inherent in the high-temperature drying of combustible material, particularly when the recirculating drying air is in direct contact with open flames.

Protective devices such as automatic burner shut-off and water deluge systems triggered by sensors responding to sudden temperature rises within the dryer are mandatory.

Fires in board dryers are almost always caused by overdrying, which lets board temperatures rise to danger levels. Overdrying also causes thermal breakdown of the wood substance and the formation of pyrophoric carbon at the board surface. This carbon is very reactive, ox-

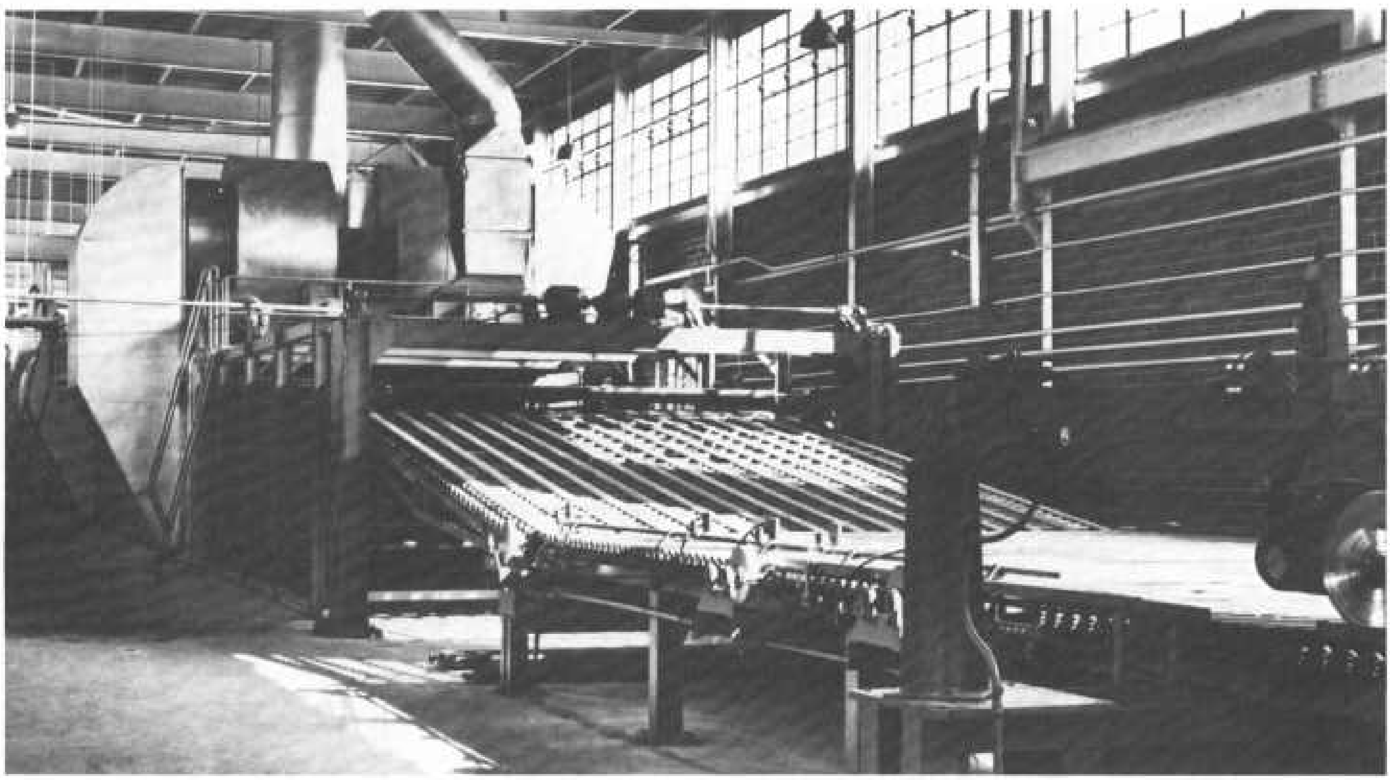


Figure 180—*Fiberboard dryer, tipple loader (Coe).*

idizes exothermically, and can cause fire or charring in stacks of overdried insulation board.

S2S pressing

Wet-formed S2S hardboard was invented simultaneously by Masonite and U.S. Gypsum in the early 1930's. Mason tried to improve the screen-back surface of the S1S board by repressing it in a press with two smooth platens. U.S. Gypsum actually tried to make hardboard from insulation board. The patent was awarded to Mason in 1938 (Mason patent). The first claim reads as follows:

> The process of making a hardboard product having high dry and wet strength from a light porous sheet of lignocellulose fiber containing the natural fiber incrustations, including the steps of drying the sheet to a bone-dry condition, and then applying pressure to the bone-dry sheet at a temperature of about 400 °F or 500 °F, sufficient to materially consolidate and densify and impart high dry strength and high wet strength to the sheet by activation of the bonding properties of the incrusting substances.

This claim presents the critical requirements for the successful manufacture of wet-formed S2S hardboard: drying the mat to the bone-dry condition and then applying press temperatures in excess of 400 °F. The low moisture content (zero percent) is necessary to allow short press cycles without the danger of steam becoming trapped in the board. The high temperatures are required to soften the lignin and to generate small amounts of water—apparently necessary in the bonding process—via destructive distillation of the wood fibers.

Mat handling. One of the most important characteristics of the S2S process is the extremely short press cycle. It is possible to press 30 press loads/hr. In the case of a 4- by 16-ft 20-opening press that would require the press line to be supplied with 600 mats/hr or 10 mats/min. The effective press line speed would have to be 160 ft/min. Considering that mats must be spaced, accelerated and decelerated, maximum mat speeds could reach 300 ft/min.

The S2S mat coming out of the dryer is a rigid but low density product and does not tolerate rough handling. Any fractures or other injuries in the S2S mat will

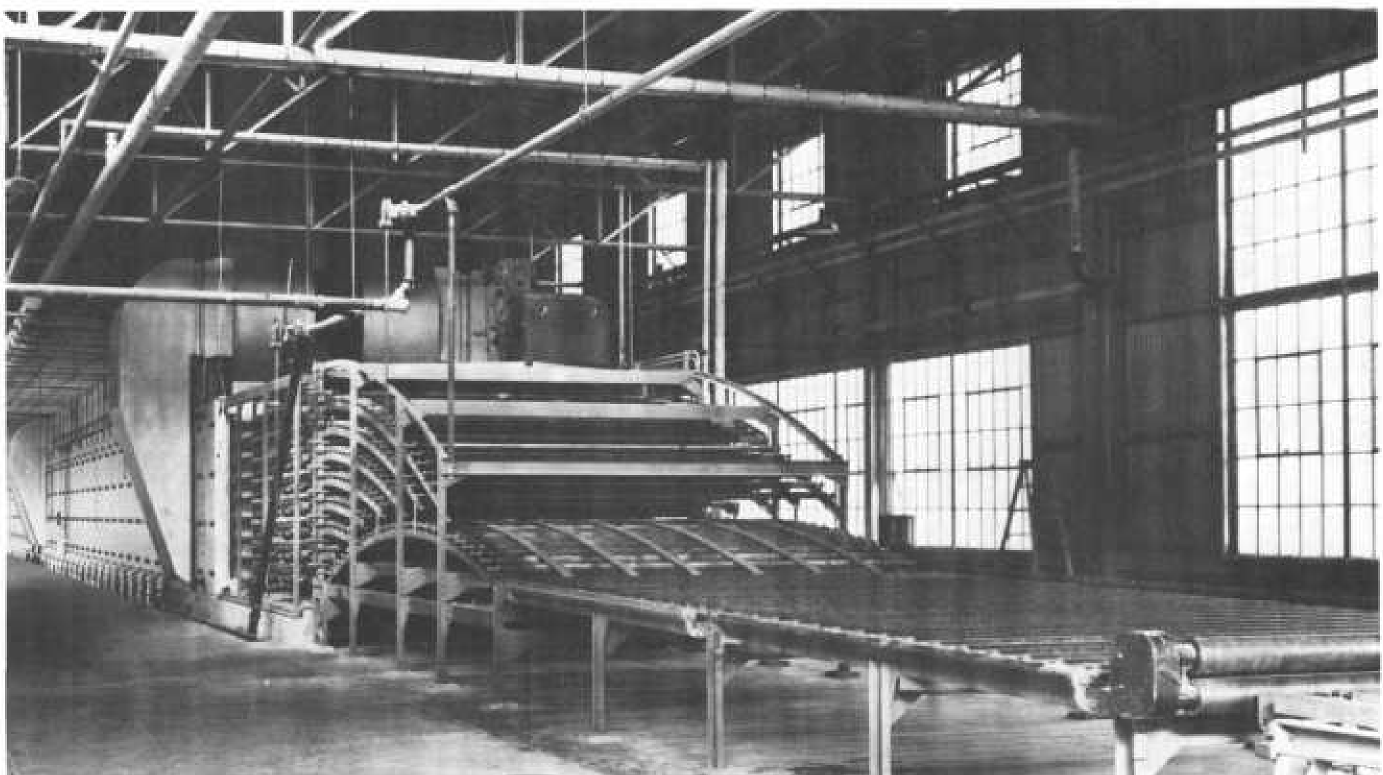


Figure 181—*Fiberboard dryer, discharge section (Coe).*

result in unsatisfactory S2S hardboard. The limitations in S2S production center here, in the high-speed handling of the mat (Eustis 1980).

The S2S mat coming out of the dryer is generally 12 ft wide and 16 ft long plus an allowance for edge trim and saw kerf. Figure 183 shows schematically the trimming operation on the **automatic double trimmer**, which reduces the mat to the size of the hotpress. The efficiency of the line could be increased somewhat by cutting double length mats (32 ft) on the forming machine. This would reduce spacing losses in the dryer and trim allowances on the trimmer. On the other hand, it would require longer speed-up sections in the dryer and larger double trimmers (Eustis 1980).

Although the output of the double trimmer could be coupled directly to the press line, this normally is not done because it is very difficult to exactly synchronize forming machine and hotpress. The S2S press generally can handle ¼-in board faster than it can be formed but gets behind on 1/8-in board. Also, due to the short press cycles, even short interruptions in forming or press line can cause considerable accumulation or lack of fiber mats. For these reasons, intermediate storage is provided after the double trimmer. Most systems are designed to also permit the removal of mats from the line between dryer and trimmer to allow for changing saws and for other down times.

Predrying or preheating. Before entering the hotpress, the trimmed S2S mats pass through a short **pre-**

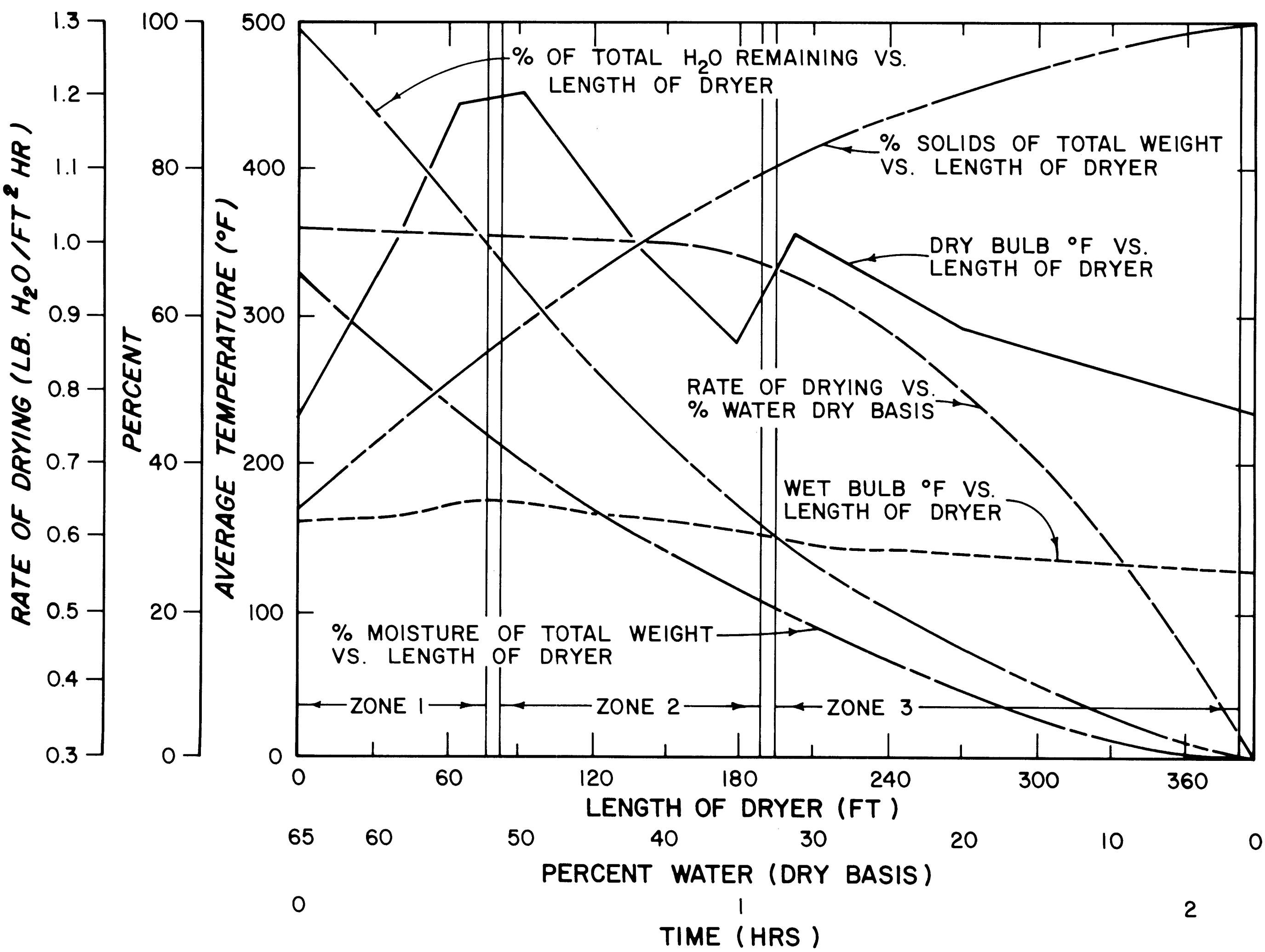


Figure 182—*Typical drying curves for a three-zone, gas-fired fiberboard dryer (Lyall 1969).*

dryer, where the moisture content is reduced from, say, 1 to 5 percent to practically zero percent, and where the mat temperature is elevated to as close to 300 °F as possible, in order to minimize the hotpress cycle.

The predryer is a "picket type" dryer, in which the mats are stored and transported on edge. The low mat moisture content allows the immediate application in the hotpress of full pressure without breathing phases in the press cycle. However, with appropriate press cycle design allowing for steam escape, S2S boards could be made without predrying the mat. Press times would, obviously, have to be increased.

Press loading. S2S mats are rigid enough to be handled without supports. This simplifies the press loading operation. The mats are loaded into the press loader, where they are supported along the edges only. As the press opens, the charging ram pushes the mats into the press simultaneously by means of a series of lugs, which engage the ends of the mats, accelerate them, push them into the press opening, slow them down, and retract, leaving the mats in exactly the same position on the press platen every time. It is very important that the edges of all mats be in exactly the same position relative to the edge of the press platen, to assure maximum control of thickness tolerances.

As the mats enter the press openings, they encounter and push forward the pressed boards until they reach pinch rolls which remove them into the unloading cage. These boards are emitting gas and thus are not actually resting on the platens but are supported by a layer of gas, which practically eliminates the friction between board and platen surfaces and lets the board slide out of position at the slightest touch (fig. 184). If the press is not leveled properly, the force of gravity may dislocate the boards. Positioning devices are often used to align both the pressed boards just before discharge as well as the mats on the platens before the press closes (figs. 185, 186).

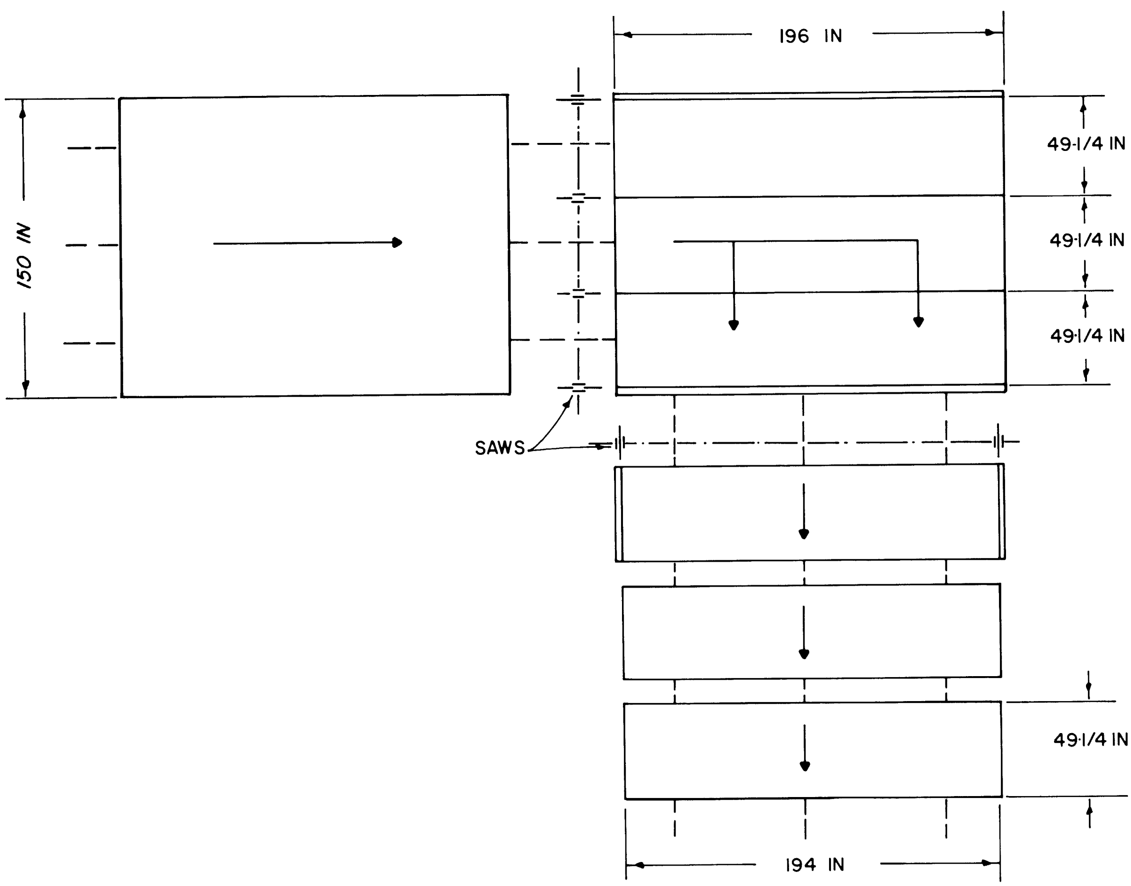


Figure 183—*Preparation of 4-ft by 16-ft S2S mats on double trimmer.*

Figure 184—*Loading of S2S press. Mats are just entering press. Finished boards show some dislocation.*

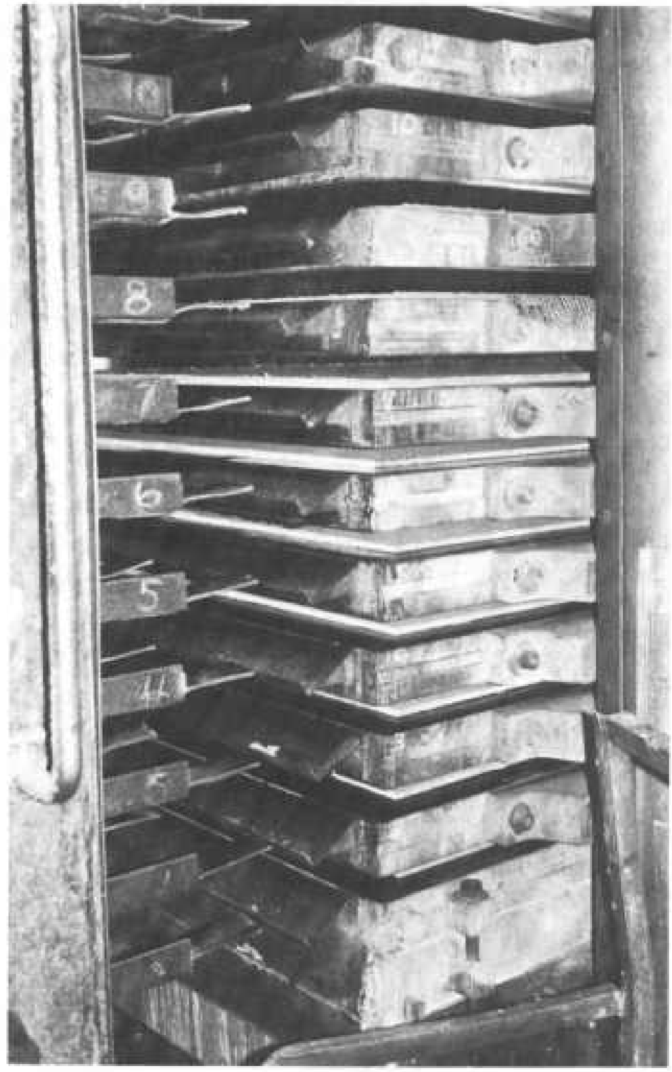


Figure 185—*Loading of S2S press. Mats in position are about ½ in thick. Press ready to close.*

S2S presses may or may not use caul plates. When plates are used, wear of the press platens is reduced but the press **daylight**—the maximum clearance between platens when press is fully opened—must be increased, because the cauls don't stay flat. The upper caul will have considerable center deflection and both cauls will show distortions due to thermal stresses.

When embossed boards are made, the mild steel-embossed plate is the top caul. Proper alignment of the mat in the press is particularly important because the final trimming has to be done relative to witness marks left on the board by the embossed plate rather than relative to the board edge. Removal and replacement of caul plates is made easier by quick-release fasteners (fig. 169).

Press cycle. Press cycles vary from mill to mill, depending on species, board thickness, board density, and press temperature. Thick boards, high-density boards, and boards made of softwood fibers require longer press cycles. High press temperatures reduce press times.

Figure 187 shows S2S press cycles for 1/8-in and ¼-in boards made from hardwood fibers at press temperatures of 450 °F. In both cases the pressure is built up as fast as the press will allow. It is then held for the required period, in this case 60 s for the 1/8-in, and 75 s for the ¼-in board, after which the pressure is released as fast as the escaping gas will allow without causing blisters. If the board is kept under pressure too long, excessive gas development, a result of destructive distillation, may cause the board to be blown out of the press. As white water systems are being closed, i.e., as more of the dissolved solids are retained in the board, these difficulties increase, for the same pollutants are now volatilized in the hot press and discharged into the air.

These dissolved solids (hemicelluloses) also increase the danger of boards sticking or clinging to the top caul or the top press platen. The boards don't really stick hard but require release by compressed air. Release agents applied to the board before pressing eliminate this problem.

Volatiles escaping from the press are vented to the outside. Substantial quantities, however, condense in the

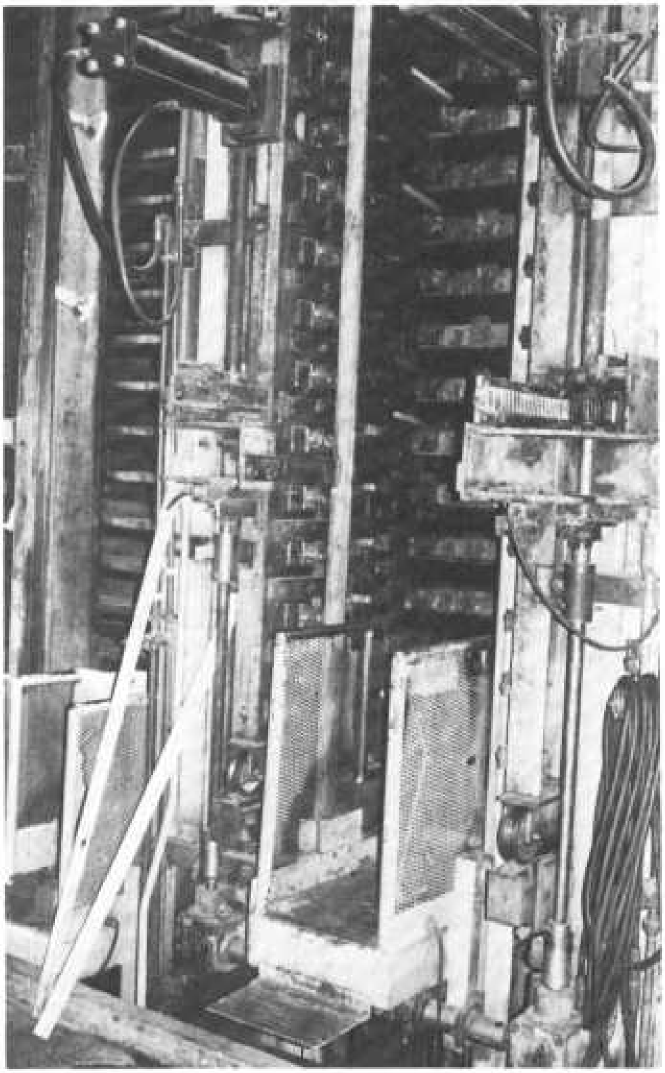


Figure 186—*Hydraulic device for lateral positioning of boards and mats in S2S press.*

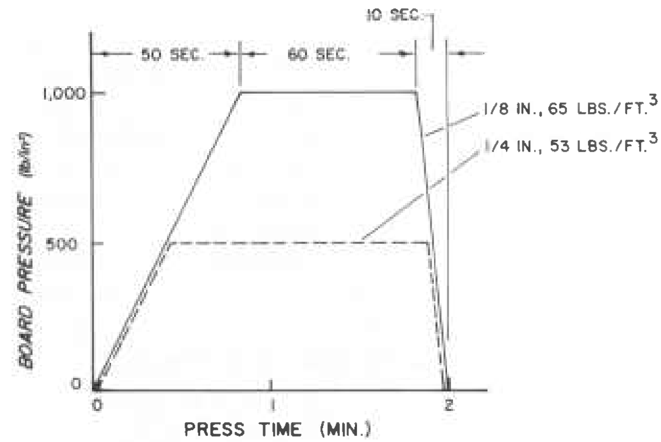


Figure 187—*Press cycles for S2S hardboard from hardwood fibers. Press temperature 450 °F.*

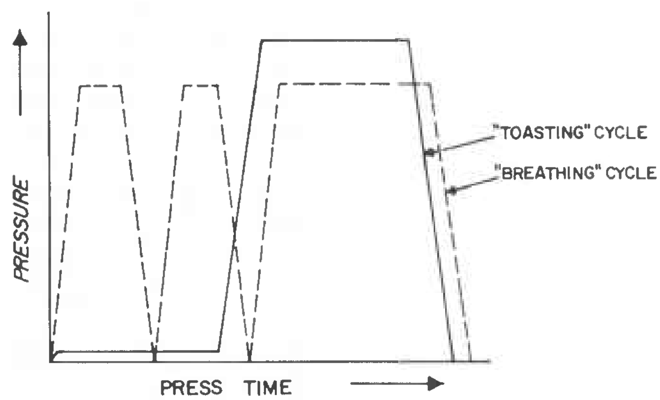


Figure 188—*Press cycles for S2S hardboard without predrying.*

vent stacks as their temperature drops below 300 °F. There they pose a fire hazard and should be burned off periodically.

Figure 188 shows two types of press cycles used when mats are not predried. The board is then either "toasted", that is, dried under very low pressure and then densified during a second high pressure phase, or the water vapor is vented by "breathing" the press one or several times.

When the S2S boards leave the press, they are right at the threshold of burning. If not immediately cooled, they will ignite spontaneously. They are cooled by rapidly moving air immediately after discharge from the press and before they are moved to a single conveyor line by the unloading elevator.

Care must be taken to keep the boards moving, because otherwise surface condensation of fumes will cause an image of contacting support members to appear on the board surfaces. Such fumes will also condense on any steel members of the cooling racks that cool below 300 °F.

Thickness tolerances. S2S hardboard is often used as substrate for high quality finishes, involving precision printers, which require close thickness tolerances.

Thickness variations of the finished board can be caused by the mechanical limitations of the press and associated equipment, such as thickness variations in the caul plates. They can also be caused by a non-uniform distribution of the furnish in the mat, and by non-uniform mat thickness resulting from roll deflection in the forming machine and wet press. Such mats coming out of the dryer could be 1/16 in thicker in the middle than at the edges. The trimmer would therefore produce one thick mat from the center and two wedge-shaped mats from the outside. These mats are not easily pressed to uniform board thickness, particularly, when they are used for the manufacture of low-density boards.

Finally, some thickness variation of the finished board develops after the press opens. Pressed boards do not always exactly maintain the thickness to which they were compressed but expand (springback) as the pressure is released. Generally, the higher the press temperature, the less springback. Higher press temperature promotes a plastification of the fiber and a relaxation of the internal compression stresses. Temperature variations within a press platen or between press platens can, therefore, cause board thickness variations within and between boards. The center of the board is generally thinner than the edges, and the top and bottom boards in a multi-opening press are often thinner than the rest because the heat losses in top and bottom platens are smaller. This problem has been greatly reduced in presses of most recent designs. Thickness variations of a 1/8-in, 65-lb/ft^3, 4-ft-wide S2S board pressed in a 20-opening press could be as high as 0.015 to 0.020 in within boards and 0.025 to 0.030 in between boards. The within board variations could be greatly reduced by pressing 4-ft boards in a 5-ft press (Eustis 1980).

Another phenomenon in S2S hardboard associated with springback is the so-called **chip pop**, a localized variation in thickness in due to the springback of a highly compressed sliver of wood or fiber bundle or other incompletely defiberized wooden particle. In these elements, the compression deformation is apparently not as plastic as it is in completely defiberized material, or it cannot be arrested sufficiently by the formation of fiber bonds. The closer the chip is located to the surface, the more severe the distortion becomes. Slush overlays will obscure these chip pops to some extent. Chip pops are not as common in S1S boards because the presence of water apparently contributes substantially to the plastification of wood under pressure.

Density distribution. A typical density distribution over the cross section of an S2S hardboard is shown in figure 189. The symmetry of this distribution (high density in both faces) is responsible for the considerable bending stiffness of S2S hardboard.

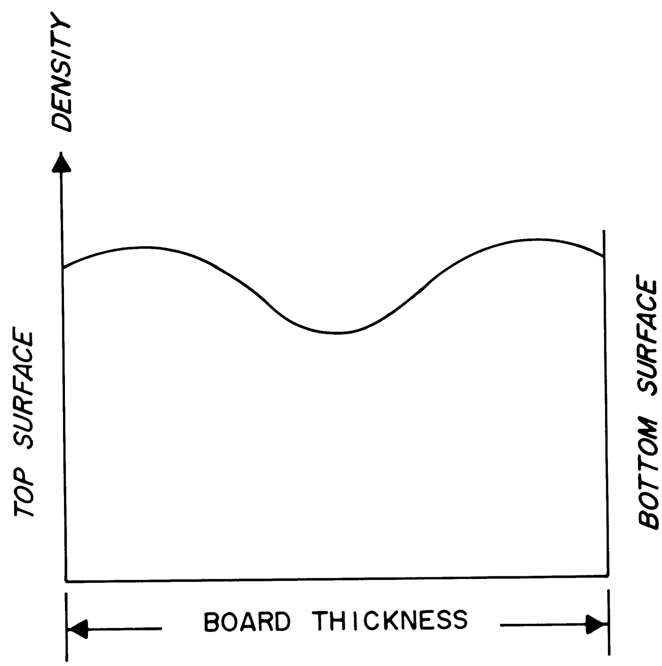


Figure 189—*Density profile for S2S hardboard (Spalt 1977).*

References

Biltonen, G.P. Method for controlling caliper and edge and corner delamination of hardboard. U.S. Patent No. 4,168,200. 1975 March 17.

Boehm, R.M. The Masonite process. Industrial and Engineering Chemistry. 22(5)–493:497; 1930.

Coe Manufacturing Company, Painesville, OH.

Edge Wallboard Machinery Company. Wet pressing guide. Downingtown, PA.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

Fuhrmeister, C.H. Vacuum cylinder formation for the manufacture of insulation board and hardboard. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard and particleboard; 1957; Vol. III; Paper 5.6. Rome: FAO; 1958. 300 p.

Hedin, B.V. Press designs, pressing technique and pressing diagrams in the manufacture of hardboard. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard and particleboard; 1957: Vol. III; Paper 5.6. Rome: FAO; 1958. 300 p.

Hedin, B.V. Development of presses and appertaining equipment. A.B. Motala Verkstad, Sweden; 1970. 23 p.

Jessen, H.C. Drying of insulating board. Tappi. 35(10): 455–467; 1952.

Kielland, K.K. Hot water versus steam heating for pressing of hardboards. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard and particleboard; 1957; Vol. III; Paper 5.14. Rome: FAO; 1958. 300 p.

Lampert, H. Faserplatten. Leipzig: VEB Fachbuchverlag; 1967. 453 p.
Lyall, K.N. Structural board. In: McDonald, R.G. (ed.). Pulp and paper manufacture. Control, secondary fiber, structural board, coating. 2d ed. New York: McGraw-Hill; 1969: 422–456. vol. 2.
Maloney, T.M. Modern particle board and dry-process fiberboard manufacturing. San Francisco: Miller Freeman Publications; 1977. 672 p.
Mason, S.G. The motion of fibers in flowing liquids. Pulp and Paper. April: 93–100; 1950.
Mason, W. Process of making lignocellulose fiber products. U.S. patent 2,120,137. 1938 June 7. 3 p.
McMahon, I.J. The energy-efficient fiberboard dryer. Painesville, OH: Coe Manufacturing Co; 12 p.
Morse, E.H. Washington Iron Works presses. In: Maloney, T.M., ed. Proceedings of the 1st Particleboard Symposium; 1967 March; Pullman, WA. Pullman, WA: Washington State University; 1967: 357–380.
Norberg, K.G.; Back, E.L. Effect of hot-pressing temperatures on the properties of hard and semi-hard fiber building boards. Svensk Papperstidning. 71(21): 774–787; 1968.
Siempelkamp Corporation. Private communication. Marietta, GA; 1980. 4 p.
Spalt, H.A. Chemical changes in wood associated with wood fiberboard manufacture. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, DC: American Chemical Society; 1977: 193–219.
Steinmetz, P.E. Hot press temperature affects linear stability of hardboard. Wood and Wood Products. 75(6): 49; 1970.
Stordalen, K.N.; Bollerslev, C. The wet batch process of hardboard manufacture. Journal of the Forest Products Research Society. 2(3): 58–59; 1952.
Strauss, R.W. Papermaking machines: the Fourdrinier. In: McDonald, R.G. (ed.). Pulp and paper manufacture: Vol. 3, papermaking and paperboard making. 2d ed. New York: McGraw-Hill; 1970. 297–366.
Superwood Corporation. Private communication. Duluth, MN.
van Hullen, K. Vorpressen, Befeuchten, Pressen. In: Kollman, F., ed., Holzspanwerkstoffe. Berlin: Springer; 1966.
Watts, E.W. Industrial experience in the manufacture of smooth-two-side hardboard. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard and particleboard: 1957; Vol. III; Paper 5.11. Rome: FAO; 1958. 300 p.
Wilcox, H. Interrelationships of temperature, pressure, and pressing time in the production of hardboard from Douglas-fir-fiber. Tappi. 36(2): 89–94; 1953.

9. Dry-Process Fiberboard Manufacture

General

Figure 1 classifies all composition boards into either wet- or dry-process boards. The technological distinction is in the forming process. Dry-process boards are those formed by using air as a distributing medium, regardless of the moisture content of the furnish at this stage or at any other stage of the process. Any board process using a fiber furnish and air forming is thus a dry fiberboard process.

The so-called semidry process differs from all other dry processes in that its mat moisture content is too high to allow the pressing of S2S board. The high moisture content may be due to using green or cooked chips without drying after refining (some drying always results from the temperature increase of the furnish during the pulping process), or it may be due to the addition of water to the board surface prior to pressing to improve surface quality. In either case, screens are required, and the boards would have the same screenback characteristic as wet-formed S1S boards. The process is "dry," however, by our definition, because air is used for transporting the fibers and for forming the mat. As was mentioned before, the first dry-process board plant in the United States was a semidry plant in Anacortes, WA. It is the only semidry plant presently in operation in the United States.

The obvious major advantage of dry-process fiberboards is that their production requires much less process water. This is of particular importance in light of the increasingly stringent regulations of effluent quality.

Another important advantage of the dry fiberboard process is the possibility of making medium-density boards in thickness ranges exceeding 1/2 in which is generally considered the upper limit of wet-process board. This allows dry-process fiberboard to compete in a market previously dominated by particle board. This medium-density, thick, dry-formed fiberboard, commonly called MDF, combines dry-process hardboard and particle board technologies in a versatile board product. Such developments suggest progress toward processes that are least discriminating in their raw material requirements.

In our discussion of dry-process fiberboard manufacture we shall distinguish between the manufacture of thin (< 3/8 in) and thick boards (> 3/8 in). The thin boards are similar to wet-process fiberboard in appearance and applications. They are governed by the same commercial standard and compete directly with wet-formed board in the market place. They are manufactured both in the medium-density range of 40 to 50 lb/ft^3 and in the high-density range, over 55 lb/ft^3. Thick boards are made in the medium-density range only; although made by a process almost identical to that of medium-density thin boards, they are governed by a different commercial standard and are sold in entirely different markets.

Any comparison of wet- and dry-process fiberboard manufacturing must therefore be limited to thin boards. Besides the two important attributes mentioned above, the dry process has the following technological limitations and advantages:

Limitations

- Elimination of hydrogen bond
- Elimination or substantial reduction of lignin bond
- Absolute necessity of resin binder addition
- Furnish handling and storage difficulties due to low bulk density
- Greater fire danger
- Air pollution problems
- Inferior board surface
- Greater linear expansion

Advantages

- S2S surface
- Higher yield
- Possibility of making multilayer board
- Reduced sensitivity to species characteristics
- Possibility of using automatic thickness and density control devices
- Absence of bias (difference in properties in the two principal directions)
- High internal bond strength

None of these limitations and advantages are decisive enough to cause a shift from wet process to dry process or vice versa, because most can be compensated for, where necessary, by adjusting process variables and by improved processing equipment.

Although it was initially believed that the dry process would become the dominant fiberboard process in North America, air pollution abatement regulation resulted in increased power requirements and capital costs for the dry process. Increases in oil prices have substantially raised fiber drying and resin costs. At the same time, the white water circulation system of the wet process was tightened up, and the effluent disposal problem reduced. Because of these developments the wet process has remained competitive (Anon. 1976).

A direct comparison of capital and manufacturing costs of wet- and dry-process plants, manufacturing 1/8-in hardboard and 7/16-in medium-density siding, is given in tables 26 and 27. An analysis of the manufacturing cost estimates indicates the following (Anon. 1976):

- Chemical costs are significantly higher for the dry process than for the wet process.
- The wet process has slightly higher power costs but lower fuel requirements.
- The higher production capacity (short press cycle) of the dry process for the 7/16-in siding significantly lowers the unit labor, supplies, administration, and depreciation costs.

Table 26—*Plant capital costs estimates for wet- and dry-process hardboard (adapted from Anon. 1976)*[1]

	Costs (thousands of dollars)	
Expenditures	Wet-process plants	Dry-process plants
Equipment		
Woodyard	800	800
Fiber preparation	1,730	2,400
Forming & pressing	4,570	4,780
Heat treatment & humidification	2,880	1,560
Finishing	650	650
Auxiliary equipment	2,050	1,620
Electrical	1,410	1,330
Total equipment	14,090	13,140
Installation & construction management	4,200	3,260
Site preparation & service incl. effluent treatment	2,000	750
Building & structures	3,850	2,950
Mobile equipment	250	250
Freight, duty & taxes (allowance)	1,110	1,050
Contingency & escalation allowance (10%)	2,500	2,100
Siding finishing line, incl. buildings, installation & engineering	2,700	2,700
Total capital cost	30,700	26,200

[1]Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm). Dry process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).

- The total unit manufacturing cost is slightly lower for the wet process than for the dry process.

These estimates are based on cost levels in the United States in 1975. Increases in oil prices since 1975 may have further increased the price advantage of the wet process. For these reasons, most dry process plants produce medium-density siding where they are most cost competitive. Some dry-formed siding products are considered to be the best available.

Efforts to produce dry-formed hardboard without the addition of resin binder have generally been unsuccessful. Only one binderless dry hardboard process exists, in Czechoslovakia (Nagy 1964; Pecina 1980; Swiderski 1963). It uses defibrator pulp refined in atmospheric Bauer refiners. The boards are pressed with sealing frames to control the release of water and gas (figs. 190, 191). Control of fiber moisture content appears to be critical.

In addition to conventional thick and thin, medium- and high-density dry-process fiberboards, a unique continuous board process, the so-called Mende process, applicable to the manufacture of both particle board and fiberboard, has been developed in Germany and is being used to some extent in the United States. Because board thickness is limited to about ¼ in, it is in direct competition with conventional dry- and wet- process hardboard. One of the attractive features of the Mende process is its capability to produce hardboard economically on a small scale.

Manufacture of Dry-Process High- and Medium-Density Hardboard

General

Figure 192 illustrates a typical dry-process hardboard plant in the United States. It shows the combination of these three important elements: atmospheric Bauer mills, suspension tube dryers, and vacuum formers. Although not the only practical or possible configuration, it represents the common industrial practice. The largest dry-process hardboard plant in the country (Masonite at Towanda, PA) uses an Asplund defibrator and raffinator[3] combination pulping unit. Weyerhaeuser at Klamath Falls, OR, uses Asplund type D and L defibrators. The illustrated plant is based entirely on roundwood as raw material. Today's mill would at least supplement the roundwood supply with purchased debarked pulp chips, whole-tree chips, or mill residue.

[3] The term "raffinator" is interchangeable with "refiner."

Table 27—*Manufacturing costs estimates for wet- and dry-process hardboard (Anon. 1976)*

Item	Wet process		Dry process	
Panel thickness (mm)	3.2	11	3.2	11
Product (type)	board	siding	board	siding
Production capacity (tons/a)[1]	65,000	72,000	60,000	90,000
Manufacturing cost (dollars/ton)				
Wood	29.40	29.20	29.15	28.52
Resin	2.10	7.70	15.40	33.60
Wax	3.30	3.30	3.30	3.15
Alum	1.17	1.17	—	—
Power	5.75	5.75	5.25	5.25
Fuel	8.08	8.08	8.72	8.51
Labor	18.46	16.67	18.00	12.00
Operating and maintenance supplies	11.73	11.74	11.08	8.57
Administration and overhead	7.04	6.21	7.65	5.14
Taxes and insurance	5.46	5.30	5.00	3.74
Cutting, priming, & packaging costs	—	26.23	—	26.23
Total manufacturing cost[2] (dollars/ton)	92.49	121.35	103.55	134.71
Depreciation[3] (dollars/ton)	28.72	28.43	26.11	19.41
Total cost (dollars/ton)	121.21	149.78	129.66	154.12

[1]a = annum = 325 days.
[2]Excluding interest & depreciation.
[3]15-year straight line.

Drying

To press hardboard without a screen requires that the mat enter the press with a moisture content below certain threshold values that depend on the board density and other variables. Excessive moisture content will cause steam to be trapped in the board, resulting in steam blisters (blows) as the press is opened.

On the other hand, the drying schedule must not be severe enough to condense the resin adhesive, which is generally applied prior to drying. This would render the resin ineffective as a binder. The drying process must therefore terminate before the resin cures; at temperatures high enough for efficient water removal, retention of the furnish in the dryer is limited to a few seconds.

Moisture content of the furnish entering the dryer is around 50 percent. Target moisture content of the dry furnish entering the forming machine is between 6 and 12 percent.

The most commonly used dryer is a **suspension** type, or **tube dryer**, in which the fibers are suspended in and transported by the drying medium—hot air or combustion gases. The ratio of air to fiber is about 50 ft^3/lb, with an air speed about 5,000 ft/min (Rausendorf 1963). Air or gas temperatures at the wet end range between 500 and 650 °F. Exit temperatures are about 150 to 190 °F.

At a temperature of 650 °F, the curing time for a phenol-formaldehyde resin is about 8 s. To prevent precure of the resin, the drying time would be limited to about 5 s, which, at 3,000 ft/min air velocity, would require a dryer length of 250 ft (Rausendorf 1963).

A **single-stage** and a **double-stage** tube dryer are shown in figure 193. Figure 194 shows a tube dryer in a medium-density fiberboard plant. Two-stage dryers are advantageous when the moisture of the incoming furnish fluctuates widely. The first stage is then used as a predryer to equalize the moisture content. The main drying occurs in the second stage.

The final moisture content must be kept within small tolerances, not only to provide proper venting in the press but also to allow accurate control of board density or board thickness. The final moisture content is controlled by adjusting the dryer outlet temperature. A moisture content control reacting to both outlet temperature variations and actual moisture content variations of the mat leaving the forming station is shown in figure 195.

Two problems are inherent in the high temperature drying of wood fibers: the danger of fire and explosions

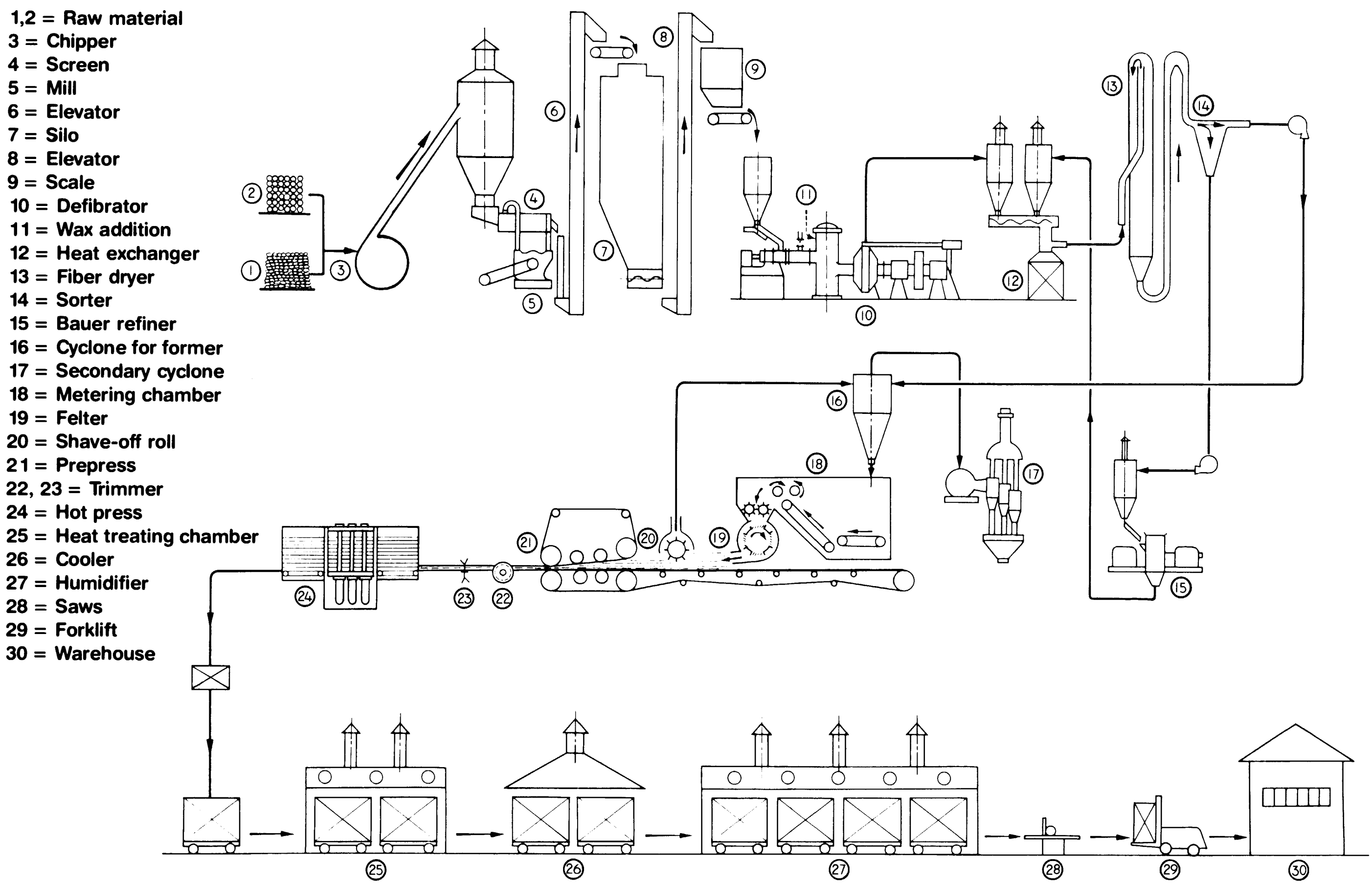


Figure 190—*Schematic process chart of Czechoslovakian binderless dry hardboard process (Swiderski 1963).*

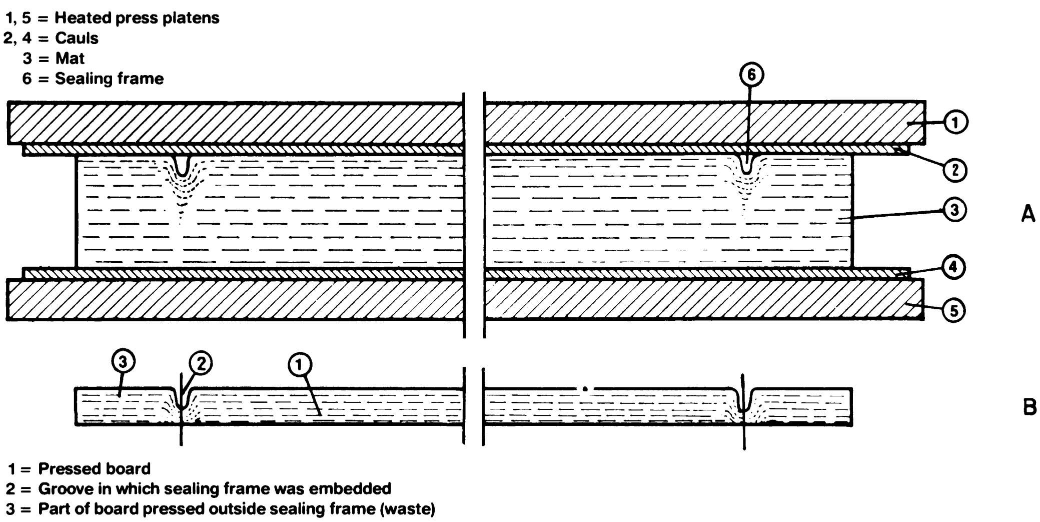
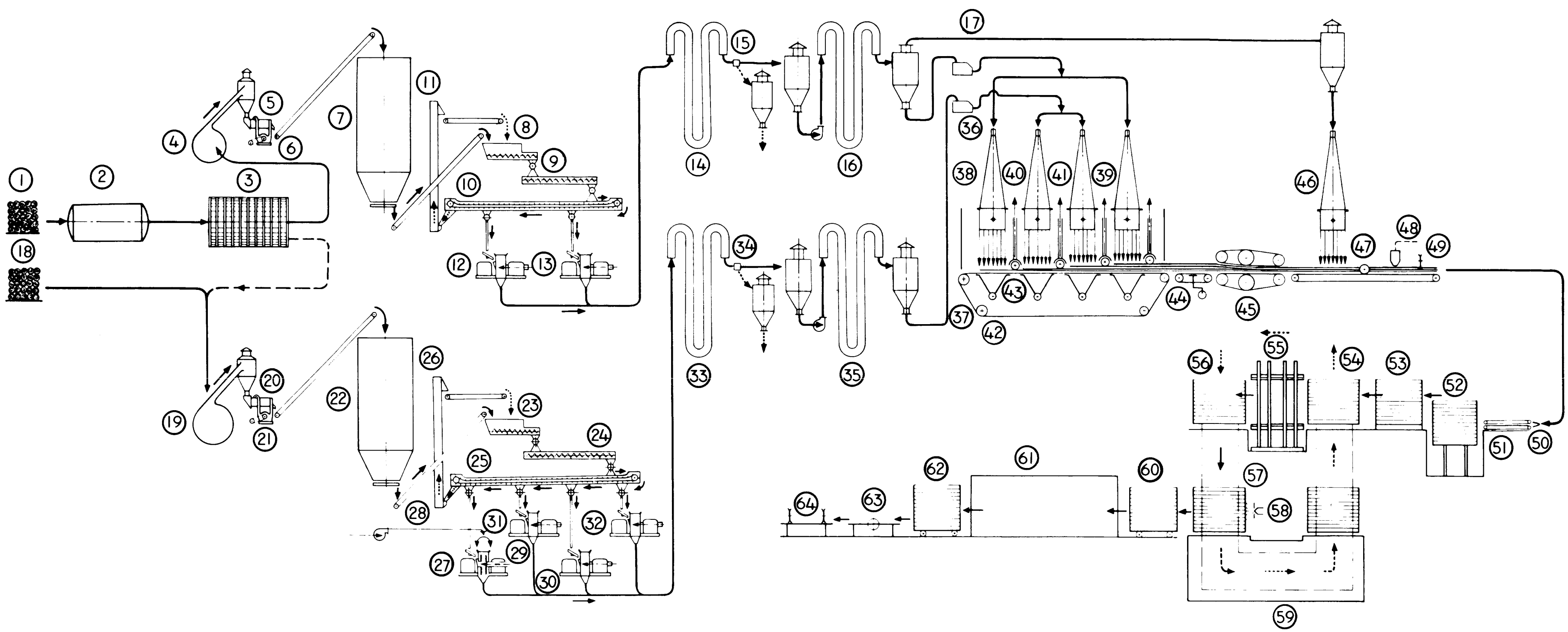


Figure 191—*Pressing of binderless hardboard (Swiderski 1963).*



1 = Raw material for surface layers
2 = Steaming drum
3 = Drum debarker
4, 19 = Chippers
5, 20 = Screens
6, 21 = Secondary mills
7, 22 = Chip silos
8, 23 = Metering devices
9, 24 = Digesters
10, 25 = Conveyors
11, 26 = Conveyors for return of excess material
12, 13, 27, 30, 31, 32 = Bauer double-disk refiners
14, 33 = Predryers
15, 34 = Separators
16, 35 = Main dryers
17, 36 = Buffer storage
18 = Raw material for core layer
28 = Air supply
29 = Adhesive addition
37 = Forming screen
38, 39 = Formers (vacuum) for surface layers
40, 41 = Formers (vacuum) for core
42 = Vacuum supply
43 = Shave-off roll
44 = Automatic mat scale
45 = Prepress
46 = Former for fine top layer
47, 49 = Saws
48 = Automatic mass sensor
50 = Tipple
51, 52, 53, 54 = Press loading
55 = 20-opening hot press
56, 57 = Press unloading
58 = Compressed air
59 = Caul return and cooler
60, 62 = Buggies
61 = Humidifier
63, 64 = Saws

Figure 192—*Schematic process chart of dry-process hardboard manufacturing plant in the United States (Swiderski 1963).*

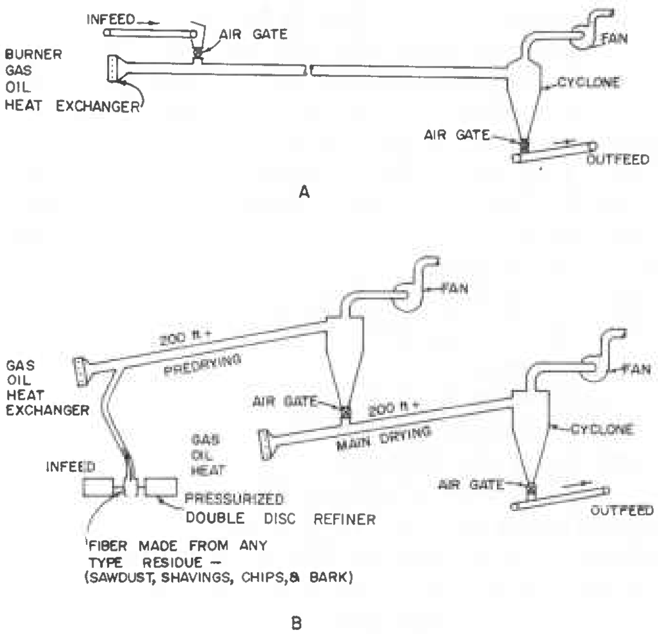


Figure 193—*Single-stage* **(A)** *and double-stage* **(B)** *tube dryers (Buikat 1971).*

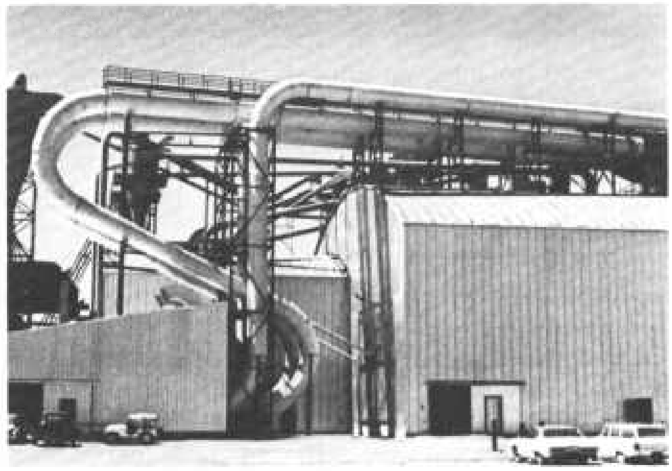


Figure 194 — *Suspension tube flash-dryer in medium-density fiberboard plant (M-E-C Co.).*

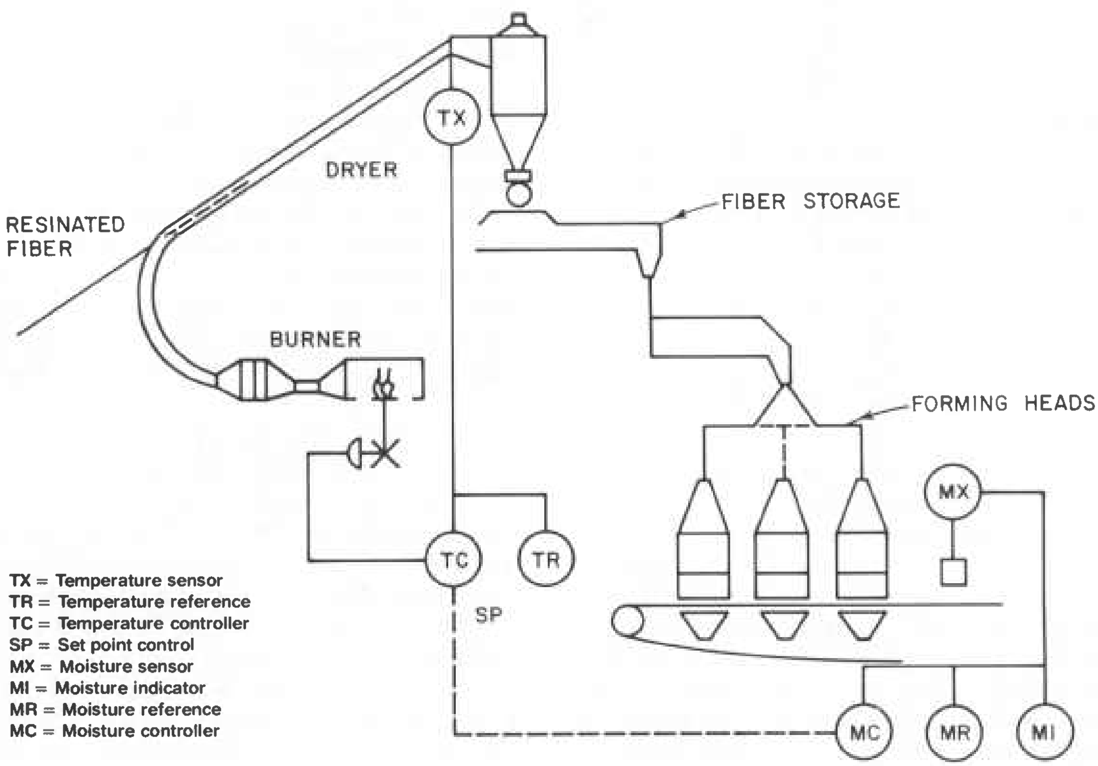


Figure 195—*Fiber dryer controlled by dryer outlet temperature and mat moisture content (Chapman 1977).*

and the emission from the dryer of fibers, fiber fractions, solid particles resulting from the combustion process, and small volatile condensation particles of volatile materials evaporated from the furnish. Sensitive fire detection and control devices are therefore imperative. Emission of larger particles such as fibers and fiber fractions can be controlled with relative ease by the installation of cyclones, filters, and scrubbers. The control of the "blue haze" caused by the evaporation of volatiles is more difficult. This evaporation could be greatly reduced if dryer temperatures were lowered, but dryer productivity and efficiency would be severely limited. The alternative is complete recirculation of exhaust gases to the dryer combustion chamber (fig. 196). The disadvantage of this system is the higher energy input required because of the high temperature of the exhaust gases.

Forming

The basic difference between water- and air-forming or between wet- and dry-forming processes results from the much lower density of the air. Some of the characteristic difficulties of the dry-forming process derive directly from two facts:

- Fibers remain in suspension in air only at considerable air velocities and will promptly settle out or "classify" when the air flow slows down.
- A fiber–air suspension does not flow laterally on a horizontal support.

Another important characteristic of dry fiber furnish is its tendency to **congregate** and to form lumps as soon as the concentration of the fiber-in-air suspension exceeds certain limit values. This phenomenon is similar to "flocculation" in the wet-forming process (fig. 135).

The technical and patent literature offers a variety of answers to the challenge of producing a mat of uniform density from such difficult furnish (Lampert 1967, Sandermann and Kunnemeyer 1957, Swiderski 1963). Most of these devices deposit the furnish by gravity, or filter the fibers out of the fiber-air suspension. There are also combinations of these principles.

The first dry process (actually semidry) fiberboard plant in the United States, at Anacortes, WA, employs a gravity forming machine that was developed and patented by the Plywood Research Foundation. A schematic picture of the process is shown in figure 197. This line does not use a dryer. The forming machine itself is a box, the so-called **felting box**, situated above the **forming belt**. The furnish enters the box through a swing spout that distributes the fibers across the width of the box and above a high-speed rotor, which agitates the fibers and creates a "snowstorm effect" in the felting chamber (Evans 1958, Robinson 1959). The fibers then gently settle down on the moving belt and build up a mat of a density of about 2 lb/ft^3, and 4 to 12 in thick, depending on the final thickness of the board (fig. 198).

An equalizer or shaving roll reduces the mat to uniform thickness; that is, it controls the uniformity of the mat by controlling its thickness. This volumetric metering results in uniform board density or uniform board thickness only if the bulk density of the furnish does not fluctuate. Close control of all process characteristics that affect bulk density, such as air velocity, pulping conditions, moisture content, etc., is therefore critical.

Another gravity-type forming machine, one used by Champion International in the former Cascades Plywood Corporation's board plant at Lebanon, OR, is illustrated by the patent drawing in figure 199. A volumetric metering device supplies the furnish to a vertical chute within which it is distributed laterally across the width of the forming machine by means of a number of horizontal screw conveyors. A series of closely spaced sawblade-like disks projects partially into slots at the bottom of the chute and transfers the furnish from the chute and through the slots to moving cauls carried through the machine by a conveyor belt. The action of the rotating disks prevents congregation of the furnish and deposits a loose uniform mat.

As the furnish falls to the cauls, a suction device creates a crosscurrent of air that deflects the fine material from the falling furnish and allows half of this fine material to be deposited ahead of the main stream, thus forming the bottom surface layer. The other half is carried forward and placed on top of the mat. Mat thickness is controlled by means of an equalizer roll before application of the top surface layer. This demonstrates the capability of the dry process for producing multilayered boards. Figure 200 shows a schematic of the entire operation.

A forming machine that filters the furnish from the fiber–air suspension is illustrated in figure 201. The metered furnish is supplied to one or more vertical chutes, which are suspended above a moving screen. These felting heads are maintained under a slight positive air pressure. Rotating brushes inside the heads agitate the furnish and discharge an air–furnish stream through a perforated plate forming the bottom of the felter head. The air stream is drawn by vacuum through the traveling screen, which filters out the furnish and builds up the mat. This vacuum-type forming machine is used by the Weyerhaeuser Corporation in the dry-process siding plant at Klamath Falls, OR. A schematic of this plant is shown in figure 202.

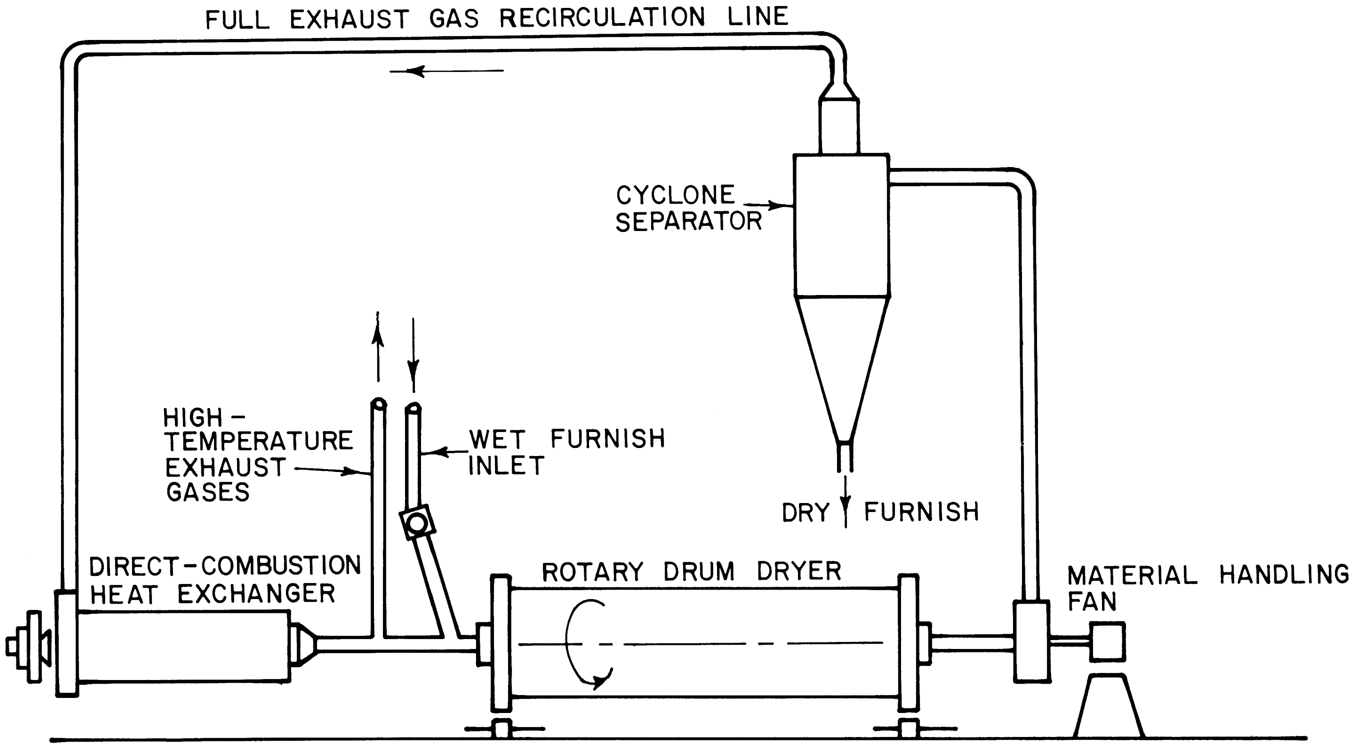
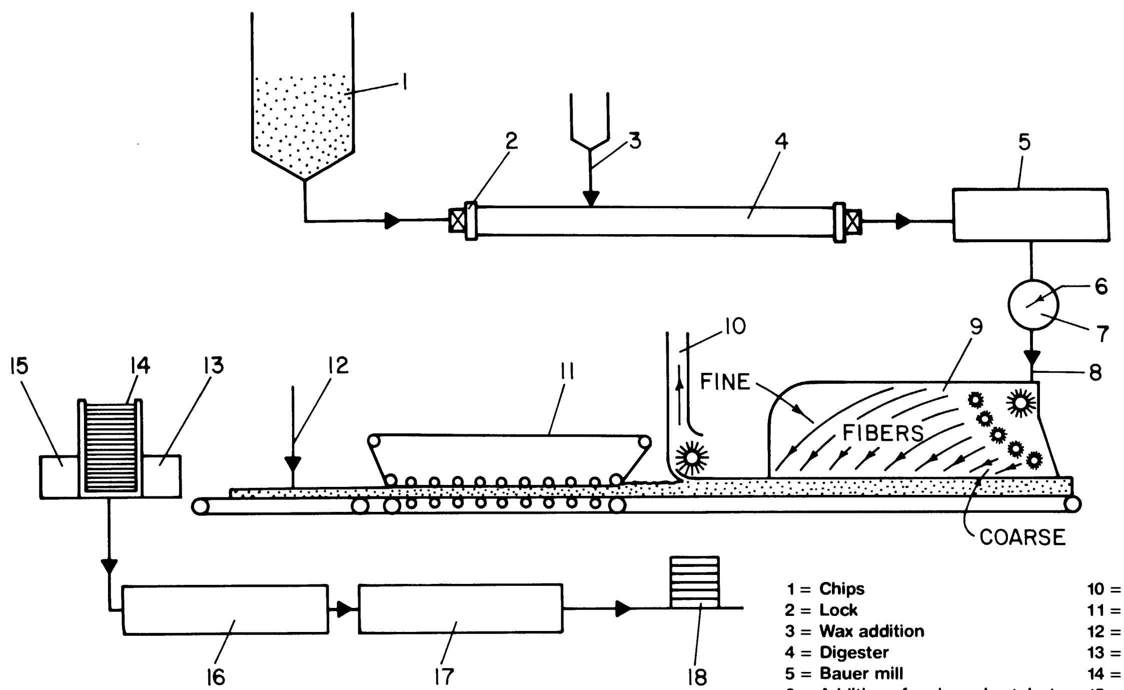


Figure 196—*Schematic diagram of drum dryer with full exhaust gas recirculation system (Junge 1977).*



1 = Chips
2 = Lock
3 = Wax addition
4 = Digester
5 = Bauer mill
6 = Addition of resin and catalyst
7 = Blender
8 = Hot air transport
9 = Former
10 = Equalizing roller
11 = Prepress
12 = Saws
13 = Press loader
14 = Hot press
15 = Press unloader
16 = Humidifier
17 = Saws
18 = Storage and shipping

Figure 197—*Schematic chart of semidry hardboard process according to Plywood Research Foundation (Sandermann and Kunnemeyer 1957).*

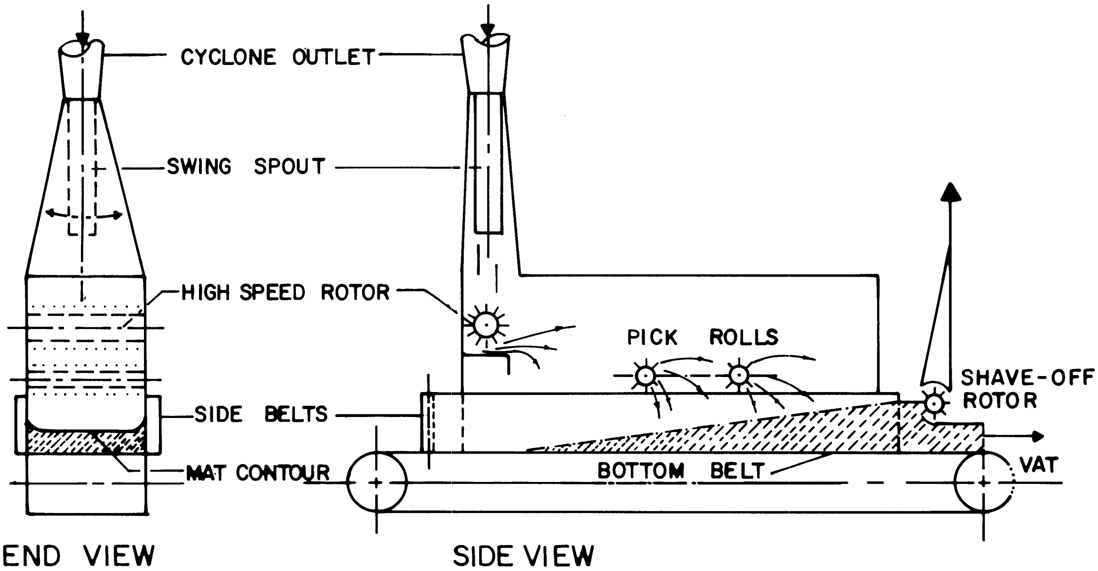


Figure 198—*Snowfall-type felter (Plywood Research Foundation) (Robinson 1959).*

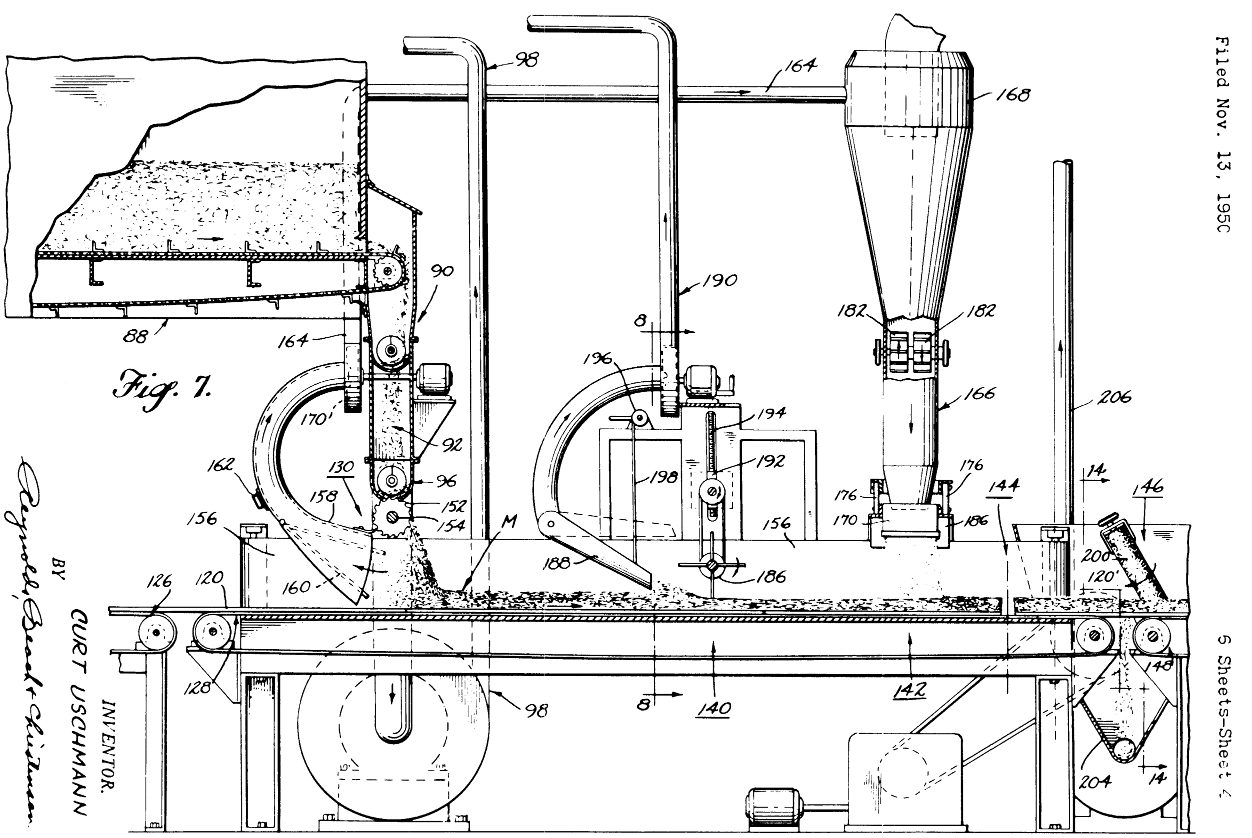


Figure 199—*Patent drawing of forming machine used in Cascade Plywood Corporation board plant at Lebanon, OR (now Champion International) (Ushmann 1956).*

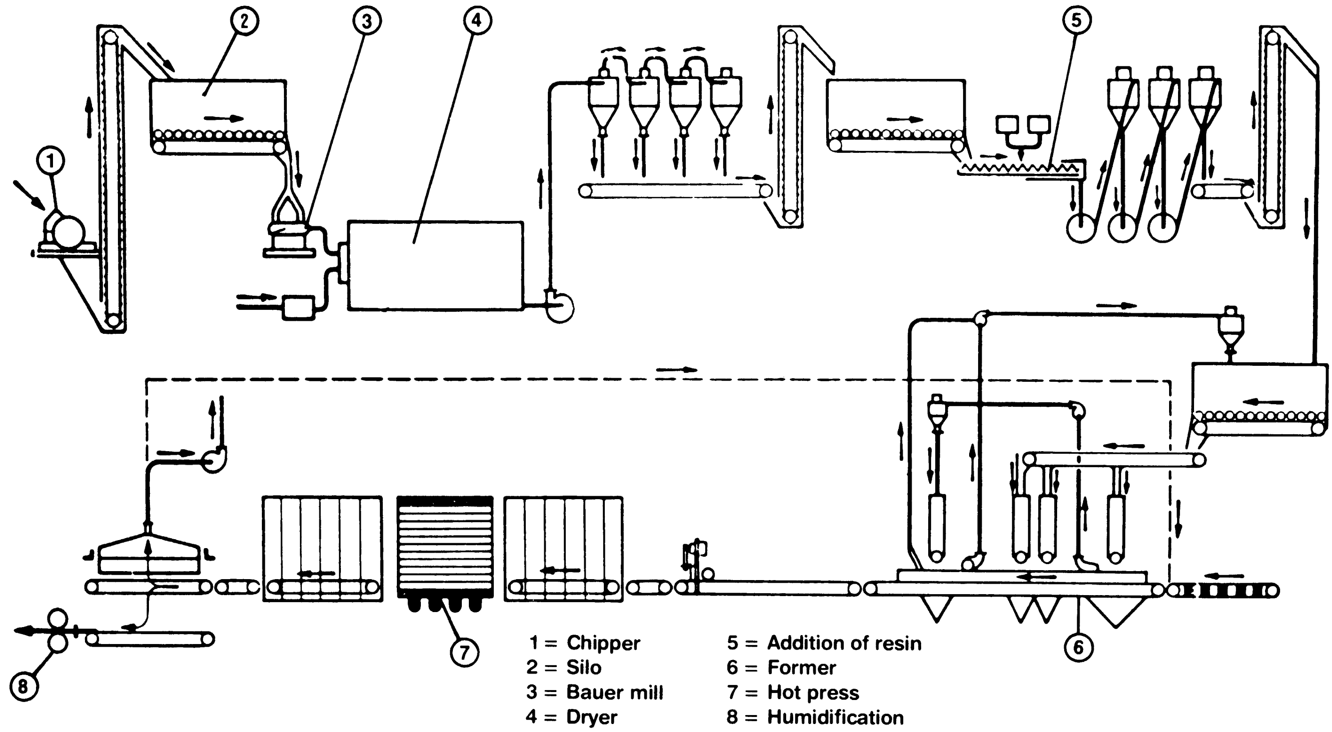


Figure 200—*Schematic chart of dry-process hardboard plant of Cascade Plywood Company in Lebanon, OR (now Champion International) (Sandermann and Kunnemeyer 1957).*

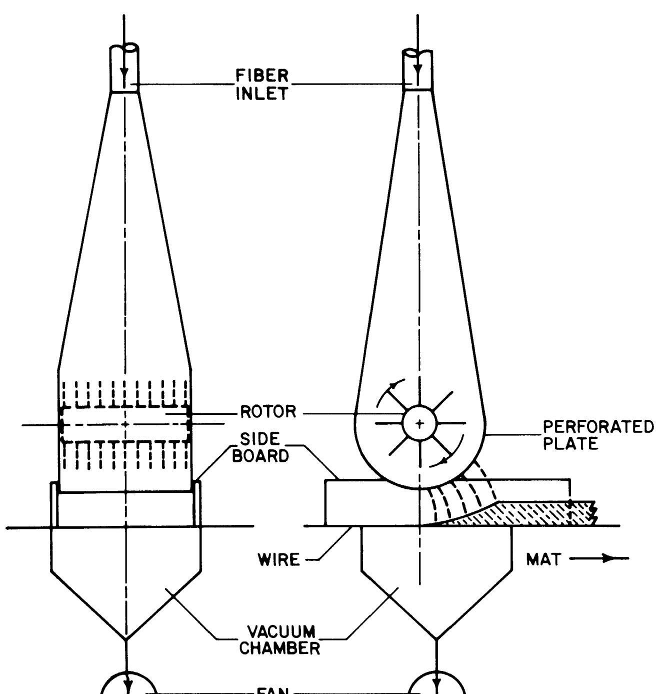


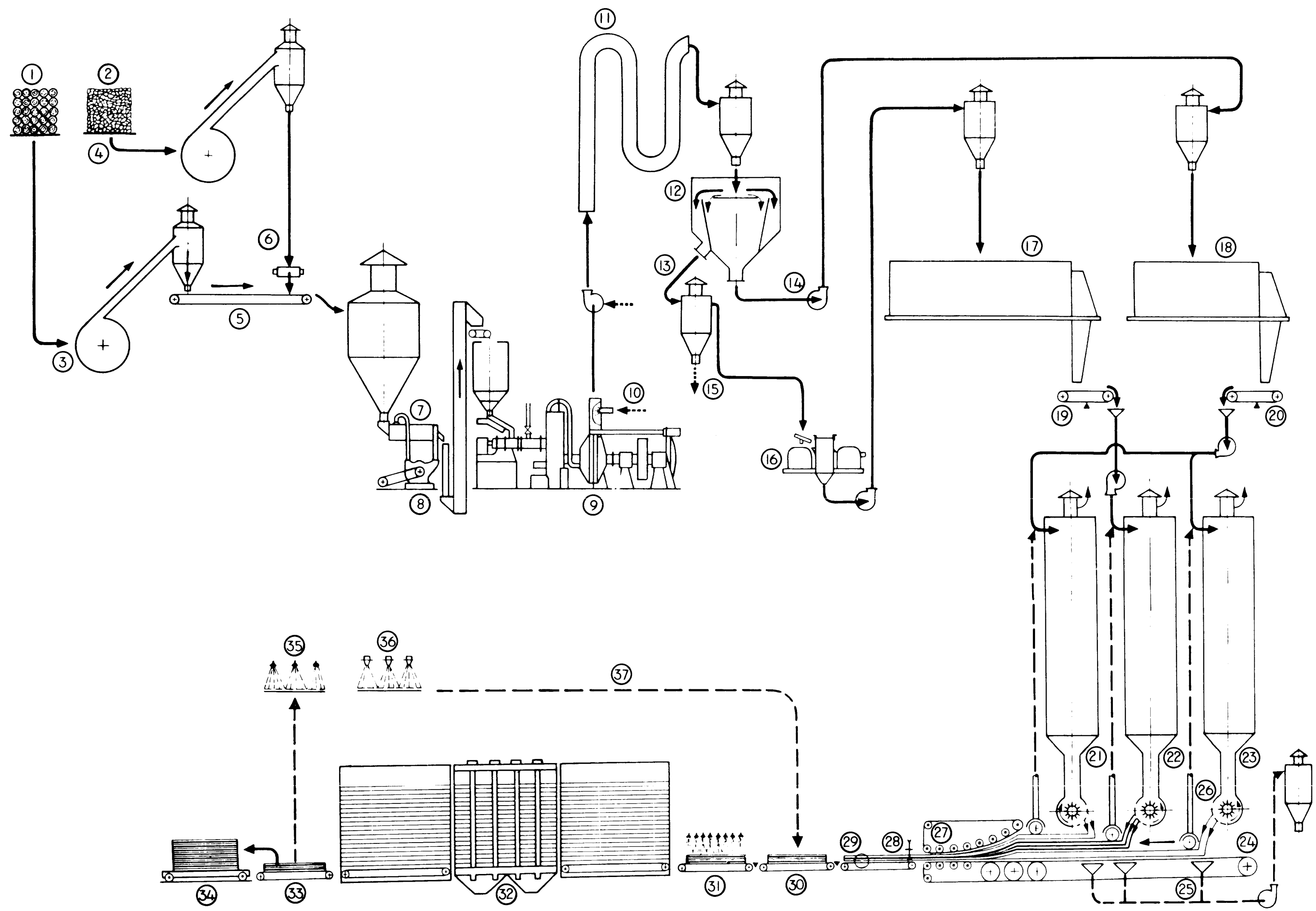
Figure 201—*Vacuum forming machine (Robinson 1959).*

Vacuum felters provide greater mat uniformity and have become the standard dry-process forming device. However, the maintenance of the vacuum requires considerable electric power. A more recent four-stage vacuum former is shown in figure 203. The furnish is distributed across the machine width by means of swing spouts that oscillate at a frequency of about 120 oscillations/min. The furnish is metered to the spouts at air speeds of 3,600 to 5,400 ft/min. To improve mat uniformity, furnish is applied in excess quantity and then reduced to the required mat thickness by shave-off rolls and vacuum devices.

Pressing

The dry-formed mat has a very low density. The mat for a ¼-in board could be 8 in thick. To reduce daylight requirements and closing times in the hotpress, and to improve handling quality of the mat and surface quality of the finished board, the mat is prepressed in a continuous **band press**. Roll pressures are about 1,000 lb/in. The mat density is thereby doubled or tripled (fig. 204). In some cases a surface layer of fine fiber material is added to the precompressed mat.

The traveling, densified mat is now trimmed by disk cutters and transferred to caul plates for the pressing



1 = Roundwood
2 = Mill waste
3, 4 = Chippers
5, 6 = Chip conveyors
7 = Screen
8 = Mill
9 = Defibrator
10 = Addition of resin
11 = Suspension dryer
12 = Separator
13 = Coarse fibers
14 = Fine fibers
15 = Separation of fiber bundles
16 = Bauer refiner
17 = Buffer storage
18 = Buffer storage
19, 20 = Scales
21, 22, 23 = Formers
24 = Forming screen
25 = Vacuum supply
26 = Nylon brush roller
27 = Prepress
28, 29 = Saws
30 = Placement of mat on screen
31 = Water spray
32 = Hot press
33 = Separation of cauls and boards
34 = Humidification of boards
35 = Washing of cauls and screens
36 = Drying of cauls and screens
37 = Caul and screen return

Figure 202—*Schematic chart of Weyerhaeuser semidry plant in Klamath Falls, OR. This plant now produces siding by the dry process (no screens) (Sandermann and Kunnemeyer 1957).*

operation. Dry-formed board is hotpressed in multi-opening presses very similar to those used for wet-formed S2S board. Presses must have rapid, simultaneous closing. Platen temperatures are high (400 °F); press cycles are short. At low mat moisture contents (5 percent), single-phase press cycles are used (fig. 205). Higher moisture contents require two or three phases (fig. 206). Two-phase press cycles work particularly well with hardwood furnish. Three-phase cycles are critical, because the total pressure release after phase one is hazardous to surface quality (Rausendorf 1963). Quick drying of the surface layers of the loose mat during the closing of the press increases their compressive strength and leads to a density distribution in the board as shown in figure 207. Surface densification, at least in the top surfaces, can be increased by adding water spray to the mat surface prior to

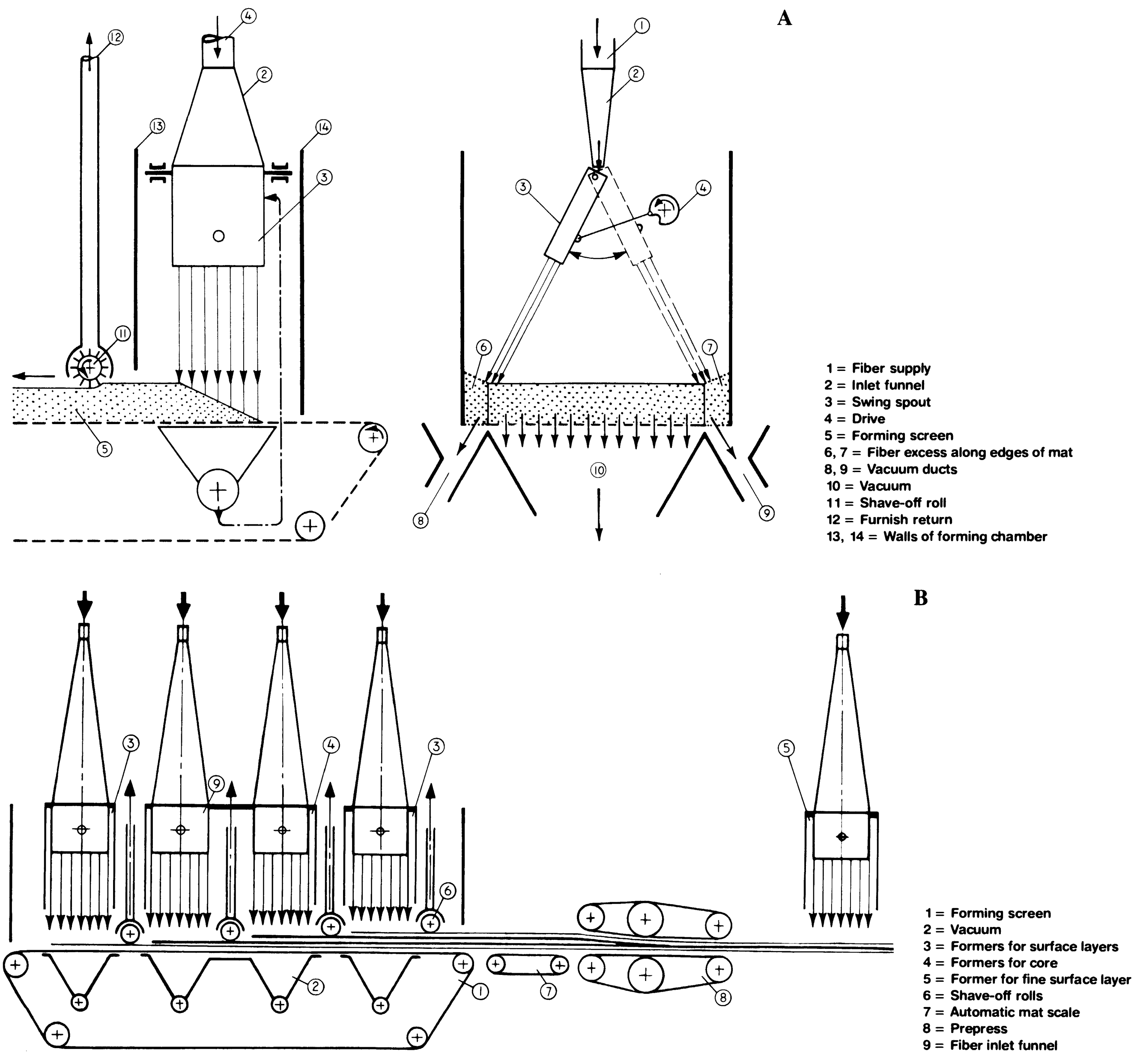


Figure 203—*Vacuum former with swing spouts (Lampert 1967).* **A**—*Schematic of swing spout former element.* **B**—*Four-stage vacuum former with element for forming fine surface layer.*

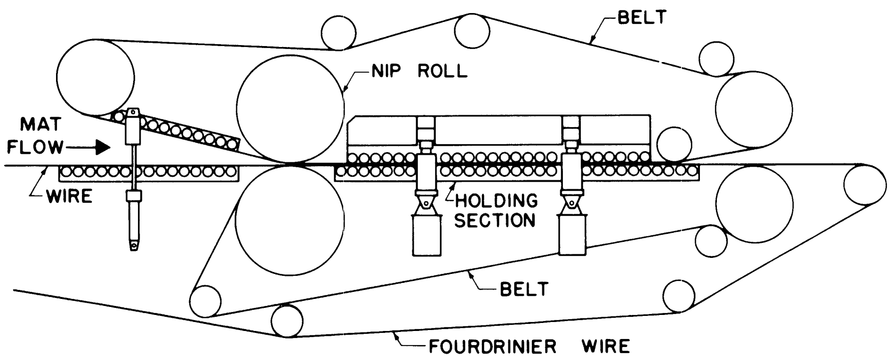


Figure 204—*Schematic drawing of a roll prepress (Peters 1968).*

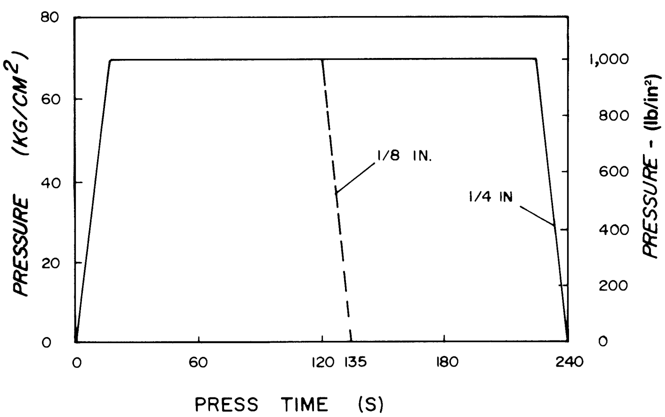


Figure 205—*Single-phase press cycles for 1/8- and ¼-in-thick dry-formed hardboard of three-layer construction. Press temperature, 455 °F (Lampert 1967).*

hotpressing. At the Weyerhaeuser plant in Klamath Falls, water at 60 g/ft^2 is applied to the surface of the siding mat. This increases the total moisture content of the mat considerably. The press cycle starts with a low-pressure phase (1½ min at 150 lb/in^2), followed by a high-pressure phase to stops. The paintability of this particular siding product is very good.

Process control

Board density is a basic property of hardboard often used as a quality indicator. It affects most of the physical and mechanical properties, such as bending strength, modulus of elasticity, hardness, thickness swelling, etc. It also affects the cost, since higher board density requires more wood, additives, process water, and energy.

Figure 208 shows the basic relationship between board density and bending strength as reported by Kumar (1958). The curve below is the derivative of this relationship and has been added to show the rate of change of the bending strength for each unit change of board density. This curve shows, for instance, that for a 1-percent change in board density, at an average board density of 58 lb/ft^3, the bending strength will change by 3 percent. A density variation of ± 7 percent either within or between boards would be reflected in bending strength variation of ± 21 percent.

It is clear, therefore, that efforts to control board properties would concentrate on board density, or, more precisely, on the mat weight. The economic advantage of such process control efforts are illustrated in figure 209, which shows a hypothetical distribution of bending strength of hardboard produced without the benefit of controlling the board density. The process is so adjusted that the board meets a hypothetical standard indicated by the lower bending strength limit. Controlling the board density within closer tolerances would reduce the variation of the bending strength about the average. The board now exceeds by a considerable margin the required bending strength. The average bending strength could therefore be dropped to a lower level either by reducing the board density or by reducing the resin content, or both. Other important board properties would be similarly affected.

Controlling the board density requires accurate measurement of the mat density, or mat weight. However, not all of the mass contained in the mat appears in the finished board. Most of the moisture contained in the mat evaporates in the press. Because mass sensing devices cannot differentiate between water and wood, mass measurements must be adjusted for water content, which itself is, of course, variable. This is one of the practical difficulties in the control of board density.

A **density control** system must therefore include accurate moisture content measurement and moisture content control. Such a system developed by the Measurex Corporation has been applied to the dry-process hardboard siding plant in Paris, TN, operated by the Celotex Corporation. The following description is based on an article by Betzner and Wallace (1980).

Figure 210 shows a schematic of the siding plant. The furnish is produced on three lines and supplied to three vacuum felters. Each felter is followed by a shave-off or equalizing roll. An additional shave-off, number 5, is positioned at the entrance to the prepress. A **scanning mass sensor** (MX scanner) is positioned between prepress and hot press. One single-point moisture (MOI) sensor is located downstream from each of the three primary felters.

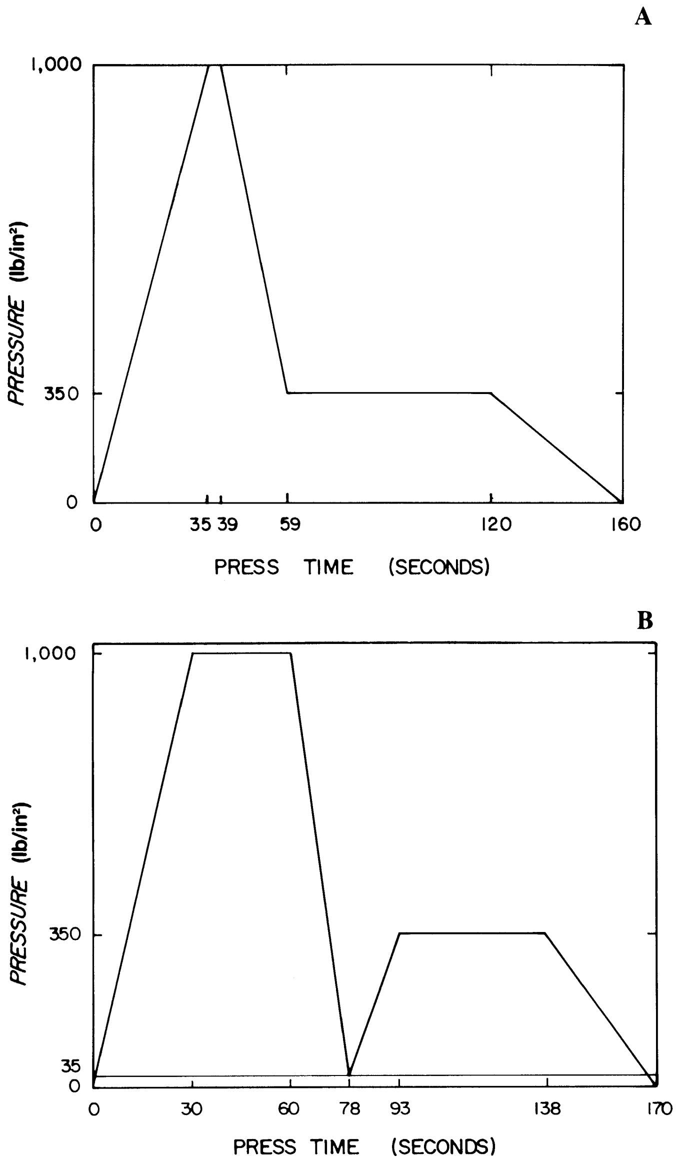


Figure 206A—*Two-phase press cycle for 1/8-in-thick dry-formed hardboard. Press temperature, 428-446 °F.* **B**—*Three-phase press cycle for 1/8-in-thick dry-formed hardboard. Press temperature, 428-446 °F (Swiderski 1963).*

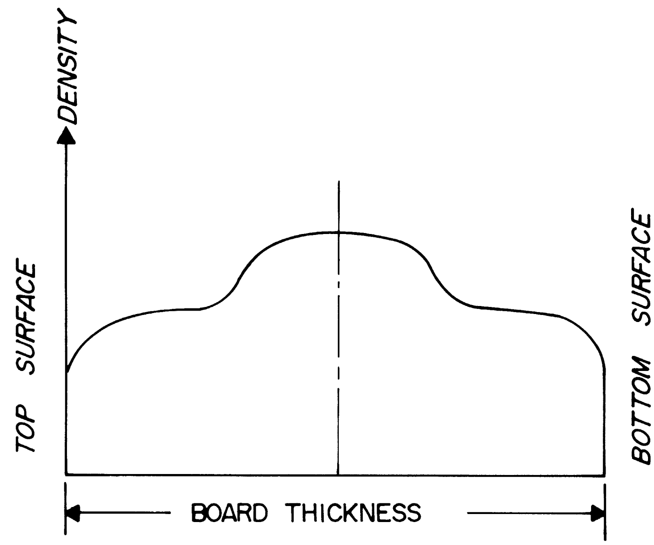


Figure 207—*Density profile of S2S dry-formed hardboard (Spalt 1977).*

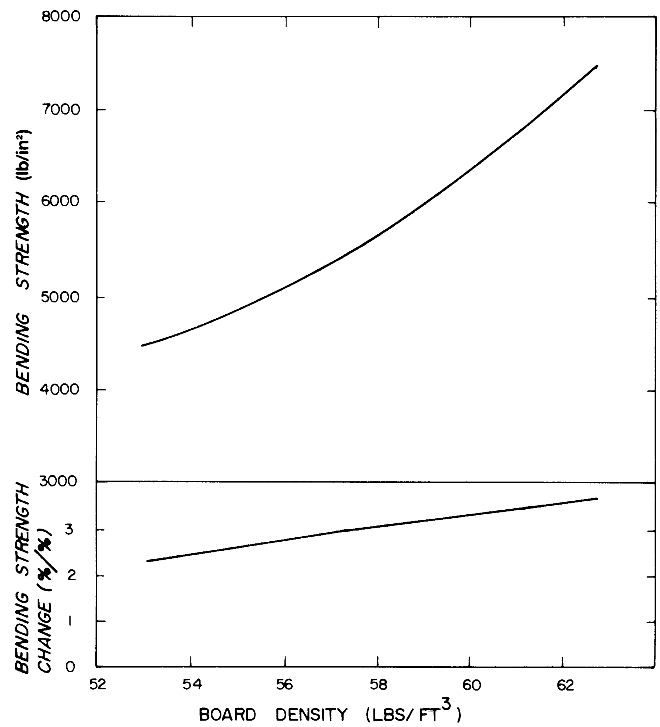


Figure 208—*Basic relationship between bending strength and board density of hardboard. upper part according to Kumar (1958). The bending strength change refers to the change caused by 1 percent change in board density.*

The principle of these **moisture sensors** is illustrated in figure 211. Infrared light is focused on the mat and reflected into the sensor, where it is split into two different wavelength components. Moisture present in the mat will absorb one wavelength (1.9 μm) and not the other (1.8 μm). A comparison of the two reflected intensities allows calculation of the quantity of water present in the mat. This information is used to control the dryer, i.e., it will change the set point of the temperature control loop, and, if called for, will establish a new equilibrium between dryer outlet temperature and burner control (fig. 212). The target moisture is set manually by the operator.

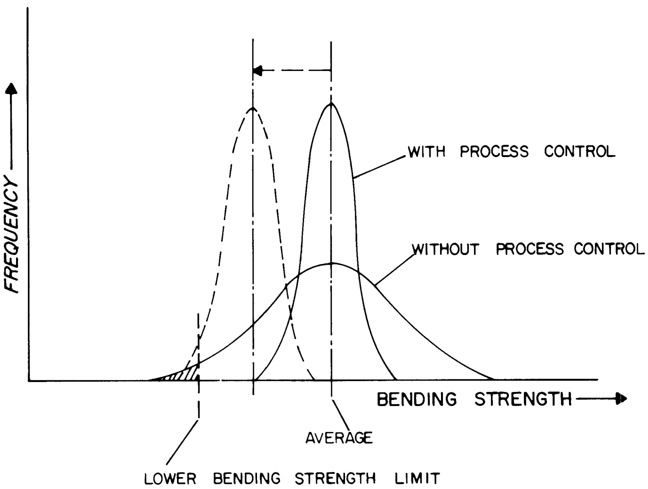


Figure 209—*Illustration of the potential benefits of mat density control.*

The moisture content information is also used to adjust the mass determination of the mass sensor. The mass sensor traverses the moving mat every 7 s, sensing the mat's absorption of gamma rays from an americium source located beneath the mat (fig. 213). The control loop is shown in figure 214; figure 215 shows an overview of the Measurex system.

Throughput maximization control is an additional feature of this system (fig. 216). It adjusts the line speed to maximize production. Changes in press cycle, for instance, will be reflected in changes in line speed. Or, if the position of the controlled shave-off device reaches an upper limit, indicating shortage of fiber at the former, the computer automatically ramps down the line speed, that is, it reduces the speed to a lower level by discrete steps, until sufficient fiber is available. When the shave-off

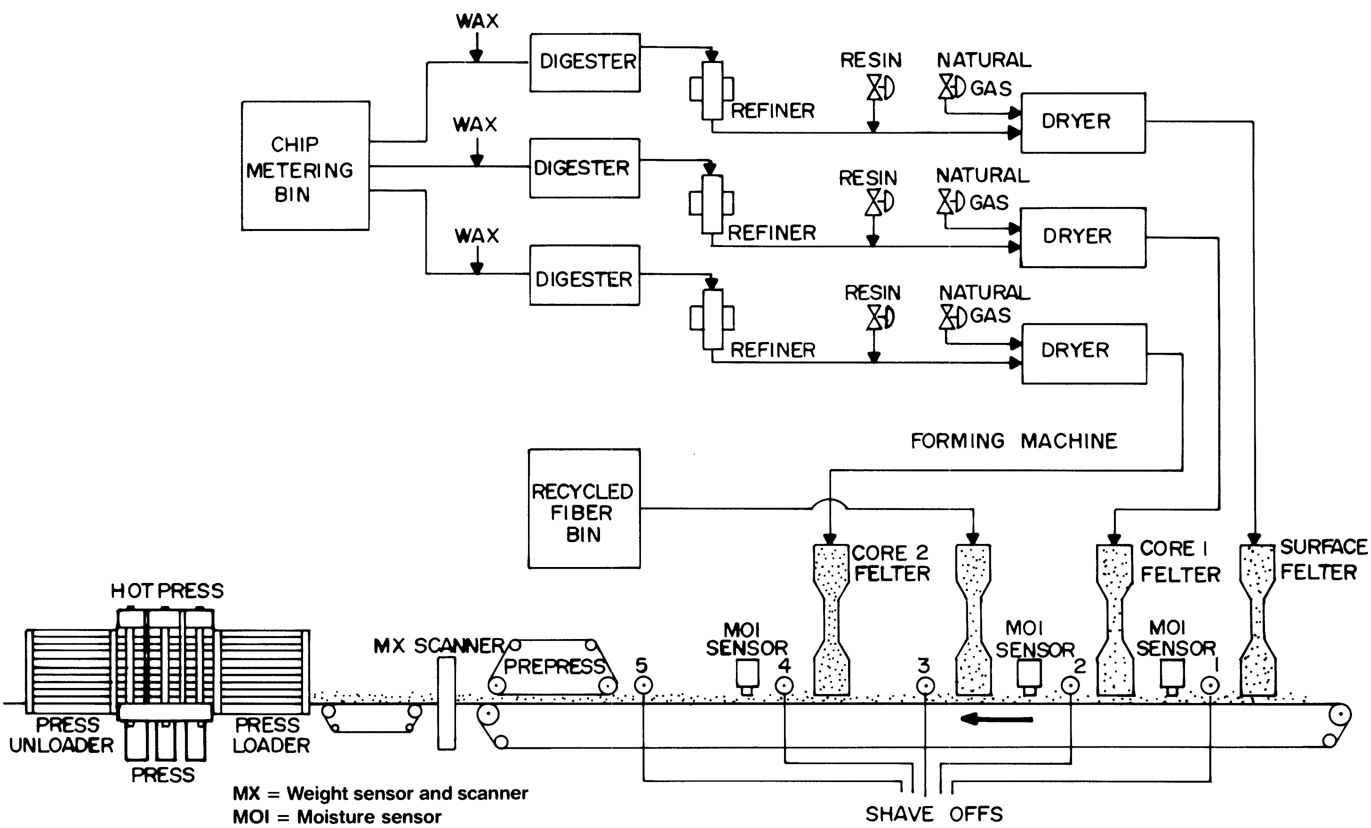


Figure 210—*General schematic of hardboard siding line at Paris, TN (Betzner and Wallace 1980).*

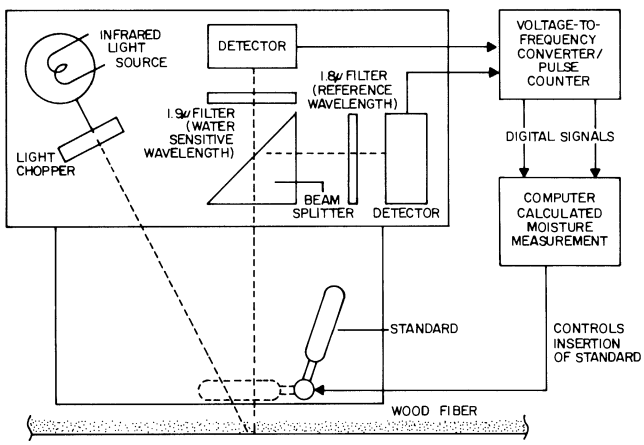


Figure 211—*Principle of Measurex moisture sensor (Betzner and Wallace 1980).*

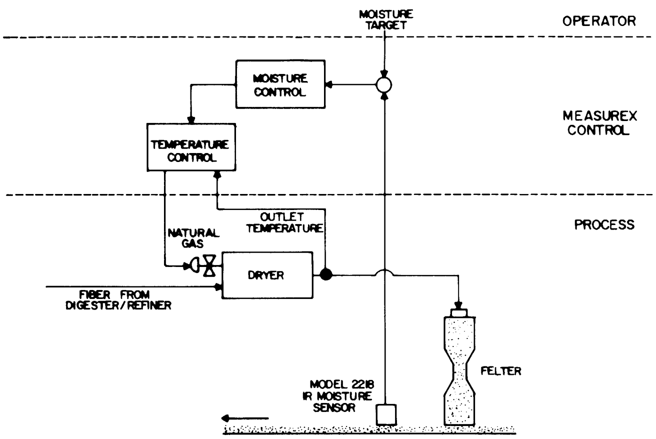


Figure 212—*Principle of Measurex mat moisture measurement and control (Betzner and Wallace 1980).*

head moves down to a normal operating range, the line is ramped back to the optimum speed as computed by the throughput maximization control.

Manufacture of Medium-Density Fiberboard

General

Medium-density fiberboard (MDF), according to the common usage of the term, refers to the thick (3/8 to 1 in) medium-density fiberboard that is generally sold in the **industrial core stock** market in direct competition with particle board. Its properties, such as bending strength, modulus of elasticity, internal bond, machinability, and screw holding power, meet the levels required for these applications.

Just what these requirements are, in terms of the above properties, is not precisely defined. The furniture manufacturer, in many cases, simply knows from experience that a certain core material is suitable in a given application. The commercial standard simply identifies those materials that can be successfully used for specific purposes.

The MDF process differs from other processes in that it has been developed for a specialized application, different from all other fiberboard applications. A unique combination of moderate overall density, suitable density profile, and resin content results in excellent edge machining and edge finishing characteristics, qualities essential to superior furniture core stock.

A typical process flow diagram for an MDF plant is shown in figure 217. This schematic differs little from the dry-process hardboard flow diagram in figure 192. Nevertheless, there are some unique elements.

Medium-density fiberboard requires the production of a pulp of very low bulk density (2 lb/ft^3 or less), which developes good resin bonding during compression to normal board density (45 to 50 lb/ft^3). This kind of pulp is exclusively produced by pressurized refiners, discussed in chapter 6.

Low bulk density of the furnish poses special problems in handling, transportation, and storage throughout the process. It also requires presses with sufficient "daylight," that is, clearance between adjacent platens, to accommodate the thick mats. The relationship between minimum press daylight, fiber bulk density, and board thickness at a board density of 47 lb/ft^3 is in-

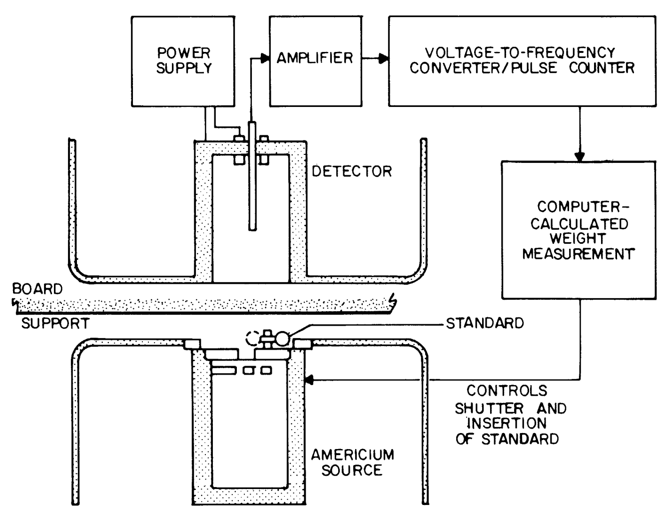


Figure 213—*Principle of Measurex weight sensor (Betzner and Wallace 1980).*

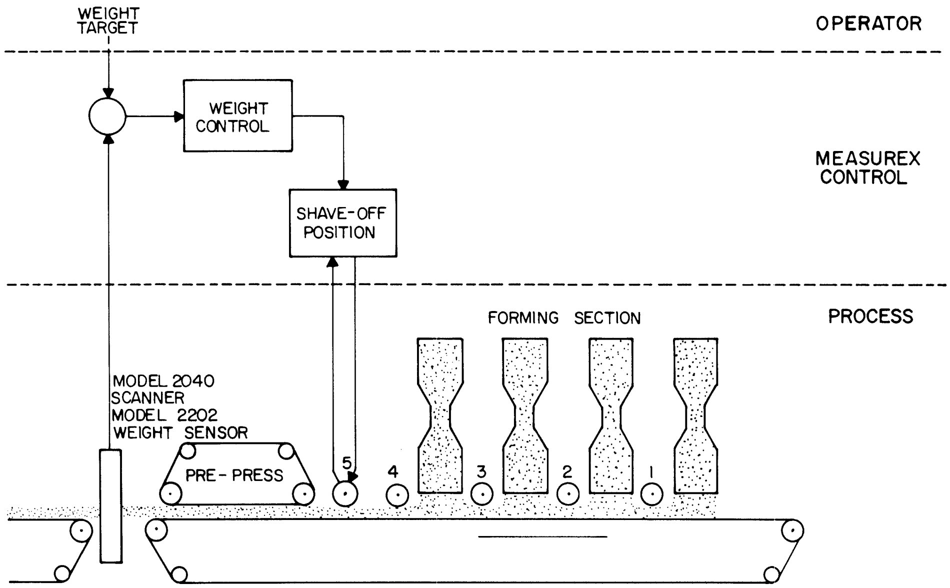


Figure 214—*Principle of Measurex weight measurement and control (Betzner and Wallace 1980).*

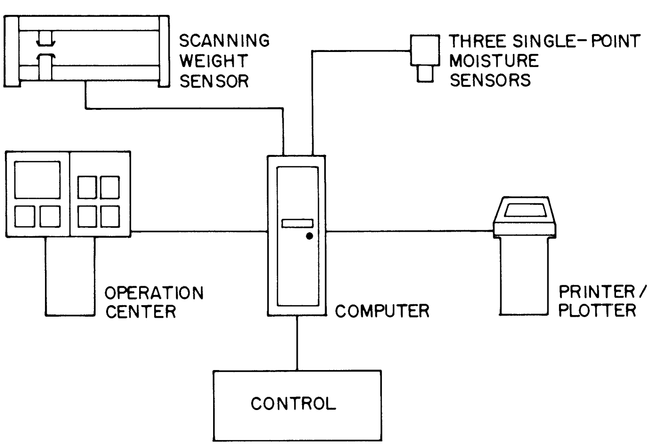


Figure 215—*Overview of Measurex mat density control system (Betzner and Wallace 1980).*

dicated in figure 218. When caul-less systems are used, the precompressed mat is transported into the press opening by loader trays that require an additional 3 in of daylight. It should be noted that these press openings are sized to accommodate mats after precompression. Before precompression they are much thicker (9 to 24 in).

The second unique element of the MDF process, at least in the initial stages of its development, is the binder formulation. To prevent the bulky fibers from lumping together, so-called *in situ* resin systems, developed by Allied Chemical Company and having low tackiness and low viscosity, are widely used. The precondensation of these *in situ* resins is terminated at a very low molecular weight, which reduces their tackiness. The condensation is completed in the hotpress.

The third unique element of the MDF process, at least in the early stages, is the curing of the resin in the press with radio frequency energy. Radio frequency heating causes a uniform temperature rise throughout the mat or board, regardless of the distance from the platen surface. All parts of the mat should have, at least theoretically, the same time-temperature relationship during the compression period. The compressibility of the mat would thus be uniform over its thickness at any given time, and there would be no density variation over the cross section of the finished board.

A uniform density over the board cross section is not necessarily always desirable. A very attractive property of medium-density fiberboard, however, is its solid edge, allowing smooth machining and finishing. It is believed to result from uniform density over the cross section, made possible by radio frequency heating in the press.

The three characteristics of the MDF process are covered by the patent issued in 1965 (Raddin and Brooks 1965).

In the meantime, regular urea-formaldehyde resins as used in the particle board industry are also used for medium-density fiberboard, and about half of the existing plants use regular steam-heated presses rather than

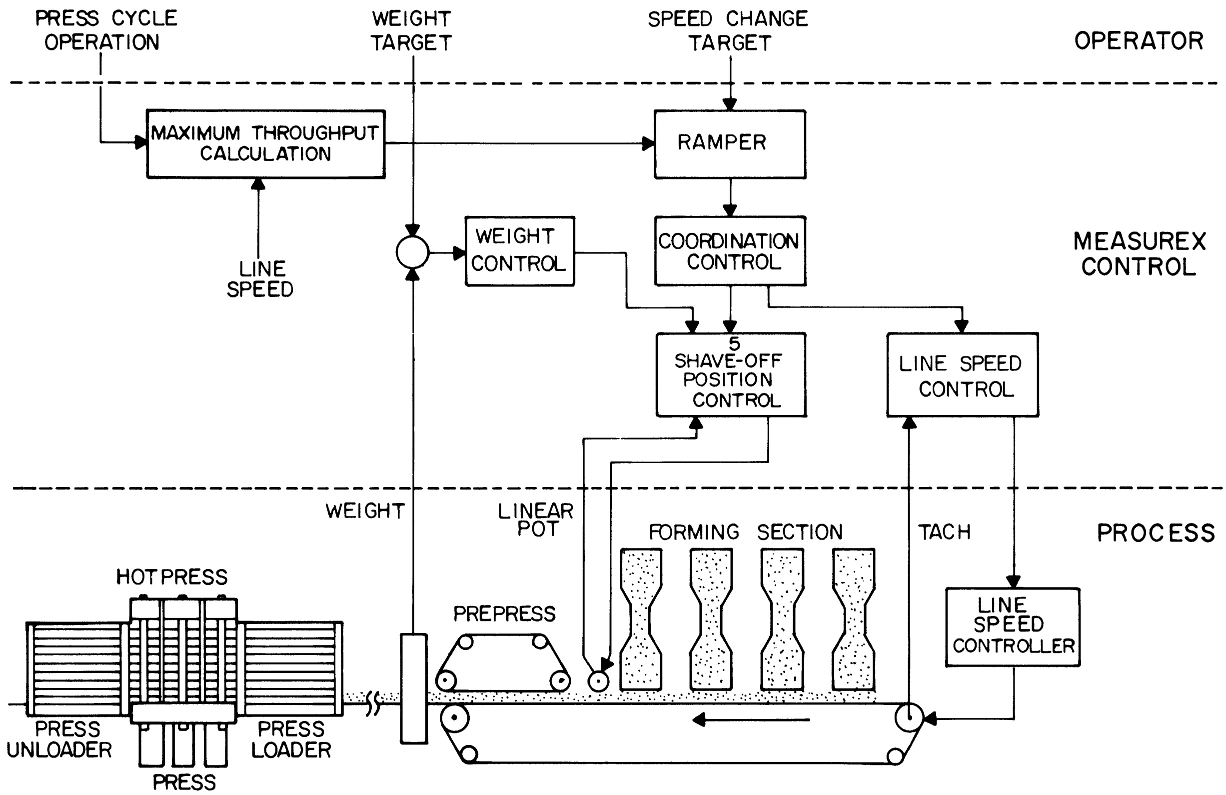


Figure 216—*Measurex speed change control and throughput maximization control (Betzner and Wallace 1980).*

radio frequency. The pressurized refiner, however, is still the typical pulping machine for medium-density fiberboard.

Drying, resin binder application, and forming

The drying of fiber for MDF occurs in tube suspension dryers or flash dryers exactly as in other dry fiberboard processes.

The resin is generally applied to the dry fibers in so-called short retention mixers (fig. 132). These mixers were developed for the particle board industry, where they represented a significant advance from the conventional resin application in large low-velocity trough-type blenders (Knapp 1971).

Figure 219 shows a schematic view of the interior of such a mixing machine. Instead of trying to expose every surface of every fiber or particle to a fine resin spray, these machines rely on transfer of resin by rubbing from one fiber to another during rapid agitation of the furnish. Spray nozzles have been replaced by liquid adhesive delivery through shaft and rotating paddles or through injection into the rotating ring of furnish (fig. 220). Retention times are only a few seconds. Mixers of this type have been equipped with agitators especially suited for handling fiber furnish (fig. 221).

These machines, when applied to fiber furnish, sometimes develop resin spots visible on the finished board as evidence of insufficient resin distribution. Injection of the urea-formaldehyde resin into blow pipes (pipes through which pulp is discharged) from the refiners is being considered as an alternative. This is, of course, common practice in dry-process hardboard manufacture, where phenol-formaldehyde resins are used. Operating experience shows that this method offers several additional benefits (besides absence of glue spots): no tackiness, clean pneumatic ducts and cyclones, higher moisture content at dryer output (14 percent versus 4 to 5 percent with blender), and no formaldehyde odor. Resin consumption, however, increases by about 10 percent (Haylock 1977).

The forming of the medium-density fiberboard mat is similar to the forming of thin dry-formed hardboard

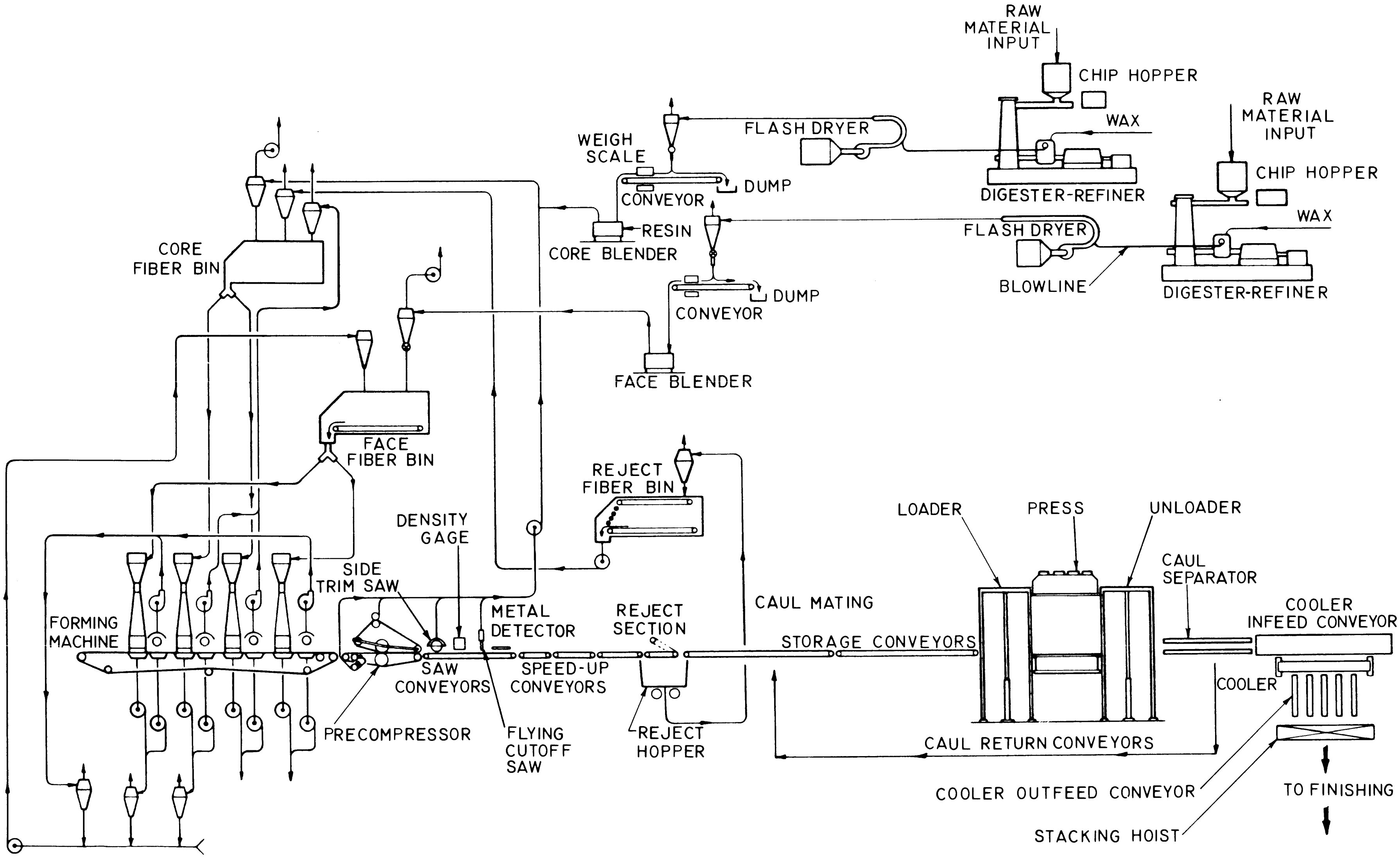


Figure 217—*Typical process flow chart of medium-density fiberboard plant (Chryst and Rudman 1979).*

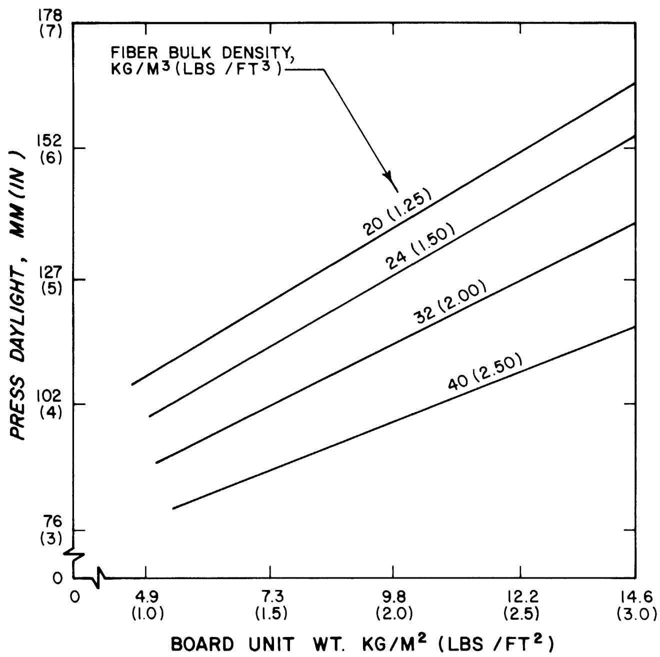
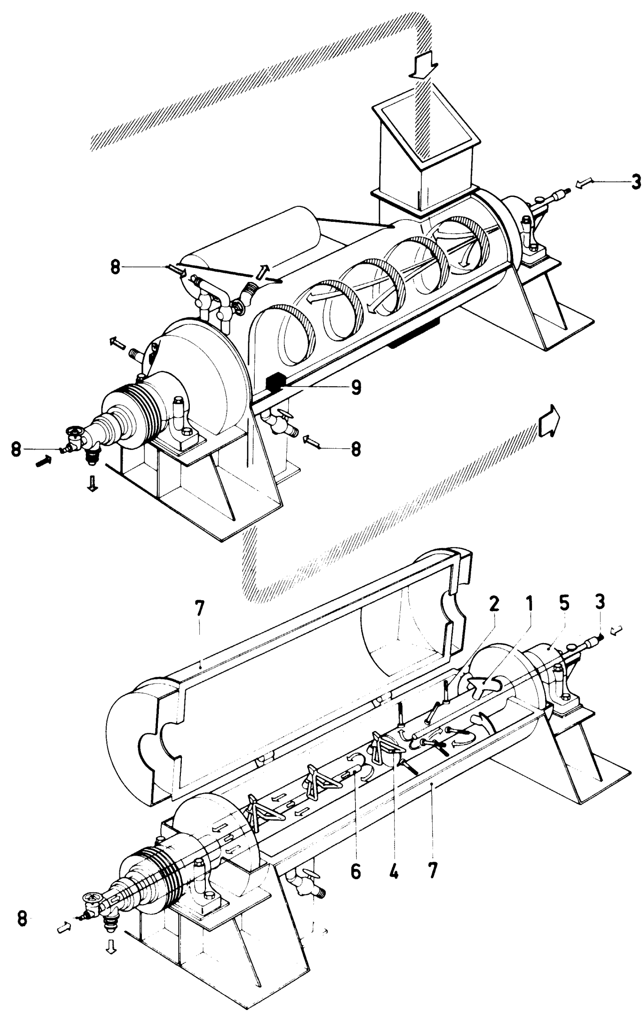


Figure 218—*Press daylight required for fiberboards for various fiber bulk densities (Chryst and Rudman 1979). "Daylight" is the clearance between adjacent press platens when press is fully opened.*

mats. The vacuum former is the standard device. Because the mat thickness is much greater, it may be questionable whether or not its upper layers benefit from the vacuum.

A more sophisticated forming machine, the Rando-Wood-MDF former (fig. 222), which attempts to form the entire mat thickness simultaneously, is described by Wood (1976).

In this former, the fibers are delivered to it pneumatically and are then separated from the air, without condensing the fibers, in the separator assembly. The fibers are then fluffed up by a pair of spike rolls and deposited on a moving floor apron, which delivers them to an inclined conveyor equipped with cleats. At the upper end of the inclined conveyor a stripping roll equalizes the flow of the fibers. At the apex of the incline the fibers are removed from the cleated conveyor by an airstream that carries them down a fiber chute into the actual forming section, resembling a horizontal extruder. The air is removed through the perforations of the lower condenser into the lower condenser chamber, which is maintained at a negative pressure. The air flow is such that the fibers are deposited and packed into the wedge-shaped gap between the upper and lower condensers, rather than on the lower screen only. This results in the simultaneous formation of the entire cross section of the mat, with finer furnish fractions concentrated on both surfaces.



1 = Transport paddles
2 = Pipes with orifices for resin application
3 = Resin supply pipe
4 = Secondary mixing paddles
5 = Bearing
6 = Hollow shaft with water cooling
7 = Drum
8 = Cooling water supply
9 = Magnetic safety switch prevents machine operation when lid is open

Figure 219—*Short retention mixer for particle furnish. Speed: 600 to 1,000 r/min (Bison Werke).*

Another modification of the vacuum former is being offered by the Swedish company, Motala-Defibrator, under the name of "Pendistor" (figs. 223, 224). The swing spout is replaced by air impulses that are operated at higher frequencies than is possible with the mechanical spouts. It is claimed that the Pendistor produces more uniform mats, up to a width of 9 ft.

The thick mats (9 to 24 in) are precompressed by continuous **band presses** (fig. 224) to a thickness range of from 3 to 6 in, depending on final board thickness. Mats are trimmed and weighed to assure proper density of the

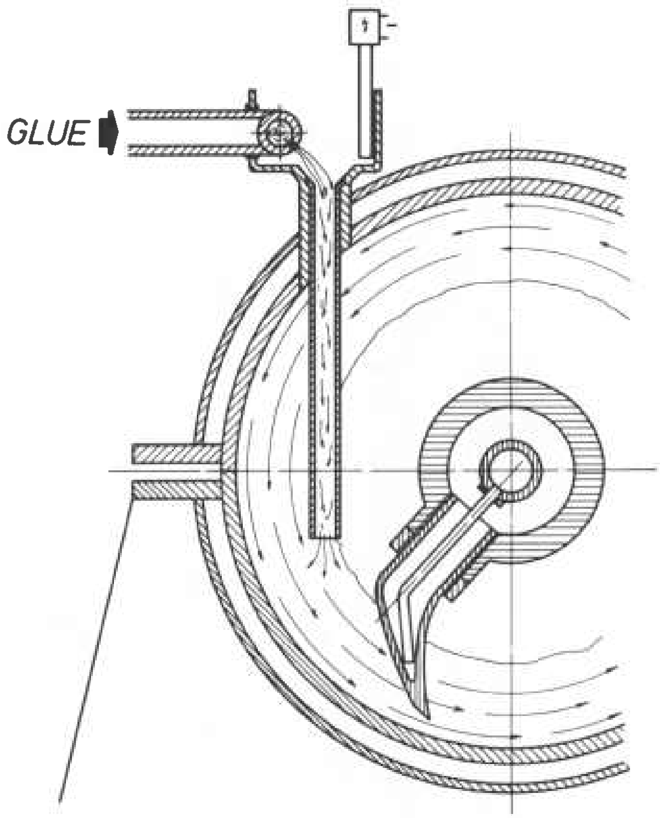


Figure 220—*Injection of liquid resin through external feeding pipes into ring of rotating furnish (Engels 1978).*

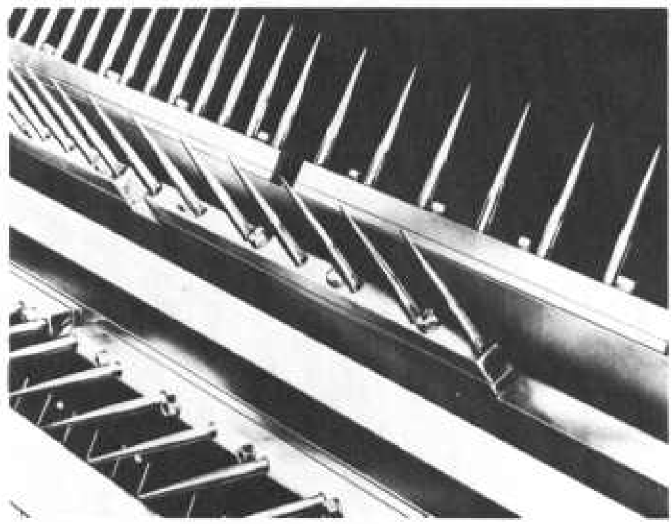


Figure 221—*Ring mixer for fiber furnish equipped with needle-type agitator arms (Engels 1978).*

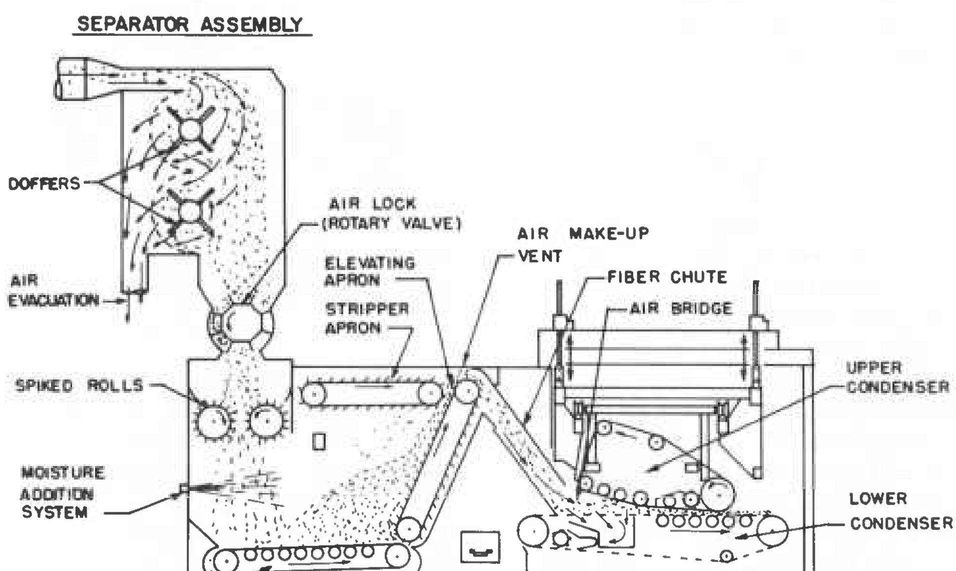
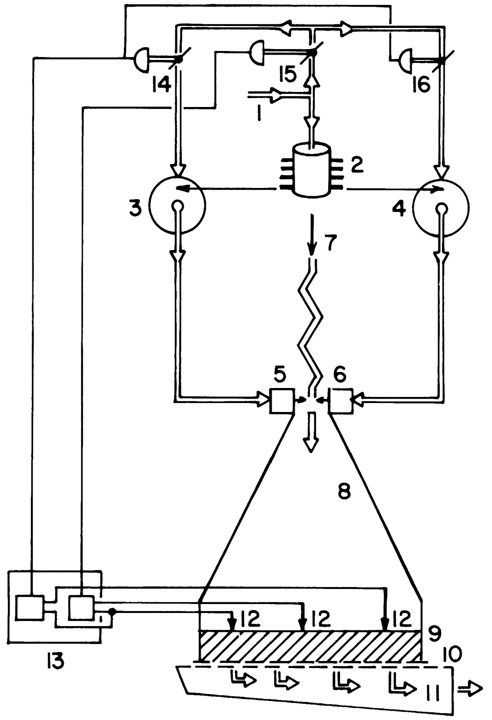


Figure 222—*Schematic drawing of Rando-Wood Former Mark II (Wood 1976).*



1 = Control-air supply
2 = Rotary valve
3, 4 = Eddy-fluidistor
5, 6 = Pneumatic chambers
7 = Fiber inlet
8 = Former
9 = Mat
10 = Forming screen
11 = Suction box
12 = Instruments for measuring mat thickness
13 = Central control instrument
14, 15, 16 = Throttles for air control

Figure 223—*Schematic drawing of Pendistor former (Carlson 1978).*

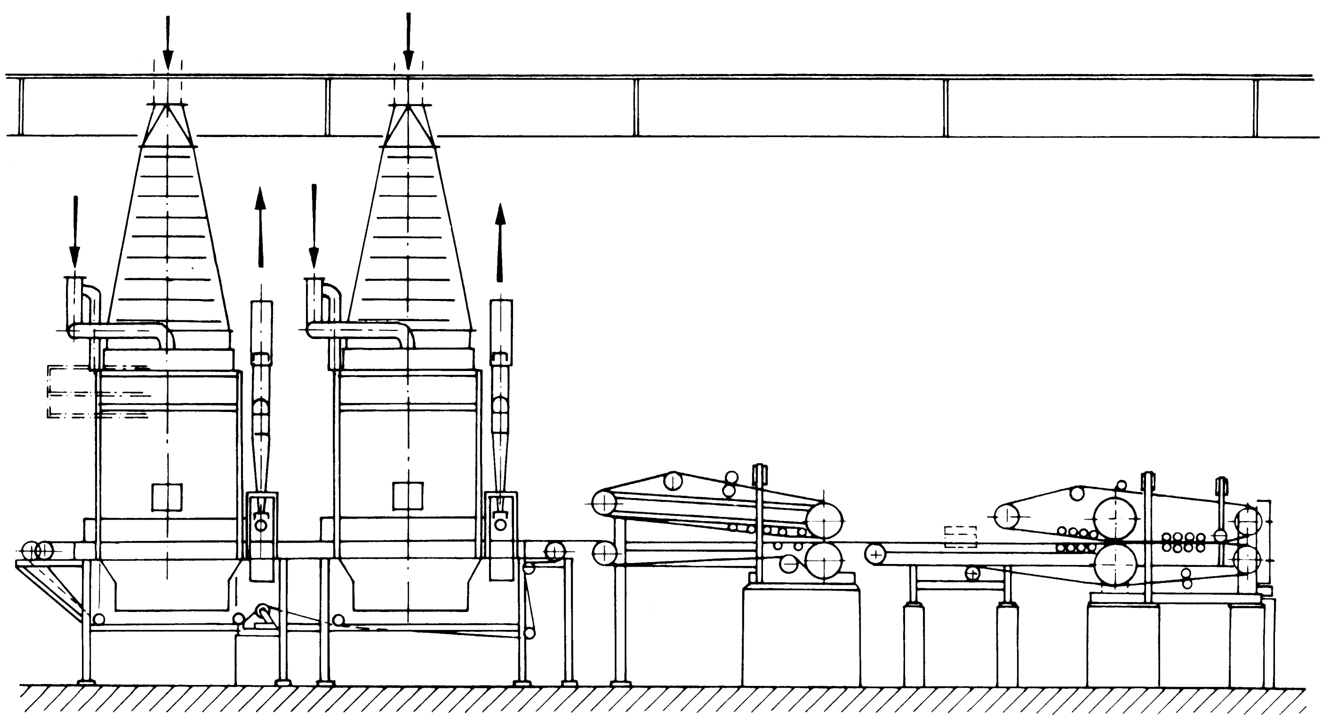


Figure 224—*Pendistor forming station. Two Pendistor formers are followed by a two-stage band-prepress. First stage is low pressure, second is high pressure (Carlson 1978).*

finished board. Mat trim waste and entire mats not meeting specifications are returned to the forming station for reuse. The mats are then transferred to the press loader either with or without cauls.

Pressing

In the manufacture of thin boards, press cycle design is greatly determined by considerations such as proper total densification of the mat and efficient water and gas release. The development of any particular density profile is of secondary importance. In thick particle board and MDF, however, the density profile can be of primary importance. Press cycles are designed to attain the most beneficial density distribution, one that balances face and core density for each particular application.

Figure 225 shows the density distribution over the board cross section of two boards of the same average density. Board A, with a high face density, should possess a high modulus of elasticity in bending, high bending strength but low internal bond strength (tensile strength perpendicular to the board surface). Board B, having the same average density as board A, would have a greatly improved internal bond strength, but its bending properties would be lower. Along with the high **density contrast** (board A) goes a relatively porous board edge, poor machinability of the edge, and poor edge screw holding power. Low density contrast (board B) would be associated with greatly improved edge properties.

Stops or gauge bars, used in the pressing of all thick boards, particle board, and thick MDF, permit modification of the density profile without changing the average density. With stops or gauge bars, the average density is independent of the applied pressure, as long as the applied pressure is high enough to close the press, i.e., to densify the mat to the thickness of the stops within the total press cycle time. Under such conditions the density contrast can be controlled, within certain limits, by controlling the **closing time**, the time period between initial pressure application and the moment at which the mat is compressed to the thickness of the stops. This closing time is, of course, a function of the applied pressure.

Figure 226 shows the effect of closing time and pressure on density contrast of MDF. Density contrast is highest at relatively short closing times, which are obtained at high pressures. Reducing the pressure moderates the density contrast until a pressure is reached that is just capable of closing the press at the end of the press cycle (point 2), which in turn is determined by the press temperature and the curing characteristics of the resin.

At short closing times only thin surface layers are heated and therefore weakened before the densification is complete, resulting in higher compression of the faces. At long closing times, the entire mat is heated while still under full pressure, and the various layers of the mat reach similar low compression strength levels at one time or another, which results in a more uniform densification of the mat and a low density contrast.

Increasing the pressure to extreme values causes instantaneous closing of the press with no density contrast at all (point 1). Here, no heat has been transferred to any part of the mat before complete densification. This is

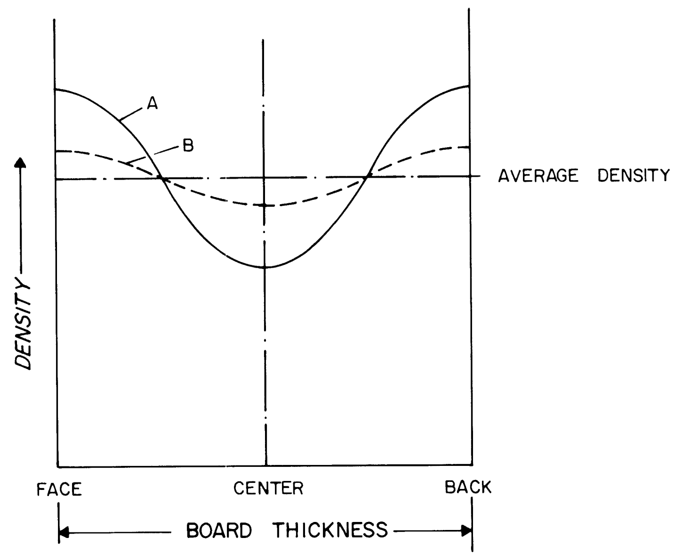


Figure 225—*Examples of density distributions over board cross section at constant average board density.*

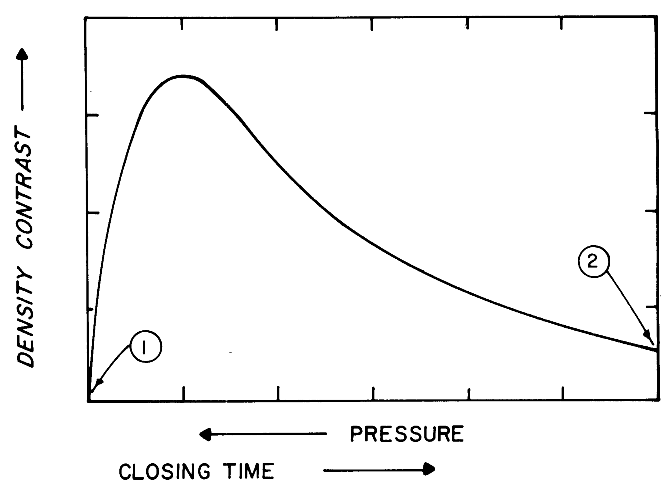


Figure 226—*Schematic illustration of relationship between pressure or closing time and density contrast over cross section of medium-density fiberboard (Suchsland and Woodson 1974).*

equivalent to cold pressing, which does not produce a density contrast. Figure 227 is another illustration of this same relationship. Here, the modulus of elasticity in bending reflects the changing density contrast as closing time is varied. The actual density profiles of some of these same boards are shown in figure 228.

In order to achieve reasonable closing times (0.5 to 1.5 min), practical pressure values are between 500 and 750 lb/in². Total press times for a ¾-in board may be 8 to 10 min.

The first medium-density fiberboard plant (Deposit, NY) was equipped with a high-frequency press. The remarkably solid edge of this board, so desirable for core stock, was quickly ascribed to a lack of density contrast due to high-frequency heating. This appears to be a reasonable claim, because high frequency heating results in a uniform temperature throughout the board thickness and should favor a more even moisture removal and uniform mat compression.

Subsequent investigations (Suchsland 1978, Suchsland and Woodson 1974) and practical experience have indicated that for boards ¾ in thick or less, these differences are slight and not significant enough to make use of high-frequency mandatory. There is no question about the advantages of high-frequency heating in the manufacture of thicker boards (1 in or more). About half the present medium-density fiberboard plants use high-frequency heating, while the other half uses either steam or hot water.

The principle of a high-frequency heated press is illustrated in figure 229. The electrodes, which could be thin sheets of copper or other conductive material, are placed between the press platens and the mat. A 10-megacycle electric field established between the two electrodes causes the mat to heat up. In addition, the press platens are heated by steam or hot water, but only to a temperature slightly above 212 °F to avoid condensation on the surfaces of the board.

A press size of 5 by 18 ft seems to be particularly suitable for the application of high-frequency heating. The power requirements increase with the number of openings. In one of the newer medium-density fiberboard plants a single-opening high-frequency press 8 ft wide and 65 ft long has been installed.

It seems to be generally accepted that the use of high frequency shortens the press cycle and thus increases the output of a given press configuration. Capital costs and

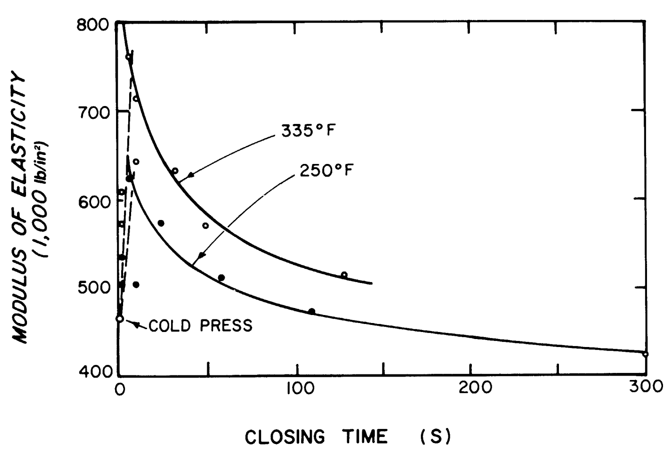
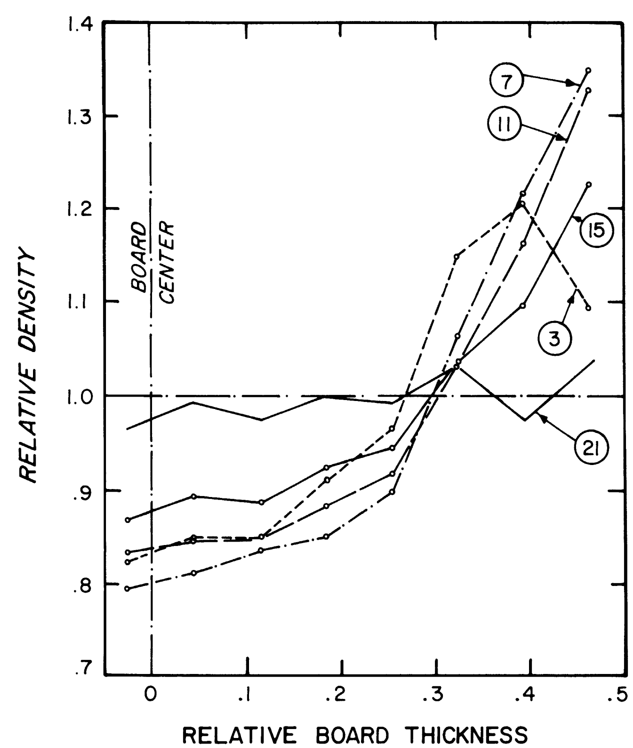


Figure 227—*Relationship between press closing time and modulus of elasticity in bending of experimental medium-density fiberboard pressed at two different platen temperatures (Suchsland and Woodson 1974).*



No.	Prepressure (lb/in²)	Pressure (lb/in²)	Closing time (s)
3	60	240	128
7	60	480	32
11	60	820	10
15	60	1500	2
21		pressed in unheated press	

Figure 228—*Density profiles of ¾-in experimental medium-density fiberboards pressed at a platen temperature of 335 °F. (Suchsland and Woodson 1974).*

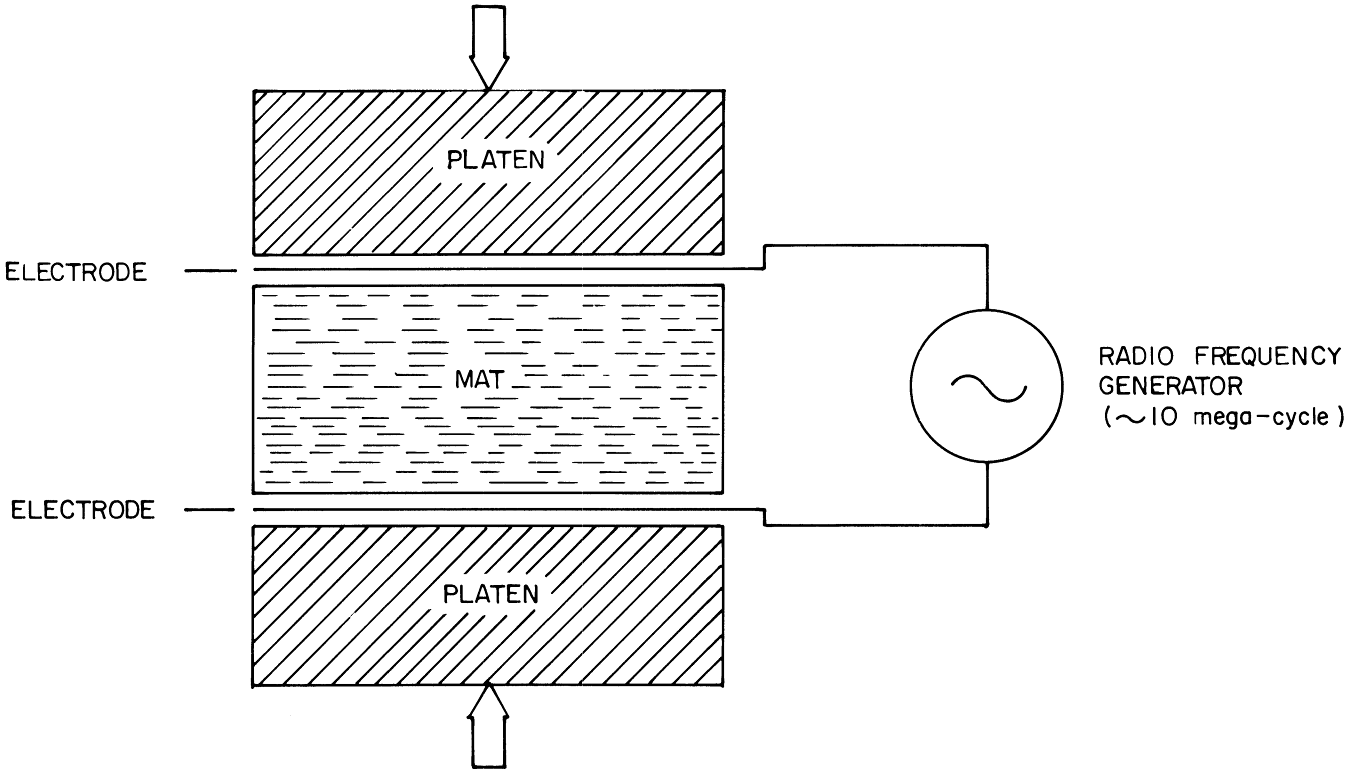


Figure 229—*Principle of radio frequency board press (Suchsland 1978).*

operating costs per unit output are higher than for a press heated with either steam or hot water.

After pressing, boards are cooled, trimmed, cut to size, and sanded.

Manufacture of Dry-Process Fiberboard by the Continuous Mende Process

The Mende process, developed in Germany and introduced in 1971, is an attempt to produce thin particle board economically on a small scale. It has had considerable success. By 1976, 50 Mende plants were in operation, 10 of them in the United States and 4 in Canada. Most of these plants are particle board plants, but the machine can handle fibers as well. One of the U.S. installations, Louisiana Pacific, at Oroville, CA, is a fiberboard plant.

The heart of the Mende process is the **continuous press,** which consists of a large-diameter (10 ft) heated and rotating drum against which the mat is pressed by a steel band. After less than one full revolution of the drum the continuous board leaves the press and is cut to size.

Figure 230 is a schematic flow chart of a Mende particle board plant. The press is shown in greater detail in figure 231.

As the steel band carrying the mat approaches the press section, it is heated from below by infrared heaters, which elevate the temperature of the steel band to about 250 °F. Pressure is first applied as the mat passes between entrance roll and press drum (fig. 232). Both of these elements are oil heated to a temperature of 355 °F. The temperature at the press drum surface is about 300 °F. Between entrance roll and heated return roll, additional infrared heaters are installed to maintain the temperature of the steel band.

Between return roll and heating drum, the pressure on the mat reaches a maximum. This pressure depends on the tension of the steel band, which can be controlled by adjusting the tension roll. As the band bends around the heating drum, it passes two more infrared heaters and two unheated pressure rolls, which press the mat to the final board thicknesseses.

As the band turns around the drive roll, the board is fully cured and is returned in the reverse direction over the forming station. The temperature of the board as it leaves the heating drum is 230 °F.

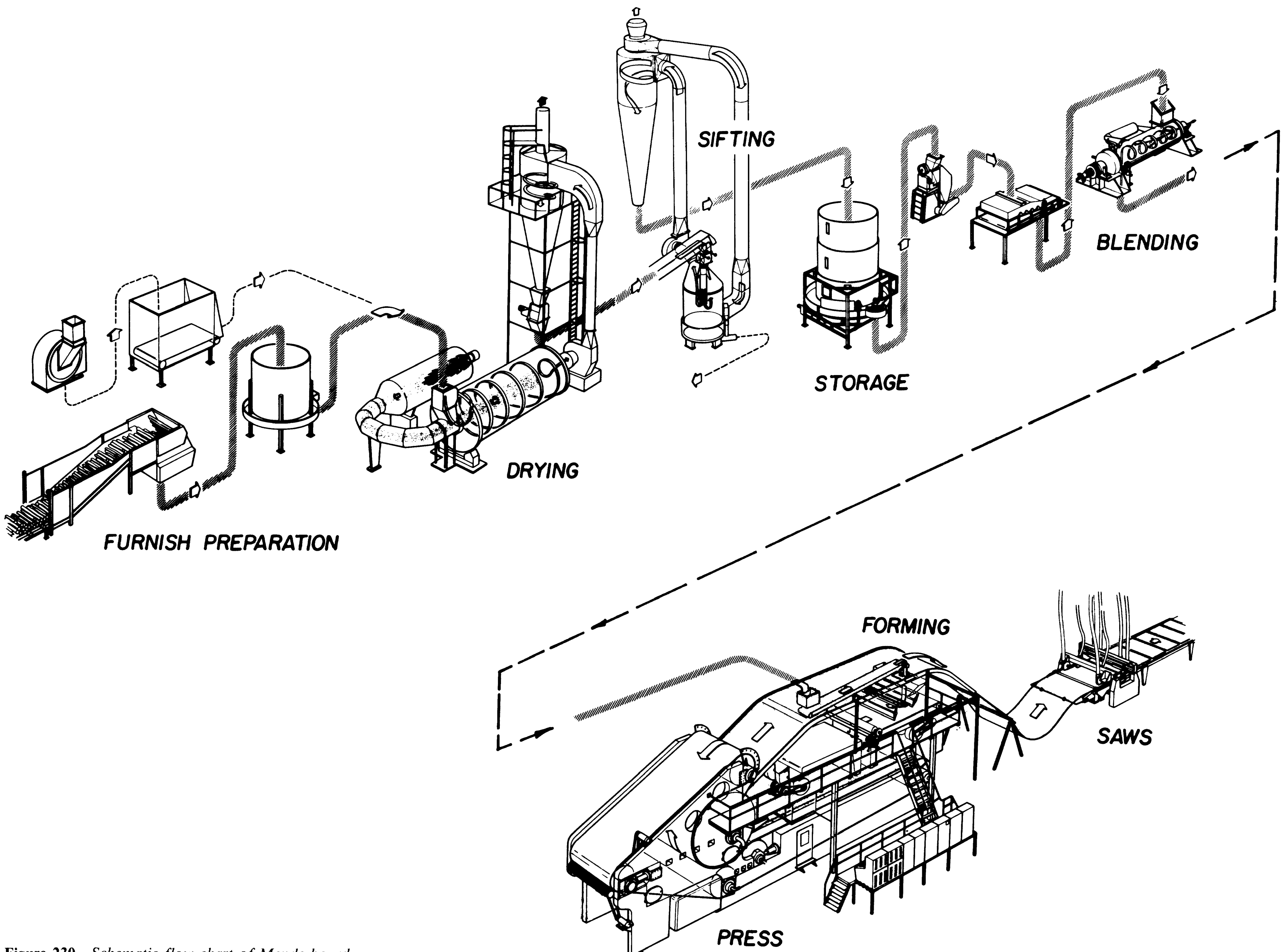


Figure 230—*Schematic flow chart of Mende board plant (Bison Werke).*

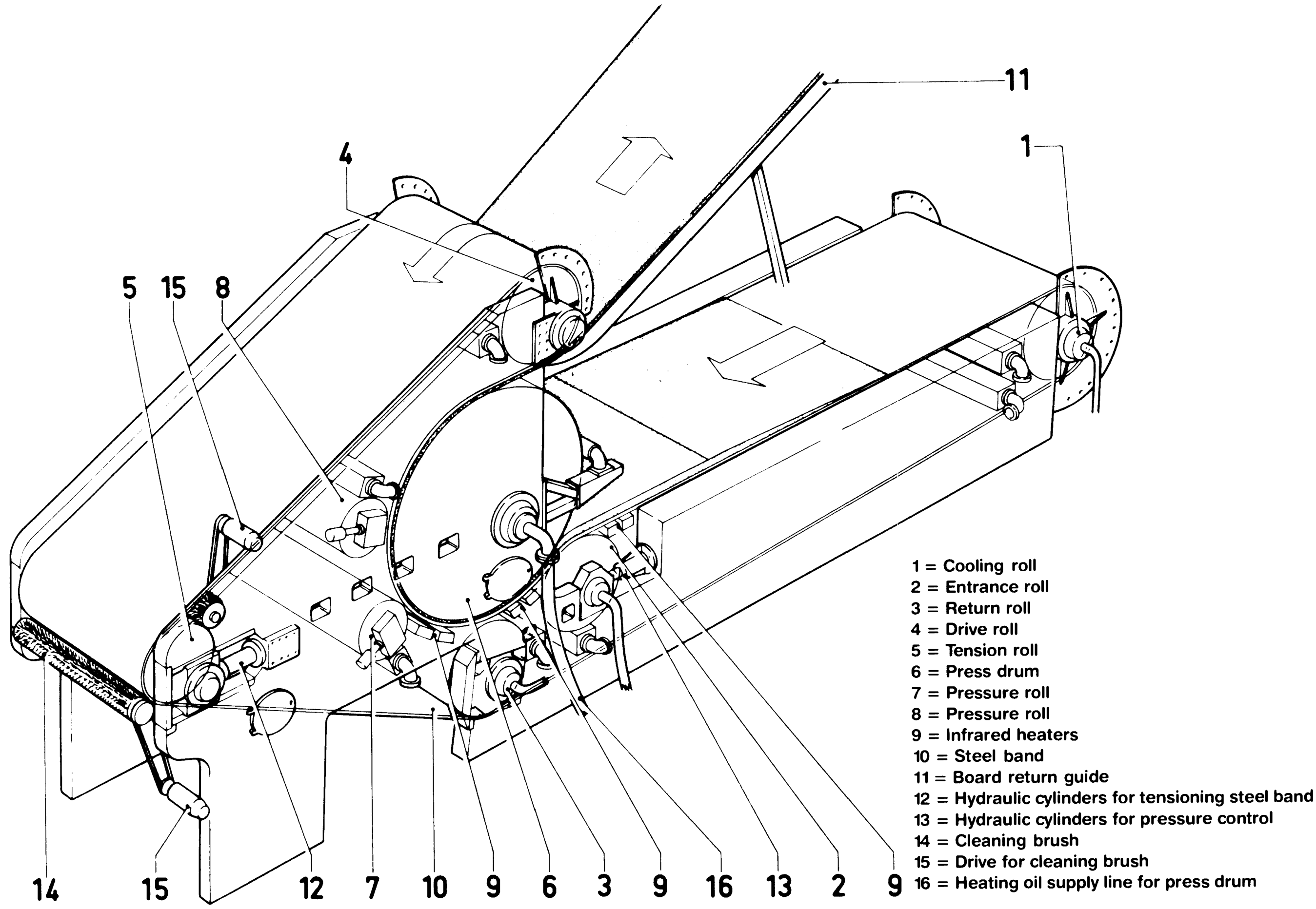


Figure 231—*Continuous Mende press (Bison Werke).*

Because the heating drum is in direct contact with the mat and therefore forms the surface, the protection of the drum surface from scoring is very important. Several rotating brushes clean both drum and steel band. The steel band returns to the forming station via a water cooled roll, which reduces its temperature to about 150 to 160 °F. This is necessary to prevent the resin from curing before the mat enters the press section.

The heating oil recirculates through the boiler, where it is heated either by gas or other fuels. Temperature of each drum can be controlled separately. The boiler produces 4 to 8 million Btu. Table 28 shows the line speed for various board thicknesses.

To modify the process for manufacture of fiberboard requires the installation of a vacuum former, the replacement of the steel band by a wire screen, and the addition of a band prepress. Handling, drying, and blending equipment would be similar to that used in other dry processes (fig. 233).

Table 28—*Relationship between board thickness and line speed of Mende continuous board process (Bison Werke)*

Board thickness		Line speed	
mm	in	m/min	ft/min
3.0	0.118	15.0	49.2
3.2	.126	14.0	45.9
4.2	.165	10.7	35.1
4.8	.189	9.4	30.8
5.6	.220	8.0	26.2
6.3	.248	7.0	22.9

Manufacture of Board With Oriented Fibers

The remarkable strength properties of solid wood in the direction of the tree axis are due to the parallel alignment of the wood cells in that direction. This is offset by much lower strength and considerable swelling and shrinking perpendicular to the fiber direction.

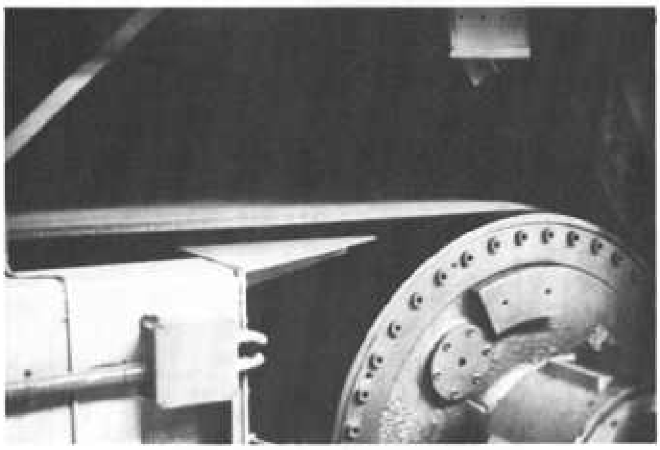


Figure 232—*Mat on steel band entering nip between entrance roll and press drum (Bison Werke).*

The manufacture of plywood, particle board, and fiberboard all stems from efforts to randomize wood properties and equalize them in all directions in the plane of the board. This randomization, however, sacrifices part of the strength associated with aligned fibers.

Attempts to reassemble particles or fibers in configurations similar to those in solid wood are obvious extensions of composition board technology. Mechanical orientation of appropriately elongated particles has reached commercial application (Elmendorf 1965, Snodgrass and others 1973). The much smaller fibers and fiber bundles used in dry-formed fiberboard respond better to aligning forces developed in an electric field. In a uniform electric field, charges present in a fiber separate very minutely, causing the fiber to act like a dipole (fig. 234). The force couple acting on the dipole developes a torque tending to rotate the fiber to a position with its axis parallel to the electric field. The torque is largest at $\Theta = 45°$. At larger angles the induced charge separation does not occur in the direction of the dipole axis, and at smaller angles the moment arm diminishes (fig. 235).

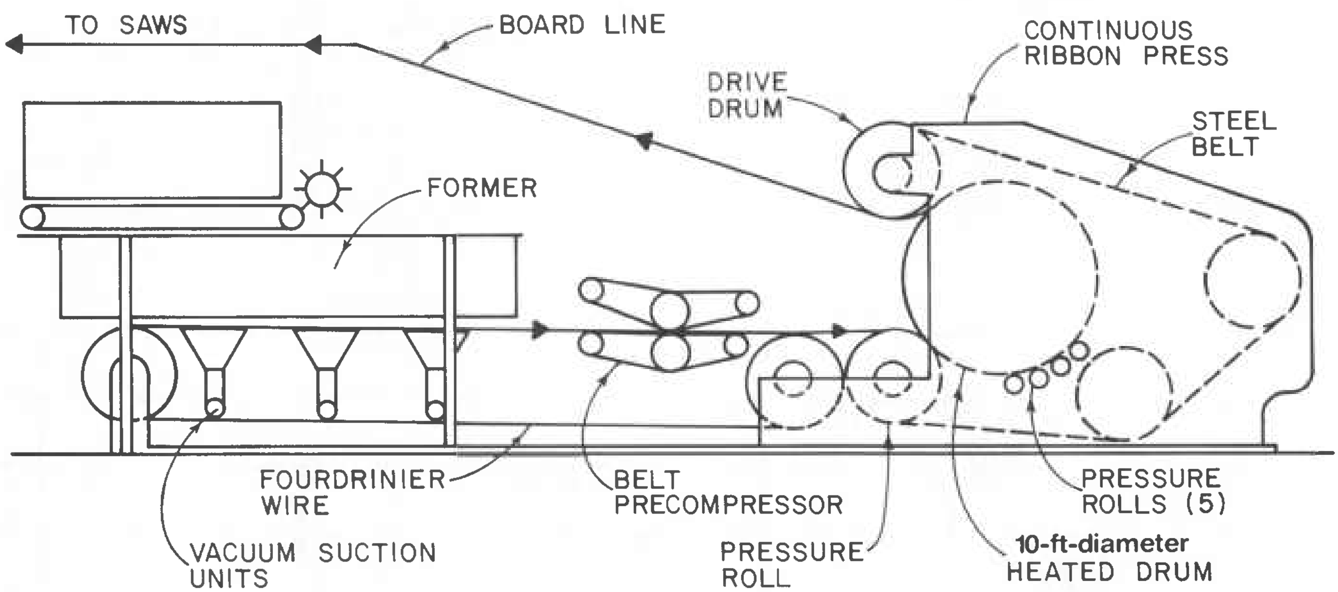


Figure 233—*Mende continuous press set up to press fiber mat (Wentworth 1971). Mat formed in former travels from left to right through precompressor and is then forced around heated drum by steel belt and pressure rolls.*

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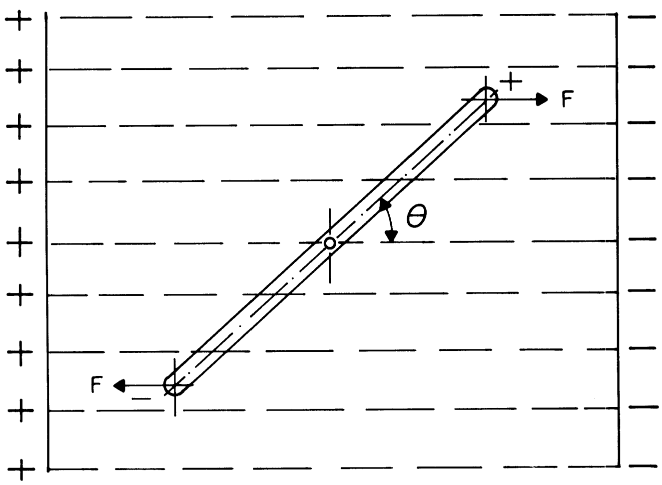

Figure 234—*Forces on dipole in electric field. Change shown on dipole end is net result of minute charge separations occuring throughout the dipole.*

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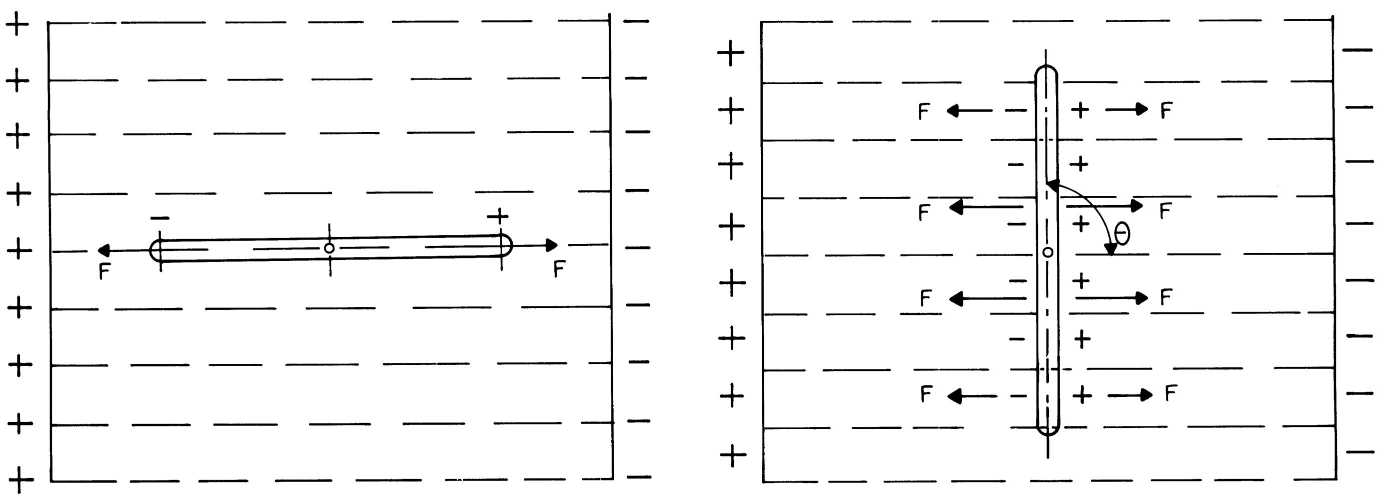

Figure 235—*Absence of torque on dipole at angles $\theta = 0°$ and $\theta = 90°$.*

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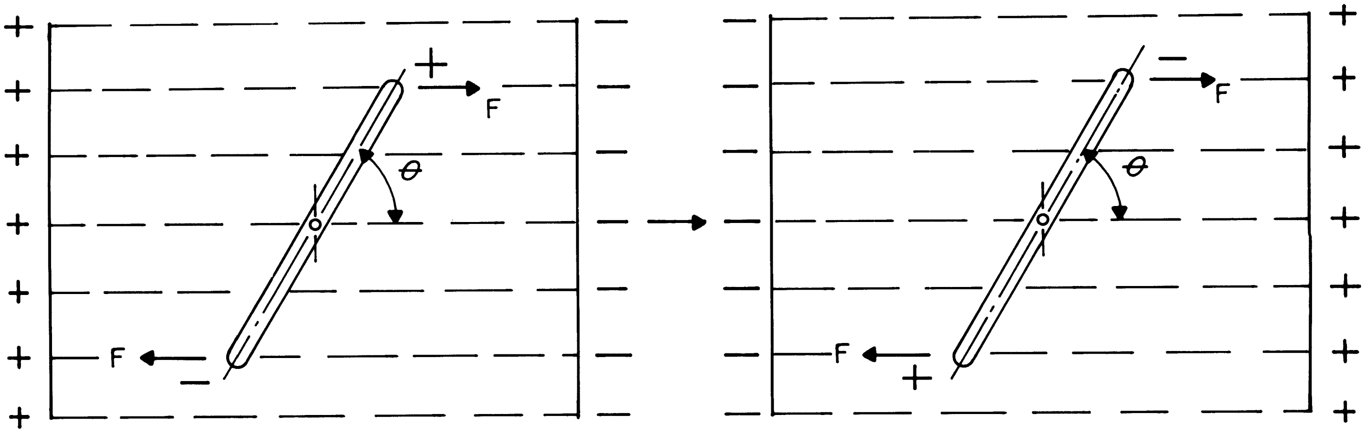


Figure 236—*Dipole in AC electric field. Time between reversal of polarity of field allows reversal of charge separation on dipole so that aligning forces always point in the same direction.*

An alternating field has a similar aligning effect as long as the frequency is low enough to allow a reversal of the charge separation, before the polarity of the field changes again. Figure 236 shows the same direction of the aligning torque at two different polarities of the field. Figure 237 indicates that frequencies of less than 100 cycles/s are most effective. Other important variables are the geometry of the particle or fiber, the moisture content, and the strength of the field.

Talbott and Logan (1974) describe a forming machine suitable for the orientation of fibers (fig. 238). The resin-coated fibers, having a moisture content of 9 to 15 percent, fall through a series of closely spaced vibrating strings to enter the 60-cycle electric field of 1,500 to 3,750 V/in, which substantially aligns the descending fibers. The air-fiber mixture moves through the field at about 50 to 100 ft/min. At the bottom of the forming box the fibers are filtered out of the air stream by a screen.

Properties of experimental dry-formed aligned fiberboards are shown in figure 239.

Industrial application of this method would benefit siding products (reduced linear expansion in the long dimension of the product) and might encourage the use of fiberboard in structural applications.

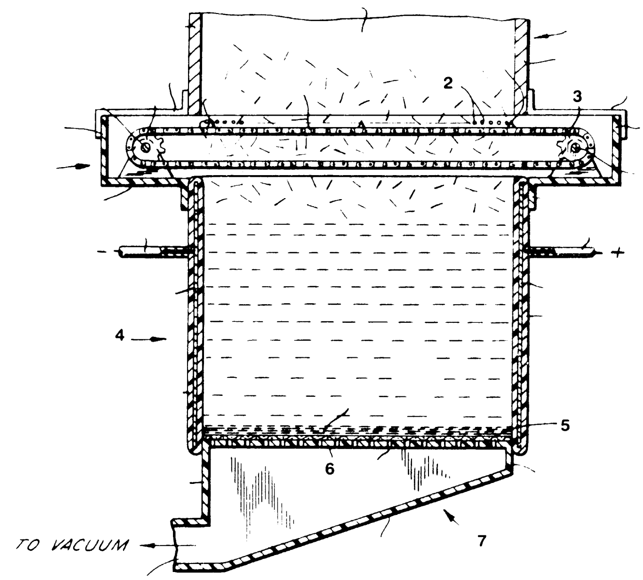


Figure 238—*Patent drawing of forming machine providing parallel alignment of fibers in mat (Talbott and Logan 1974).*

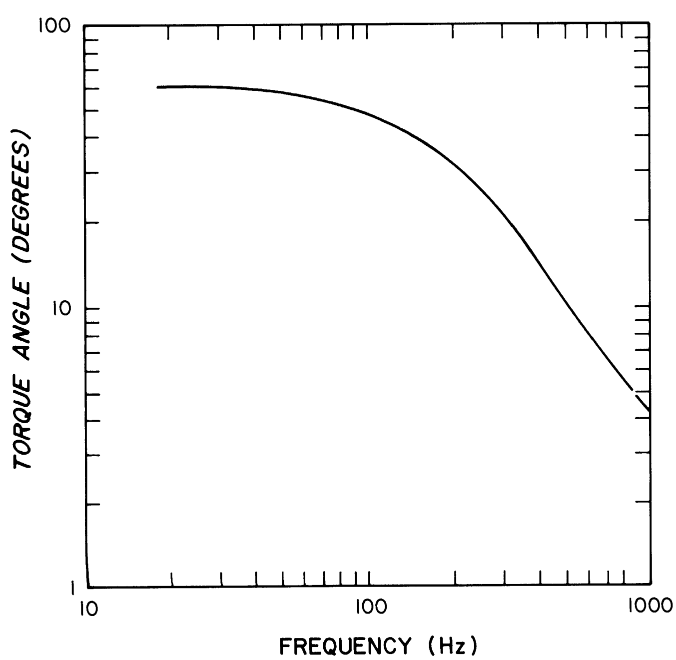


Figure 237—*Frequency response of torque on a wood particle (Talbott and Stefanakos 1972).*

References

Anonymous. Proceedings, world consultation on wood based panels; 1975 February; New Delhi. Brussels: Miller Freeman Publications; 1976: 311-382. Section V.

Betzner, W.; Wallace, B. Computer control in a dry-formed fiberboard process. Forest Products Journal. 30(7):30-34; 1980.

Bison Werke. Promotional literature. Springe, Germany.

Buikat, E.R. Operating problems with dryers and potential solutions. In: Maloney, T.M., ed. Proceedings, 5th particleboard symposium; 1971 March; Pullman, WA. Pullman: Washington State University; 1971: 209-216.

Carlson, B. Die Erzeugung mitteldichter Faserplatten-MDF. Holz als Roh- und Werkstoff. 36(2): 49-52; 1978.

Chapman, K.M. Improved uniformity in medium density fiberboard. In: Maloney, T. M., ed. Proceedings, 13th particleboard symposium; 1979 March; Pullman, WA. Pullman: Washington State University; 1979: 237-253.

Chryst, J.R.; Rudman, D.W. Considerations in conversion of a particle board plant to medium density fiberboard. In: Maloney, T.M. ed. Proceedings, 13th Particleboard symposium; 1979 March; Pullman, WA. Pullman: Washington State University; 1979: 223-236.

Elmendorf, A. Oriented strand board. U.S. patent 3,164,511. 1965 January 5.

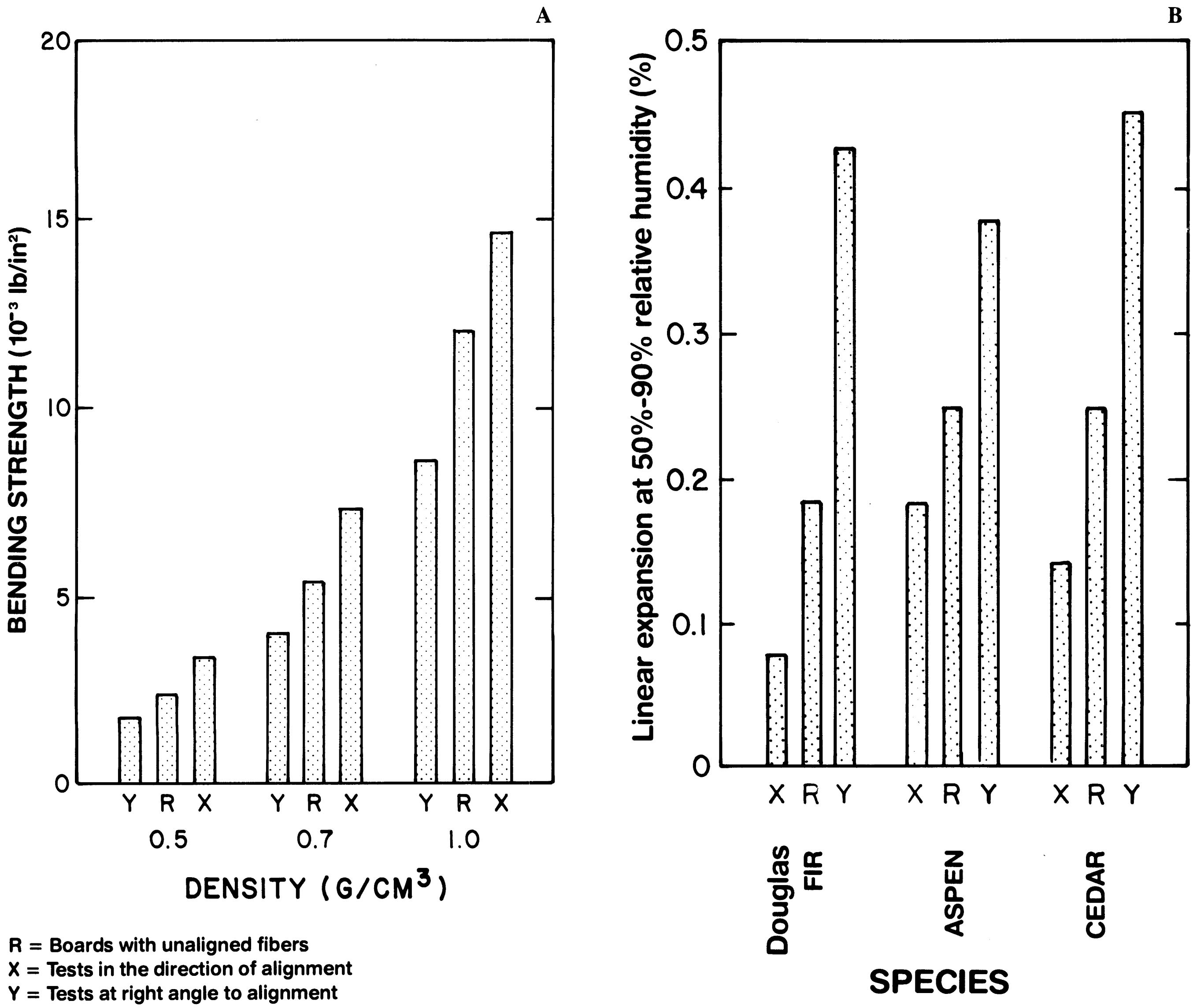


Figure 239A—*Effect of fiber alignment on bending strength of fiberboard at three density levels (three species averaged) (Talbott 1974).* **B**—*Effect of fiber alignment on linear expansion of fiberboard made from three different species (Talbott 1974).*

Engels, K. Latest European developments in blending. In: Maloney, T.M., ed. Proceedings, 12th particleboard symposium; 1978 March; Pullman, WA. Pullman: Washington State University; 1978: 317-360.

Evans, H.R. Air felting formation for the manufacture of hardboard. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard, and particleboard; 1957, Vol. III, paper 5.8. Rome: FAO; 1958. 300 p.

Haylock, O.F., Medium density fiberboard in New Zealand. In: Maloney, T.M., ed. Proceedings, 11th particleboard symposium; 1977 March; Pullman, WA. Pullman: Washington State University; 1977: 157-178.

Junge, D.C. Analysis of emission control strategies for wood particle and fiber dryers. In: Maloney, T.M., ed. Proceedings, 11th particleboard symposium; 1977 March; Pullman, WA. Pullman: Washington State University; 1977: 199-230.

Knapp, H.J. Continuous blending, 1948-1971. In: Maloney, T.M., ed. Proceedings, 5th particleboard symposium: 1971 March; Pullman, WA. Pullman: Washington State University; 1971:45-56.

Kumar, V.B. Untersuchungen uber die Dickenschwankungen bei Holzfaserplatten. Holz als Roh- und Werkstoff. 16(10): 371-377; 1958.

Lampert, H. Faserplatten. Leipzig: VEB Fachbuchverlag; 1967. 453 p.

M-E-C Co.: Neodesha, KA.

Nagy, V. Erkenntnisse und Erfahrungen auf dem Gebiet der Herstellung zweiseitig glatter Faserplatten nach dem Trockenverfahren ohne zusatzliche Bindemittel in der CSSR. Holztechnologie. 5(3): 217-225; 1963.

Pecina, H., Der Einfluss einiger technologischer Parameter auf die Bindung lignozelluloser Fasern untereinander. Holztechnologie. 21(3): 147-153; 1980.

Peters, T.E. The vacuum former. In: Maloney, T.M., ed. Proceedings, 2nd particleboard symposium: 1968 March; Pullman, WA. Pullman: Washington State University; 1968: 375-384.

Raddin, H.A.; Brooks, S.H.W. Method of making fiberboard. U.S. patent 3,207,819. 1965 September 21.

Rausendorf, D. Technologie des Trockenverfahrens zur Herstellung von Faserhartplatten und seine Entwicklung in Japan. Holz als Roh-Werkstoff. 21(6): 210-217; 1963.

Robinson, J.G. Dry process hardboard. Forest Products Journal. 9(7): 11A-14A; 1959.

Rydholm, S.A. Pulping processes. New York: Interscience Publishers; 1965. 1269 p.

Sandermann, W; Kunnemeyer, O. Uber Trocken- und Halbtrocken Faserplatten. Holz als Roh-und Werkstoff. 15(1): 12-18; 1957.

Snodgrass, J.D.; Saunders, R.J.; Syska, A.D. Particle board of aligned wood strands. In: Maloney, T.M., ed. Proceedings, 7th particleboard symposium: 1973 March; Pullman, WA. Pullman: Washington State University; 1973: 415-448.

Spalt, H.A. Chemical changes in wood associated with wood fiberboard manufacture. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, D.C.: American Chemical Society; 1977: 193-219.

Suchsland, O. Medium-density fiberboard production possibilities in the Tennessee Valley region. TVA Technical Note B29. Norris, TN: Tennessee Valley Authority, Division of Forestry, Fisheries and Wildlife Department; 1978. 173 p.

Suchsland, O.; Woodson, G.E. Effect of press cycle variables on density gradient of medium-density fiberboard. In: Maloney, T.M., ed. Proceedings, 8th particleboard symposium: 1974 March; Pullman, WA. Pullman: Washington State University; 1974: 375-398.

Swiderski, J. Vergleich der Verfahren zur Herstellung von Hartplatten. Nass-, Halbtrocken- und Trockenverfahren. Holz als Roh- und Werstoff. 21(6): 217-225; 1963.

Talbott, J.W. Electrically aligned particle board and fiberboard. In: Maloney, T.M., ed. Proceedings, 8th particleboard symposium: 1974 March; Pullman, WA. Pullman,WA: Washington State University; 1974: 153-182.

Talbott, J.W.; Logan, J.D. Method for forming boards from particles. U.S. patent. 3,843,756. 1974 October 22. 8 p.

Talbott, JW.; Stefanakos, E.K. Aligning forces on wood particles in an electric field. Wood and Fiber. 4(3): 193-203; 1972.

Ushmann, C. Fiber mat forming apparatus and methods. U.S. patent 2,743,758. 1956 May 1. 14 p.

Wentworth, I. Unpublished data.

Wentworth, I. Production of thin particle board in a continuous ribbon. In: Maloney, T.M., ed. Proceedings, 5th particleboard symposium: 1971 March; Pullman, WA. Pullman: Washington State University; 1971: 59-70.

Wood, D.E. Pneumatic web formation and the Rando-Wood medium-density fiberboard former. In: Maloney, T.M., ed. Proceedings, 10th particleboard symposium: 1976 March; Pullman, WA. Pullman: Washington State University; 1976: 161-174.

10. Heat Treatment, Tempering, and Humidification

General

Heat treatment and **tempering** are optional processing steps that follow the hotpress. They are used only in the manufacture of thin medium- and high-density fiberboards. Insulation board, thick MDF, and particle board are not heat treated or tempered.

Heat treatment is the exposure of pressed fiberboard to dry heat. Tempering is the heat treatment of pressed board, preceded by addition of drying oils. The major function of the heat treatments is to improve dimensional stability and to enhance some important mechanical board properties.

Humidification of fiberboard is the addition of water to bring the board moisture content into equilibrium with air conditions expected in service. Where heat treatment or tempering is used, humidification immediately follows those treatments.

In general, heat treating and tempering are more effective on wet-formed than on dry-formed board. Heat-treated boards and particularly tempered boards are substantially more expensive than untreated boards.

Improvement of Board Properties

Dimensional stabilization

Dimensional change in wood products from adsorption and desorption of water in the cell wall is an important hazard, particularly in high-density products. This follows because the volumetric expansion of wood approximately equals the volume of water adsorbed by the cell walls. As wood is densified by reducing the pore volume, the same amount of water will still be adsorbed under a given exposure condition (unless, of course, the hygroscopicity of the cell wall has been modified in the process), resulting in a greater relative volumetric expansion.

This is illustrated in figure 240, where 1 cm^3 of cell wall substance (specific gravity = 1.46) at 100 percent relative humidity adsorbs 28 percent of its weight in water (1.46 x 0.28 = 0.40 g). This is the maximum amount of water the cell wall can adsorb. Additional water uptake would fill the pore volume without further swelling. The expansion of the cell wall by 0.40 cm^3 results in different relative volumetric expansion values, depending upon the

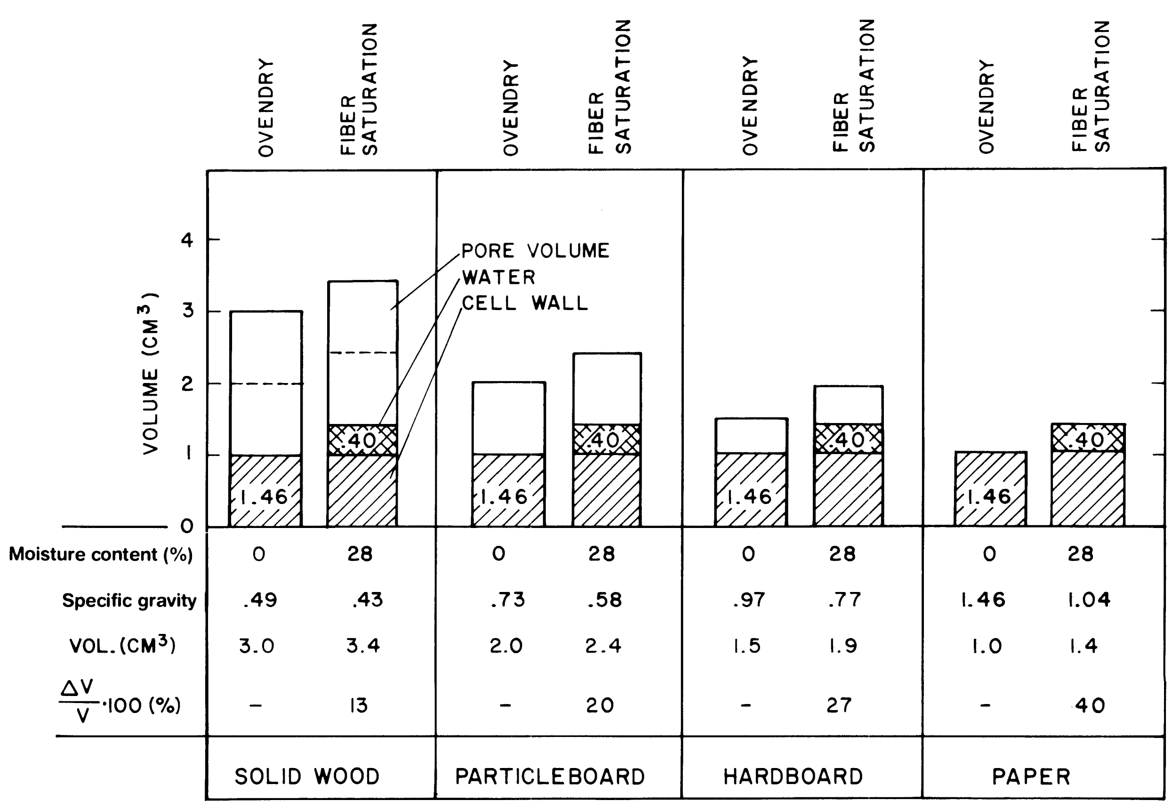


Figure 240— *Relationship between specific gravity and volumetric swelling of solid wood and densified wood products.*

total volume (cell wall plus pore volume) of the product. In the case of solid wood with a specific gravity of 0.49 (1 part cell wall, 2 parts pore volume) the volumetric expansion is 13 percent; in the case of hardboard with a specific gravity of 0.97 (1 part cell wall, ½ part pore volume), it would be 27 percent; and in the case of a paper with no pore volume at all, the volumetric expansion would be 40 percent.

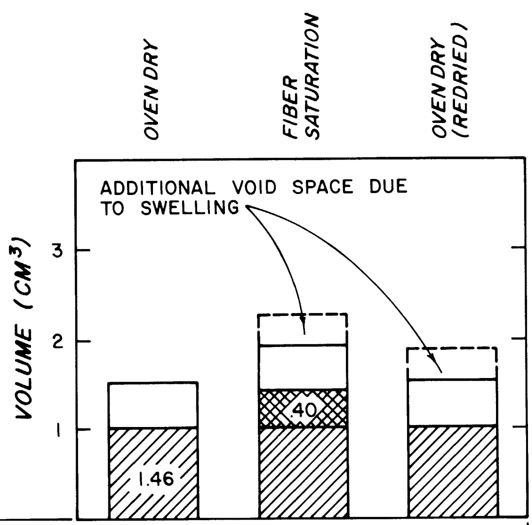
Densified products, generally, swell in the direction of densification, which in fiberboard is in the direction of board thickness. Swelling in the plane of the board is very small, due to a mutual restraint of the "cross-laminated" fibers.

In addition to the increased relative expansion resulting from the reduction of pore volume, densification causes another swelling component called springback. It is due to swelling forces causing partial failures of bonds between fibers, which in turn creates additional void space. Part or all of this additional void space created during the swelling process is permanent and will not disappear upon redrying of the board (fig. 241). This adds substantially to the swelling of densified board such as particle board and hardboard and is often accompanied by a permanent strength reduction (fig. 242).

Heat treatment improves this behavior in two ways; it reduces the water adsorption by the cell wall, and it improves the bond between fibers, which in turn helps resist the creation of voids during swelling. Figure 243 shows the reduction of the permanent thickness swelling (springback) after heat treatment at various temperatures and for various times. See also figure 244.

The **linear expansion**—that is, changes in dimension in the plane of the board that occur because of change in moisture content—and its modification by heat treatment are more complicated. Figure 245 (Klinga and Back 1964) shows the linear changes of a wet-process hardboard exposed to a sequence of relative humidity cycles before and after a 2½-h heat treatment at 190 °C (375 °F). There is a net contraction of the board dimensions as a result of the heat treatment, and the dimensional changes between 30 percent and 100 percent relative humidity exposure have increased somewhat, but the component corresponding to the 65 percent to 100 percent relative humidity interval has been reduced.

The demonstrated heat stabilization has found several explanations. A theory attributing it to a cross-linking reaction between hydroxl groups on adjacent cellulose chains has been disproved (Seborg and others 1953). It is now proposed that initial thermal degradation of wood results in furfural polymers of breakdown



Moisture content (%)	0	28	0
Specific gravity	.97	.65	.80
VOL. (CM³)	1.50	2.33	1.83
$\frac{\Delta V}{V} \cdot 100$ (%)	—	49	22
	HARDBOARD		

Figure 241—*Effect of springback on volumetric swelling of hardboard.*

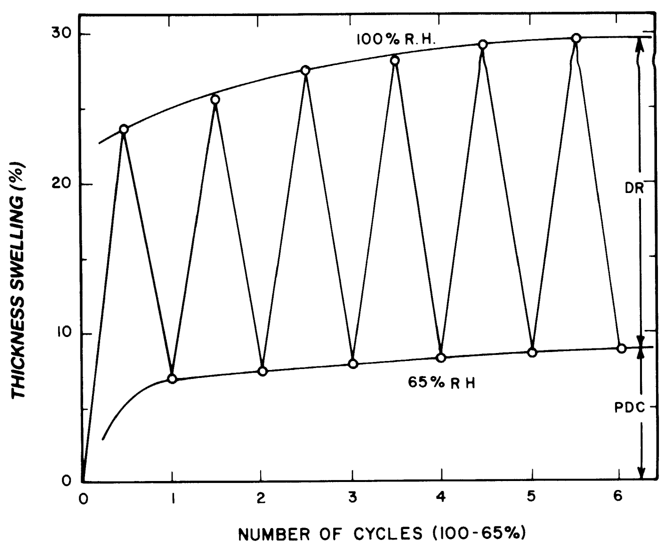


Figure 242—*Dimensional range (DR) and permanent dimensional change (PDC) in thickness swelling of wet-formed hardboard during cyclic exposure. PDC is equivalent to springback (Klinga and Back 1964). RH = relative humidity.*

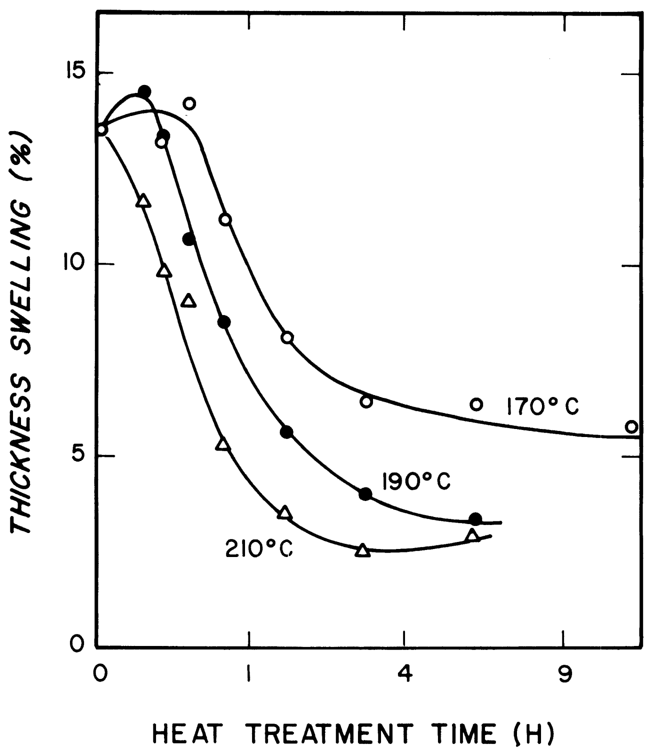


Figure 243 — *Reduction of permanent thickness swelling after heat treatments at various temperatures (after Braun and Strand 1958).*

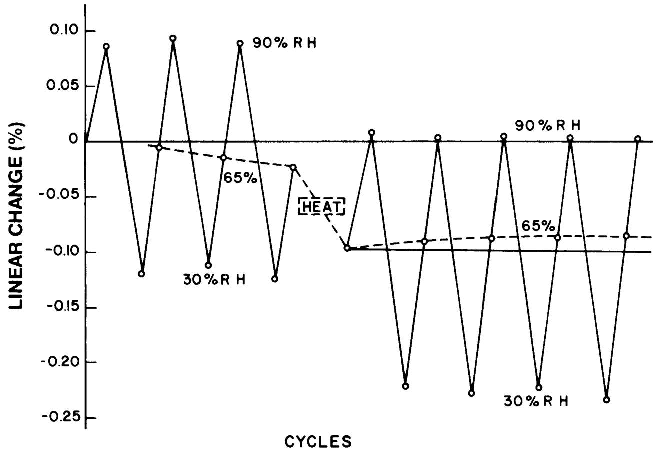


Figure 245—*Linear changes in response to cyclic exposure of 1/8-in hardboard before and after heat treatment at 375 °F for 2½ h (Klinga and Back 1964).*

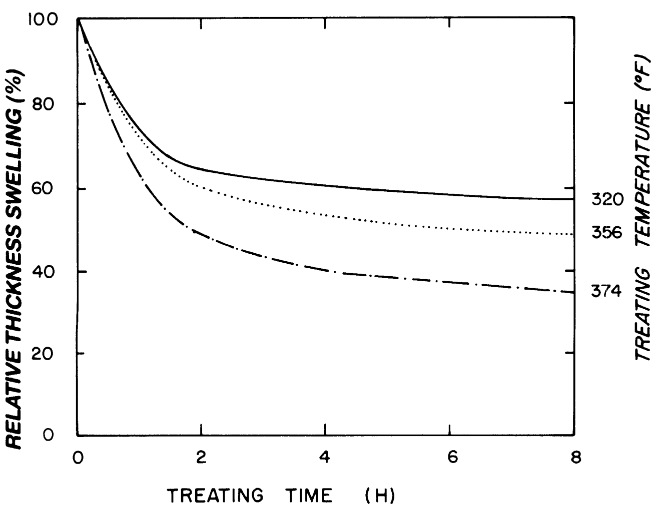


Figure 244—*Reduction of thickness swelling of ⅛-in hardboard after heat treatment at various temperatures (after Braun & Strand 1958).*

sugars, which are less hygroscopic than the hemicellulose from which they are formed (Stamm 1964). Spalt (1977) concludes that wax added to fiberboard furnish is redistributed during the heat treatment to coat all fiber surfaces causing an increase in water repellency. Other theories suggest cross linking between cellulose molecules by acetyl groups as responsible for the reduction of both the total swelling and of the permanent expansion component (Klinga and Back 1964).

The effect of tempering on the dimensional changes is limited because rather small quantities of oil are applied and to the surfaces of the board only. Any reduction in water absorption and improvement of some standard strength properties is largely due to the heat treatment following the application of tempering oil.

Improvement of strength properties

Improvement of the mechanical properties during the heat treatment may be viewed as a continuation of the bonding process started in the hotpress. Figure 246 shows the hypothetical development of fiber bonding in the hotpress and the simultaneous deterioration of the fiber strength. At the end of the press cycle the board has sufficient strength to maintain the target caliper after pressure release. During subsequent heat treatment, bond formation may continue even while fiber strength deteriorates further due to thermal degradation of cell wall components. Strength properties of the board will thus rise until the fiber becomes the weak link in the system. This explains the characteristic relationships between treating

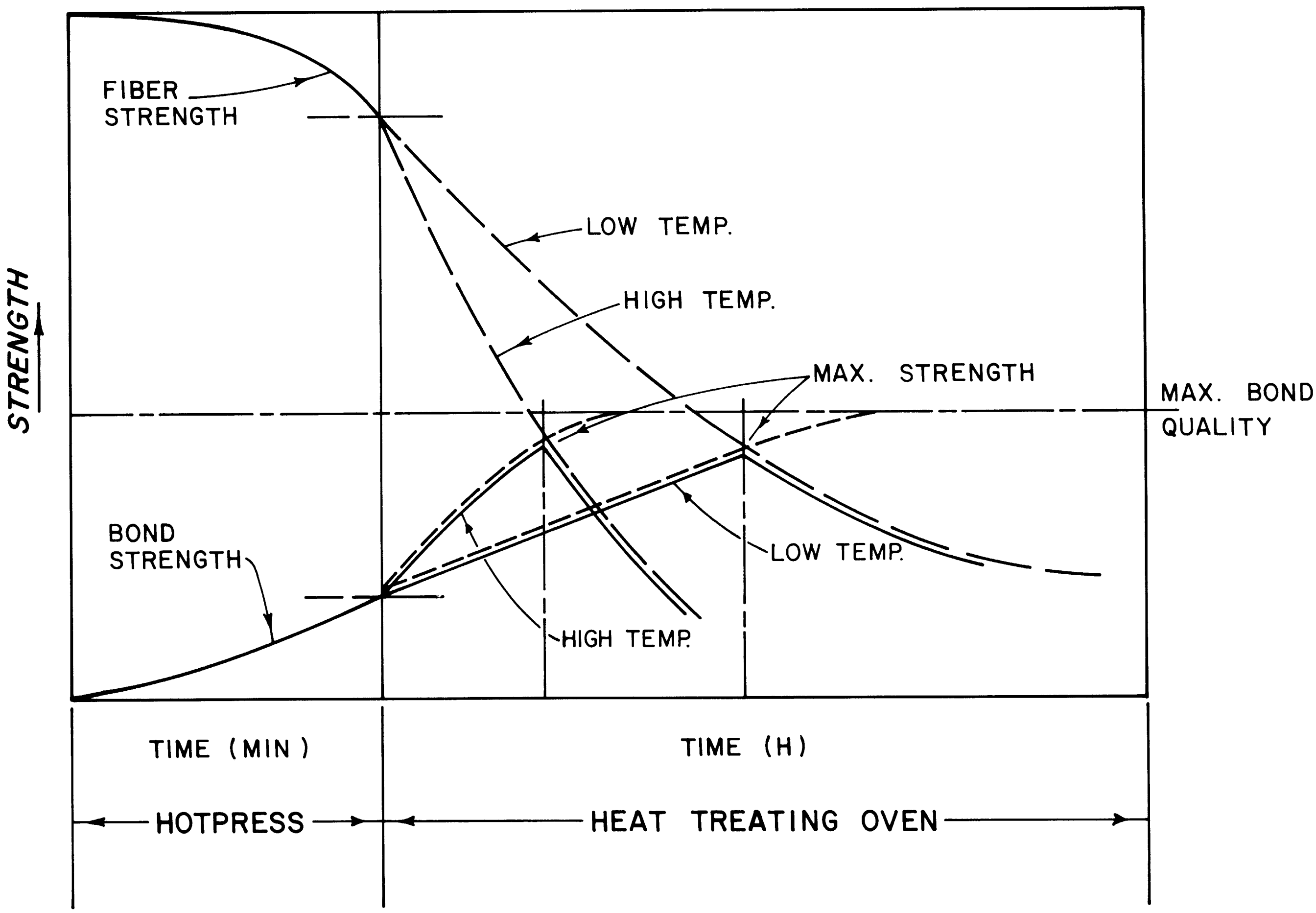


Figure 246—*Hypothetical development of board strength as affected by changing bond strength and fiber strength during pressing and heat treating.*

temperature, heating time, and board strength as illustrated in figures 247 and 248. Figure 249 shows the concurrent weight loss.

Oil tempering contributes little to most strength properties with the exception of bending stiffness and bending strength, properties that are very sensitive to surface quality improvement, particularly where both surfaces are coated, which is the practice in S2S manufacture.

Oil tempering does, however, substantially improve the surface hardness, which is of great importance in the manufacture of premium quality, factory-finished wall panels.

The importance of tempering and heat treatment is reflected in the Commercial Standard for Basic Hardboard (USDC NBS 1982), which recognizes 5 classes of hardboard. Two are designated as tempered hardboard, which here is strictly a quality indicator without specific reference to oil treatment, quantity of oil, and heat-treating conditions (table 29).

Industrial Practices

Although a very large percentage of all hardboard is heat treated, tempering is limited to only those products where its specific benefits are essential. Some mills are so designed that all boards manufactured must go through the heat-treating line. Only a few small mills have no heat-treating facilities at all.

Abitibi and U.S. Gypsum temper about 80 percent of their S2S wet-formed hardboard that is prefinished for use as interior wall paneling. Tempering provides improved paint hold-out; high resistance to abrasion, scratching, and scarring; and generally improved wear

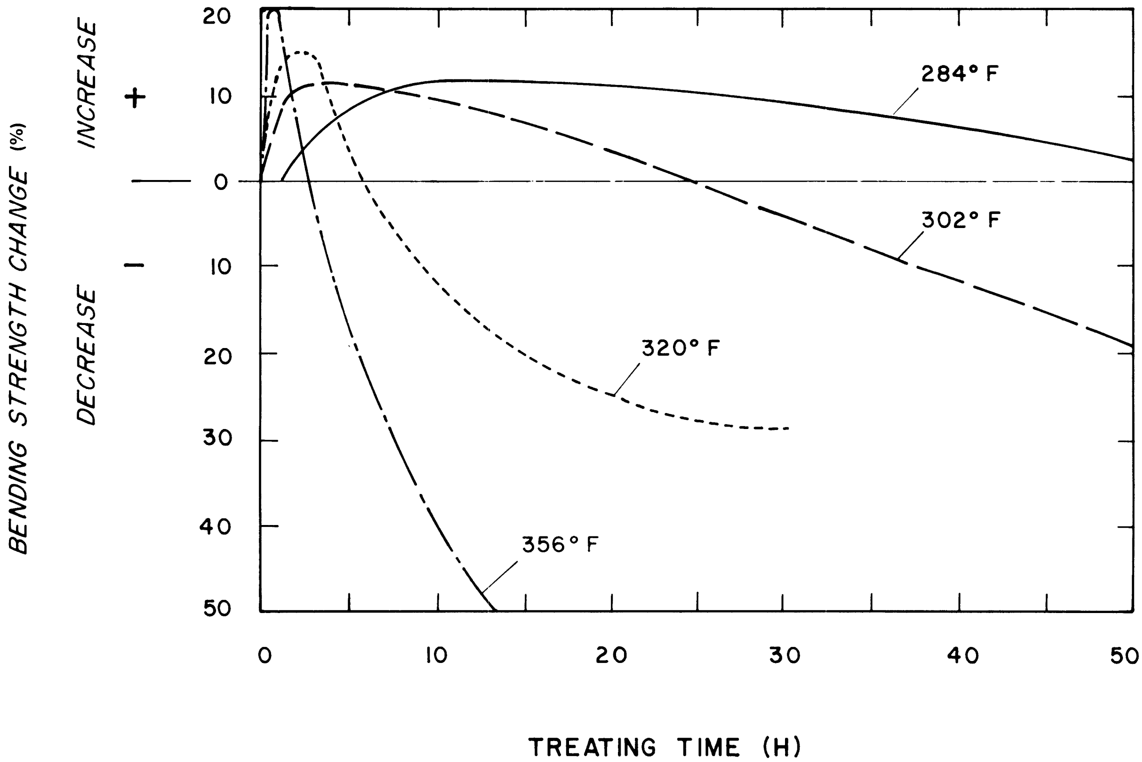


Figure 247—*Bending strength of 1/8-in hardboard as affected by temperature and treating time (Voss 1952).*

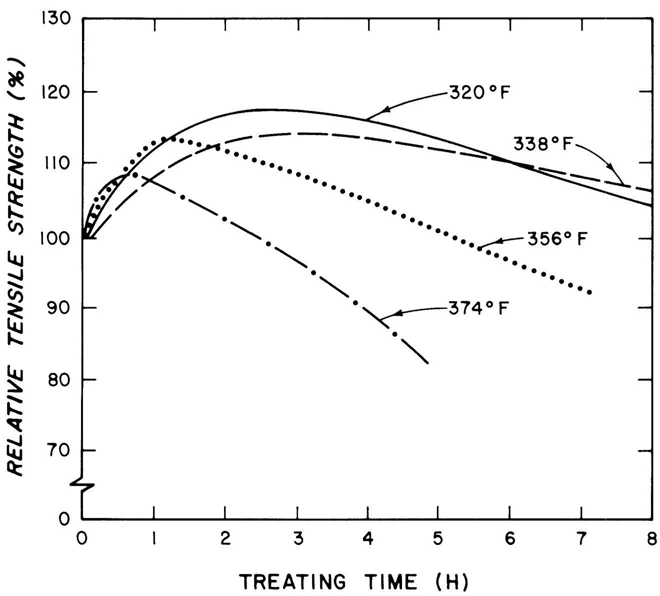


Figure 248—*Tensile strength of 1/8-in hardboard as affected by temperature and treating time (Braun and Strand 1958).*

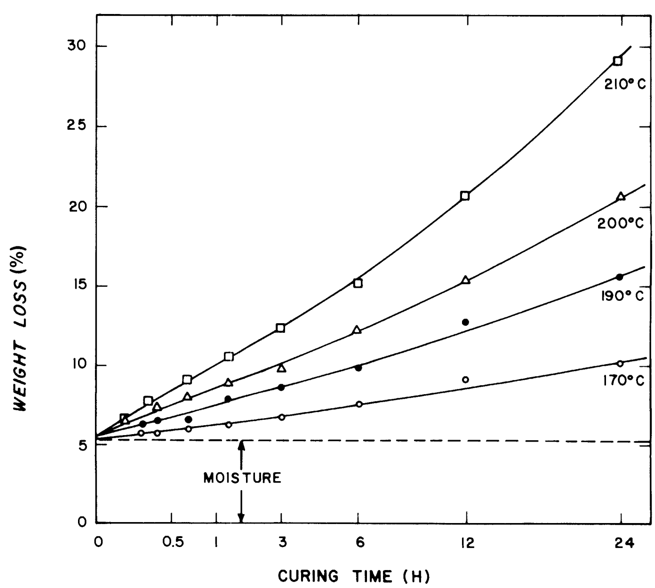


Figure 249 — *Weight loss of 1/8-in hard board as affected by temperature and treating time (after Voss 1952).*

Table 29—*Classification of hardboard by surface finish, thickness, and physical properties (USDC NBS 1982)*

Nominal thickness (in)	Water resistance (max. av./panel)		Modulus of rupture (min. av./ panel) (lb/in²)	Tensile strength (lb/in²) (min. av./panel)	
	Water absorption based on wt (%)	Thickness swelling (%)		Parallel to surface	Perpen-dicular to surface
Class 1—Tempered			6,000	3,000	130
1/12	30	25			
1/10	25	20			
1/8	25	20			
3/16	25	20			
1/4	20	15			
5/16	15	10			
3/8	10	9			
Class 2—Standard			4,500	2,200	90
1/12	40	30			
1/10	35	25			
1/8	35	25			
3/16	35	25			
1/4	25	20			
5/16	20	15			
3/8	15	10			
Class 3—Service-tempered			4,500	2,000	75
1/8	35	30			
3/16	30	30			
1/4	30	25			
3/8	20	15			
Class 4—Service			3,000	1,500	50
1/8	45	35			
3/16	40	35			
1/4	40	30			
3/8	35	25			
7/16	35	25			
1/2	30	20			
5/8	25	20			
11/16	25	20			
3/4	20	15			
13/16	20	15			
7/8	20	15			
1	20	15			
1 1/8	20	15			
Class 5—Industrialite			2,000	1,000	25
1/4	50	30			
3/8	40	25			
7/16	40	25			
1/2	35	25			
5/8	30	20			
11/16	30	20			
3/4	25	20			

Table 29 — *continued*

Nominal thickness (in)	Water resistance (max. av./panel) Water absorption based on wt (%)	Thickness swelling (%)	Modulus of rupture (min. av./panel) (lb/in²)	Tensile strength (lb/in²) (min. av./panel) Parallel to surface	Perpendicular to surface
Class 5—Industrialite			2,000	1,000	25
13/16	25	20			
7/18	25	20			
1	25	20			
1 1/8	25	20			

quality. Tempering also increases surface water resistance, which is very important for hardboard used in shower enclosures, for instance. Most S2S boards are tempered on both surfaces.

A very much smaller percentage of S1S board is tempered. Siding is generally not tempered. Unfinished board, such as is sold to the furniture industry for use as drawer bottoms, furniture backs, and similar applications, is generally not tempered.

Tempering

Oil tempering is an invention patented by the Masonite Corporation, whose aim was to force considerable quantities of oil into pressed hardboard to substantially improve board properties. This was accomplished by soaking the hot boards in heated oils for various periods of time up to a half hour. The most common tempering oil is linseed oil, but soybean oil, tung oil, and tall oil are also used. Synthetic resins are sometimes blended with the oils. Quantities of oil absorbed by soaking are around 6 percent by weight, which for a 4- by 8-ft by 1/8-in board of a density of 62.5 lb/ft^3 would be equivalent to 1.25 lb of oil.

Today, oil is applied to one or both sides of the board, either by ordinary direct roll coaters or in certain cases by precision roll coaters. An ordinary **direct roll coater** consists of a rubber contact roll and a steel doctor roll (fig. 250). The oil is fed into the nip between the two rolls. The amount of oil transferred to the board surface is controlled by the gap between doctor roll and contact roll. As the contact roll transfers the oil to the board surface, it also feeds the board through the machine (fig. 251).

The **precision roll coater** works like an offset printer. A precisely embossed steel roll transfers a measured amount of oil to the rubber contact roll. Precision roll coaters can apply oil in very small quantities, as little as 1½ oz per 4- by 8-ft sheet. Precision roll coaters are used for tempering embossed panels, where they cover only the top of the embossed pattern without applying oil to the low spots.

The oil, applied either by soaking or coating, is oxidized in heating chambers immediately after application. These ovens are used both for baking oil-treated boards and for heat-treating boards without oil treatment.

Other uses of tempering oil includes the addition of drying oil to the furnish as described in chapter 7. The oil serves as in the regular tempering process—it dries by oxidation and forms a thin hard layer on the fiber surfaces, increasing the interfiber bonding. Tempering oil is also used in paper-overlaid hardboard as described in chapter 8. The oil is applied to the back of the printed paper,

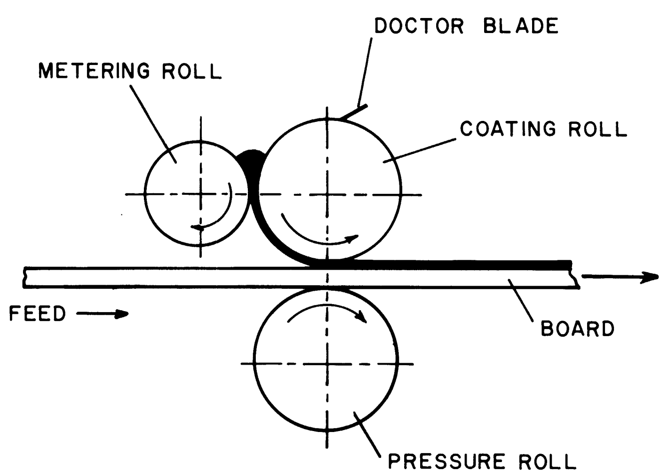


Figure 250—*Principle of direct roll coater.*

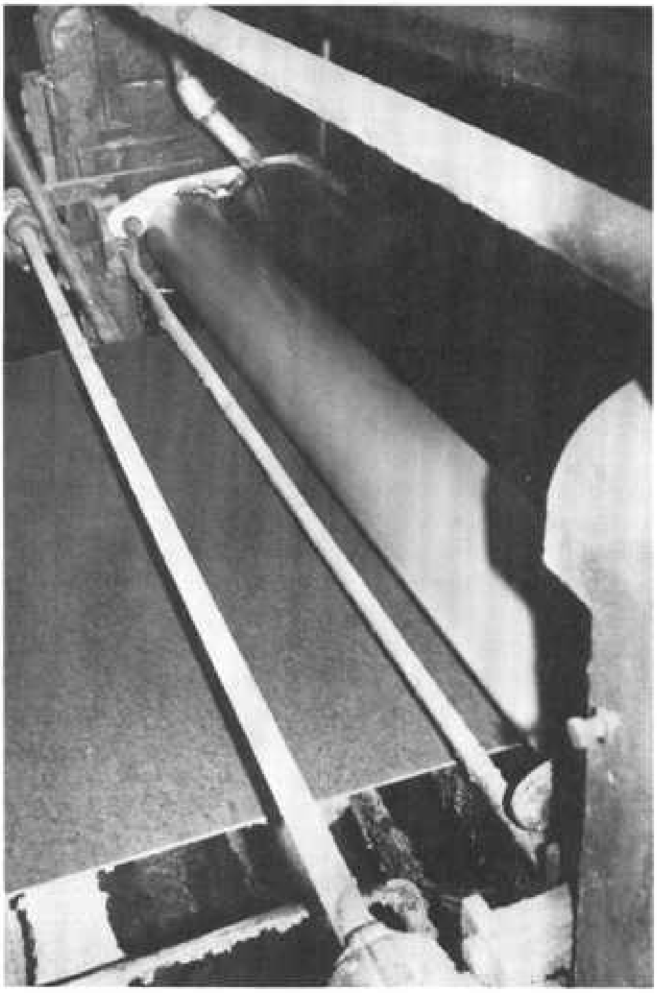


Figure 251—*Application of tempering oil to surface of hardboard by precision direct roll coater.*

which is positioned on the wet mat before pressing. The oil reinforces the paper structure and bonds the paper to the mat.

Heat treating

Heat treating of hardboard, oil treated or not, requires the development of a board temperature of about 300 °F. Close control of temperature and exposure time is critical for two reasons: hardboard and especially the lower density boards can ignite at temperatures of 300 °F and heat treatment causes exothermic reactions in hardboard, particularly in tempered hardboard. These reactions will raise the board temperature above the oven temperature, thereby rapidly increasing the danger of fire.

Hot boards coming directly from the press are air-cooled before entering the heat treatment oven to limit board temperatures to safe levels. Board temperatures are brought up to 300 °F slowly and the heat of reaction is removed from the boards by circulating the air at high velocities (750 to 1000 ft/min).

Heat treatment ovens may be continuous, progressive, or batch type. Continuous ovens provide a means of transporting the boards through the oven at a uniform speed. Boards could be suspended, supported on edge by pickets mounted on endless chains, or they could be moved by roller drives as in insulation board dryers. In the progressive type, or **tunnel oven**, the boards travel on trucks or buggies, positioned either vertically on edge or horizontally, separated by spacers (fig. 252). As one truck enters the oven, another leaves it at the other end. Trucks travel on tracks and are either pushed by hand or moved intermittently by chain or hydraulic drives.

In the batch process, the oven is charged with a certain number of loaded trucks or buggies, and the entire charge is treated together and removed simultaneously. Heat treating times are about 3 h.

Treating ovens can be coupled directly with the press, in which case the capacity and the length of the oven must be designed to accommodate the output of the press continuously without interruption. With in-

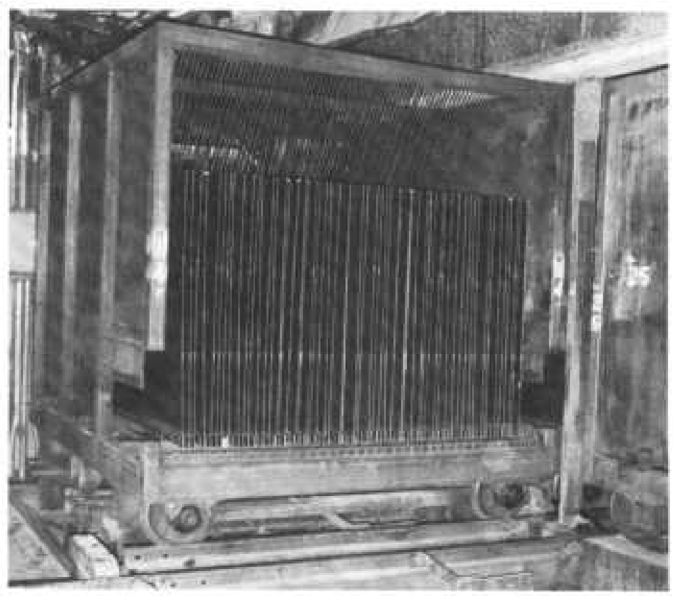


Figure 252—*Buggy loaded with hardboard ready to enter heat treating oven. Boards are standing on edge.*

termediate storage, the heat treating operation can be made independent of the press output.

Heat treating of tempered boards releases volatiles from the oil, which are classed as air pollutants. In some States fume incinerators are mandatory on tempering ovens. This is another reason for limiting oil quantities to surface treatments and to boards that benefit from the specific characteristics of oil treatment.

Heating ovens must be equipped with deluge systems that will flood the boards in the event of a fire. The water spray units are so arranged that the spray is directed into the spaces between boards.

A schematic of a progressive-type heat treatment oven coupled to a humidifier of the same type is shown in figure 253 (Lofgren 1958).

Humidification

Newly pressed hardboard, whether heat treated, tempered, or untreated, has a moisture content of essentially zero percent. In service, hardboard will equilibrate with the surrounding air, which for usual relative humidities would be a moisture content between 3 percent and 10 percent (fig. 254). Such increases in moisture content would cause linear expansion, which might lead to buckling of wall panels or siding, and, if the moisture uptake is abrupt and non-uniform, would result in bowing, twisting, and other distortions. Controlled preconditioning of the board to a moisture content near the midrange of expected service conditions minimizes such difficulties and is therefore standard procedure. The most common types of humidifiers are continuous or progressive-type chambers following, and often integrated with, the treating oven. In a progressive-type humidifier, the boards coming out of the heat treatment chamber remain on the buggies and simply continue through the humidifier (figs. 253, 255). A **wicket-type** humidifier is shown in figure 256.

A humidifier is like a dry kiln operated in reverse: Air of high relative humidity is forced through the stacks of hardboard, where it will give up some of its water vapor to the boards and gain some of the latent heat of vaporization released by the board as the water is being adsorbed (see fig. 257, interval between point *4* and *1*) (Vranizan 1968).Upon leaving the boards, the air is heated as it passes over steam-heated pipes and reaches point *2* on the chart. Moisture is then added by steam

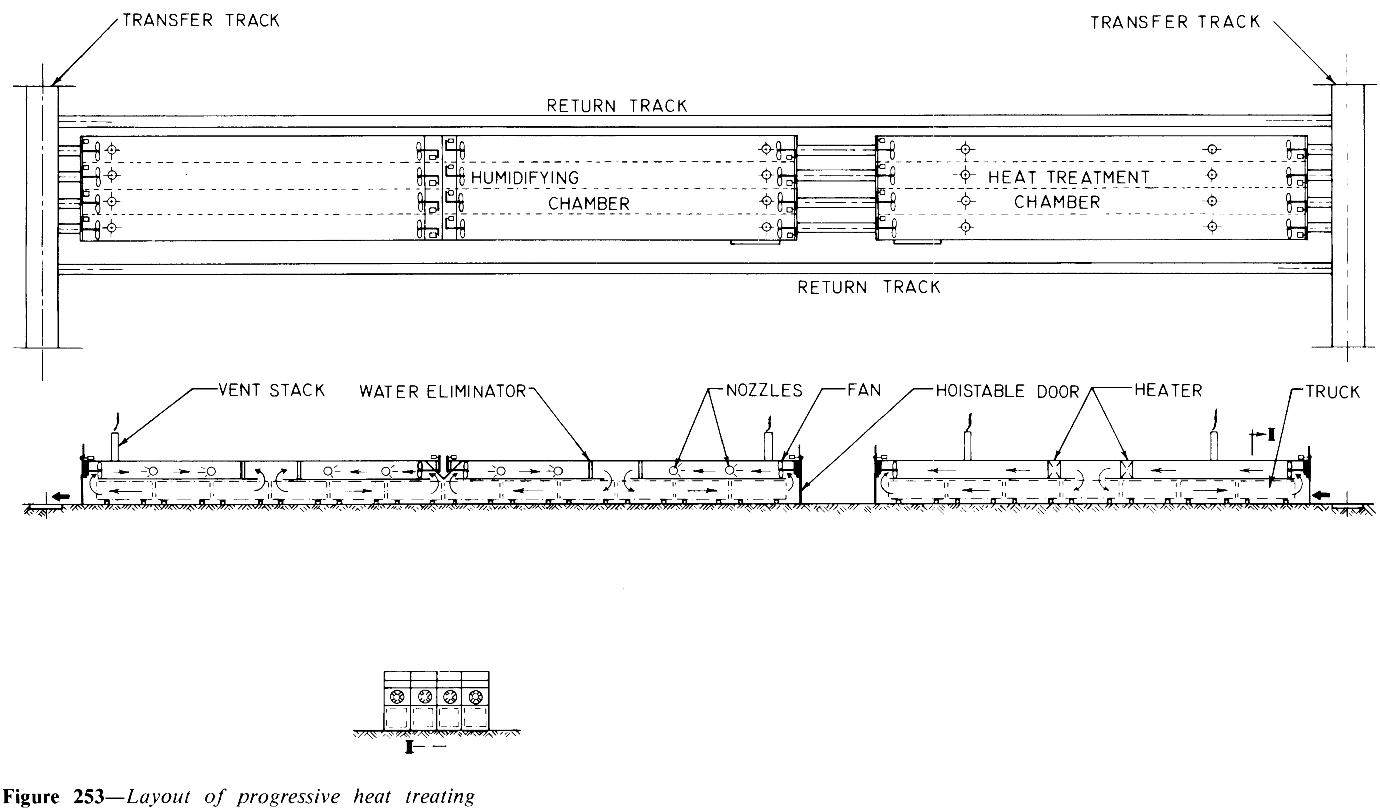


Figure 253—*Layout of progressive heat treating chamber and humidifier in hardboard plant (Lofgren 1957).*

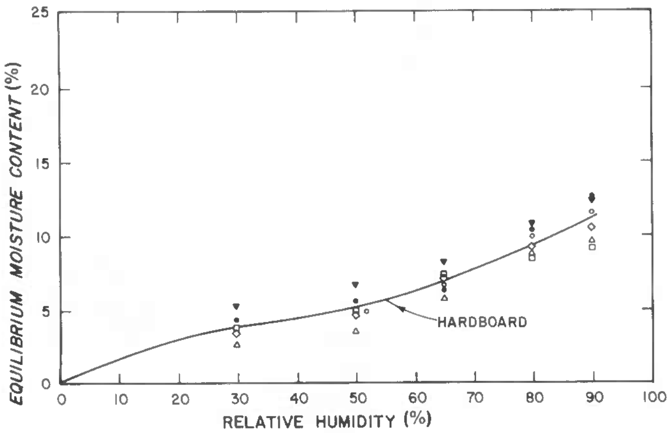


Figure 254—*Equilibrium moisture content of 1/4-in tempered hardboard manufactured by various manufacturers (McNatt 1974).*

Figure 255—*Hardboard being unloaded from buggy and inspected after leaving humidifier. Boards are stacked on edge.*

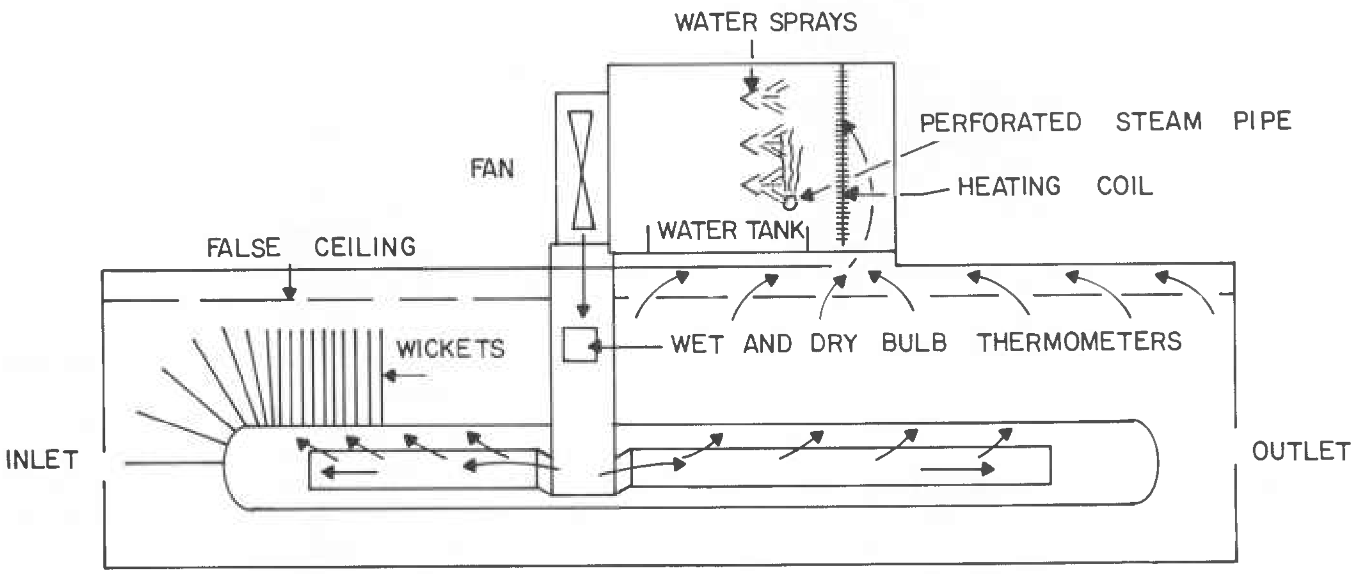


Figure 256—*Wicket-type continuous humidifier (Wehrle 1957). Wickets are spacers mounted on the conveyor that boards are placed between.*

spray (point *3*). Steam spray adds too much heat, and the air is then cooled almost to saturation by water spray (interval between points *3* and *4*).

The entire process is controlled by a dry bulb–wet bulb controller (fig. 258), which functions as described by Vranizan (1968):

> Moisture is introduced by low pressure steam, which also introduces large quantities of latent heat. The latent heat is in excess of the heat requirements of the chamber. Excess heat results in forcing the dry bulb temperature above the desirable set point. This results in what is commonly referred to as "dry bulb over-ride."
>
> In order to compensate for this undesirable effect, a water spray system is used. The water spray cools the air stream by evaporative cooling and

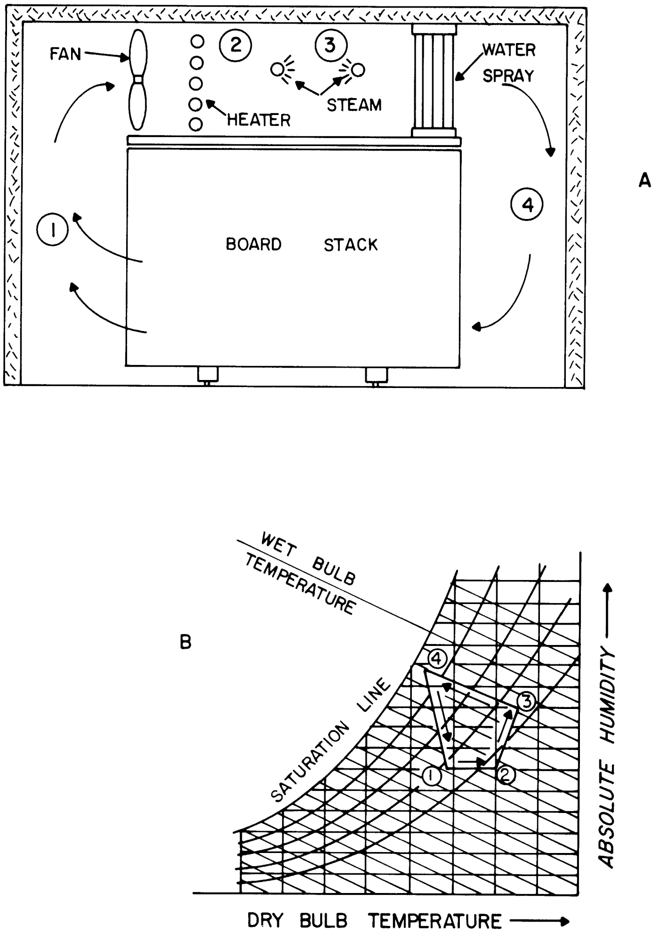


Figure 257A—*Air circulation in humidifier chamber (Vranizan 1968).* **B**—*Humidifying process on psychrometric chart (Vranizan 1968).*

brings the dry bulb temperature back down. In so doing, the water spray causes the wet bulb temperature to over-ride, and thereby raises the humidity level above set point. In order to compensate for the excess humidity level, the vents open and exhaust moisture, which brings the wet bulb temperature down.

In exhausting moisture, fresh air is brought into the chamber, which reduces the dry bulb temperature below set point. This change is sensed by the instrument, which calls for the heating coil to come on, thus imparting more thermal energy in the air stream back up to the desired set point.

As moisture is taken up by the board, the wet bulb temperature falls, and the wet bulb instrument calls for more moisture to be introduced into the

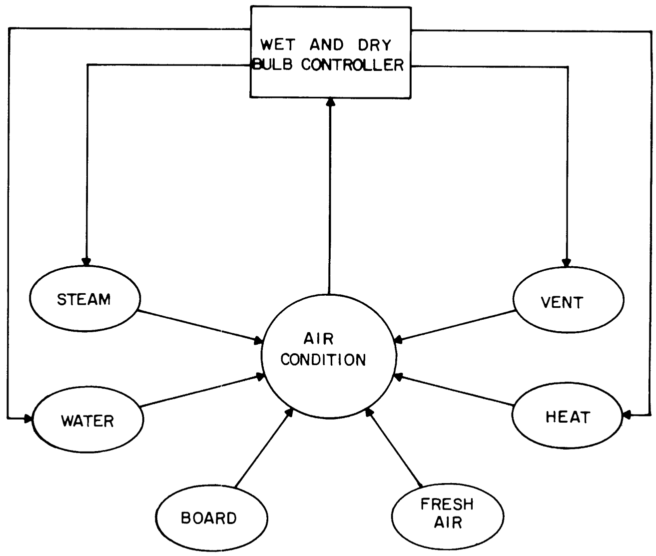


Figure 258—*Schematic of humidifier control.*

tunnel. The steam sprays come on again and the cycle begins to repeat.

Air conditions in the humidifier are limited by the danger of corrosive condensation. Temperatures and relative humidities are, therefore, moderate (140 °F and 70 to 80 percent relative humidity). Higher temperatures and relative humidities would increase the moisture transfer rate but would require extremely well-insulated chambers. Liquid water collecting on board surfaces causes water spots. Humidification cycles vary between 6 and 9 h, depending on board thickness.

Other methods of humidification include spraying of water on the back side of the board, followed by stacking back-to-back; applying vacuum to force moist air through the board; and applying liquid water by roll coaters, followed by surface heating through contact rolls, which disperses water throughout the board (figs. 259, 260).

References

Back, E.L.; Klinga, L.O. Reaction in dimensional stabilization of paper and fiber building board by heat treatment. Svensk Papperstidning. 19(10): 745-753; 1963.

Braun, O.; Strand, A. Varmebehandling av harda trafiberskivor. Svensk Papperstidning. 14(7): 437-444; 1958.

Klinga, L.A.; Back, E.L. Drying stress in hardboard and the introduction of cross-linking stresses by heat treatment. Forest Products Journal. 14(9): 425-529; 1964.

Lampert, H. Faserplatten. Leipzig: VEB Fachbuchverlag; 1967. 453 p.

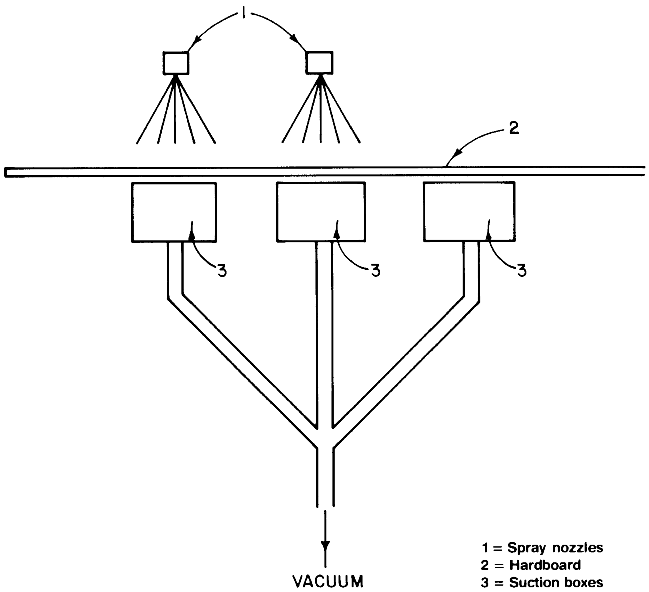


Figure 259—*Vacuum-assisted humidification of hardboard (Lampert 1967).*

Lofgren, B.E. Continuous and discontinuous heat treatment and humidification of hardboard. In: Fiberboard and particleboard. Proceedings of international consultation of insulation board, hardboard and particle board; 1957; Vol. III; paper 5.17. Rome: FAO; 1958. 300 p.

McNatt, J.D. Effects of equilibrium moisture content changes on hardboard properties. Forest Products Journal. 24(2): 29–35; 1974.

Seborg, R.M.; Tarkow, H.; Stamm, A.J. Effect of heat upon the dimensional stabilization of wood. Forest Products Journal. 3(9): 59-67; 1953.

Spalt, H.A. Chemical changes in wood associated with wood fiberboard manufacture. In: Goldstein, I.S., ed. Wood technology: chemical aspects. Washington, DC: American Chemical Society; 1977: 193–219.

Stamm, A.J. Wood and cellulose science. New York: Ronald Press; 1964. 549 p.

U.S. Department of Commerce, National Bureau of Standards. American National Standard ANSI/AHA A-135.4-1982: basic hardboard. Washington, DC; 1982. 5 p.

Voss, K. Die Warmebehandlung von Holzfaserplatten. Holz als Roh- und Werkstoff. 10(8): 299–305; 1952.

Vranizan, J.M. Design considerations—a corrison-free hardboard humidifier. Forest Products Journal. 18(9): 60–64; 1968.

Wehrle, A. Continuous humidifiers for conditioning hardboard. In: Fiberboard and particleboard. Proceedings of international consultation on insulation board, hardboard and particle board; 1957; Vol. III; paper 5.18. Rome: FAO; 1958. 300 p.

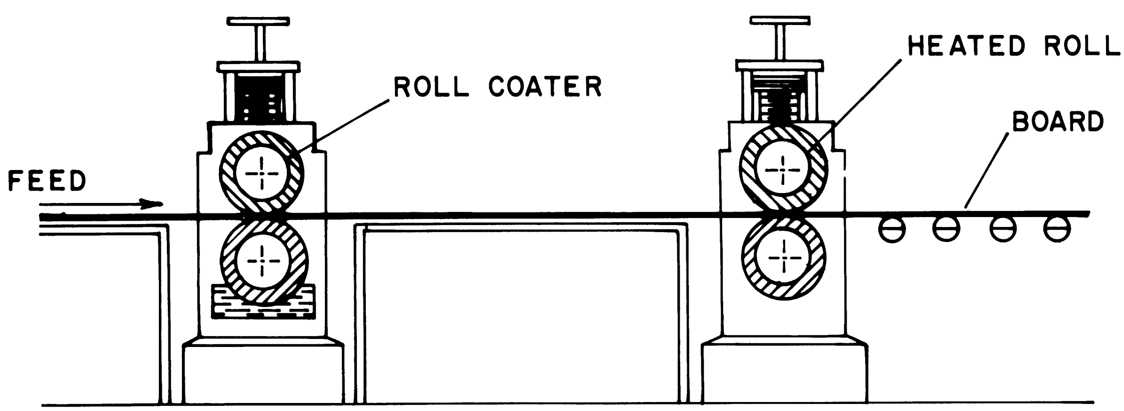


Figure 260—*Humidification of hardboard by applying water with roll coater and dispersing it with heated roll (Lampert 1967).*

11. Fiberboard Fabricating and Finishing

General

Hardboard and insulation board are manufactured to dimensions (length and width) that are determined by manufacturing efficiency considerations, equipment limitations, and the final dimensions of the product. Such boards are almost always made larger than the final product, but sizes are chosen that can be subdivided into products of various final dimensions with a minimum of waste.

This subdividing together with laminating and other machining needed to give products their final sizes and shapes is called **fabricating**. In the manufacturing mill, fabricating may well be limited to the production of "standard" board sizes such as 4 ft by 8 ft, with further fabricating and finishing in a different location or by an independent fabricator. In other cases all fabricating and finishing operations occur in the manufacturing mill.

Fabricating is generally followed by **finishing**, a process that applies surface treatments affecting appearance and performance. The finishing of hardboard has developed into a sophisticated technology that adds substantially to the value of the product. Some of these products are judged more by the quality of the finish than by the quality of the substrate.

Fabricating and finishing often overlap and cannot easily be treated separately, as in the case of insulation board, which may receive its first coat of paint between wet press and dryer.

Today, very little hardboard and insulation board is sold as "brown" board, the standard size sheet without extensive fabricating and without finish. Rather, many manufacturing lines are set up to produce exclusively interior paneling, for instance, or tileboard, or siding. This specialization extends back to raw material selection and pulping procedure. The end products of such lines are ready for installation and require no further manufacturing steps.

This is not true of thick MDF, where the fabricating, as for most particle boards, is generally limited to "cutting to size."

This chapter provides a brief overview of fabricating and finishing practices for insulation board and hardboard, without going into the details of machine and tool design, paint technology, finish evaluation, or materials handling and energy considerations. The fabricating and finishing of thick medium-density fiberboard is not covered and the reader is referred to Maloney's treatment of this subject (Maloney 1977).

Fabricating and Finishing of Insulation Board

Figure 261 is a schematic representation of the fabricating and finishing department of an insulation board plant (Dyer 1960). This is a continuous fabricating area designed to produce either single thickness or laminated products, painted or asphalt coated. It may be noted that this line offers great flexibility because individual operations such as painting and laminating can be passed through singly or in series, or they can be bypassed altogether. After passing the laminating and/or paint line, the boards can go through the resawing and edge fabricating loops, or they may go to the asphalt line directly. Painted boards with or without edge fabricating go through the bypass line and may be removed from there to the separate tile fabricating area (not shown).

Downstream of the cross-cut saw (fig. 261) and tipple is an emergency storage area capable of holding 1 hour's board production. Because the dryer, of course, cannot be shut down until it is empty, temporary storage is needed for repair of any breakdown. Boards are then fed into the auxiliary tipple and can later be fed back into the line.

The double trimmer

The **double trimmer** may be considered the first element in the fabricating department, although its operation is vital to the manufacturing department because it is directly coupled to the continuous forming machine.

The double trimmer reduces the board size to standard 4- by 8-ft dimensions in two passes (figs. 261, 183). The saws may be mounted with movable saw collars on a long arbor that runs in bearings attached to a large beam spanning the trimmer. This allows for positioning the saws by sliding them along the arbor. Usually a double set of arbors on the first pass can be raised and set up for a size change, while the other is operating.

With continuous arbors, split saws are used to facilitate replacement (fig. 262). Saws commonly measure 1 ft in diameter, carry 60 carbide-tipped teeth, and operate at 3600 r/min. Outside saws are usually mounted on special saw collars equipped with breaker teeth to break up the trim for reuse as board furnish.

Some trimmers have individual saw drives, the motors being movable on the chain beam to allow for size adjustments. In that case the saws are solid.

Saws are overhead mounted, cutting from above through the board and into wood blocks that stabilize the blades and provide solid support to the flexible board. The board is fed through the first pass by pinch rolls. Leaving the first pass, the board drops on the bed of the

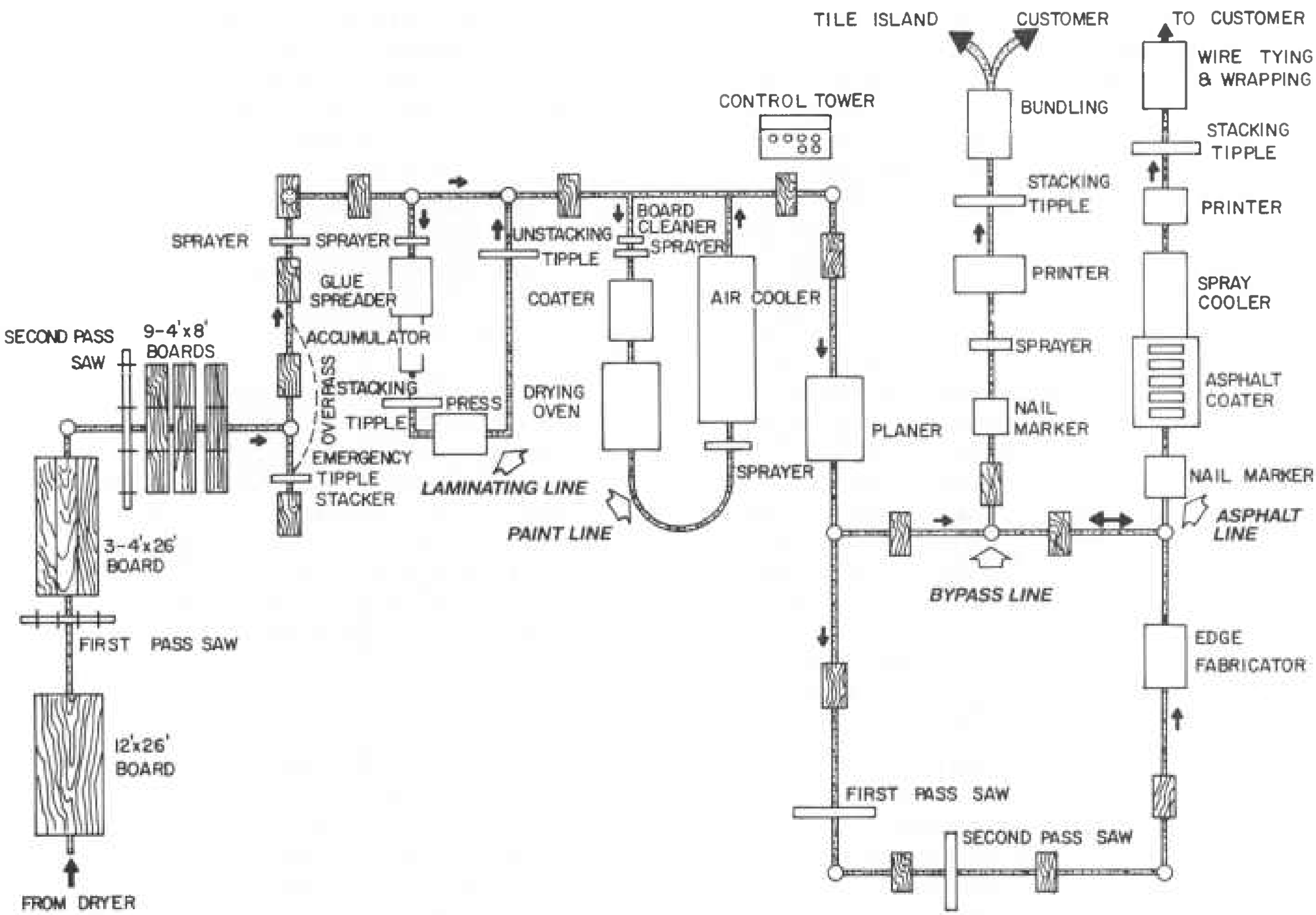


Figure 261—*Continuous fabricating area in insulation board plant (Dyer 1960).*

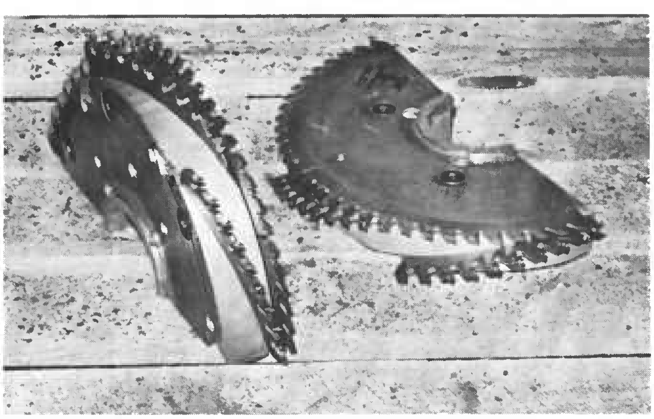


Figure 262—*Split-edge trim saw equipped with breakers to reduce trim for easy pneumatic handling.*

second pass machine. A limit switch activates chain rails that move the board at right angles through the second pass saws.

The sawdust is bulky and fibrous. It is blown directly into a wet collector, pumped back to the wet end, mixed with water, and added continuously to the furnish. This reduces the considerable fire hazard at the trimmer (Eustis 1980).

Laminating and coating

Referring again to figure 261, we will follow the description of this particular line by Dyer (1960):

> The laminating line consists of the following equipment: water spray, to bring up the moisture content by 1 to 2 percent; glue spreader, which applies a quick setting adhesive to the top of the bottom

panels of the sandwich, to both sides of the intermediate panels, and to the bottom side of the top panel; accumulator where the sandwich is formed; stacking tipple which builds a 50-in pile of sandwiches; hydraulic press, where the entire stack is compressed for 7 min; and unloading tipple for transfer back into the main conveyor.

The coating line next to the main conveyor is comprised of the following basic equipment: board cleaner; water spray; curtain coater, gas-fired 60-ft oven where the panels are dried at 500 °F in 30 s (panels traveling at 120 ft/min; powered horseshoe conveyor; water sprayer; and 80-ft-long air cooler. The water sprayers are used to equalize surface moisture and prevent warping of the board.

The main conveyor then carries all boards through a bottom-head planer. They can then go through the secondary saws and edge fabricator and on to the asphalt line or bypass line. The bypass line includes a nail marker; water sprayer; printing roll; and a stacking tipple.

The asphalt line includes a five-roll coater contained in its own enclosure. Hot asphalt is applied to both surfaces and all edges by the first set of rolls. A second set of wiper rolls smooths out the asphalt coating. The asphalt is next "struck" in the panel by three sets of rolls heated to 450 to 500 °F. Heat is supplied by propane gas burners inside the rolls. The panels are conveyed out of the enclosure into a 40-ft-long water and air spray cooler, then through a printing roll which applies the trademark, and stacking tipple. The bundles are either wrapped or strapped, then warehoused in the immediate area by fork lift trucks.

Painted panels destined for fabrication into ceiling tile are picked up from the bypass line's tipple and fork-lifted to the separate tile operation. This line is similarly continuous and automatic within itself. The following equipment sequence prevails: unloading tipple; bottom head sander (the painted surface is topside); first and second pass saws; multiple drill with bypass around it; first and second edge fabricators; 3-color pattern roll printer and dryer with bypass around it; inspection belt; wall plank take-off, or tile accumulator (stacker); carton filling; carton sealing; and palletizing elevator.

The speed of all conveyors and the cycling operation of transfers are all integrated through an electric Selsyn drive system. Individual boards are held in exact synchronism by means of gates located ahead of transfer points which are operated from cams driven from the same Selsyn system. The complete route to be traveled by the continuous stream of boards is programmed on the central graphic console from which the speed of the entire system is regulated.

Acoustic tile is manufactured in 1/2-, 5/8-, and 1-in thicknesses. The first two are of homogeneous structure; the 1-in product is laminated. Holes in acoustic tiles are either drilled or punched with needlelike pins that penetrate up to seven-eights of the total tile thickness (fig. 263).

Roof insulation is produced in thicknesses of 1/2 in and multiples of 1/2 in. This material is usually embedded in hot asphalt or pitch on the roof deck.

Asphalt-impregnated sheathing is produced in thicknesses of 1/2 in and 25/32 in. The 4- by 8-ft and larger units have square-cut edges for butt jointing. The 2- by 8-ft units have a V-joint on the long edge. The 25/32-in thickness is laminated from 25/64-in boards using an adhesive-containing asphalt emulsion (Walton 1951) (fig. 264.)

Embossing

Wood grain or other decorative patterns can be embossed in the surface of insulation board by hot rolls. The board surface is wetted down with water and then passes under a profiled roll that is heated internally by gas flames to a temperature of about 500 °F. As the water contacts the roll it boils, and the pattern is pressed into the softened board surface. Profile depth is limited and profile edges must not be sharp to avoid surface cracking and painting difficulties (Eustis 1980).

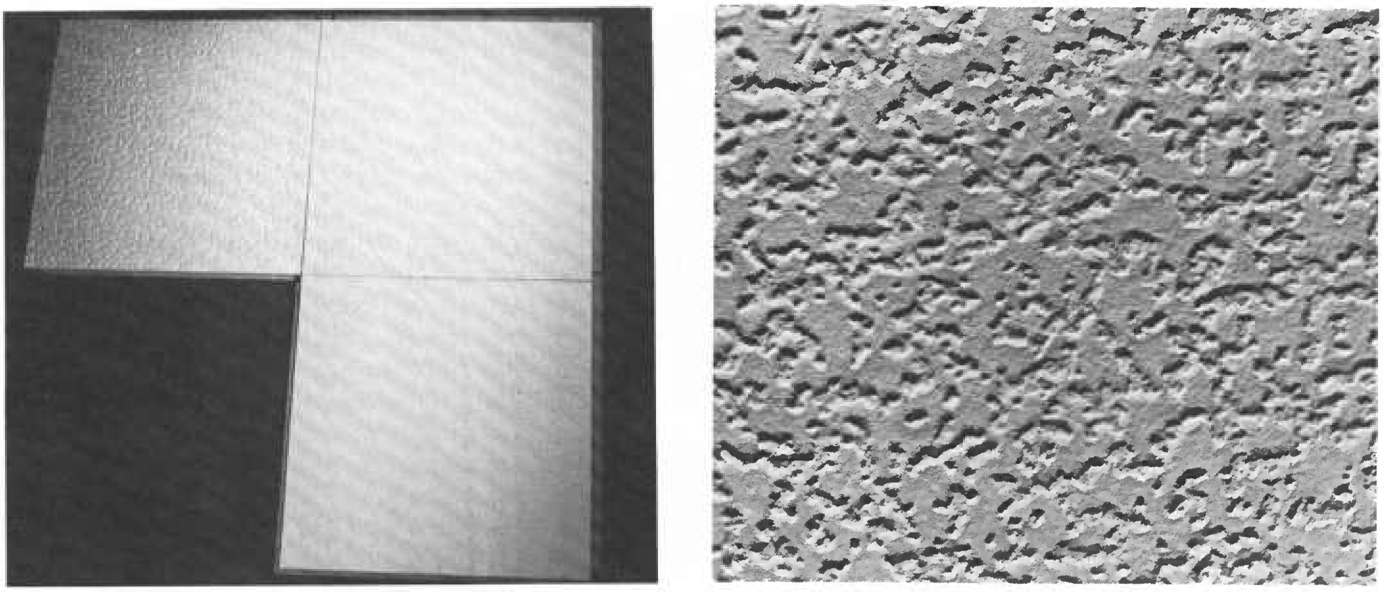
The same technique is used with smooth rollers that simply iron the surface smooth. When bevels are cut on decorative insulation board, they are wetted with paint and ironed immediately after cutting by a heated shoe pressing against the bevel.

Ironing and embossing are normally followed by application of white water-based paint.

Fabricating of Hardboard

Sanding

Where thickness tolerances are critical, hardboard is sanded. This includes certain finishing operations and applications like overhead garage door panels that must fit in grooves machined into wood rails. S1S panels have relatively large thickness tolerances and are generally backsanded. S2S wet-formed boards do not normally require sanding. Print lines cannot tolerate variations in



A

B

Figure 263A—*Acoustic tile.* **B**—*Acoustic tile surface characteristic.*

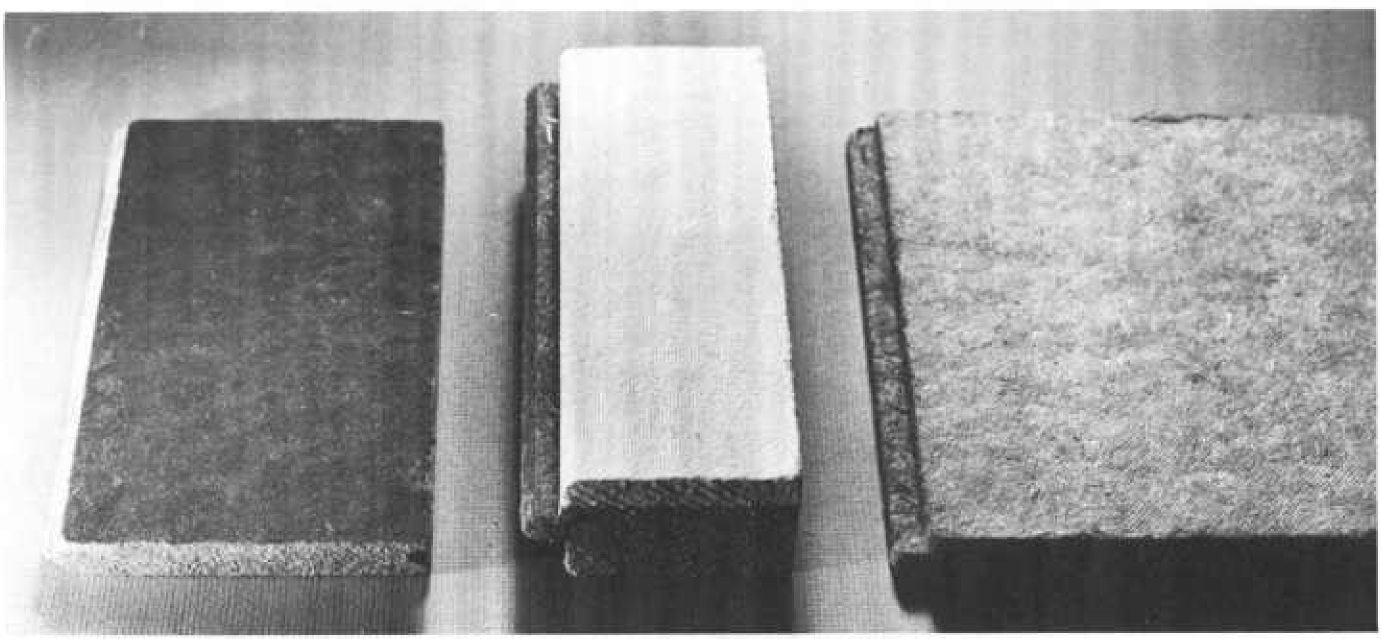


Figure 264—*Samples of asphalt-impregnated insulation board sheathing.*

thickness of more than 0.010 to 0.015 in, so sanding is normally required. Sanding dry process boards not only reduces the variations in thickness but also improves paintability.

Sanding may take place right after humidification, before trimming. Single-head wide-belt sanders are used with abrasive grits varying from 24 to 36. Finer grits produce smoother surfaces, but loading of the abrasive belt becomes a problem. An open-grit belt (24 to 36) will sand 40,000 to 50,000 panels. Very fine (320 to 400) grit sanding is done on some finishing lines to improve surface quality without removing much material (Eustis 1980).

Years ago, planers equipped with solid carbide planer knives and vacuum planer beds were used to plane tempered hardboard for certain applications in the automotive industry (fig. 265).

Trimming

The double trimmer used for the sizing of hardboard is similar to the machines used for insulation board except that the first pass normally produces a single standard-width board (4 or 5 ft wide). To capitalize on the rugged and accurate feed system offered by these machines, some operators mount additional machining tools on the trimmer.

Figure 266 shows a **vacuum feed** loading 16-ft hardboard into the first pass of the double trimmer. To overcome the difficulty of separating tightly stacked sheets (particularly S2S), the vacuum seal between sheets is broken by picking up one corner first; then the rest of the vacuum cups engage and lift and move the board into the roll feed, which discharges the board on a conveyor leading to the trimmer (Eustis 1980).

The board is moved first through the **edge trimmer,** by feed rolls or a precision feed chain. Figure 267 shows the outfeed side of the edge trimmer equipped with feed chains. The chains run in machined ways and each link carries a rubber pad. The board is held down by closely spaced holddown rolls. The overhead mounted saws cut through the board and into stabilizing hardwood support blocks that are placed beneath the board to prevent saw deflection. Sawblades are 1 ft in diameter and carry 60 carbide-tipped teeth. Figure 262 shows a trim saw in split design for easy removal from shaft and equipped to break up the trim for easy collection and pneumatic handling.

S2S boards may show flaky edges after trimming. This condition is improved by rounding the edges with special cutterheads. Rounded board edges also facilitate the fitting of trim molding strips used with wall paneling.

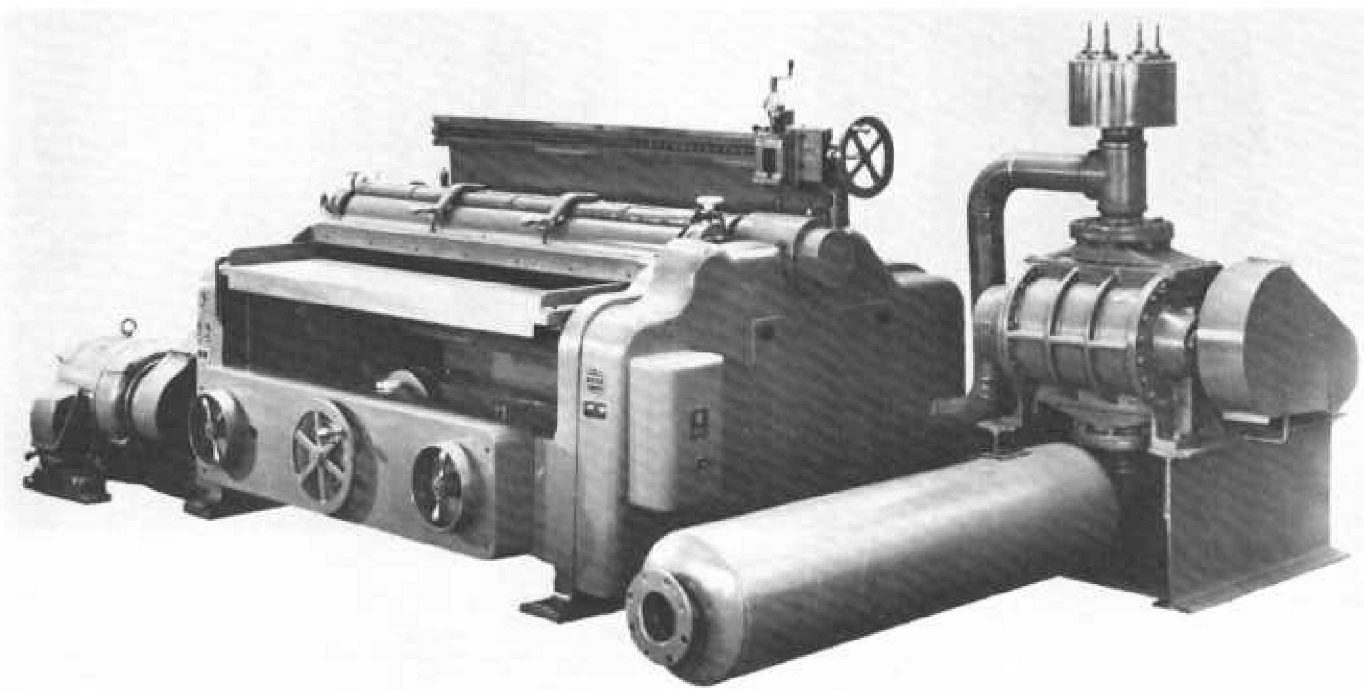


Figure 265—*Buss Micro Surfacer. A 52-in-wide single surfacer equipped with carbide knives and vacuum bed (note vacuum pump at right) (Buss).*

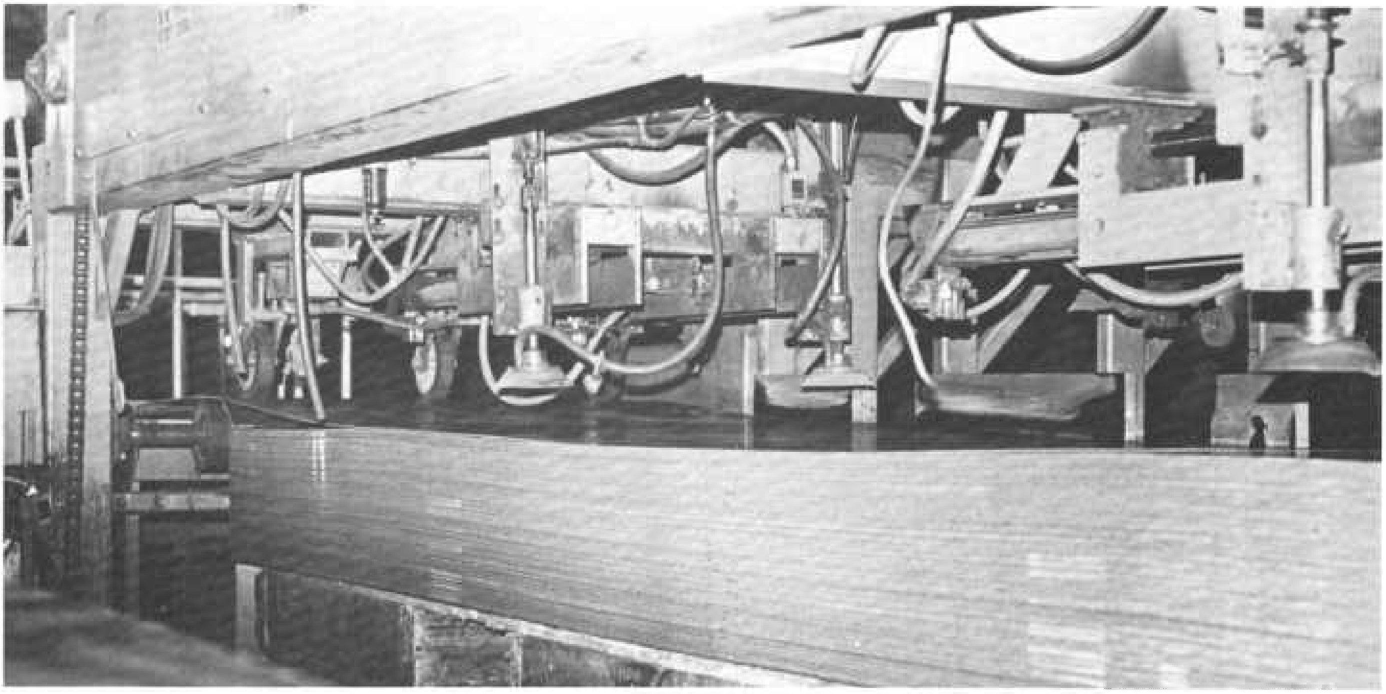


Figure 266—*Vacuum feed loading of hardboard into first pass of double trimmer.*

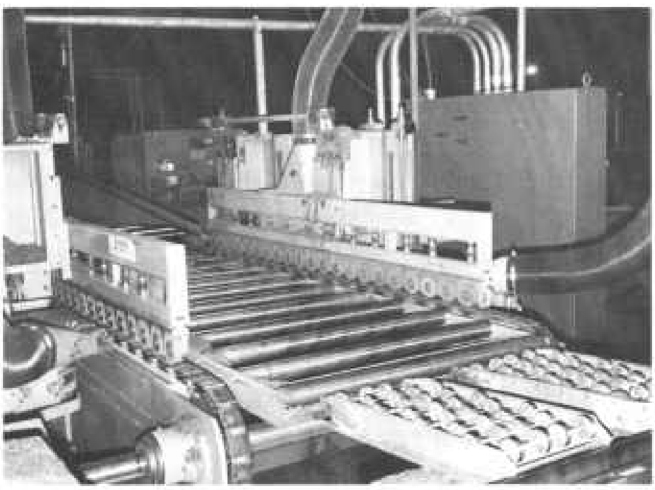


Figure 267—*Outfeed end of edge trimmer. Note feed chains and hold-down rolls.*

These high-speed cutterheads (6 to 12 in diam, 7200 r/min carbide-tipped) could be mounted on the edge trimmer (first pass) (see fig. 268).

The plank effect on wood-grain-printed wall paneling is generated by score lines—shallow grooves machined along the length of the board by overhead scoring saws. These score lines give the impression of random plank width, but there is always a line at 16-in spacing for nailing through the groove into wall studs, which are normally spaced 16 in apart. The scoring saws may be mounted on common arbors to be raised and lowered according to pattern, or they may be mounted individually. A recent development is the use of stationary cutters for this operation.

After passing the edge trimmer, the board is transferred to the cross trimmer, which cuts the boards to product lengths (fig. 269). Feed chains are equipped with lugs to keep the board edges exactly perpendicular to the saw lines. There must be at least two chains (two lugs) for each piece being cut. Saws mounted on an overhead beam have individual motor drives and can be repositioned along the beam for various length cuts (fig. 270). End saws have special blades to break down edgings. Cutterheads for rounding short edges can also be added.

Trimmer accuracy must meet tolerances prescribed by the commercial standards, all three of which (basic hardboard, prefinished paneling, and hardboard siding) limit the tolerances on nominal width and length to ± 1/64 in/linear ft. For a 4- by 8-ft board, the length and width tolerances would thus be ± 1/8 in and ± 1/16 in,

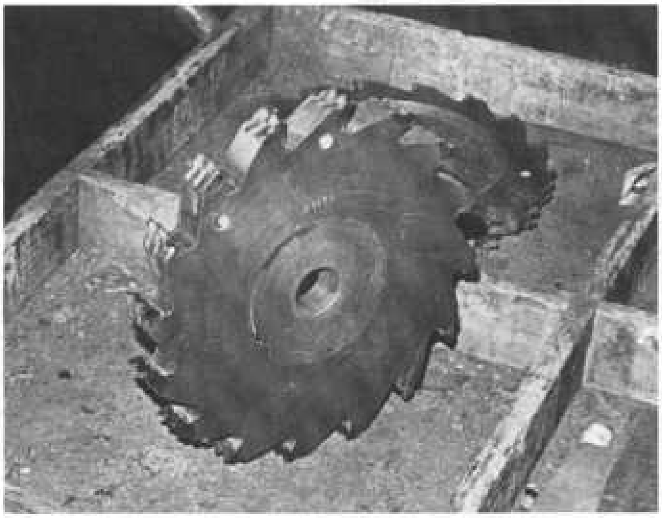


Figure 268—*Carbide-tipped cutterhead for rounding hardboard edges.*

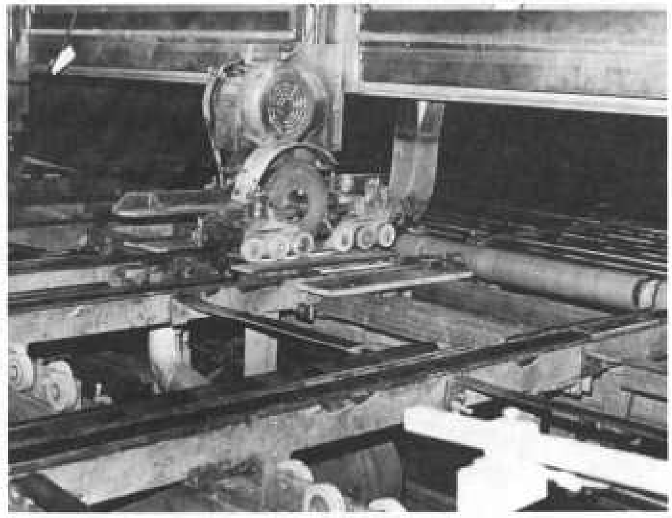


Figure 270—*Cross trimmer saw unit with individual drive for easy positioning along overhead beam.*

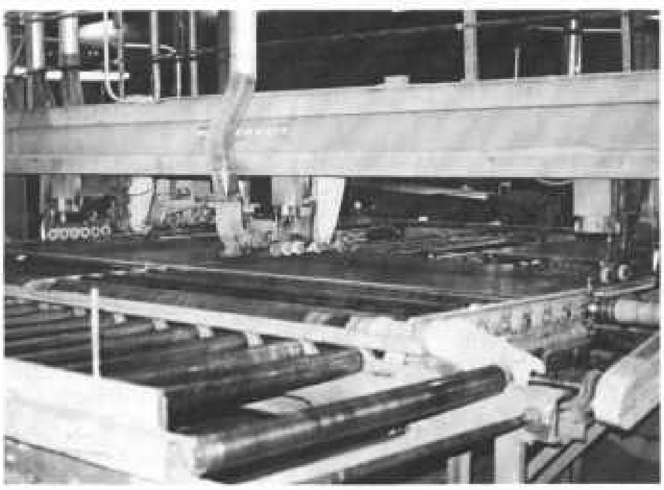


Figure 269—*Outfeed end of cross trimmer. Note feed lugs on infeed side.*

respectively. Maintaining these tolerances requires accurate positioning of sawing units.

Other standard requirements related to trimmer performance are edge straightness and squareness. A hardboard edge must be straight within 1/64 in/ft of board edge length. The tendency of the first pass machine to make a bow cut can be caused by uneven pressure on the hold-down devices. If the board is squeezed harder along one edge, it will be pulled towards that side. Differences in board thickness may have the same result (Eustis 1980). When breaker saws are used, greater trim waste on one edge could also cause bow cutting, the greater energy required to break up the wider edge slowing the board down. For this reason, some mills do not use breaker saws but break up the long edgings subsequently.

Squareness of the trimmed sheet is a matter of cross cutting on the second pass machine. Out-of-square boards may be caused by chain wear or by lugs being pushed into the edge of the board. On a square board, the two diagonals are of exactly the same length. The standard limits the difference between the diagonal lengths to 1/64 in for each foot of board length. Opposite sides of the board must not vary in length by more than 1/8 in.

Trimmer speeds are high, ranging between 100 and 400 ft/min. At 233 ft/min a trimmer would process 7,000 4- by 16- ft boards in 8 h, which is equivalent to one 100-piece unit (4 by 8 ft) every 3½ minutes. The limiting factors are clearly board handling and board transport to and from the trimmer. In general, fabricating departments tend to outproduce the board line two shifts for three (Eustis 1980).

Saw life between sharpenings depends on the type of cut made. Breaker saws (end saws breaking down trim waste) last 40,000 to 50,000 cuts. Center saws, cutterheads for rounding edges, and scoring saws must be exchanged every 4,000 to 5,000 cuts.

Dust collecting systems associated with these sawing machines use recirculating air to avoid heat losses and are equipped with flame detecting and anti-explosion devices.

Some hardboard mills serving industrial markets that require a large number of different sizes—calling for setup changes to be made several times in one shift—may employ more sophisticated cut-up machinery that allows substantial reduction of set-up times by computer-controlled hydraulic saw positioning. This type of panel-sizing machine, illustrated in figure 271, is common in the particle board industry.

Fixed knife cutting

The double trimmer, with its high-speed saw blades and cutterheads, is a noisy machine. Sound intensity at an adjacent grading station has been estimated at 110 to 115 decibels (Eustis 1980), which greatly exceeds the threshold of 89 decibels at which the Occupational Safety and Hazard Act (OSHA) requires ear protection. It must be remembered that an increase in the decibel level by 10 is sensed by the human ear as a doubling of the sound level.

Efforts to reduce noise pollution in the fabricating department, therefore, have a high priority. One very promising development in this area is **fixed-knife cutting**, presently applied to the scoring of panelboards. In this method, the board is advanced against a series of carbide-tipped knives, rigidly held in place, and so adjusted that

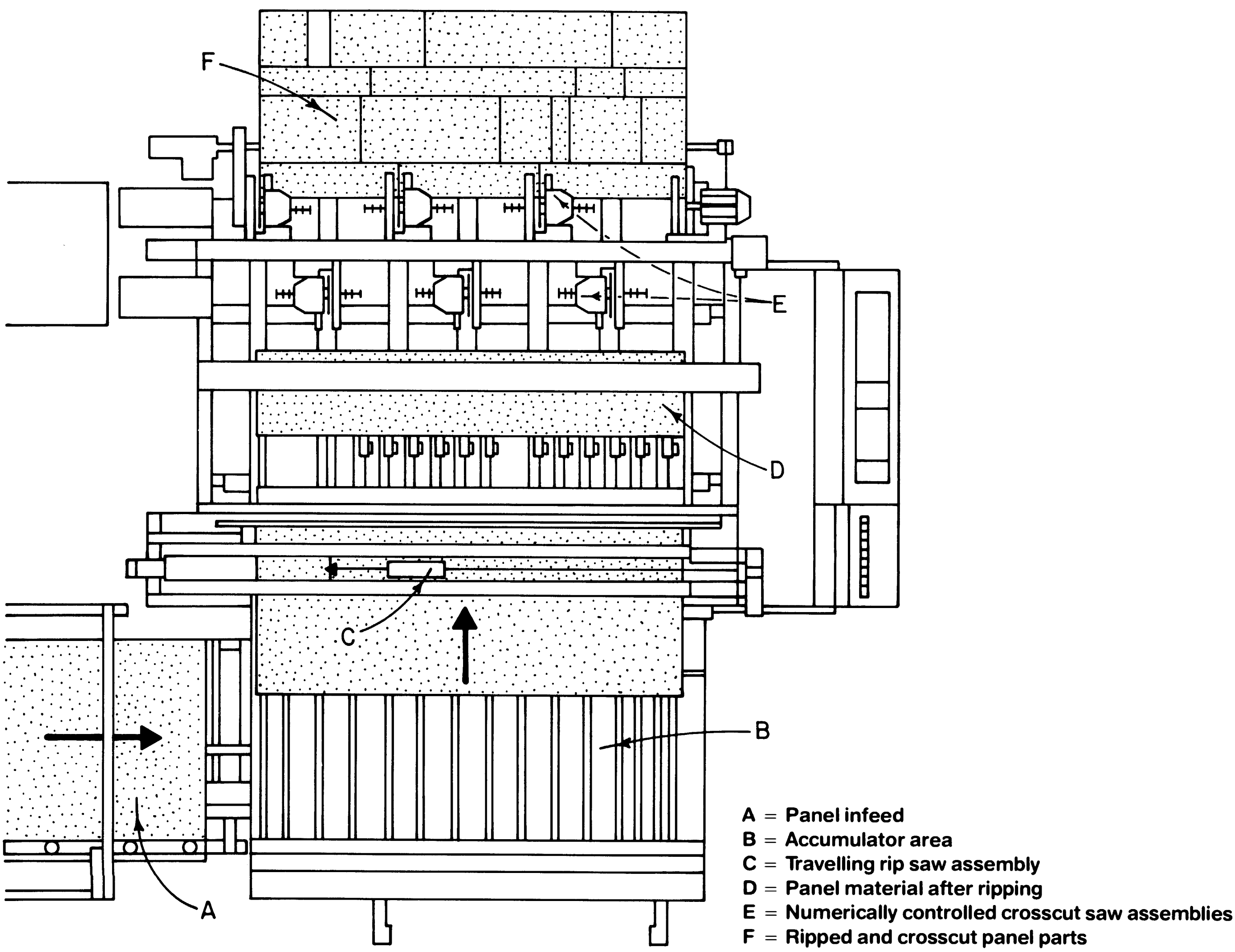


Figure 271—*Schematic drawing of panel-sizing machine (McMillin 1982).*

they will generate a continuous shaving as long as the board (figs. 272–275).

Fixed-knife cutting has several important advantages: It is practically noiseless, tools are relatively inexpensive, and tool life between sharpenings is about 10 times as long as that of a regular scoring saw (40,000 to 50,000 panels compared with 4,000 to 5,000 panels).

The feeding system has to be absolutely rigid because the cutting force reactions in the direction of board travel are considerably greater than those for sawing.

At the present time, fixed-knife cutting is limited to panel scoring. Actual panel trimming, however, seems to be a logical and not altogether impossible extension of this technology. Fixed-knife scoring can be incorporated into the double trimmer or it can be done on a separate machine.

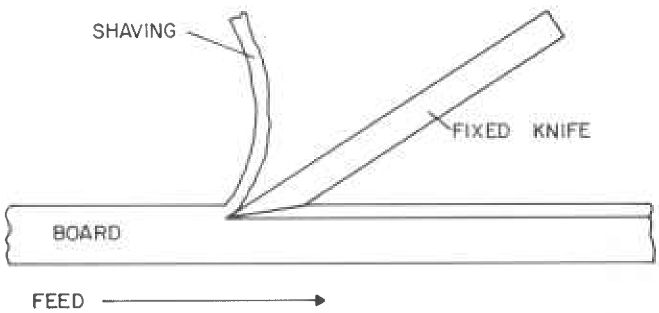


Figure 272—*Principle of fixed-knife cutting as applied to the scoring of hardboard panels.*

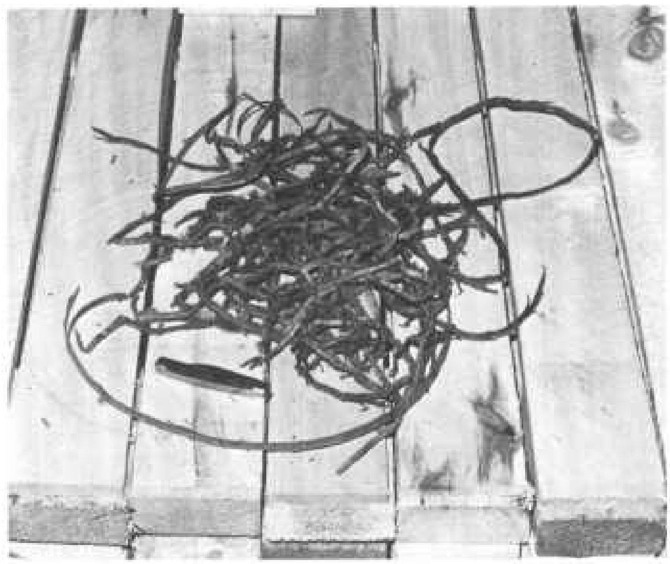


Figure 274—*Shavings generated by fixed panel-scoring knives.*

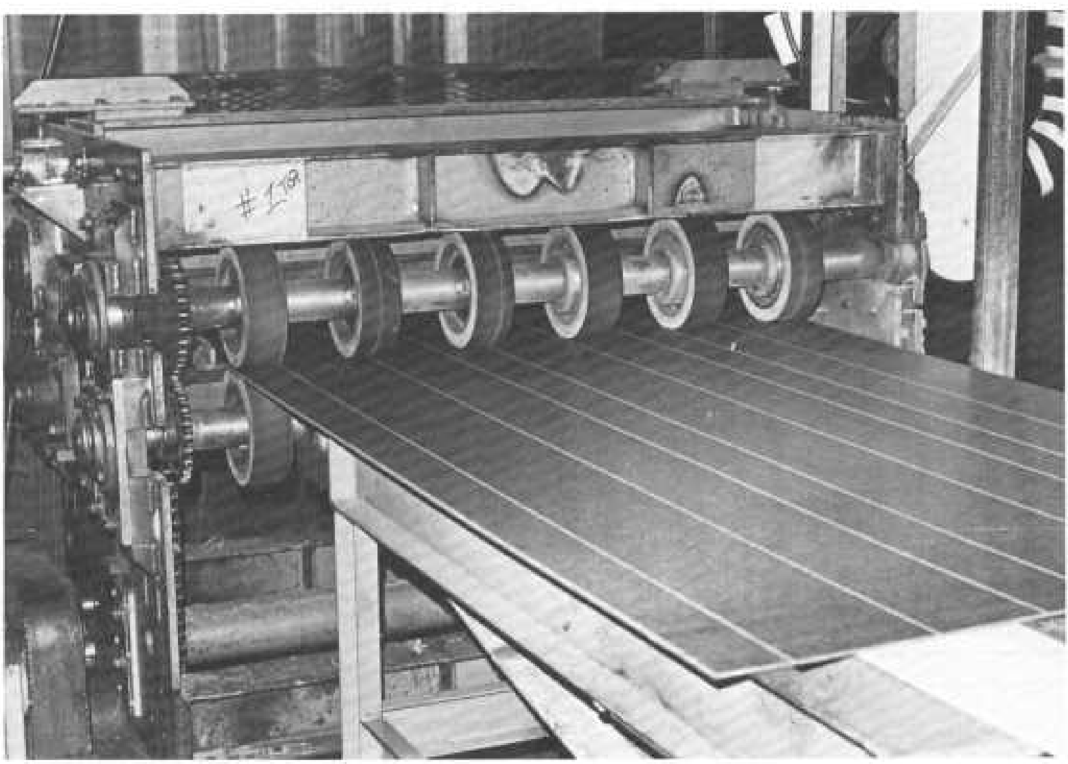


Figure 273—*Outfeed end of fixed-knife panel-scoring machine.*

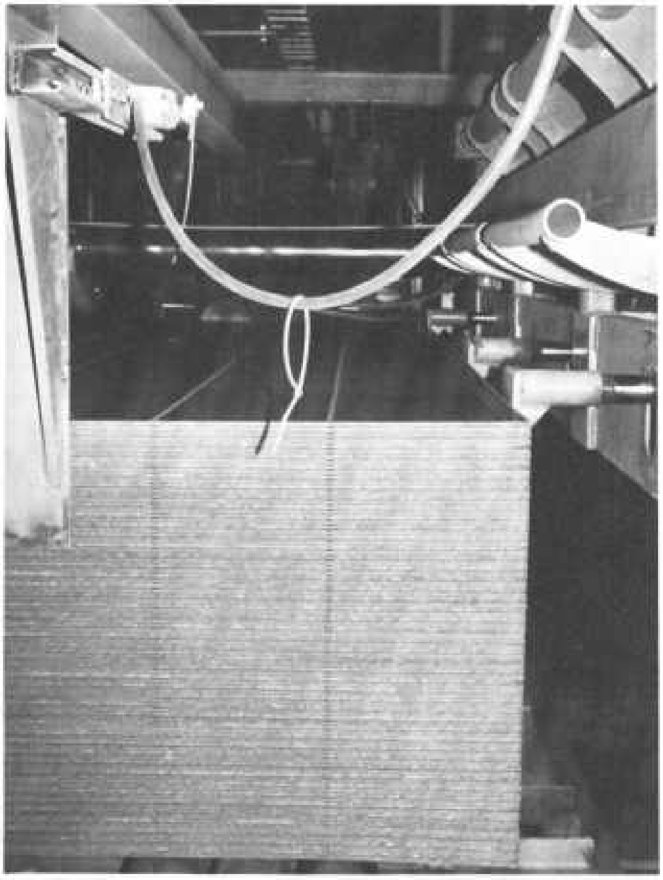


Figure 275—*Stack of hardboard panels scored with fixed knives.*

Punching

The punching of hardboard refers to the perforating of the sheet for use as the familiar **pegboard**. Two types of pegboard are made: 1/8-in-thick board with 3/16-in-diameter holes, and 1/4-in-thick board with 9/32-in-diameter holes. These hole sizes correspond to the various types of hooks and other attachments that can be purchased in hardware stores. Pegboards are used extensively in store fixtures, window displays, workshops, and for other purposes (fig. 276).

The operating principle of the punch press is shown in figure 277. Figure 278 is a close-up of the press showing the bed plate with three rows of holes and the head with stripper plate in the raised position. The punching is an intermittent operation. In this particular machine, three rows of holes are punched in one stroke. While the head is in the raised position, the board is advanced. The head is lowered, the stripper plate contacts the board, and then the punches move through the stripper plate, punching the holes and pushing the cut-out plugs into bushings in the bed plate. The punches are square across the ends and fit smoothly and exactly into the holes in the stripper plate and the bed plate. On the return stroke, which takes more power than the cutting stroke, the punches have the tendency to pull the board up, which results in undesirable deformations (volcanos) (fig. 279) on the top surface. This can be avoided only by a very close fit of the punches in the stripper plate. For this reason, the good side of the board is always turned down in the punch press. Very high density boards can stall the machine on the upward stroke (Eustis 1980).

The fabricating process in the mill is generally completed with a final inspection and grading before **unitizing**, which is the packaging or banding of manageable stacks of board for delivery to the finishing plant or the distributor (fig. 280).

Embossing of hardboard

To improve its appearance in use, much hardboard is embossed by substituting a profiled caul for the usual smooth top caul in the press. The result is a slightly contoured board surface that can enhance the resemblance of the board to a variety of preferred models, such as sawn wood, weathered wood, brick, etc. (fig. 281). Embossing

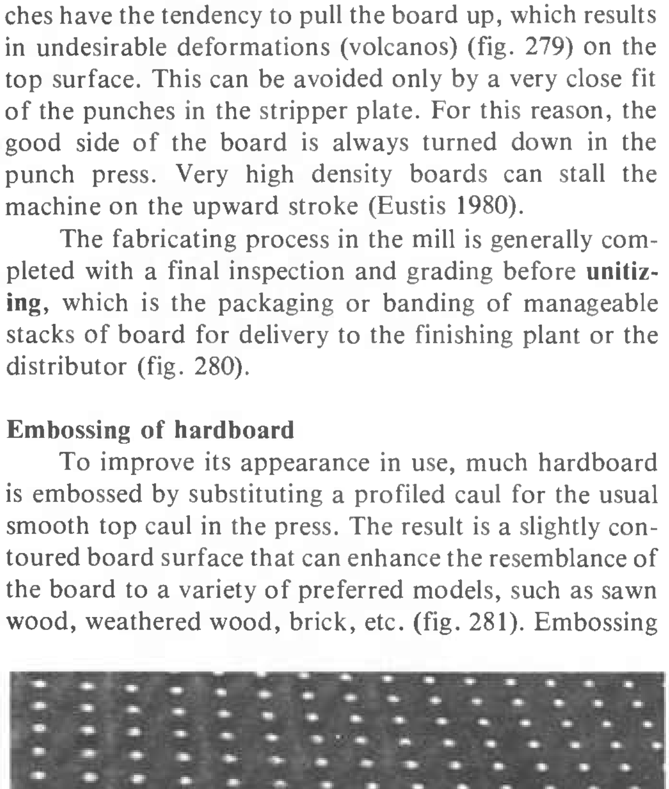


Figure 276—*Pegboard.*

lends an appearance of depth to the hardboard panel and helps overcome the image of a thin flexible sheet. Although actually a special pressing operation, it is discussed here because of its close relation to finishing.

Historically there are examples of embossing being done on the finished board. A west coast plywood manufacturer tried to emboss resin-coated hardboard

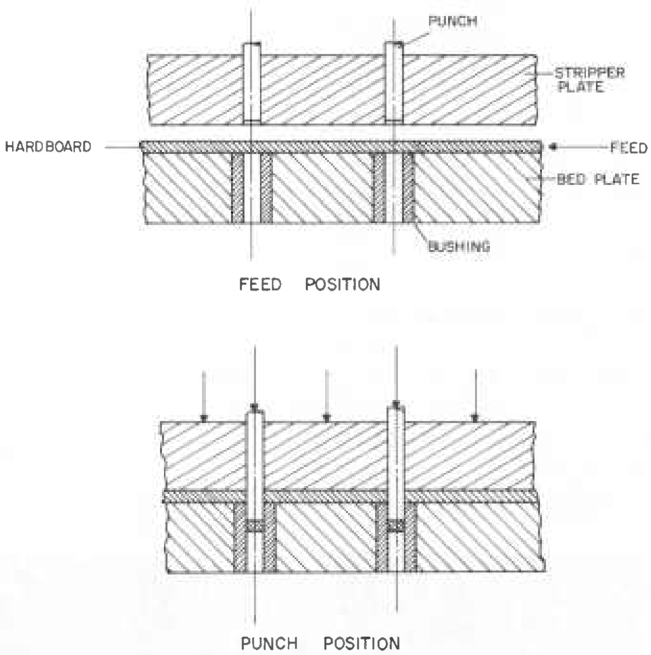


Figure 277—*Principle of operation of punch press in the manufacture of pegboard.*

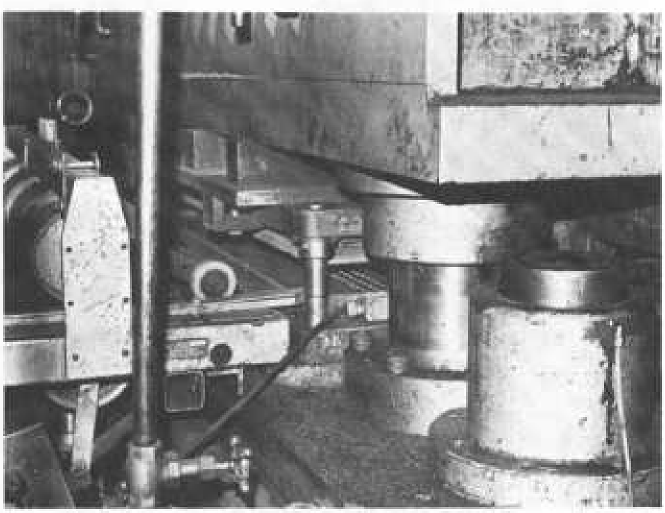


Figure 278—*Closeup of punch press showing bed plate and raised head with stripper plate. Advancement of panel and operation of punch proceed automatically.*

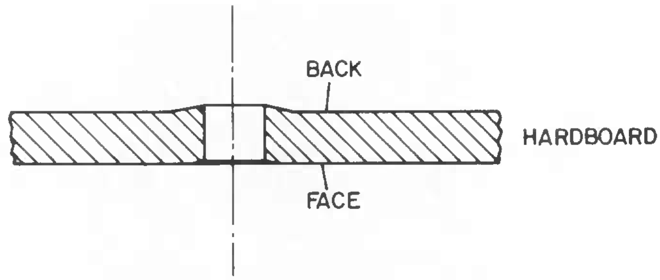


Figure 279—*Schematic illustration of possible distortion of pegboard surface (volcano).*

Figure 280—*Hardboard banding machine.*

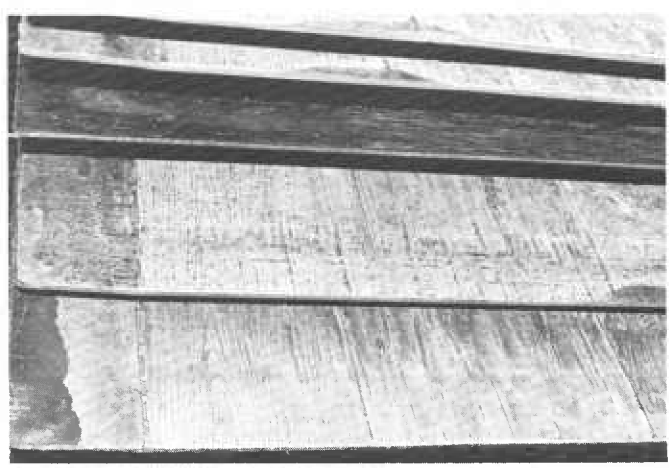


Figure 281—*Stack of profiled cauls for the manufacture of embossed hardboard panels.*

with a heated embossing roll, but the process was not commercially successful because of its low speed (Eustis 1980).

Other attempts at producing profiled board surfaces to simulate weathered wood grain, for instance, have involved contoured planer blades. Limited quantities of this type of board have been sold, but it has never been popular (Eustis 1980).

Face-embossed hardboard. Most embossed hardboard is face embossed, that is, only one surface is profiled, the other surface remaining flat. This technique imposes the limitation that the depth of the profile can be only a fraction of the total board thickness. Male-female embossing or the manufacture of molded hardboard is free from this limitation (fig. 282).

The deeper the embossing, the higher will be the density of the embossed portion of the board. And that density is limited to about 65 to 70 lb/ft^3. At greater densities, blisters occur in these areas and, in S1S boards, fibers are pressed into the carrying screens. The low-density areas should have a density of about 40 to 45 lb/ft^3 to insure a durable panel. Therefore, a density contrast of 40:70 represents the maximum practical degree of embossing; in a 1/4-in board that would be equivalent to an embossing depth of 1/10 in. Boards that are 1/8 in thick are generally pressed at higher overall densities and, therefore, do not lend themselves to deep embossing.

When embossing wood grain, the striations normally run lengthwise to the board and may therefore reduce the bending stiffness and the stability of the panel.

The manufacture of the caul plate starts with a photograph of the real material to be simulated, such as

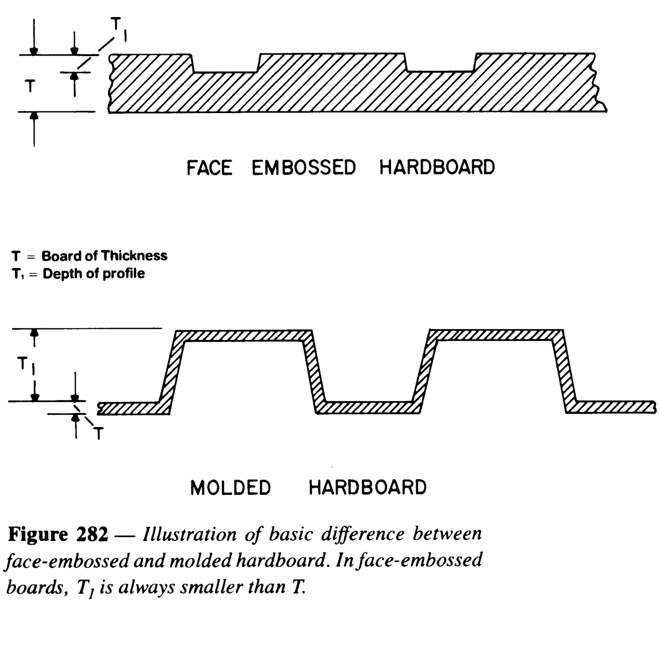


Figure 282 — *Illustration of basic difference between face-embossed and molded hardboard. In face-embossed boards, T_1 is always smaller than T.*

weathered wood or a fieldstone wall. The photograph is enlarged if neccessary and transferred to a master, which is then etched to an exact replica of the original. Modifications are made on the master, such as relieving sharp corners and eliminating undercuts. This steel master sheet is then mounted around a cylinder of a circumference equal to the length of the repeat pattern (60 or 96 in). The caul plate, generally 16½ ft long and made of hot-rolled steel, is wrapped around a second cylinder and coated with wax. As the two rotating rolls (the smaller one carrying the master and the larger one the caul plate) contact each other, the wax coating is worn away from the caul plate at the points of contact, allowing it to be etched. This process is repeated until the caul plate develops a profile that is the exact negative of the master. The caul plate is then removed from the cylinder and inspected for flaws and possible acid undercuts. After these are repaired, the caul plate is chrome plated (Eustis 1980).

Caul plates are very expensive and only a few are made of each pattern, so that in a 20-opening press, several patterns are pressed at the same time or embossed boards are pressed together with flat boards. This requires special attention to thickness control because the compression characteristics of embossed mats differ from those of flat mats. It is generally necessary to control the thickness of embossed boards by sanding the backside. As mentioned in an earlier chapter, embossed boards are surface tempered in an effort to increase wear resistance of the high spots (lower density).

Some embossed patterns must be trimmed in registry, either relative to the long edges as in plank patterns, or relative to both long and short edges as in brick patterns. For this purpose, the caul plates are designed to develop reference marks, such as flat spots or grooves on the board outside of the final trimmed dimension, that can be spotted and used for alignment by special sensing devices. Such devices can correct out-of-alignment pressing of up to 3/4 in.

An interesting variation of the embossing process is the manufacture of printed-paper-overlaid hardboard at Abitibi's Alpena, MI, plant to which reference has been made in earlier chapters. The embossed pattern carries the print down into the low spots, whereas in regular embossed board the printed pattern, being applied after embossing, appears only on the high spots. The paper is made to stretch in the press and is covered with a wax-coated release sheet that softens the contours and minimizes the cracking of the printed paper. Upon removal from the press the release sheet is separated from the finished board (Eustis 1980).

The manufacture of embossed board allows a modification of the stock freeness in the direction of shorter drainage times, particularly in the manufacture of S2S embossed board. This results in faster machine speeds, higher productivity, and refiner energy savings. This modification is possible because the embossed pattern will obscure the more visible fiber pattern of the freer stock. How far one can go depends on the characteristics of the pattern and is also limited by strength reductions of the mat. A northern mill reduces drainage time from 22 s to either 20 or 18 s when shifting from ¼-in S2S flat board to ¼-in S2S embossed board. Forming machine speed is increased by 10 to 20 percent.

This is only practical, of course, if the board line makes only embossed board. If flat and embossed boards are pressed simultaneously, the stock quality must be adjusted for flat board. Because S1S stock is already much freer than S2S stock, potential savings are much more limited; however, slight reductions in press cycle are possible.

Male-female embossed hardboard. Although male-female embossing would overcome the geometric limitations of face embossing, very little of it is done by board manufacturers. Both Weyerhaeuser and Masonite produce dry-formed door skins that simulate frame and panel construction with deep draws (fig. 283). There is, however, an industrial effort, separate from the manufacture of flat sheets, which specializes in the manufacture of molded products, both on a wet- and dry-formed basis (fig. 284). These products are aimed at very specific markets, and the manufacturing units are relatively small.

Finishing of Hardboard

Hardboard is a good substrate for the industrial application of finishes both in solid colors and printed patterns. It presents a smooth and hard surface, can be manufactured to close dimensional tolerances, and its properties can be controlled and modified to suit special applications.

The printing of simulated wood grain patterns on hardboard, in particular, has reached a degree of perfection that often deceives even the discriminating examiner and has opened important markets. Similarly, the remarkable commercial success of hardboard siding is due to a reputation of durability based on the quality of industrially applied finishing systems.

These successes clearly are the results of close cooperation between the manufacturers of hardboard, finishing equipment, and finishes.

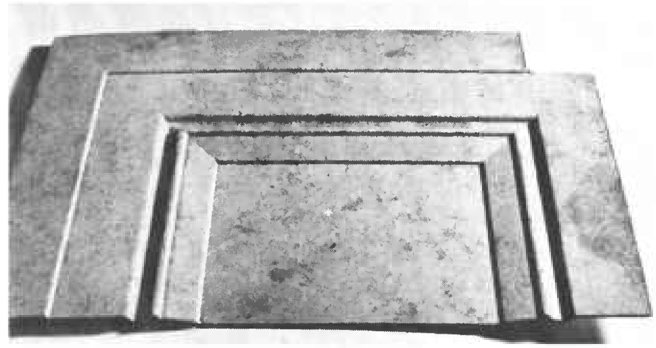


Figure 283—*Molded fiberboard doorskin.*

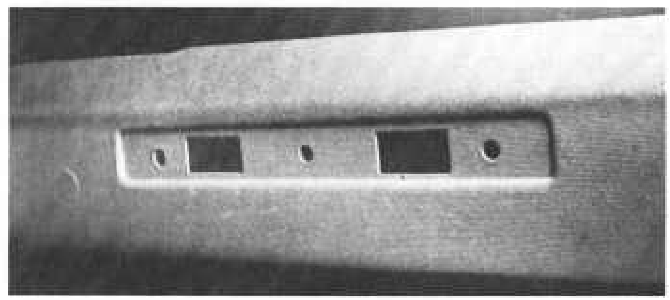


Figure 284—*Molded fiberboard automotive panel.*

Most hardboard is factory finished. Only a relatively small quantity of hardboard, manufactured for certain industrial markets, is traded unfinished. The ratio of finished to unfinished board can be as high as 9:1 in some hardboard operations.

Categories of finished hardboard products

Although any hardboard product could be used as substrate for any one of the finished product categories listed below, generally the substrates are manufactured for a specific end use:

Interior Paneling—Flat or Embossed. Wall paneling that is printed with wood grain and grooved for plank appearance or embossed and painted to simulate brick or stone wall. The substrate is generally a 1/4-in S1S board made at weights of about 925 lb/1,000 ft^2, which corresponds to a specific gravity of about 0.73, or a board density of 45.6 lb/ft^3 (table 30 and fig. 285). The 1/4-in thickness is desirable when the panel is mounted directly on a 2 by 4 wall without the added support of drywall. Wall paneling at 1/8-in thickness is made at higher densities.

Decorative Board. Paneling boards finished in solid colors or printed with designs other than wood grain and not normally grooved. They include vinyl-overlaid boards featuring a wallpaper look, and tile boards, the latter category often used on bathroom walls and as shower enclosures, one of the most demanding applications of hardboard.

Light solid colors and high gloss surfaces require very high quality substrates and the utmost cleanliness in the finishing operation. S1S substrates are not suitable because the screen back carries and releases particles that may settle on the wet finish. S2S boards are the ideal substrates for this application. A board thickness of 1/8 in is sufficient, because decorative boards are generally applied over gypsum board (drywall).

Table 30—*Weight of prefinished hardboard products of various thicknesses*

Type	Board weight ($lb/1,000\ ft^2$)		
	1/8 in	1/4 in	7/16 in
Paneling			
S1S	700-750	950	—
S2S	750	925	—
Decorative board			
S1S	700-750	950	—
S2S	750	925	—
Siding			
S1S	—	—	1,500
S2S	—	—	1,500

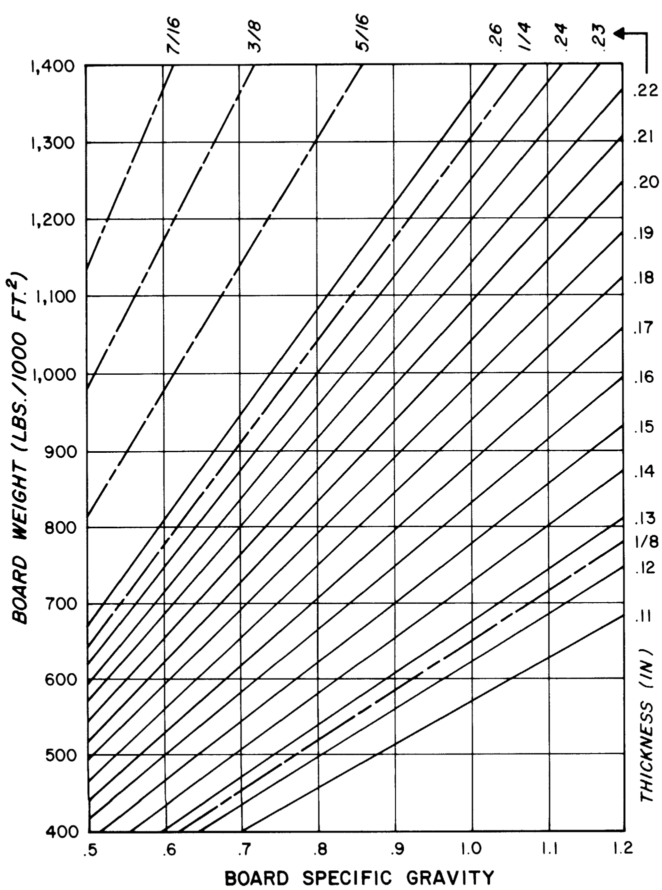


Figure 285—*Relationship of weight and specific gravity of board.*

Siding. *Hardboard siding made as lap siding or panel siding, either with a smooth or embossed surface.* Embossed siding often tries to simulate rough cut lumber, for example. Siding boards are made at 7/16 in thickness and at relatively low densities (see table 31). Both S1S and S2S boards are used.

Embossed boards (paneling and siding) have some unique finishing requirements: the base coat must be applied with a pile roll to reach into the crevices created by the embossing. Pile rolls are applicator rolls covered with a sleeve of soft material, similar in structure to pile carpeting. For two-tone effects, the high spots are then coated with the smooth roll of a precision roll coater. In general, embossed boards can tolerate more surface imperfections because the embossed surface profile obscures some defects.

Basic finishing materials

All finishes have three basic components:

Resin or binder. *The component that develops the necessary adhesive and cohesive forces to form the film and to bond it to the substrate.* It also controls many of the important properties of the finish such as water resistance, chemical resistance, weatherability, and strength. Table 31 (Bufkin and Wildman 1980) lists some important binder types and their applications. Most commonly used in hardboard finishing are acrylic, alkyd, and polyester resins. Their preferred applications, relative water resistance, and relative costs are listed in table 32. Combinations of these resins are also used.

Pigments. *The color in coatings.* Some common pigments employed in the coatings industry are listed in table 33.

Solvents. *The component that maintains the coating in the liquid state and controls its working properties, most importantly its viscosity.* Solvents are not permanent parts of the coating but evaporate soon after application so that the coating can solidify. Solvents are selected on the basis of their capability to dissolve the resin component, on their rate of evaporation, toxicity, flash point (temperature at which the gaseous phase can be ignited by a spark), and, of course, cost. In addition, because the solvent upon evaporation from the film mixes with the air, air quality standards may limit the quantity of solvent that can be evaporated and vented into the atmosphere, or may prohibit the release of certain solvents. In such cases, it becomes necessary to either trap or incinerate the solvent.

Solvents used in hardboard finishing are usually organic compounds—for example, toluol and xylene, which have high rates of evaporation, requiring incineration; butyl acetate, 2-butoxyethanol (butyl Cellosolve) and 2-ethoxyethyl acetate (Cellosolve acetate), which have slower rates of evaporation, so that incineration is not required. Water as a solvent of industrial finishes has the important advantage of low cost and complete safety from the standpoints of both worker exposure and atmospheric pollution. These advantages will undoubtedly provide strong incentives for significant future developments in this area of finishing and finishes. However, water-borne finishes do not develop the high water resistance achieved with finishes that are borne by other solvents.

Table 31—*Typical binders used in the coatings industry and their application areas (Bufkin and Wildman 1980)*

Binder type	Typical application areas
Alkyd polyesters	Metal topcoats Wood furniture and fixture paints Coil coatings Primers Machinery finishes Marine coatings Paper and paperboard coatings Industrial maintenance Appliance finishes
Epoxies	Chemically resistant coatings Marine coatings Can coatings Appliance finishes Automotive primers
Acrylics	Automotive coatings House paints Coil coatings Appliance finishes Machinery finishes Paper and paperboard coatings
Cellulosics	Automotive coatings Furniture finishes
Vinyl resins	Automotive coatings Can coatings Tank coatings House paints Plastic coatings
Urethanes	Coatings for flexible substrates (plastics) Wood furniture and fixture coatings Automotive coatings Paper and paperboard coatings
Rubber-base products	Sealers Swimming pool paints Marine coatings

High-speed finishing requires considerable input of heat energy for solvent evaporation, and to provide temperatures needed for chemical reactions involved in solidification.

Vinyl films or paper overlays represent an entirely different method of surface treatment. Here, printed paper or plasticized vinyl film, usually 2 to 6 mils thick (0.002 to 0.006 in), normally embossed with a cloth weave pattern, is laminated to the substrate with a water-based adhesive.

Industrial practices

Finishing installations should not be thought of as minor appendices to the hardboard manufacturing process. Finishing is a quite significant phase in the manufacture of siding, decorative board, and paneling. It is capital and energy intensive and reflects a major engineering effort in board processing and materials handling.

In many mills, the finishing department is indeed an extension of the board manufacturing process. In others, it is removed and independent of board manufacturing and may serve more than one board plant.

Although there does not exist a "standard" finishing line, and no two finishing lines may be exactly alike, all

Table 32—*List of binders used in hardboard finishes by relative cost, relative water resistance, and primary application*

Resin	Relative cost	Relative water resistance	Primary application
Acrylic	High	High	Tile board, siding
Polyester	Medium	Medium	Tile board, siding
Alkyd	Low	Low	Paneling

Table 33—*Pigments typically employed in the coatings industry (Bufkin and Wildman 1980)*

Pigments	Property
Color	
Organics	
Diazo pigments	Yellow, orange, blue
Quinacridone pigments	Red, violet
VAT pigments	Yellow, orange, blue, violet, red, brown
Phthalocyanine pigments	Blue, green
Tetrachloroisoindolinone pigments	Yellow, orange, red
Inorganics	
Oxides	White, red, yellow, brown, green
Chromates	Yellow, orange, green
Cadmium pigments	Yellow, orange, red
Ferrocyanide pigments	Blue
Carbon	Black
Metallics	Numerous
Noncolor	
Extenders or fillers	
Calcium carbonate	Modify gloss, viscosity, and/or other properties
Clay	
Mica	
Talc	
Amorphous silica	
Pigments used primarily for functional reasons	
Cuprous oxide	Antifouling action
Zinc dust	Anticorrosive action
Zinc oxide	Mildew-static action
Red lead	Anticorrosive action

apply the same finishing technology and contain essentially the same processing steps.

The following descriptions of finishing lines are intended to illustrate, in a general way, the status of hardboard finishing.

Finishing line for interior wall paneling and for decorative board. The line illustrated in figure 286 can be used either for grooved wood grain printed interior paneling or for decorative board. This flexibility is offered by providing alternative coating machines.

The boards are put into the line by means of a vacuum feed device (fig. 287). A brush cleaner removes dust from the board surface and prepares the board for the two-step application of the **fill coat**.

The fill coat is applied by one or two reverse roll coaters, each followed by a high velocity hot-air dryer. The **reverse roll coater** is a direct roll coater (fig. 250), followed by a highly polished, chrome-plated roll rotating opposite to the board feed. This forces the fill coat into the surface pores, wipes off any excess material, and leaves a smooth surface for subsequent coats (figs. 288, 289).

In the **high-velocity hot-air dryers**, jets of air impinge on the board surface where rapid energy transfer evaporates the solvent (fig. 290). These dryers are gas fired and may be equipped with solvent incinerators and heat exchangers for the recovery of the combustion heat (fig. 291).

The dried fill coat is then buffed lightly with fine grit sandpaper (320 to 400 grit). The grooves on wall panels are now spray painted, generally in a contrasting dark color.

The **ground coat** is applied next. It is of a color that serves as a background for the printing process. On

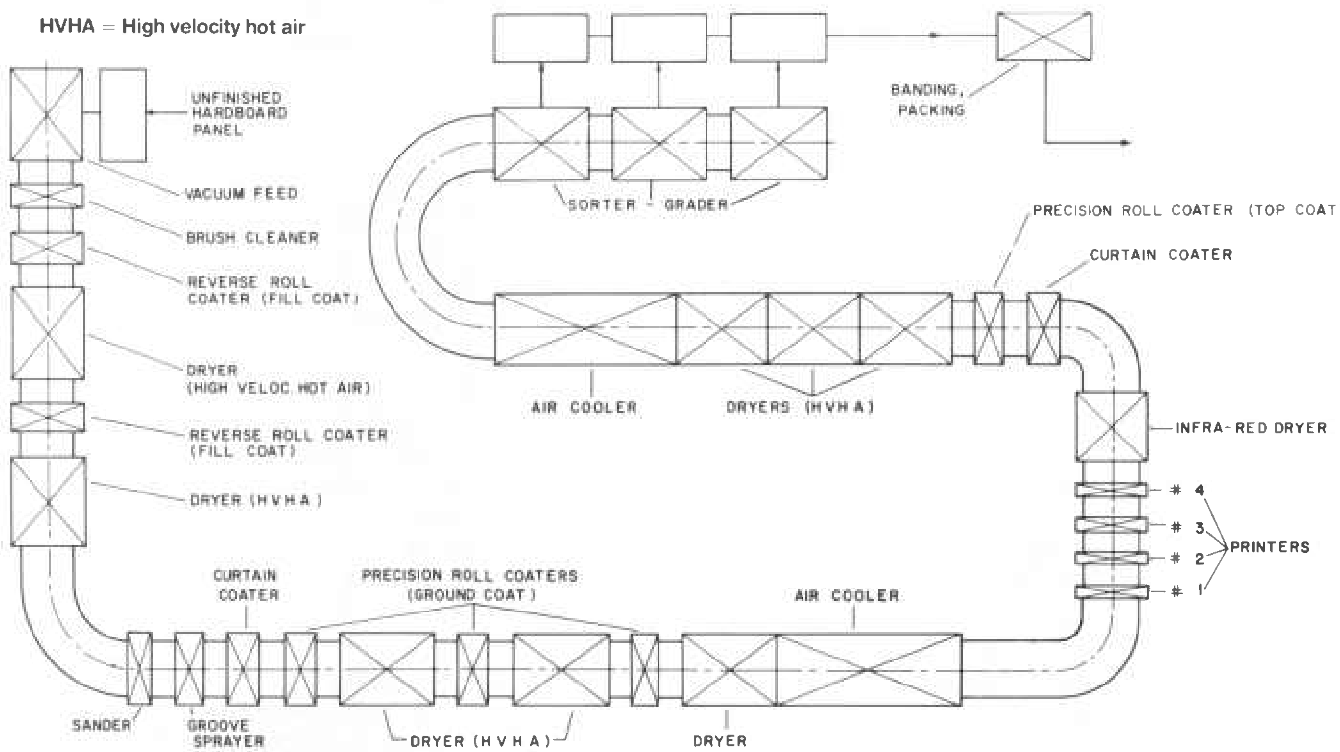


Figure 286—*Finishing line for wood-grain-printed interior paneling or for decorative board.*

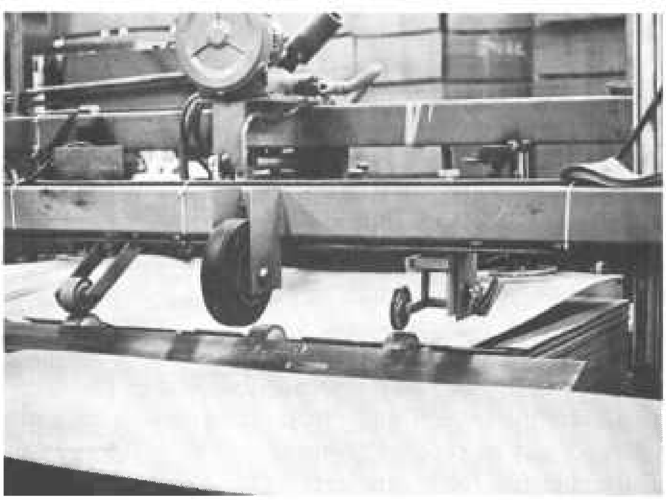


Figure 287—*Vacuum feed. Boards are removed from stack by vacuum cups and transferred to finishing line.*

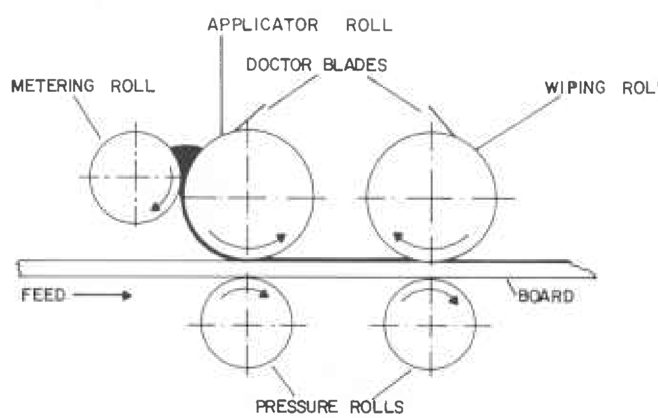


Figure 288—*Schematic illustration of reverse roll coater.*

grooved hardboard panels, the ground coat is applied with precision roll coaters that apply the coating only to the top surface of the board (fig. 292). The spray-painted grooves are not ground coated. On decorative panels the ground coat is applied with a **curtain coater,** which produces a film of excellent surface smoothness (figs. 293, 294). Figure 286 shows three ground coat applications, each followed by a high-velocity hot-air dryer and a final air cooler.

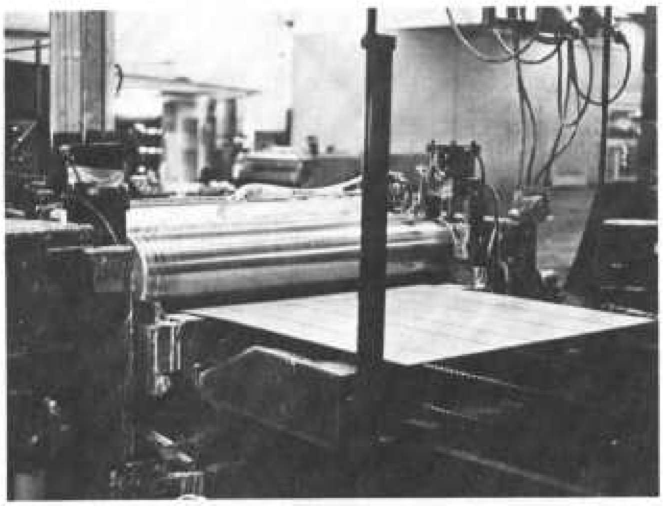


Figure 289—*Outfeed end of reverse roll coater applying fill coat to grooved panel.*

The boards are now ready for printing. The printing of wood-grained and certain decorative panels is done on one or more **offset printers** (fig. 295). Their principle of operation is identical to that of precision roll coaters: a metering roll transfers printing ink to a **gravure cylinder** on which the desired pattern is engraved. A doctor blade removes the ink from the cylinder except for the engraved areas. The ink collected in the engraved areas of the gravure cylinder is then transferred, by contact, to the offset or print roll. The relatively soft print roll in turn transfers the ink to the substrate (fig. 296).

The **wood grain pattern** to be printed is based on a photograph of a real wood panel, which is then separated into several different patterns, and applied successively in different colors by a number of printers in series. It is common in the board industry to have three or four printers on the print line. A printer will, of course, produce a repetitive pattern that may repeat itself even on the same board. Ideally, a 96-in repeat would be used for

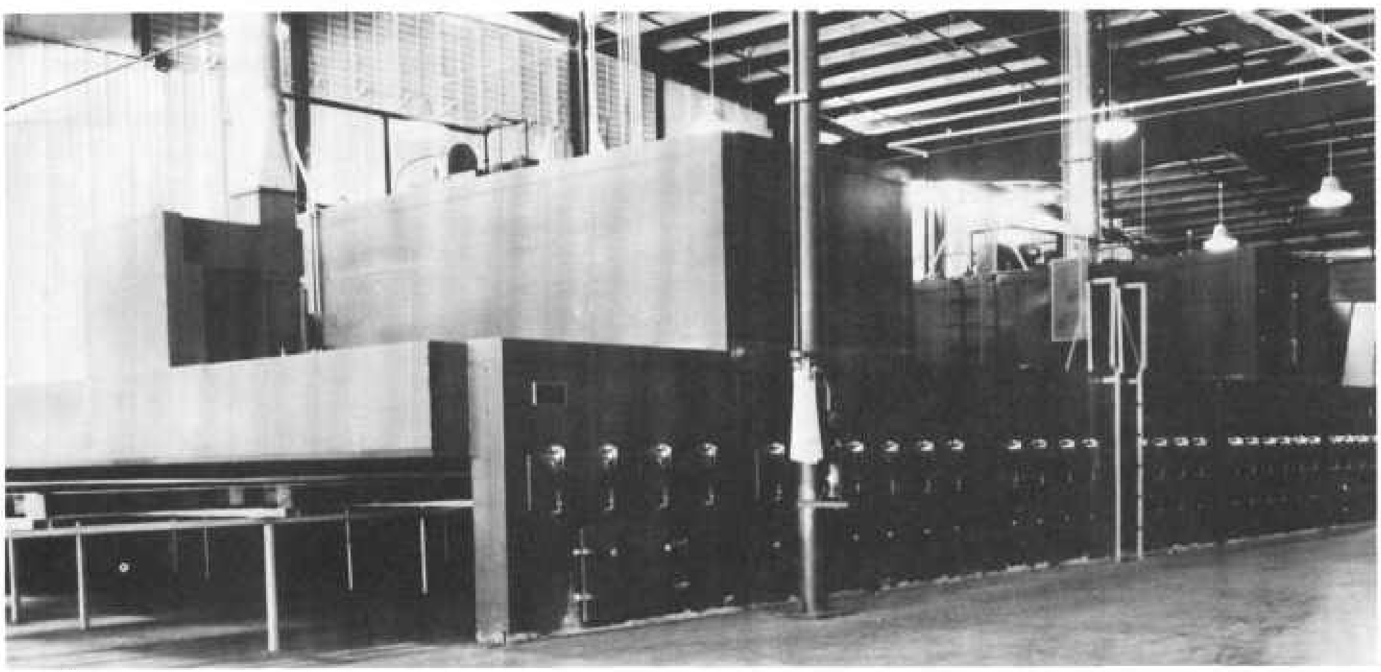


Figure 290—*High-velocity hot-air oven, fired with natural gas (Thermal Engineering Corp.). Cross transfer conveyor line visible at left feeds 4- by 8-ft boards laterally. This is a "double pass" oven—two units in series.*

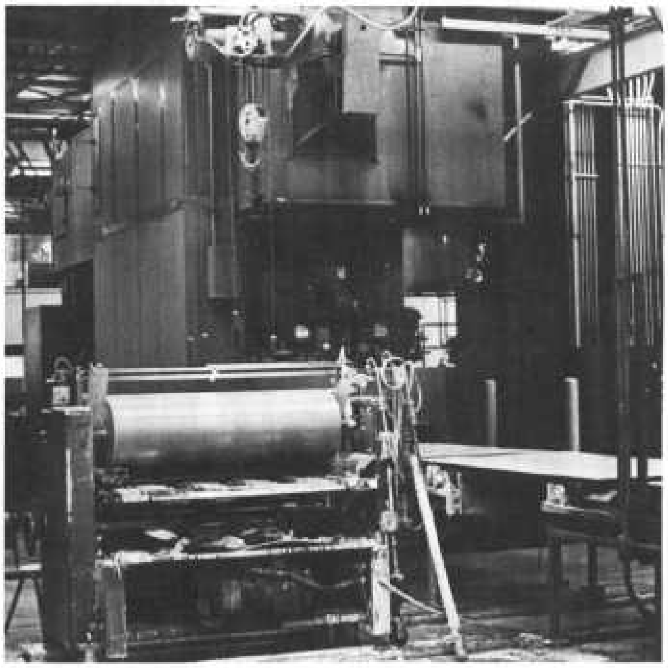


Figure 291—*High-velocity hot-air dryer for drying fill coat. This dryer is similar to that shown in figure 290, except that it is equipped with an incinerator for burning evaporated solvent and heat exchanger for recovery of heat of combustion. Both elements are housed in superstructure. Precision roll coater in foreground is mounted on tracks and temporarily removed from line.*

96-in paneling, which means that the circumference of the gravure cylinder would have to be 96 in, with a 30.6-in diam. Commonly, a 60-in repeat (19-in diam) gravure roll is used for wall paneling. Smaller rolls would produce patterns that would tend to look artificial in a fully assembled wall.

The steps involved in producing a gravure cylinder are described by Davis (1966):

> A gravure cylinder is made by a photo-engraving process. The copy, i.e., the real panel, is first photographed, and the photograph is touched up by hand for a good tie-in of beginning and end, plus alterations of certain features such as knots. A transparency is made that will fit around the cylinder, usually in two parts. This is attached to a light-sensitive gelatine sheet that has a screen pattern exposed on it. The screen determines the number of cells per square inch that will hold ink in the press. Gravure printing is based on the principle of many small cells of equal surface area and varying depths holding and depositing ink—the deeper the cell, the darker the image. After exposure, the gelatine is separated from the transparency and attached to a copper cylinder. The treated gelatine becomes insoluble in water where light strikes it. The exposed cylinder is then washed in warm water, where the darkest areas exposed to the transparency wash away the most, and the lightest areas wash

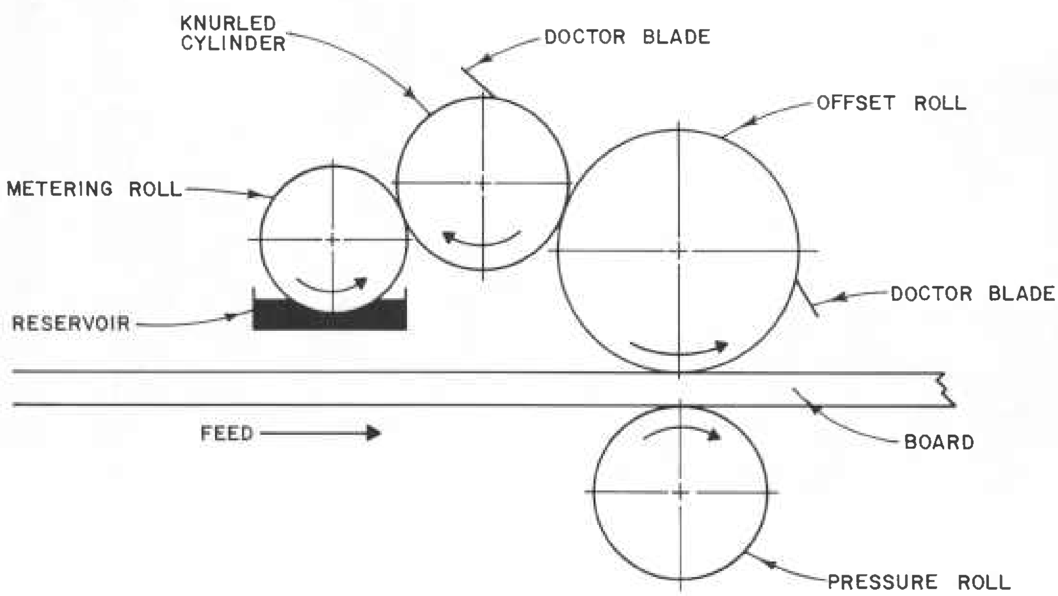


Figure 292—*Schematic illustration of precision roll coater.*

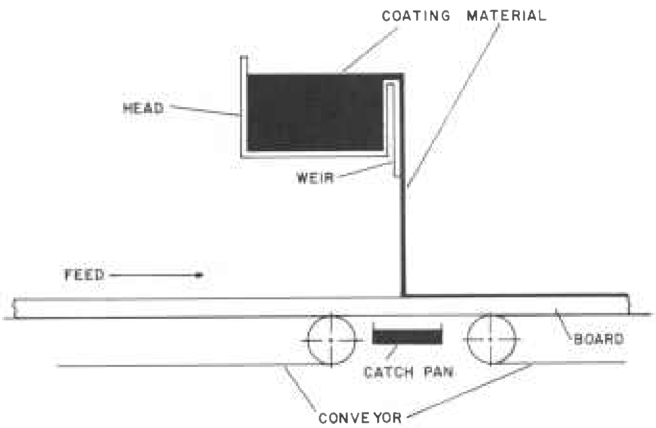


Figure 293—*Schematic illustration of curtain coater.*

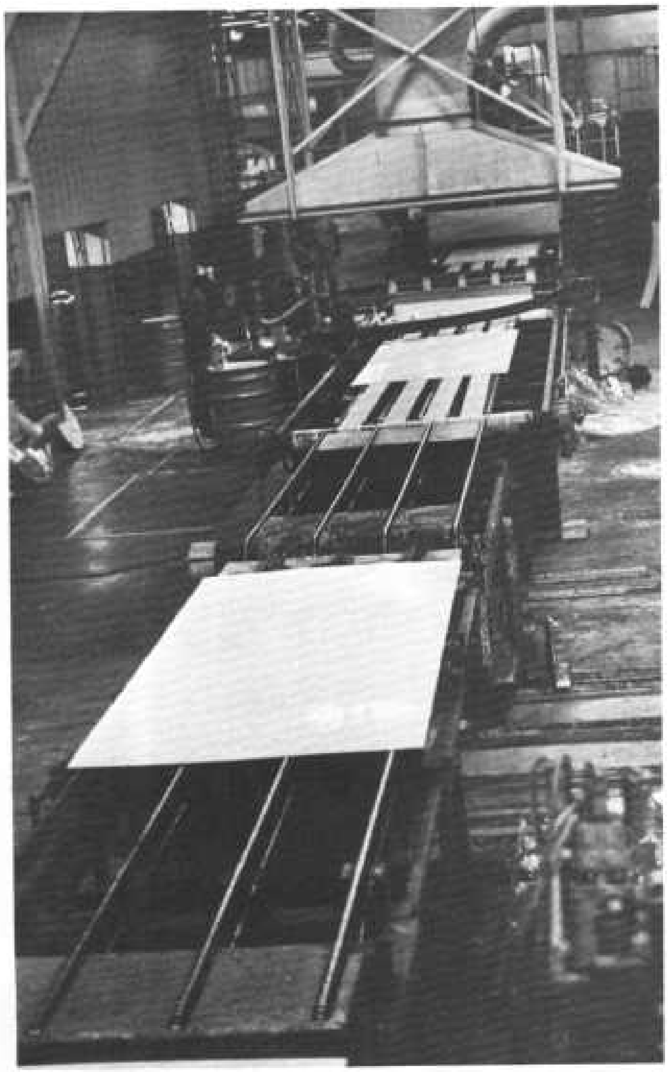


Figure 294—*Groundcoat applied to decorative board by curtain coater (under hood).*

away the least. The cylinder is then washed in acid, which attacks the parts with least gelatine first, thus etching the deepest cells where the transparency was darkest. Imperfect spots on the etched cylinder are then "hand-tooled" by an engraver. A good engraver can create, in copper, a gravure cell at the flick of a wrist. Finally, the cylinder is plated with hard chrome after it is approved for quality.

Of great importance in the printing process is the perfect registry of the several printers involved. Normally, they are close enough together so that the front end of a 4-by 8-ft sheet engages the second printer before the rear end leaves the first, assuring uniform speed of the boards through the printers. Caliper is important here, because thickness variations will result in speed variations.

In the printing of embossed boards, the printer pattern must match the embossed pattern. This requires conveyor feed employing lugs, so that every board contacts the printer at exactly the same spot.

A **brick pattern**, such as Chicago common brick, which has black and white and brown bricks all in the same pattern, would be printed by three printers, one for the white bricks, another for the black bricks, and a third for the brown bricks. Before printing, the entire board would be coated with a ground coat (pile roll) of the color of the mortar joint (fig. 297).

The print coat may dry sufficiently just utilizing the heat energy contained in the board, or the board may be passed through a gas-fired **infrared dryer** (Davis 1966) (fig. 298). Some solid color decorative boards may, of course, bypass the print line altogether.

The boards are now ready for the top coat, which is applied to grooved and embossed panels by a precision roll coater and to decorative boards by a curtain coater. This operation is followed by evaporation of part of the solvent into ambient air, called an **air flash** (fig. 299), and by several dryers, which bring the surface temperature up to 500 °F. Then, the boards are cooled (fig. 300) to a maximum surface temperature of 115 to 120 °F to prevent **blocking** (the dulling of the surface at pressure points during stacking) (Davis 1966). Finished boards are graded, stacked, and packaged (fig. 301).

Line speeds of this type of finishing line are between 150 and 200 ft/min for 1/4-in board (interior paneling) and 120 ft/min for tile board. Interior paneling requires less top coat and, therefore, allows greater line speed. Tile boards will be exposed to high humidities and therefore require a heavier top coat, which slows down the line. Line speeds are generally limited by the dryers. If drying temperature is pushed too high for quicker drying,

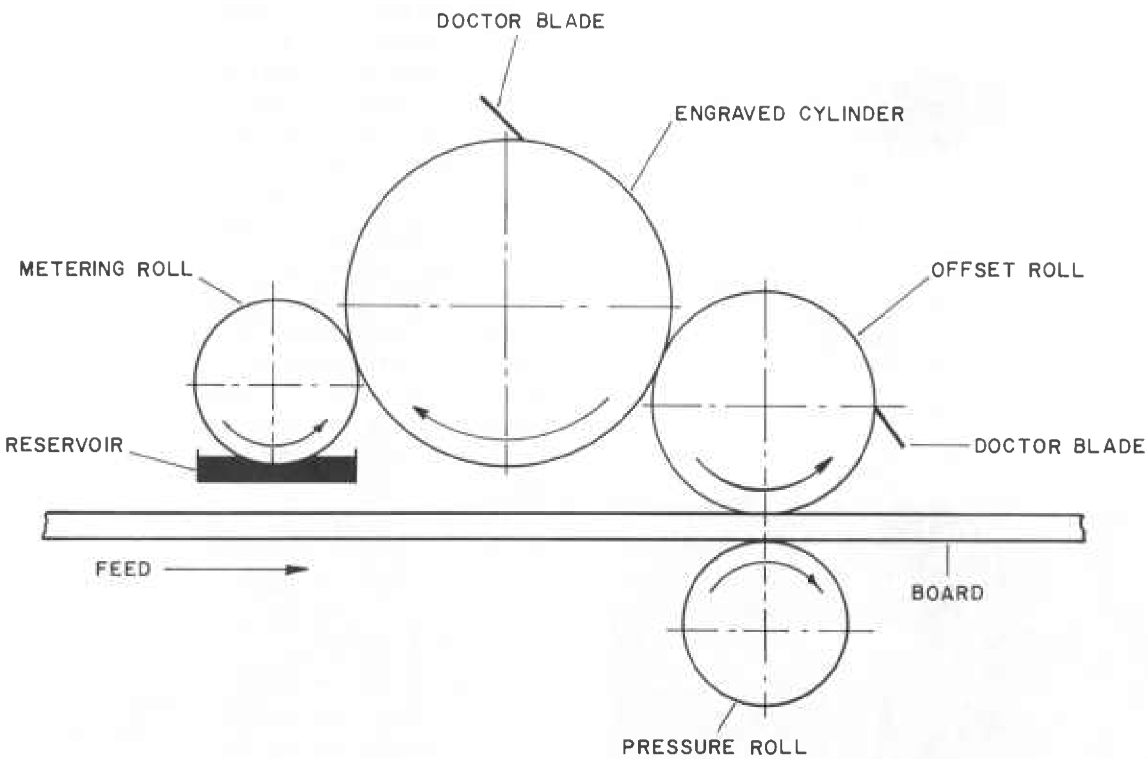


Figure 295—*Schematic illustration of offset printer.*

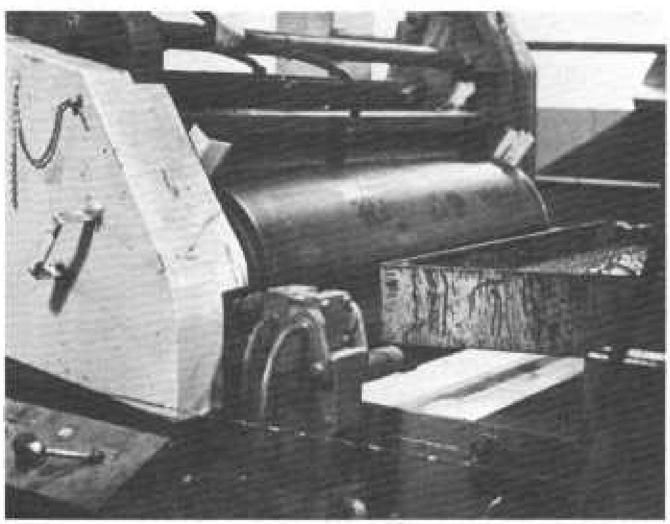


Figure 296—*Print roll of offset printer applying floral pattern to decorative board.*

coatings become brittle. The following are examples of practical thicknesses of finishing coats:

1/4-in interior paneling	
Fill coat	0.3 dry mil
Ground coat	0.8 dry mil
Top coat	0.6 dry mil
Total	1.7 dry mil
Tileboard	
Fill coat	0.3 dry mil
Ground coat	1.1 dry mil
Top coat	0.8–1.0 dry mil
Total	2.2–2.4 dry mil

Note: "dry mil" is the thickness of the dry coat in 1/1000 in.

Finishing line for hardboard siding. Figure 302 shows a siding finishing line. All coats on siding are top coats (thermal-set acrylic latex). The thickness of the coats (2.0 to 2.2 dry mils total) varies with the time for which the siding is guaranteed. However, only about 30 percent of all hardboard siding is completely prefinished; 70 percent is only primed. Primed siding provides greater flexibility regarding color selection of the final coat or

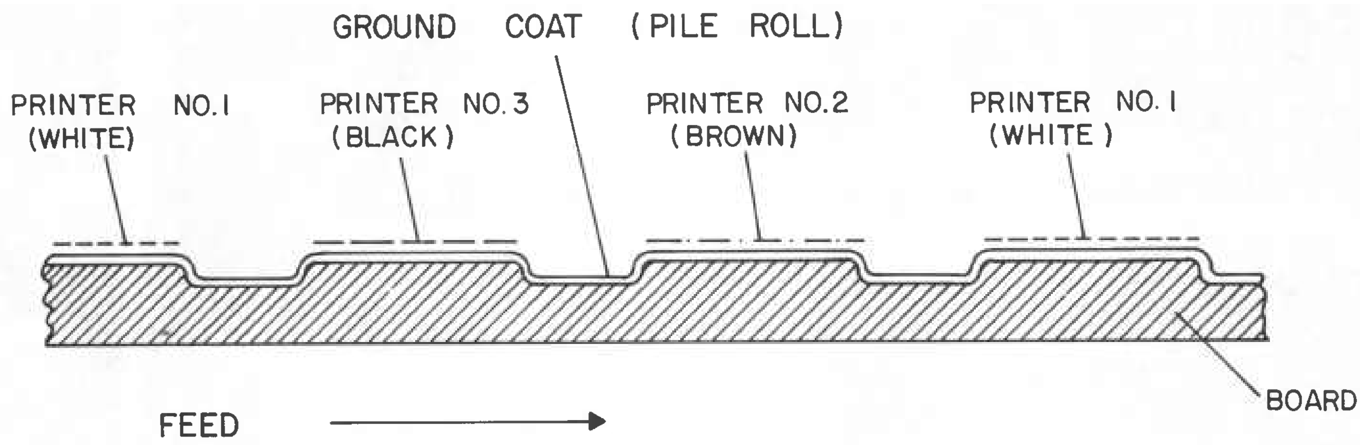


Figure 297—*Multicolor printing of panels, to resemble a wall with bricks of three colors, with three offset printers in series, one for each brick color.*

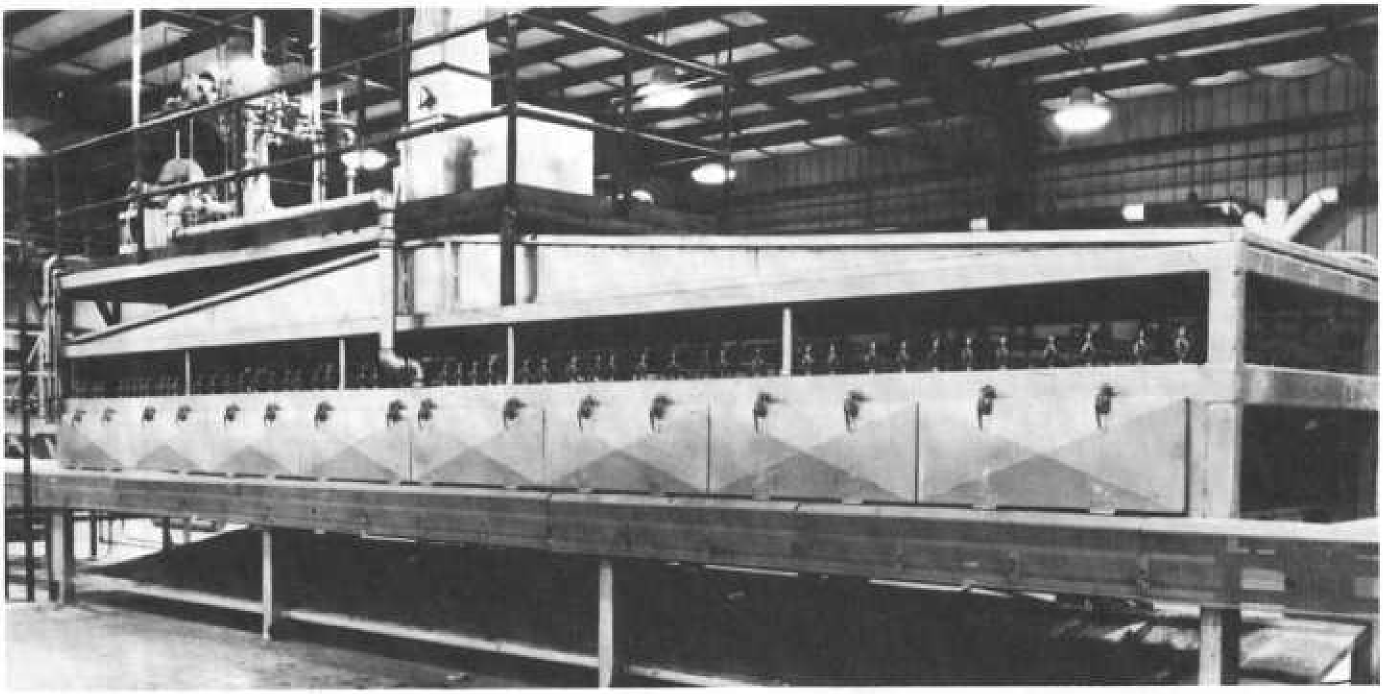


Figure 298—*Infrared oven for single pass of 4- by 8-ft board used for the drying of print coat (Thermal Engineering Corp.).*

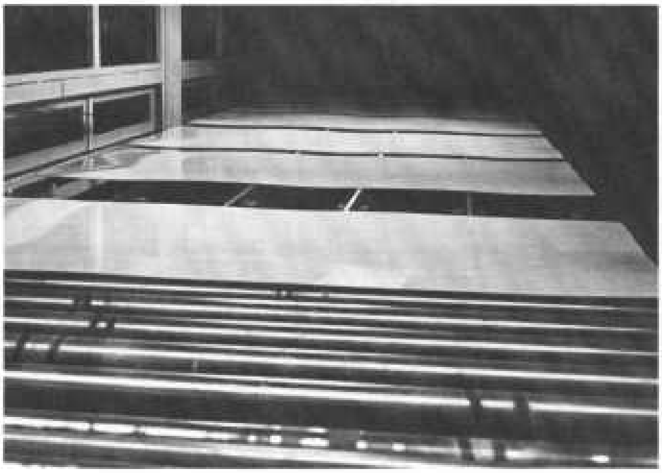


Figure 299—*Panels, just after having received top coat, are being exposed to ambient air for evaporation of part of solvent (air flash). This is followed by high-velocity hot-air dryers.*

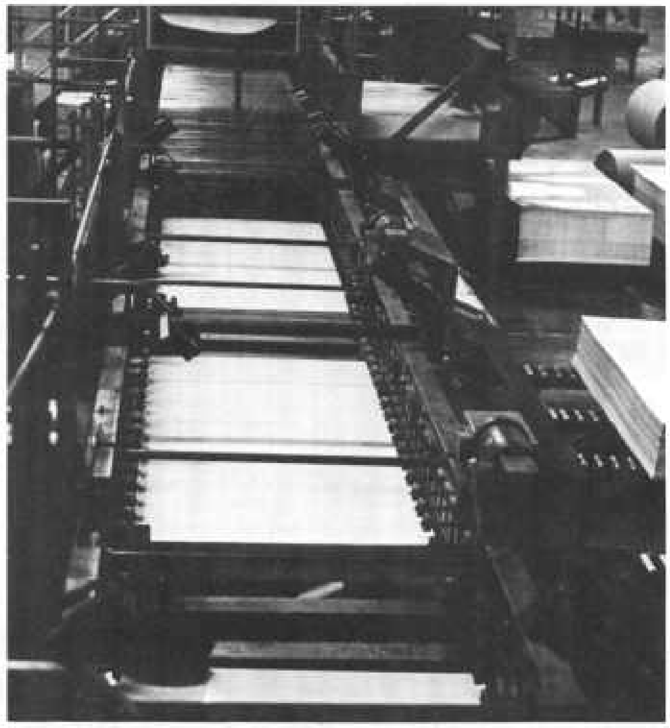


Figure 301—*Grading station for finished decorative hardboard.*

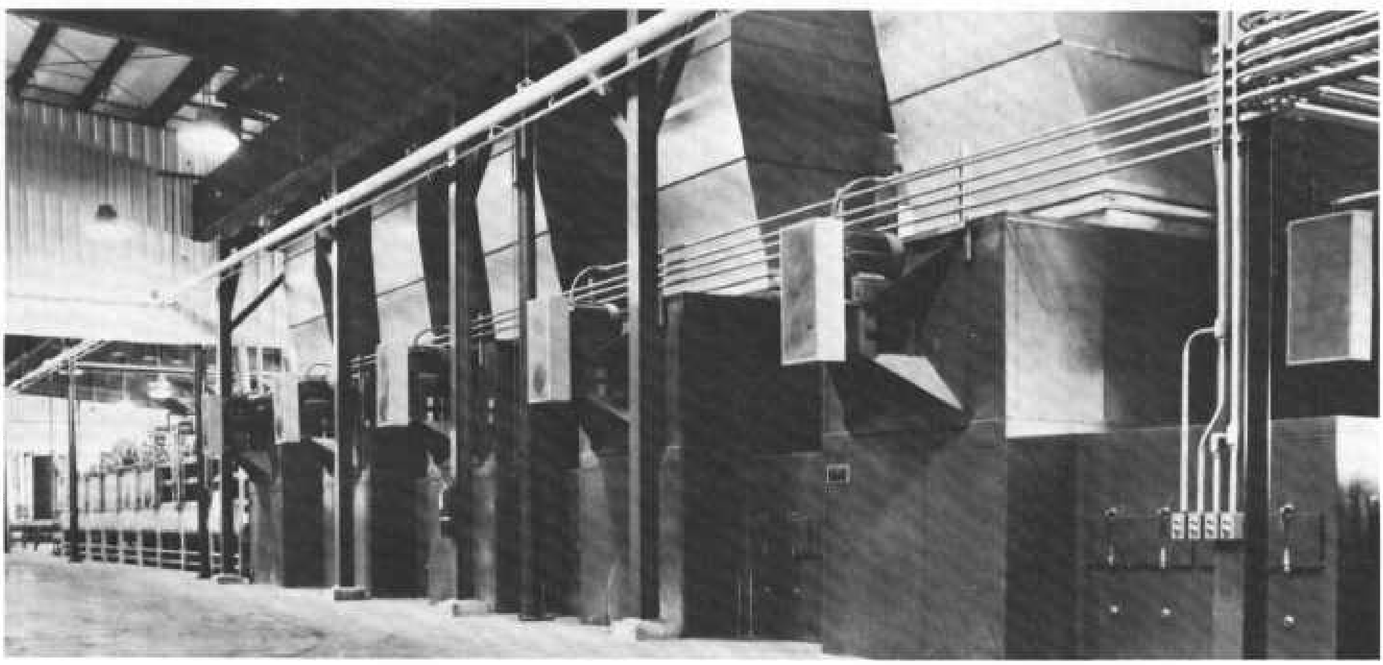


Figure 300—*High-velocity impinged air cooler at end of hardboard finishing line. Note massive intake and exhaust ducts. (Thermal Engineering Corp.)*

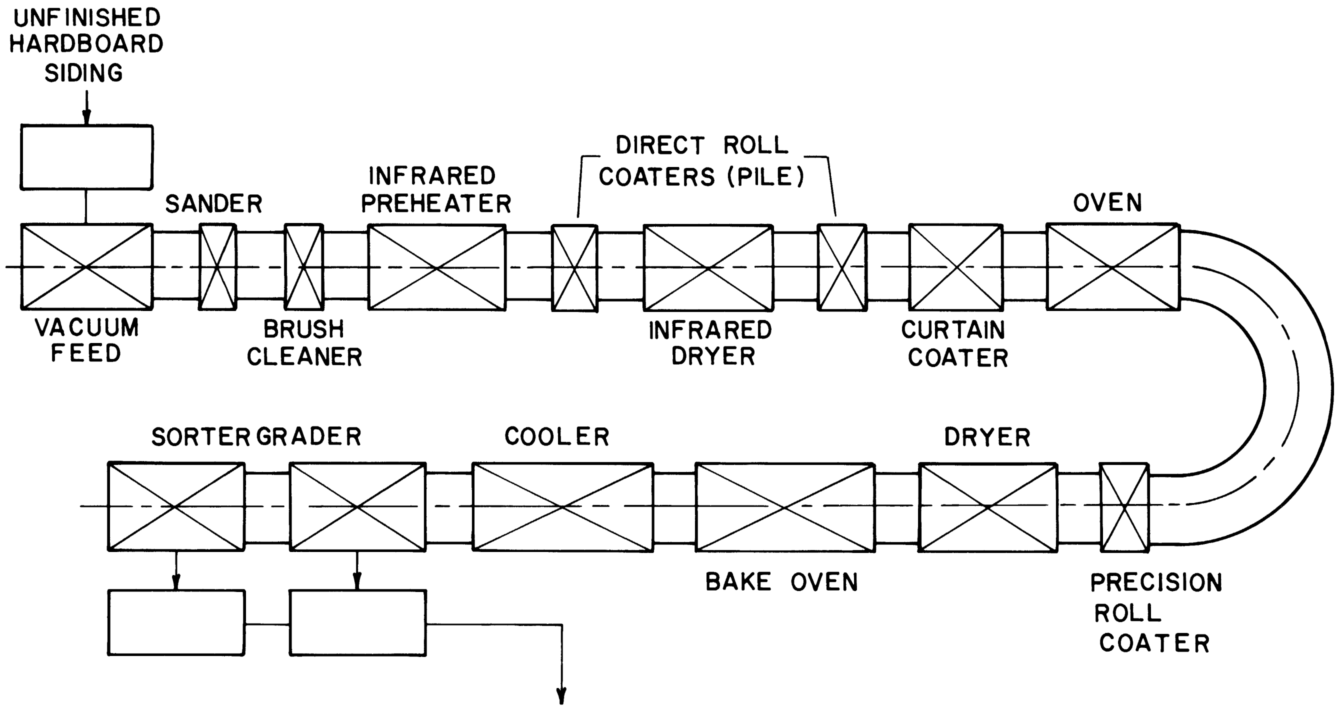


Figure 302—*Finishing line for hardboard siding.*

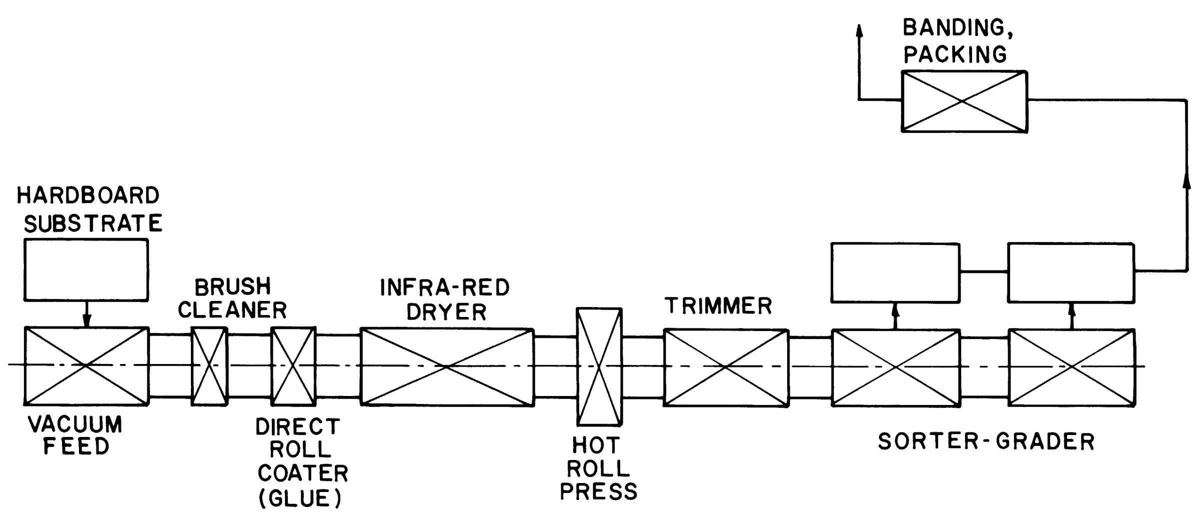


Figure 303—*Finishing line for vinyl or paper overlaid hardboard.*

coats applied after installation. Limiting the prefinishing operation to a prime coat also avoids the burden of providing a performance guarantee for the finished product. Line speed is about 150 ft/min.

Sanding the bottom surface of the board to reduce thickness variation is particularly important for two-tone embossed siding products, where the high spots are coated with precision roll coaters.

Regular embossed siding is coated with direct roll coaters equipped with pile rolls. For only lightly embossed boards and flat boards, a curtain coater is used. The solvent is removed in a dryer, and the resin is cured in a bake oven at a surface temperature of 300 °F. This is followed by air cooling (1 min), grading, and packing.

Finishing line for vinyl and paper overlays. This type of finishing line is shown in figure 303. A latex glue is rolled on the substrate by a direct roll coater. The glue is dried in an infrared dryer and the overlay is applied by a heated press roll (fig. 304). The excess overlay is trimmed off by knives or abrasive wheels or the overlay is laminated to an oversize board and trimmed to size with the board (fig. 305). The Abitibi paper overlay method by which the printed paper is applied to the wet mat of S1S board before pressing with embossed caul plates has been mentioned in previous chapters. After fabrication, a pile coat is applied to the "paper" surface, after which a **"pick off" coater** (direct roll coater) picks surplus paint off all the high spots. This leaves the accent coat, which was applied with a pile coater only in the low spots and gives it a very attractive appearance. This is followed with a top coat (fig. 306) (Eustis 1980).

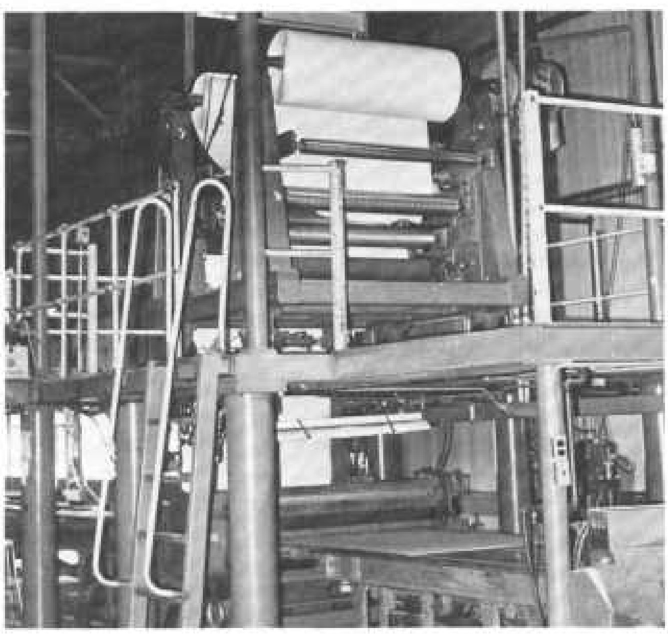


Figure 304—*Infeed end of vinyl overlay line. Two rolls of vinyl overlay are visible on top of machine. Material from one roll is being fed down vertically to substrate conveyor where it is applied to adhesive-coated board.*

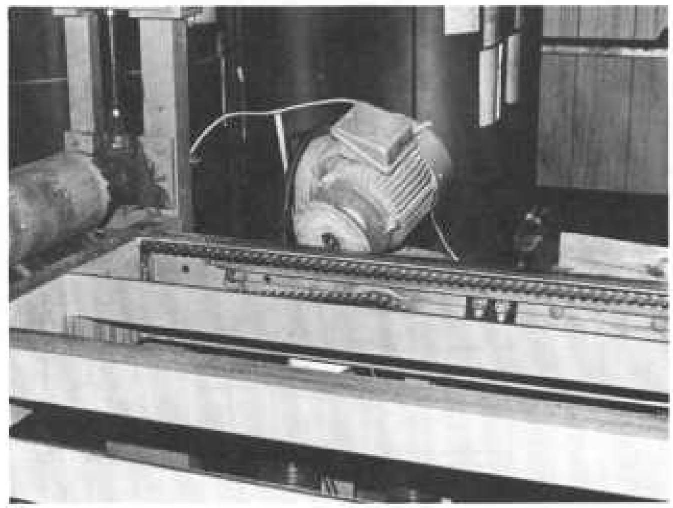


Figure 305—*Abrasive wheel for trimming excess overlay along board edges.*

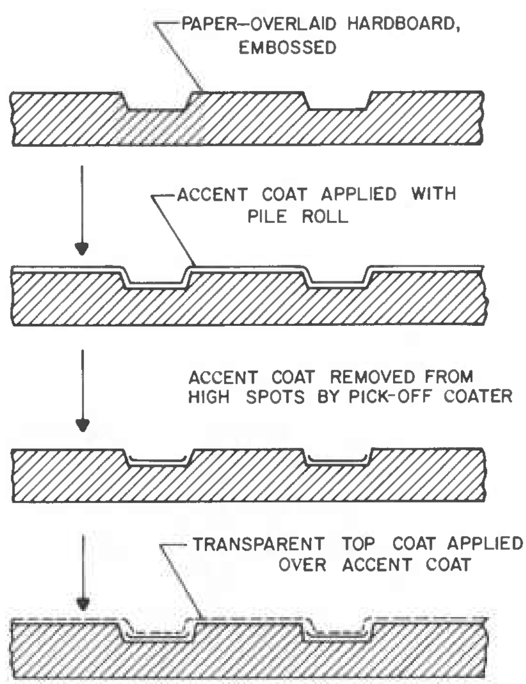


Figure 306—*Finishing sequence of paper-overlaid embossed hardboard.*

Packaging

Some finished hardboard products and many embossed boards are wrapped in paper, either individually or two pieces per bundle. Automatic wrapping machines wrap paper around the face of the board and attach it with an adhesive to the back. The face of the board is thus protected until the wrapper is removed before installation at the site (figs. 307, 308).

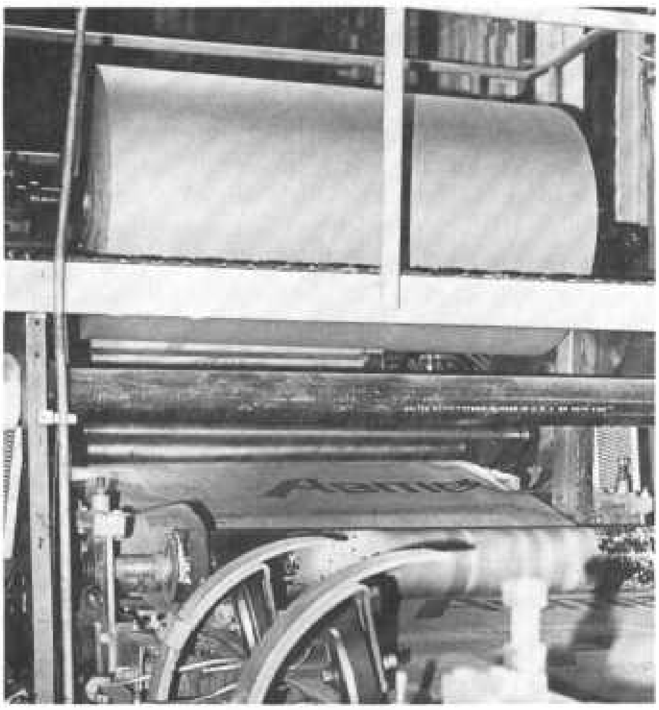


Figure 307—*Automatic wrapping machine for finished hardboard. Rubber covered rolls in foreground fold paper around edges of each board.*

Figure 308—*Wrapped and unitized finished hardboard panels. Panels are wrapped individually. Spacer blocks and wood stringers are included in each package to facilitate handling by fork lift truck.*

References

Abitibi-Price Corp. Troy, MI.

Bufkin, B.G.; Wildman, G.C. Environmentally acceptable coatings for the wood industry. Forest Products Journal. 30(10): 37–44; 1980.

Davis, B. Wood graining on a modern production line. Forest Products Journal. 16(3): 31-36; 1966.

Dyer, H. Celotex starts up world's most automated fiberboard mill. Paper Trade Journal. November: 30-39; 1960.

Eustis, O.B. State of the art of the fiberboard industry. 1980. Unpublished manuscript.

Maloney, T.M. Modern particle board and dry-process fiberboard manufacturing. San Francisco: Miller Freeman Publications; 1977. 672 p.

McMillin, C.W. Computer numerical control of woodworking machines in secondary manufacture. 1982. Unpublished manuscript.

Thermal Engineering Corp. Columbia, SC.

Walton, A.T. How insulating board products are made by the Simpson Logging Company. Forest Products Journal. 1(1): 91-94; 1951.

12. Water Use and Treatment

General

Low fiber concentrations employed to manufacture wet-process fiberboard require large quantities of **process water** (see fig. 133). Without any conservation effort the manufacture of 1 ton of board would require up to 100 tons of fresh water, most of which would be discharged from the mill carrying a variety of contaminants.

Legal restrictions on the contaminant level of discharged process water have encouraged water conservation by reuse or recycling and have necessitated treatments to reduce contaminants in the discharged portion of the process water. Recycling of water poses certain manufacturing problems and can result in reduced board quality. **Waste water** treatment increases both capital investment and operating costs.

This chapter outlines important aspects of the water problem and describes some practical solutions. For a more comprehensive statement of the problems and more detailed analyses of various solutions, the reader is referred to the two EPA documents (1973, 1978) listed in this chapter's references.

The Water Problem

The contaminants or impurities occurring in the waste water of fiberboard mills may be placed in the following categories (Gran 1972):

1) Suspended solids (fibers and cell fragments).
2) Colloidal organic substances originating from the wood raw material.
3) Dissolved solids (soluble organic substances released from the wood raw material).
4) Soluble and insoluble chemicals added during the manufacture of fiberboard; e.g., alum, paraffin, fungicides, synthetic resins, etc.

In addition, the process water is discharged at higher temperature and reduced pH value.

Discussion here is limited to the categories identified above as suspended solids (SS or TSS) and dissolved solids (DS or TDS) because they constitute the vast majority of the waste water impurities.

Suspended solids when released may kill fish and shellfish by clogging their gills and respiratory passages and may cause abrasive injuries. Excessive discharges of such fiber material may also blanket lake or river bottoms, killing eggs and food organisms and destroying spawning beds (EPA 1978). Thick fiber deposits on lake bottoms eventually decay and rise to the surface, creating noxious conditions and oxygen depletion. The harmful effect of suspended solids release depends largely on specific conditions such as the carrying capacity of a river, the size of a stream or lake, etc.

Removal of suspended solids from the effluent is called **primary treatment** of waste water and is practiced by most pulp and paper mills.

The suspended solids content of a water sample is determined by passing it through a standard glass fiber filter. The retained solids are dried at 103 to 105 °C. The suspended solids content is expressed as the dry weight of the solids per unit weight or volume of water sample (kilograms per 1,000 kilograms, milligrams per liter, or pounds per ton). Average values of total suspended solid concentrations in the waste water of various fiberboard mills are shown in table 34 (EPA 1973, 1978).

Dissolved solids are generated by the hydrolysis of hemicelluloses and the acetyl groups accompanied by the formation of acetic acid, which further accelerates the hydrolysis (Gran 1972). These reactions occur during thermal treatment of pulp chips prior to or during the pulping operation. The treatment conditions are therefore important parameters affecting the loading of process water with dissolved solids (figs. 309, 310) (EPA 1978, Asplund 1972) (See also Dallons 1978 and fig. 84).

Dissolved solids decompose relatively quickly in the receiving waters and can cause **oxygen depletion**, which in turn could inhibit fish life. Fish require a dissolved oxygen level in the water of about 5 ppm; cold-water fish require slightly more, warm water fish slightly less (Beak 1963). If the effluent of a pulp mill should reduce the oxygen content of the receiving waters below these levels then the effect on fish life could indeed be harmful. Clearly, local conditions such as size of the receiving waters, flow rates, assimilative capacity, etc., have important bearing on the severity of any specific pollution problem.

Removal of dissolved solids from the effluent is called **secondary treatment** and is considerably more expensive than primary treatment.

The dissolved solids content of a water sample is determined indirectly by measuring its **biochemical oxygen demand** (BOD). The BOD is a measure of biological decomposition of organic matter in a water sample. It is obtained by measuring the oxygen required by micro-organisms to oxidize the organic contaminant of a water sample under standard laboratory conditions, including incubation for 5 days (BOD_5). The oxygen demand is expressed in terms of the weight of oxygen consumed per unit weight of water sample (kilograms per 1,000 kilograms, milligrams per liter, or pounds per ton). BOD_7 is a modification of the standard test in which the incubation period is 7 days; it is used in Sweden.

Table 34—*Representative values of raw waste water loading in wet-process fiberboard manufacture (EPA 1978)*

Type of board	Criterion 1	Criterion 2
Insulation board		
Production		
tons/day	200	400
kkg/day	180	360
Waste water flow		
million gal/day	0.48	0.96
kkl/day	1.8	3.6
Waste water/production unit		
kgal/ton	2.4	2.4
kl/kkg	10.0	10.0
Influent BOD (mg/l)	3,600	3,600
Influent TSS (mg/l)	1,600	1,600
S1S hardboard		
Production		
tons/day	100	300
kkg/day	91	270
Waste water flow		
million gal/day	0.28	0.84
kkl/day	1.1	3.2
Waste water/production unit		
kgal/ton	2.8	2.8
kl/kkg	12.0	12.0
Influent BOD (mg/l)	3,300	3,300
Influent TSS (mg/l)	1,300	1,300
S2S hardboard		
Production		
tons/day	250	—
kkg/day	230	—
Waste water flow		
million gal/day	1.5	—
kl/day	5.7	—
Waste water/production unit		
kgal/ton	5.9	—
kl/kkg	24.6	—
Influent BOD (mg/l)	2,600	—
Influent TSS (mg/l)	600	—

BOD = biochemical oxygen demand, TSS = total suspended solids, kkg = 1000 kilograms, kkl = 1000 kiloliters.

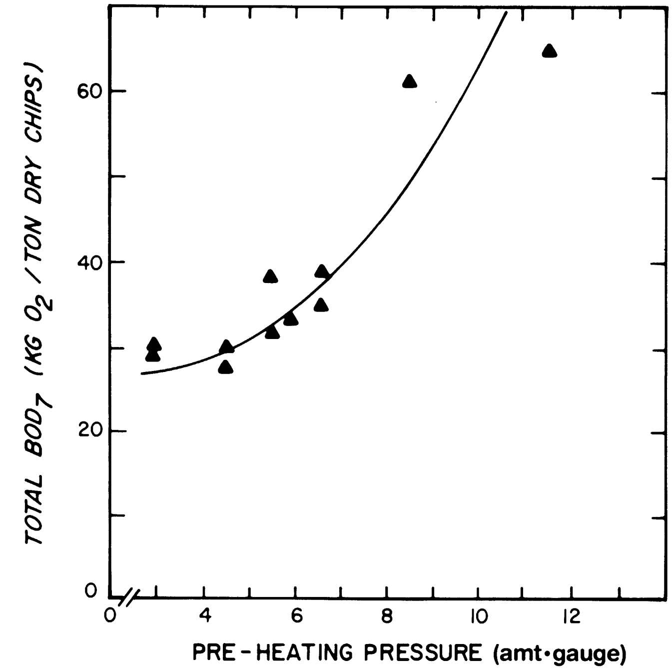


Figure 309—*Variation of BOD₇ with chip preheating pressure (EPA 1978).*

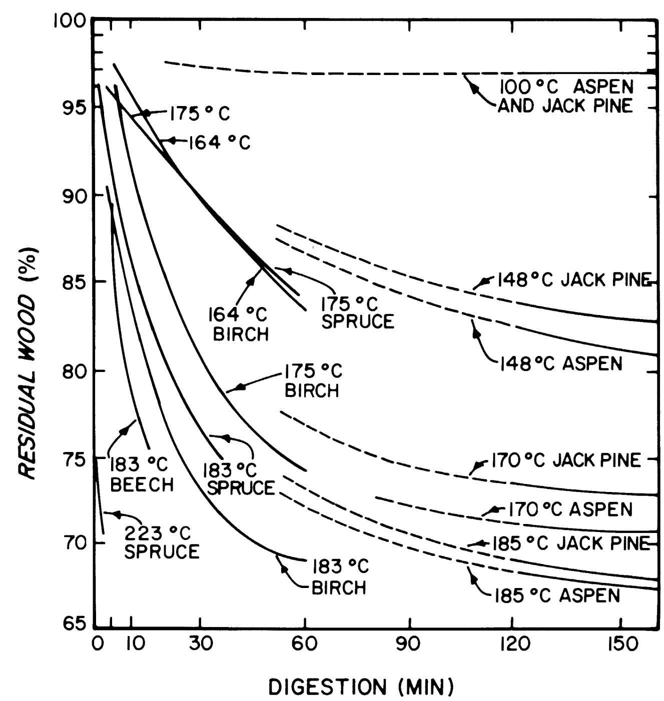


Figure 310 — *Influence of preheating time and temperature on the yield of pulp after thermomechanical pulping of some hardwoods and softwoods (after Asplund 1972).*

Average values of BOD loading of waste water in various fiberboard mills are shown in table 34.

Limits of discharged water quality in terms of 30-day maximum average and daily maximum BOD_5 and suspended solids levels are shown in table 35. This table also indicates the range of acceptable pH values. Waste water, which normally has a pH value of between 4 and 5, requires neutralization. However, a properly functioning biological treatment system will buffer itself somewhere between a pH of 6.8 to 8.0, thus making neutralization unnecessary.

The pollution problem posed by the release of process water from a fiberboard mill is quite different from that posed by many other industrial processes because fiberboard process water contains no chemicals at levels that must be considered poisonous or harmful to any humans who consume or come into contact with it. Neither is the pollutant difficult to degrade. The problem is nevertheless real and an important challenge to the fiberboard industry that may require structural shifts and modification of process technology.

Treatment Methods

Several approaches can be used to reduce the waste water problem:

Removing suspended solids

- Reduction of effluent by water recycling (closing of the process water system)
- Filtration or screening
- Sedimentation

Removing dissolved solids

- Reduction of effluent by water recycling (closing of the process water system)
- Reduction of wood dissolution by less severe thermal treatment of chips
- Biological waste water treatment (bacterial or biochemical oxidation of dissolved solids)
- Evaporation (concentration and solidification of dissolved solids into fuel or other salable products)
- Spray irrigation (disposal of waste water on agricultural lands)

Most fiberboard mills employ a combination of two or more of these approaches.

Closing the process water system

This approach deals with both major types of contaminants and is being applied in varying degrees by most fiberboard mills.

Figure 311 shows a simplified schematic of a Masonite fiberboard plant without water recycling. By far the greatest water quantity is required for the dilution of stock in the stock chest prior to wet forming (see also fig. 133).

Table 35—*Maximum pollutant and pH levels acceptable to EPA for wet hardboard effluent (EPA 1973)*

	30-d average	Daily maximum
BOD_5		
lb/ton	5.2	15.6
kg/kkg	2.6	7.8
Suspended solids		
lb/ton	11.0	33.0
kg/kkg	5.5	16.5
pH	6.0–9.0	6.0–9.0

BOD_5 = biochemical oxygen demand including incubation for 5 days.

Figure 312 shows the same plant with partial recycling of the process water. Two major water flow systems can be distinguished. One is the **washing cycle** in which most of the dissolved solids are removed from the pulp. The other is the machine (forming machine) **white water cycle.** White water is relatively free from dissolved solids and is reintroduced into the process. Dissolved solids (mostly sugars) in the waste water from the washing cycle are recovered in an evaporation plant and sold as cattle feed. Condensate from the evaporator and part of the machine white water are sent to waste water treatment facilities.

A similar system in a defibrator plant is illustrated in figure 313. No pulp washer is used here, and the sugars are retained in and recirculated with the machine white water. The drawing also indicates the flow in liters per metric ton of board (1,000 liters = 1 metric ton) and the pulp concentration (numbers in parentheses). About 85 percent of the machine white water is being recirculated.

The closing of the process water system has certain limitations that are expressed in figure 314. The right end of this graph represents a completely open process water flow. One hundred cubic meters of water (100 metric tons) per ton of board are flowing through the process. All the dissolved solids are contained in the waste water (100 percent). If the process water system were closed to a waste water volume of 10 m^3 (10 metric tons) water per ton of board, a reduction of 10:1, the total amount of dissolved solids leaving with the waste water would only have been reduced by about 8 percent. The reduction of waste water flow simply causes a corresponding increase in the dissolved solids concentration. Only substantial closing of the system will appreciably reduce the total

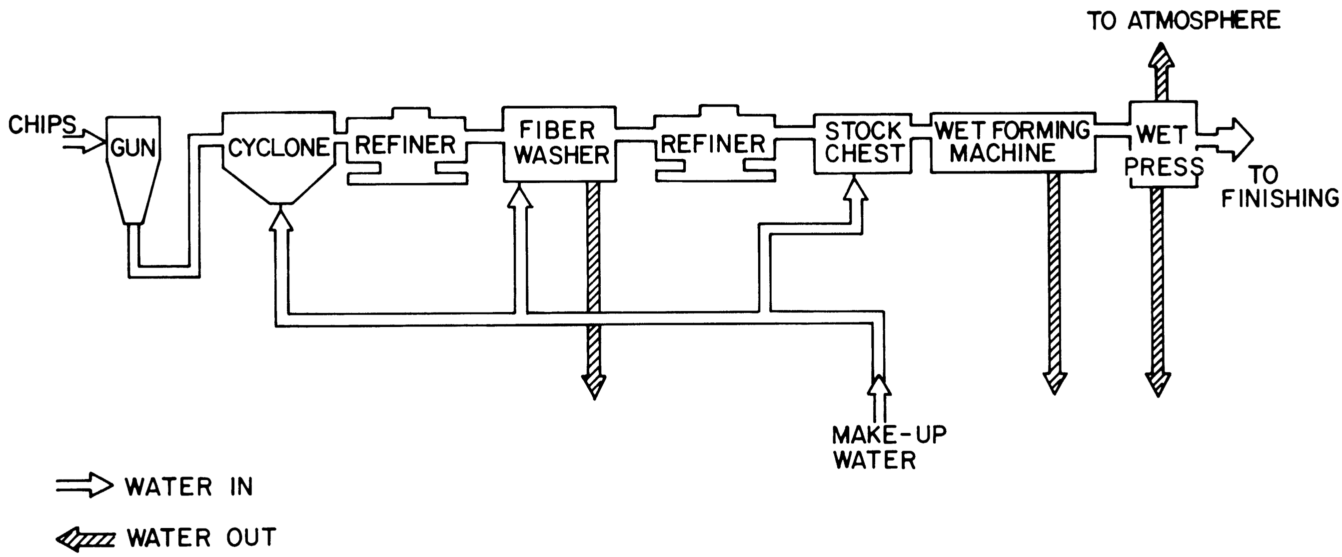


Figure 311—*Schematic of a Masonite fiberboard plant without water recycling (EPA 1973).*

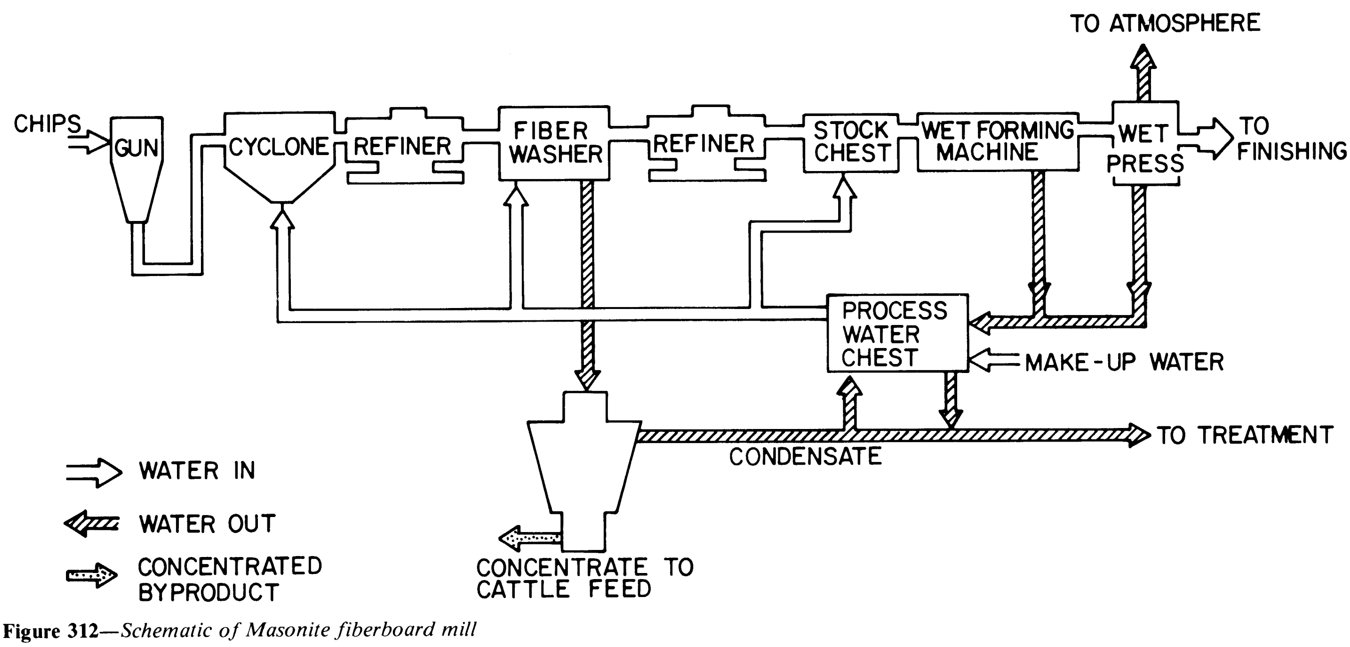


Figure 312—*Schematic of Masonite fiberboard mill with partial recycling of process water (EPA 1973).*

outflow of dissolved solids. That portion of the dissolved solids that is not contained in the waste water is retained in the board. Large concentrations of solubles in the board cause difficulties such as formation of surface spots, sticking of boards to the screens and to the press platens or cauls, and more rapid build up of carbon and dirt on cauls, resulting in increased downtime. They also have a limiting effect on the quality of finishes that can be developed on such boards and increase water absorption. These difficulties can be overcome to a large extent

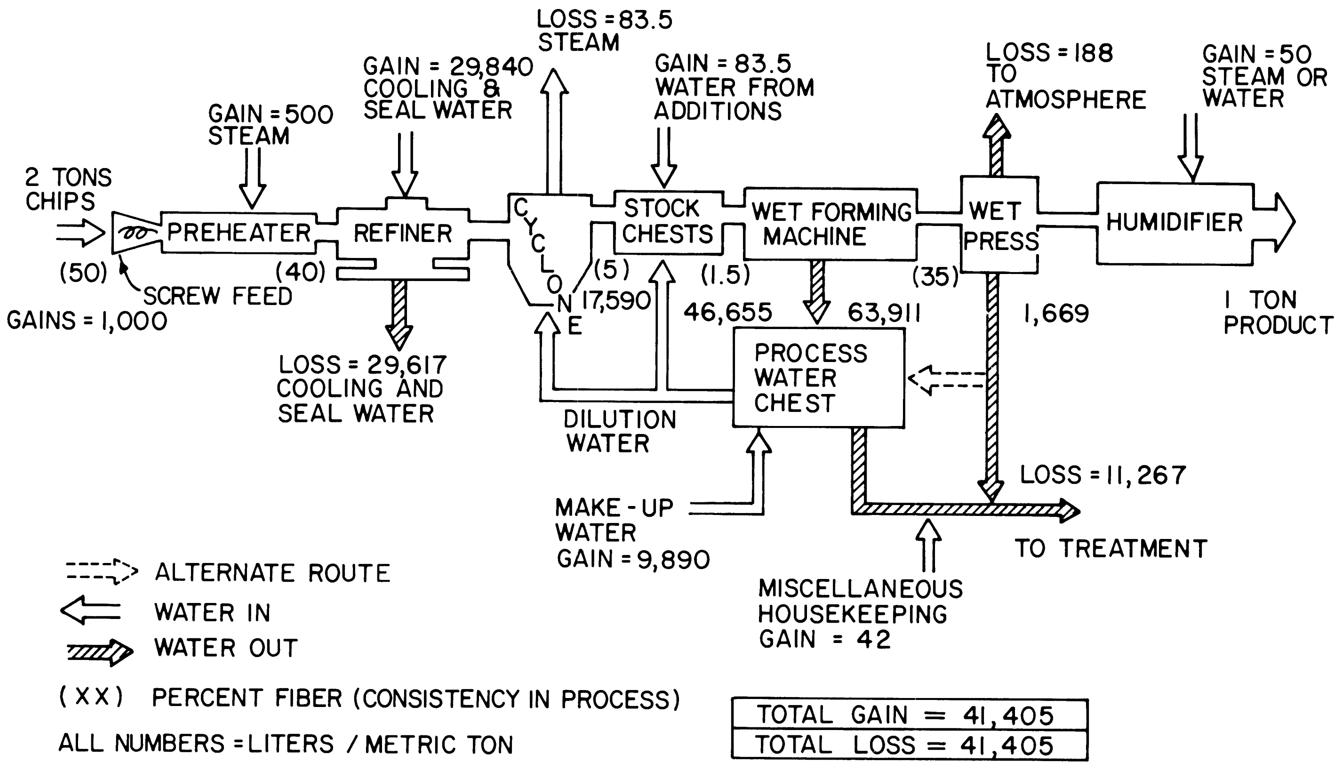


Figure 313—*Recycling of process water in defibrator-type mill without washer and without pulp press (EPA 1973).*

by the use of pulp presses, which greatly reduce the dissolved solids content in the machine white water cycle.

Figure 315 shows a water flow system containing a pulp press. The pulp entering the press is of high consistency (15 percent). This consistency is brought up to 30 percent in the press. The amount of water removed in the press is relatively small (3.3 tons/ton of board) but has a high concentration of dissolved solids and is routed to the waste water treatment facility. Machine white water is leaving the forming machine at a rate of 64 tons per ton of board and is completely recirculated (system closed). Such a system has the added advantage of conserving chemicals added to the pulp in the stock chest prior to the forming machine. Since no water leaves the process, the chemical concentration will build up to an equilibrium level so that only the amount actually retained in the board must be added. A very similar system is illustrated in figure 114.

Another consequence of closing the water system is higher water temperature. High water temperatures, up to 180 °F, may cause certain corrosion problems and unpleasant working conditions due to high relative humidity (Gran 1972). Unless forming machine wire fabrics are specifically designed to handle higher stock temperature, these fabrics can stretch or fail and generally have a shorter life. Also, suspended solids recycled with the water have a tendency to reduce the freeness of the pulp.

Removal of suspended solids (primary treatment)

Suspended solids can be removed by screening, sedimentation, or filtering.

Screening is required as a first step to remove from the effluent all coarse material that could damage pumps and other elements of the water handling system. Such screens may consist of closely spaced steel bars and are self cleaning.

The fine fractions of the suspended solids are removed by gravity in **sedimentation ponds** or in **clarifier tanks** of various designs. The efficiency of such sedimentation basins or tanks is a function of their surface area. For a given installation, the rate of removal of suspended solids from the water depends on retention time and overflow rate. Figure 316 (Weston and Stack 1963) shows three designs of sedimentation facilities. Rotating elements collect and remove the **sludge** from the bottom of the tank, while clarified water overflows into peripheral or central troughs.

When sedimentation ponds are used, sludge removal is discontinuous. Two or more ponds are usually necessary for this method. One pond is used until it is nearly full of sludge and then dewatered by decanting and by evaporation and seepage into the ground, while the second pond is placed in operation. After a long drying process the partially dried sludge is removed by earth handling equipment to a permanent disposal site (Foster 1963). Because of the high cost of sludge removal in the pond method, most newer installations use rectangular or circular tanks with mechanical sludge removal equipment.

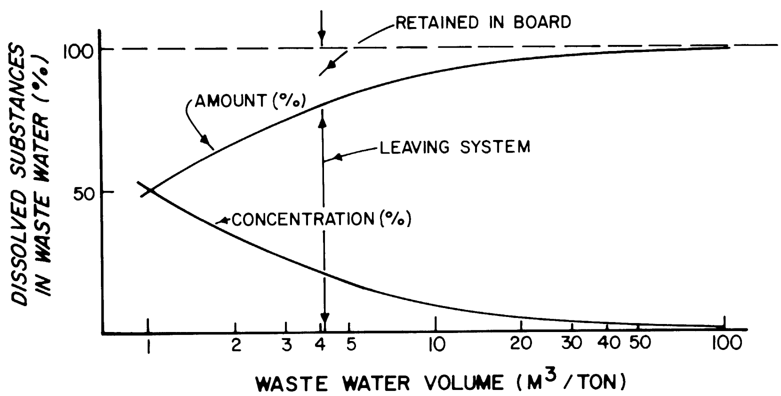


Figure 314—*Percentage of dissolved substances leaving the system with the waste water and their concentrations (Gran 1972). As waste water volume per ton of board is reduced (closing of system), the concentration of dissolved solids in the waste water increases, the total amount of dissolved solids leaving the system decreases, and the amount of dissolved solids retained in the board increases.*

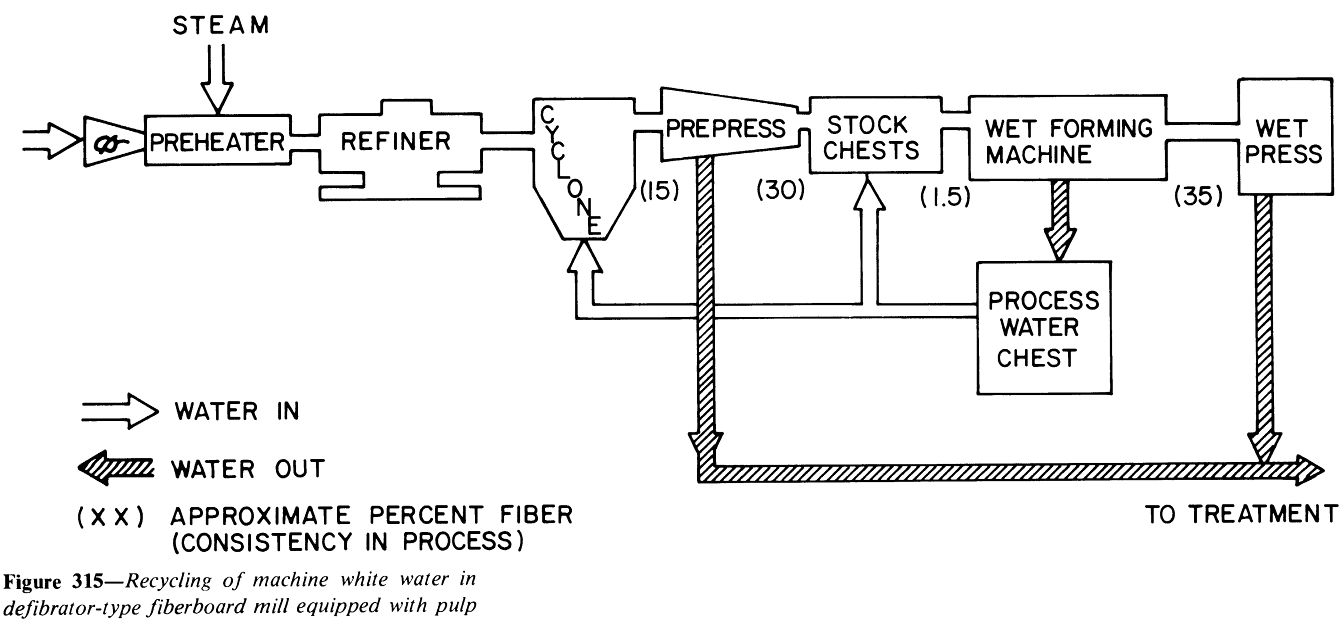


Figure 315—*Recycling of machine white water in defibrator-type fiberboard mill equipped with pulp press (EPA 1973).*

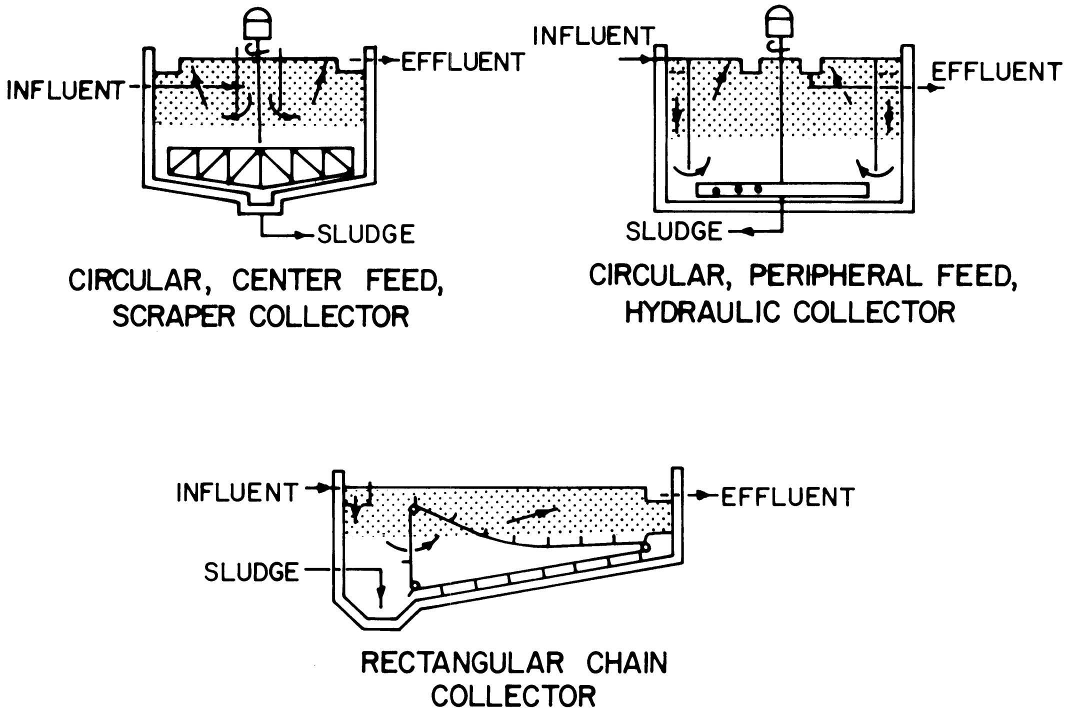


Figure 316 — *Types of waste water sedimentation facilities (Weston and Stack 1963). (© 1963 TAPPI. Reprinted from Tappi Journal, May 1963, pp. 166A – 176A.)*

A circular clarifier with center feed and peripheral overflow is shown in figure 317. Similar clarifier tanks in a southern insulation board mill have the following specifications:

Diameter	45 ft
Depth	12 ft
Bottom slope	1.75 in/ft
Speed of rake arms	1/10 r/min
Feed	Center feed-well, 12 ft diam, 6 ft deep
Sludge removal	6-in-diam pipe, ¼-in/ft slope
Solids content of sludge	4%

Sludge disposal requires further dewatering unless sufficient land area is available for direct discharge of sludge into lagoons or basins. In cold climates this method is unsatisfactory. Vacuum filtration is used to dewater sludge in some mills. The sludge solids are separated from the water by means of a porous filter medium that retains the solids and allows the water to pass. Sludge cakes having solids contents of 20 to 30 percent can be produced. Types of filter media include cloth, steel, wire mesh, and wound coil spring (Foster 1963). Such dewatered sludge can be used as land fill. Other possibilities include further drying of the sludge and its utilization as fuel.

Removal of dissolved solids (secondary treatment)

The clarified water could be disposed of by **spray irrigation** of agricultural land without further treatment. The feasibility of such a disposal system depends on the availability of land, the climate, the infiltration capacity of the soil, and many other factors. Runoff leading to stream pollution can occur if the capacity of the soil is exceeded. If the organic loading is too high, anaerobic conditions will develop and cause odors (Weston and Stack 1963). The spray irrigation method is used by some western hardboard manufacturers.

The dissolved solids content of clarified waste water may be very significantly reduced by **biological treatment** methods in which naturally occurring micro-organisms utilize organic matter as a food source. This process involves two types of reactions: the conversion of organic matter into energy and the synthesis of organic matter into protoplasm (growth and reproduction). The first of the two reactions represents, of course, the desired form of disposal of organic matter; the second is necessary for sustaining the continuity of the micro-organism population but does create its own disposal problem.

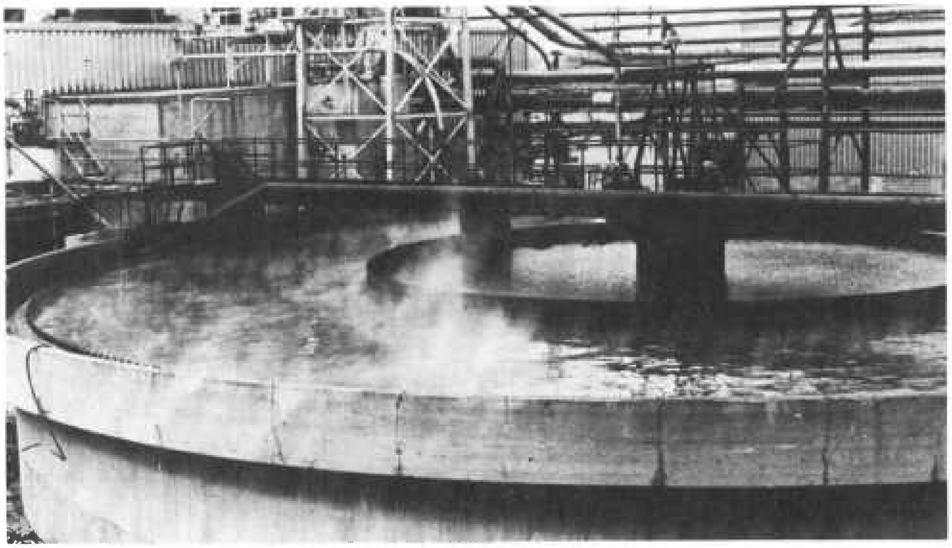


Figure 317—*Circular waste water clarifier with center feed and peripheral overflow. Sludge is removed mechanically from the bottom by a continuously rotating scraper.*

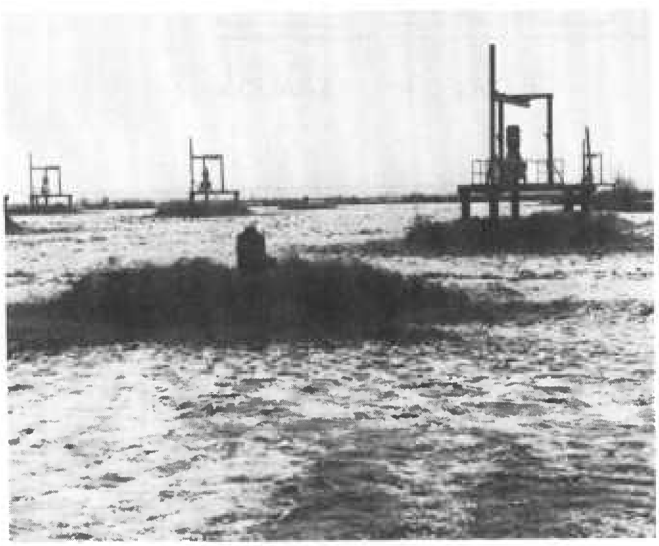


Figure 318—*Aeration lagoon with mechanical aerators.*

These reactions may occur both with or without the presence of oxygen. In the presence of oxygen (aerobic condition) the reactions occur at faster rates and are odor free. Therefore, such industrial biological water treatments are always aerobic.

The necessary oxygen is supplied by air entrainment in **aeration lagoons** (fig. 318). Various mechanical aeration systems are shown in fig. 319. In addition to oxygen, nitrogen may be added in the form of ammonia, ammonium salts, or nitrates, and phosphorous as phosphoric acid or phosphates as nutrients. The pH value of the waste water is controlled by choosing suitable nutrients or by adding pH-controlling chemicals like sodium hydroxide (Gran 1972).

The **activated sludge** method is a biological treatment used by several fiberboard mills.

> This is a process in which the waste water is aerated and the biological cell material (micro-organisms) produced during the oxidation of organic matter is settled from the waste water and returned to the aeration tank or lagoon. As this cycling of settleable cell material is continued a readily settleable flocculent growth accumulates. This accumulated growth is called "activated sludge." It can oxidize organic matter at a rapid rate and has the ability to clarify the waste water as well as remove soluble and colloidal organic matter (Weston and Stack 1963).

The excess sludge is continually removed from the process, dewatered, and disposed of as landfill or used as fuel. Landspreading can be used as an alternative to landfill. Land requirements are higher, here, and a program of crop growth is used to remove excess nitrogen from the soil. An activated sludge process in a northern hardboard mill is outlined schematically in figure 320. Figures 321, 322, and 323 show equipment used in water treatment at the same mill.

The effluent from the clarifier goes to the aeration lagoon (fig. 318), where aerators supply oxygen to the water. The total connected aeration power is 2100 hp.

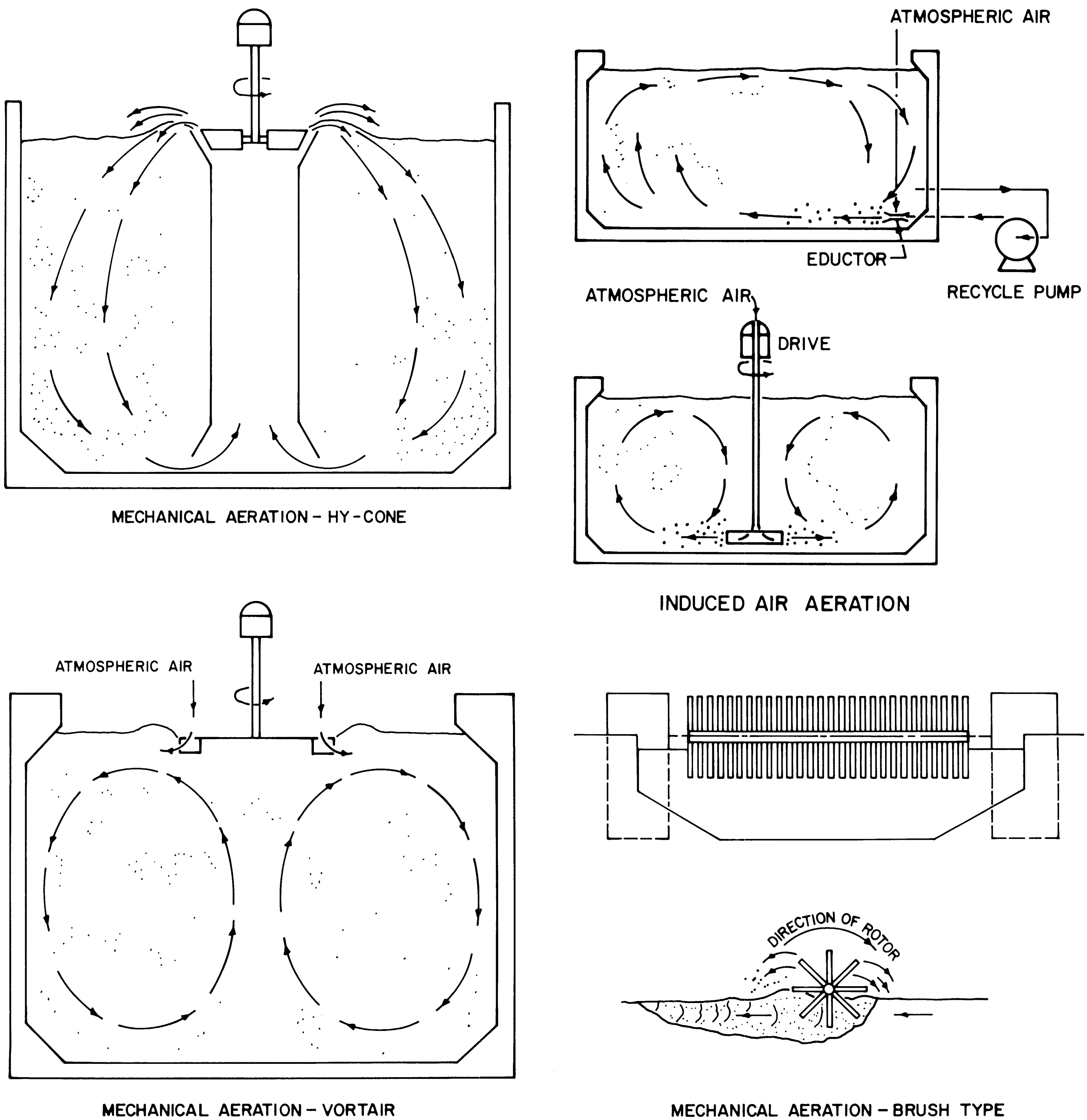


Figure 319 — *Various mechanical aeration systems (Weston and Stack 1963). (© TAPPI. Reprinted from Tappi Journal, May 1963, pp. 166A – 176A.)*

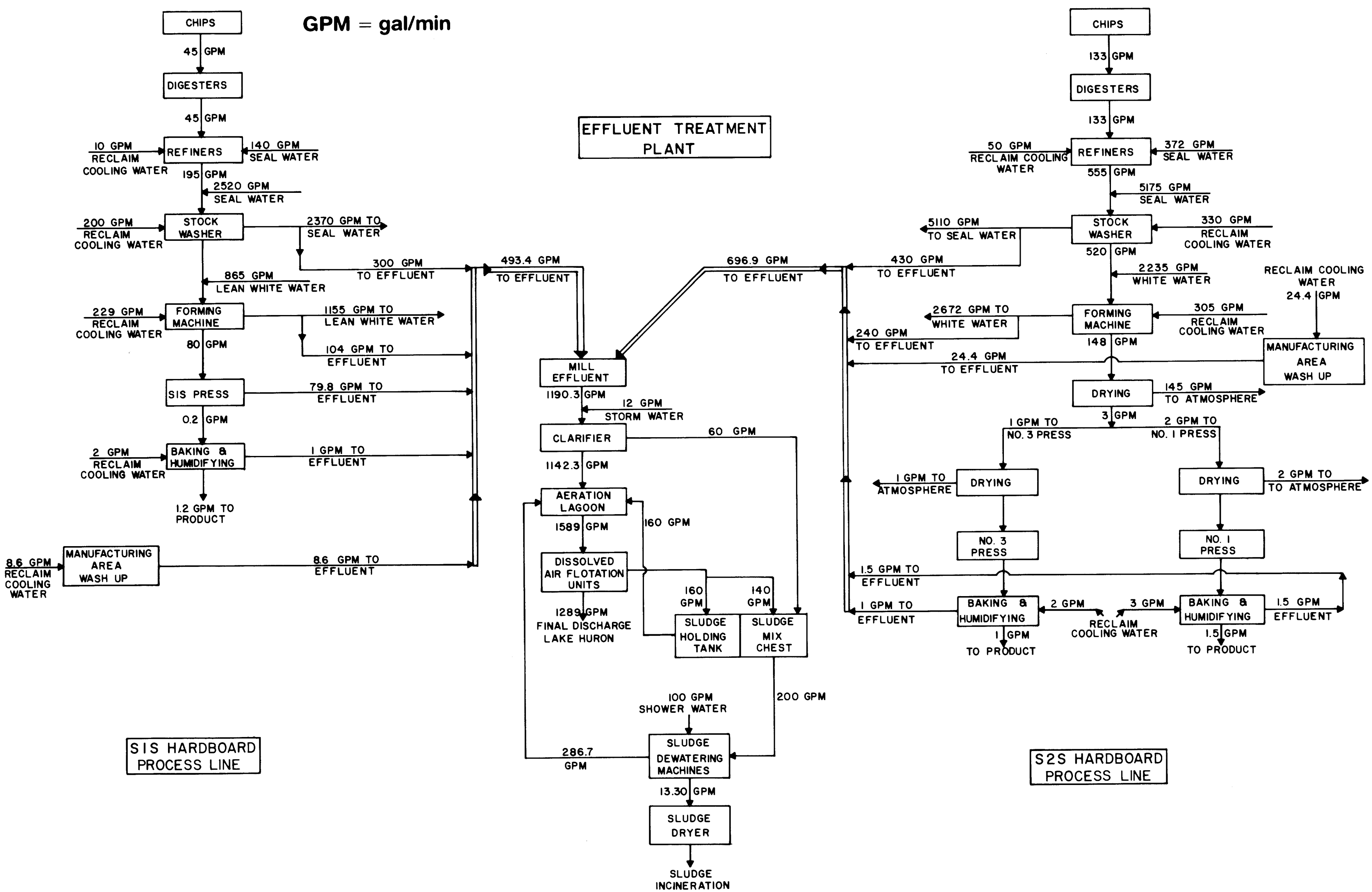


Figure 320—*Diagram of effluent treatment plant for mill with two production lines.*

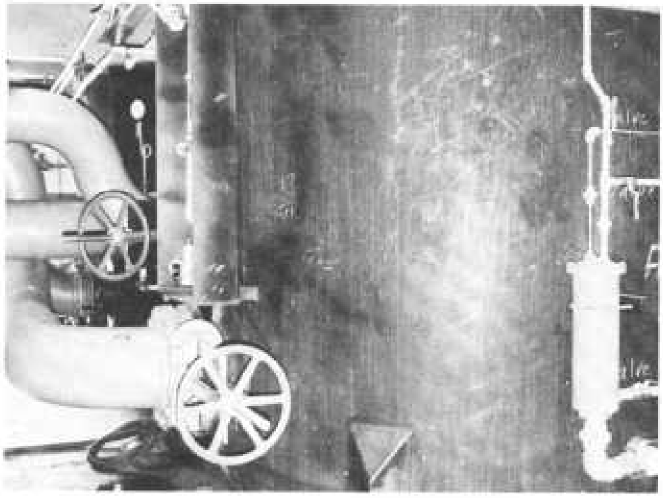


Figure 321—*Injection of air into pressurized tanks of air flotation system.*

Figure 323—*Outfeed end of continuous sludge dewatering press.*

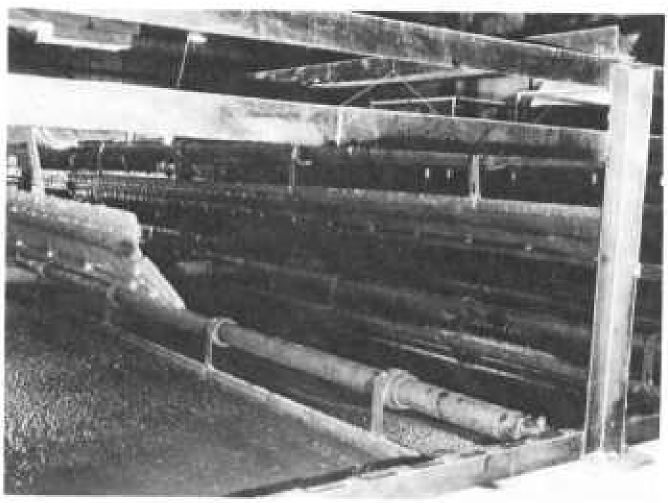


Figure 322—*Mechanical skimming of surfaced sludge.*

The sludge (micro-organisms) is separated from the water in air flotation units where air is dissolved under pressure in the water (**dissolved air flotation method**, DAF) (fig. 321).

When the water is released into long troughs the air is expelled in the form of tiny bubbles. The rising bubbles carry the suspended micro-organisms with them to the surface, where a sludge blanket is being formed. This blanket is skimmed off mechanically (fig. 322) and removed to the sludge tanks, and the water is released to the lake. Part of this sludge is returned as ''activated sludge'' to the aeration lagoon, the rest is mixed with the suspended solids sludge from the primary clarifier and dewatered to a solids content of 15 to 25 percent on a continuous dewatering press (**sludge dewatering machine**, SDM). The dewatered sludge is dried to a moisture content of about 8 percent in a drum dryer (fig. 324) and used as fuel in the powerhouse, and the water from the dewatering press is returned to the lagoon. Both DAF and SDM operations require chemical treatment of incoming waste water. A similar system is shown schematically in figure 325 except that in this case (Masonite) part of the process water is evaporated, and the residue is sold in liquid or dried form as cattle feed supplement. This mill is reported to be evaporating 3,250 tons/24 h of waste water containing just over 100 tons of BOD_5 to produce 180 tons of concentrate (Gran 1972).

Such a system requires large energy inputs and its efficiency increases with increasing concentration of dissolved solids in the waste water, that is, the more the process water system is closed. The rest of the process water is treated by an activated sludge process and then released into an impoundment prior to discharge into the creek.

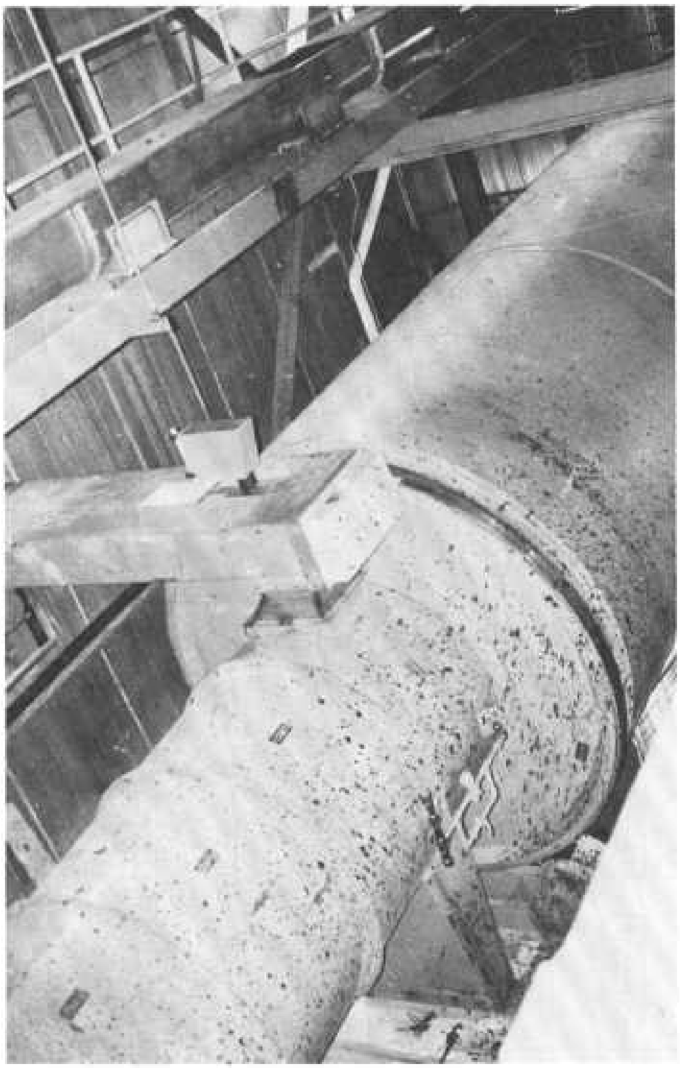


Figure 324—*Drum dryer for drying sludge.*

References

Asplund, A. Trends and developments in the manufacture of fiberboard. In: Proceedings, 7th world forestry congress. Buenos Aires, Argentina: 1972; 6675–6685.

Beak, T.W. Water pollution problems of the pulp and paper industry. Tappi. 46(5): 160A–166A; 1963.

Dallons, V. Pollution from several wood species in hardboard production. Forest Products Journal. 28(1): 42–47; 1978.

Environmental Protection Agency. Development document for proposed effluent limitations guidelines and new source performance standards for the plywood, hardboard and wood preserving segment of the timber products processing point source category. EPA 440/1-73/023. Washington, D.C.; 1973. 317 p.

Environmental Protection Agency. Revised technical review of the best available technology, best demonstrated technology, and pretreatment technology for the timber products processing point source category. EPA Project 78-052. Washington, DC; 1978. 360 p.

Fields, W.F.; Lewis, T.W. Primary treatment for an insulating fiberboard plant. Tappi. 46(5):178A–187A; 1963;

Foster, J.H. Fundamentals of primary treatment. Tappi. 46(5): 155A–160A; 1963.

Gran, G. Waste water from fiberboard mills. Pure and Applied Chemistry. 29(1-3): 229–321; 1972.

Weston, R.F.; Stack, V.T., Jr. Fundamentals of biological treatment. Tappi. 46(5): 166A–176A; 1963.

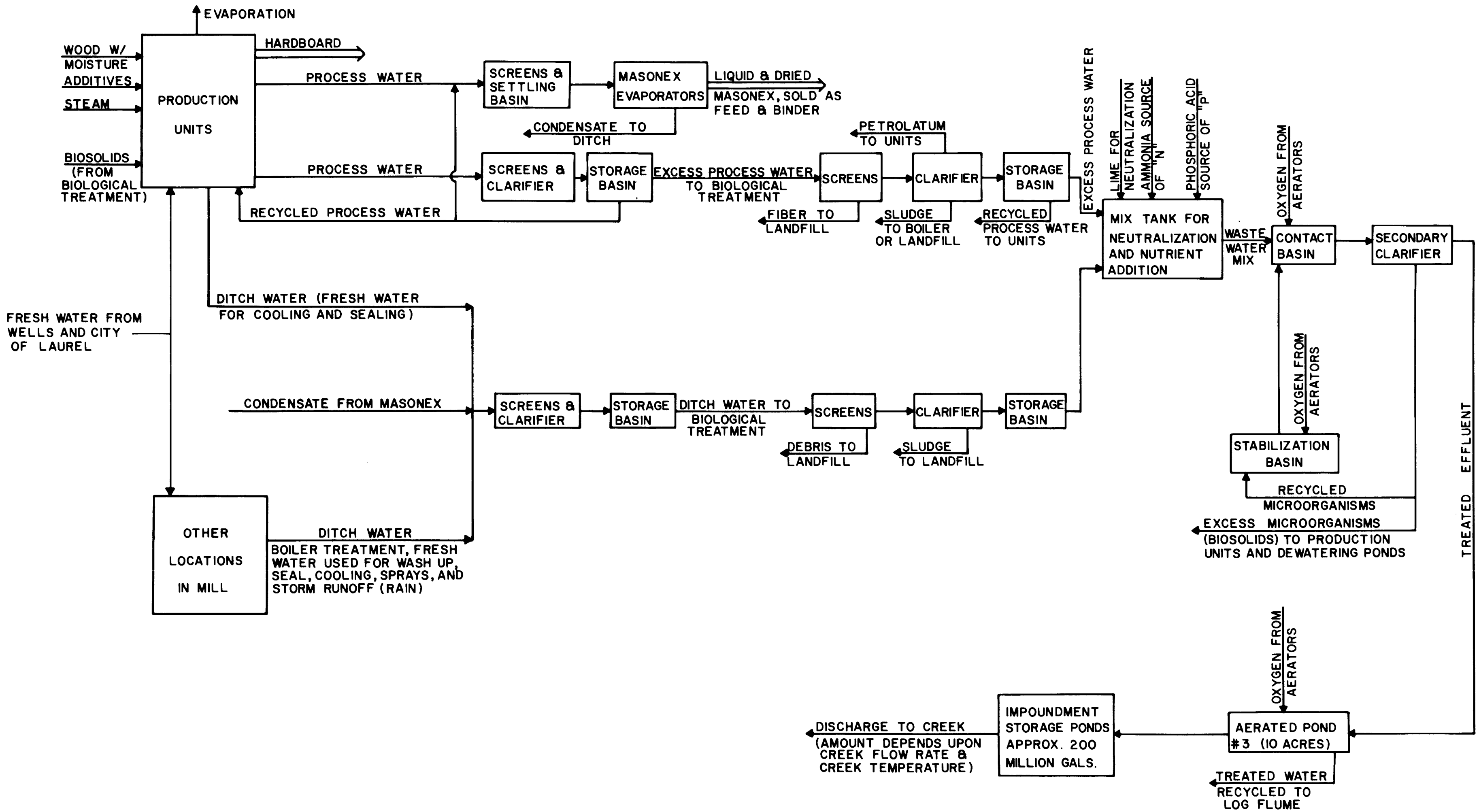


Figure 325—*Schematic of water flow and waste water treatment of Masonite fiberboard plant.*

13. Board Properties and Markets

General

Successful marketing of industrial products always includes the technically satisfactory and economical matching of product properties and application requirements. For this matching process, the plant must measure, monitor, and control product properties and also be able to modify these properties to improve marketability. Both functions require a thorough knowledge of the relationships between raw material and process variables on one hand and product properties on the other. Also needed is a set of realistic application requirements for which easily measured and controllable product characteristics can be specified.

Because of the limited scope of this publication, our discussion is confined to a survey of certain "standard" properties of commercial hardboard and medium-density fiberboard, a short presentation of the important subject of viscoelasticity, and a brief treatment of thermal insulation. The more important fiberboard markets are enumerated and illustrated after this discussion.

Properties of Commercial Hardboard

Hardboard standards

Hardboard dimensional and quality requirements are described in three product standards:

- ANSI/AHA A 135.4–1982: Basic Hardboard;
- ANSI/AHA A 135.5–1982: Prefinished Hardboard Paneling;
- ANSI/AHA A 135.6–1983: Hardboard Siding (USDC NBS 1982 a,b, 1983).

These standards do not distinguish between medium- and high-density boards but define hardboard as fiberboard compressed to a density of 31 lb/ft^3 or greater (specific gravity $\geq$ 0.50).

The **Basic Hardboard** standard classifies boards by thickness and by the following physical properites: water absorption, thickness swelling, modulus of rupture, tensile strength parallel to surface, and tensile strength perpendicular to surface. Hardboard panels are available with either one (S1S) or two (S2S) smooth sides.

Table 30 (chapter 10) defines the spectrum of commercial hardboard qualities based on this classification, which makes no reference to any specific end use. It simply provides the consumer a means of selecting the product by quality level in terms of the listed properties, matching them with his particular application requirements. Any hardboard sold under this standard and bearing a grade stamp indicating the particular quality class must conform to all the requirements of this standard.

Of course, requirements listed in table 30 fall far short of completely defining hardboard in terms of all of its characteristics; in many cases, consumer and manufacturer develop additional specifications for certain applications. The standard also provides that the properties be determined according to test methods listed in the ASTM Book of Standards (American Society for Testing and Materials).

The other two hardboard standards cover two important end use categories, **paneling** and **siding**. Here, very specific properties are defined and used to classify prefinished hardboard paneling into two quality classes, and, in the case of siding, to provide minimum or maximum performance levels for panel and lap siding materials.

The property requirements for hardboard paneling **finishes** listed in table 36 are in addition to the basic hardboard requirement of the previously discussed standard. Definitions of these finish properties and the appropriate methods for their evaluation are included in the standard.

The hardboard siding standard deviates even in physical properties from the basic hardboard standard. This is a consequence of the normally lower density of siding boards. Hardboard siding is a truly exterior product. Weatherability, stability of finish, and dimensional stability are therefore of primary concern. Maximum linear expansion values as imposed by the standard are listed in table 37. These values are based on moisture absorption of samples when exposed until equilibrium is reached, first to 50 percent and then to 90 percent humidity.

Thick medium-density fiberboard is not covered by the hardboard standards.

Hardboard properties

Considerable research effort has gone into the evaluation of raw material and process variables and into the establishment of basic properties of commercial hardboard products. Reference to some of the relevant literature has been made in previous chapters. The following articles are further examples of such efforts (Keylwerth 1955, Kumar 1958, Law and others 1975, Chow and Reiss 1974, Ruffin 1960, Shen 1972, Stillinger and Coggan 1956, Turner and others 1948, Lundgren 1958, Steinmetz and Fahey 1971, Currier 1957).

Evaluation of commercial boards, of course, may quickly be outdated by process improvements and modifications and by changes in the raw material com-

Table 36—*Properties of hardboard paneling finishes (USDC NBS 1982)*

Property	Requirement: Class I	Requirement: Class II	Reference to test method described in this standard
Abrasion resistance	5 L of sand without marring print	3 L of sand without marring print	3.1
Adhesion	Less than 1/8 in of coating "picked up"	Same as class I	3.2
Fade resistance	100 h of light exposure with no loss of gloss and only a slight color change when visually inspected by an individual competent in the field	60 h of light exposure with no loss of gloss and only a slight color change when visually inspected by an individual competent in the field	3.3
Gloss			
High	50 units and over	Same as class I	3.4
Medium	25 to 50 units		
Low	Under 25 units		
Heat resistance	Slight color change when visually inspected by an individual competent in the field	See footnote 1	3.5
Humidity resistance	No blistering, peeling, cracking, crazing, or more than a slight color change when visually inspected by an individual competent in the field	See footnote 1	3.6
Scrape adhesion	6 kg	4 kg	3.7
Stain resistance	No effect using staining agents (a-l)[2]	No effect using staining agents a through f. Not greater than superficial effect using staining agents g through l	3.8
Steam resistance	No blistering, loosening, or separation of coating	See footnote 1	3.9
Washability	No more than 5 units of change if under 50 units and no more than 10 if over 50 units	Same as class I	3.10

[1]Class II finish has limited heat, humidity, or steam resistance requirements because it is not meant to be used where these conditions are excessive, such as around stoves, furnaces, showers, and bathtubs. Note: Physical properties of the hardboard substrate can be found in ANSI/AHA 135.4-1980. (USDC NBS 1982a).

[2]Staining agents: (a) mineral oil (USP), (b) freshly brewed, strong coffee, (c) china-type marking pencil, (d) nonsmearing lipstick, (e) reconstituted lemon juice (10% citric acid by weight), (f) carbonated cola drink, (g) household ammonia solution (10% ammonia by weight), (h) homogenized milk, (i) alcohol (denatured), 190 proof, (j) aqueous household bleach (5.5% sodium hypochlorite by weight), (k) 1% trisodium phosphate solution (by weight), and (l) nail polish remover, which contains 24% butyl acetate, 28% ethyl acetate, 24% isopropyl alcohol, and 4% diglycol laurate (by volume).

Table 37—*Maximum linear expansion of hardboard siding (USDC NBS 1983)*

Type of siding	Thickness range (in)	Maximum linear expansion (%)
Lap siding	0.325–0.375	0.38
	over 0.376	.40
Panel siding	0.220–0.265	.36
	0.325–0.375	.38
	over 0.376	.40

position. However, the most recent of these studies (Werren and McNatt 1975; McNatt 1970, 1974) may well serve as a guide to the actual property levels and property variations of various types of hardboard manufactured in the United States today.

The Werren & McNatt study (1975) was undertaken by the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, with the cooperation of the American Hardboard Association and 11 hardboard manufacturers. Twenty different hardboard types were included in the tests. Tables 38–43 characterize board types A, B, C. . .L in these tests, and figures 326–333 summarize the results as frequency curves. The variation between board types within each of the various categories is considerabe for most of the properties. The board density, however, was a dominant variable only in the case of internal bond or tension perpendicular to the board surface (fig. 334). The strong correlation is rather remarkable if one considers the wide range of manufacturing methods, raw materials, and additive levels represented by the sample. In all other cases, this correlation did not exist, which does not mean that these properties are unaffected by board density. Rather it means that other, more dominant variables such as tempering or raw materials may have obscured the density effect, which, within each board type, may well exist as suggested by figure 335.

The effect of tempering was greatest on those properties that reflect, or at least include, the strength of the surface layers (bending strength and tensile strength) and least in those that reflect primarily the center layer strength, such as internal bond.

The greatest linear expansion values were associated with dry forming of the mat, possibly pointing to a greater vertical fiber orientation component in those boards.

Properties of Dry Process Mende-Board

The Mende-board is the result of the application of particle board technology to the manufacture of hardboard. Board densities of the Mende-board are generally lower than those of either wet-or dry-formed hardboard. As a result, most mechanical properties are inferior. A notable exception is the internal bond strength (table 44). These values were determined for various commercial Mende-boards manufactured in the United States in 1976–77. Linear expansion values are high compared to those of either conventional hardboard or particle board.

However, the Mende-process is a relative newcomer in this field, and the quality of its products is subject to refinements and improvements. Such improvements may

Table 38—*Identification of hardboard panels included in comprehensive hardboard evaluation at U.S. Forest Products Laboratory (Werren and McNatt 1975)*

Board type	Method of manufacturing			Number of 4- by 8-ft panels			
				¼-in thick		⅛-in thick	
	Method of felting	Condition at pressing	Surface	Tempered	Standard	Tempered	Standard
A	Wet	Wet	Screenback	20	10	10	10
B	Wet	Wet	Screenback	10	—	—	—
C	Wet	Dry	S2S[1]	10	—	—	—
D	Air	Dry	S2S	10	—	—	—
E	Wet	Wet	Screenback	20	20	20	20
F	Wet	Wet	Screenback	10	—	—	—
G	Wet	Wet	Screenback	10	—	—	—
H	Wet	Dry	S2S	10	—	—	—
J	Air	Wet	Screenback	20	10	10	10
K	Air	Dry	S2S	10	—	—	—
L	Air	Dry	S2S	10	—	—	—

[1]S2S = both faces smooth.

Table 39—*Elastic and strength properties in static bending of commercial hardboard (FPL evaluation) (Werren and McNatt 1975)*[1]

Board type	Moisture content Average (%)	Moisture content SD (%)	Moisture content CV (% of %)	Specific gravity[2] Average	Specific gravity[2] SD	Specific gravity[2] CV (%)	Modulus of elasticity[3] Average (1,000 lb/in²)	Modulus of elasticity[3] SD (1,000 lb/in²)	Modulus of elasticity[3] CV (%)	Stress at proportional limit Average (lb/in²)	Stress at proportional limit SD (lb/in²)	Stress at proportional limit CV (%)	Modulus of rupture Average (lb/in²)	Modulus of rupture SD (lb/in²)	Modulus of rupture CV (%)
¼-in-thick tempered															
A	7.3	0.2	3.1	0.95	0.03	3.0	710	62	8.7	3,730	430	12	7,230	595	8.2
B	7.6	.4	4.9	.93	.03	2.8	820	74	9.0	3,850	540	14	7,630	545	7.1
C	5.7	.1	1.3	.98	.01	1.5	860	56	6.5	2,730	360	13	6,910	460	6.7
D	6.4	.2	2.6	1.03	.03	2.9	815	69	8.5	3,240	510	16	7,650	765	10.0
E	6.3	.5	7.4	.99	.02	2.4	805	49	6.1	3,270	520	16	8,360	580	6.9
F	7.8	.2	2.2	.96	.03	2.9	645	39	6.0	2,580	270	10	6,990	475	6.8
G	6.4	.1	1.9	.98	.01	1.2	790	23	3.0	3,440	330	10	8,400	300	3.6
H	6.1	.2	2.6	.97	.02	1.8	1,040	41	3.9	3,820	310	8	7,060	730	10.4
J	8.1	.3	3.8	.97	.04	3.9	715	52	7.3	2,650	330	12	7,010	635	9.1
K	5.8	.1	1.7	1.02	.01	1.3	670	27	4.0	2,600	190	7	6,360	245	3.8
L	7.2	.2	2.4	1.02	.03	2.5	700	54	7.7	2,050	170	8	5,650	410	7.2
¼-in-thick standard															
A	6.9	.2	2.8	.92	.03	3.5	505	67	13.3	2,020	300	15	4,490	605	13.4
E	5.4	.1	2.5	.95	.02	2.1	600	43	7.1	2,310	240	10	5,690	455	8.0
J	7.7	.2	2.1	.98	.03	3.1	675	65	9.6	2,930	360	12	6,890	715	10.4
⅛-in-thick tempered															
A	6.7	.3	3.9	.95	.05	4.9	735	63	8.6	3,740	350	9	8,780	620	7.1
E	6.6	.4	5.9	.96	.03	2.9	635	54	8.5	2,920	340	12	7,120	515	7.2
J	7.9	.2	3.2	.96	.02	2.4	555	36	6.5	2,840	360	13	7,150	450	6.3
⅛-in-thick standard															
A	7.6	.3	3.7	.88	.05	5.7	515	76	14.7	2,320	360	16	5,280	860	16.3
E	5.7	.3	4.7	.93	.03	2.9	495	38	7.7	1,970	200	10	5,160	465	9.1
J	7.8	.2	2.5	.89	.02	2.7	450	46	10.2	2,350	270	12	5,570	610	10.9

[1]Tests made by center loading over a simply supported span of 24 times the nominal thickness according to ASTM D 1037; material at equilibrium at time of test. Average value, standard deviation (SD), and coefficient of variation (CV). Each average based on 100 determinations.
[2]Based on volume at test and weight when ovendried.
[3]Based on tangent modulus.

Table 40—*Elastic and strength properties in tension parallel and perpendicular, and compression parallel to surface of commercial hardboard (FPL evaluation) (Werren and McNatt 1975)*[1]

Board type	Tension parallel to surface						Tension perpendicular to surface (internal bond strength)			Compression parallel to surface					
	Modulus of elasticity[2]			Tensile strength[2]						Modulus of elasticity[2]			Compressive strength		
	Average (1,000 lb/in²)	SD (lb/in²)	CV (%)	Average (lb/in²)	SD (lb/in²)	CV (%)	Average (lb/in²)	SD (lb/in²)	CV (%)	Average (1,000 lb/in²)	SD (1,000 lb/in²)	CV (%)	Average (lb/in²)	SD (lb/in²)	CV (%)
¼-in-thick tempered															
A	795	87	11.2	4,140	390	9.4	160	43	26	730	90	12.9	4,020	485	12.0
B	875	63	7.3	4,690	360	7.7	185	33	18	760	61	8.1	4,590	395	8.6
C	965	75	8.3	4,130	275	6.7	240	35	14	780	45	5.9	4,520	240	5.3
D	1,010	65	7.2	5,000	360	7.2	360	100	28	800	57	7.2	5,900	490	8.3
E	830	54	6.9	4,430	275	6.2	235	55	24	715	52	7.4	4,620	335	7.2
F	680	57	9.2	3,870	325	8.5	185	35	19	595	66	11.2	3,800	400	10.5
G	835	36	4.5	5,470	280	5.1	380	25	7	755	35	4.7	4,920	150	3.0
H	1,035	60	6.3	4,380	330	7.6	230	45	19	925	72	7.9	5,880	290	4.9
J	680	66	10.2	4,100	375	9.2	180	38	21	650	61	9.6	3,740	385	10.3
K	720	25	3.7	3,920	170	4.4	445	39	9	700	30	4.4	4,230	570	13.5
L	845	57	7.0	3,610	215	6.0	265	39	15	785	46	6.1	4,180	305	7.3
¼-in-thick standard															
A	715	82	11.4	3,400	480	14.2	160	39	25	690	65	9.4	2,890	475	16.4
E	740	48	6.5	3,830	290	7.6	220	62	28	720	47	6.6	3,460	450	13.0
J	745	63	8.4	4,720	420	8.9	225	36	16	720	54	7.5	3,780	390	10.3
⅛-in-thick tempered															
A	910	112	12.3	5,640	575	10.2	260	77	30	835	90	10.8	4,990	585	11.7
E	850	88	10.4	4,690	390	8.4	280	87	31	815	75	9.2	4,410	550	12.5
J	740	62	8.4	4,590	335	7.3	190	42	22	690	51	7.3	4,220	430	10.1
⅛-in-thick standard															
A	660	95	14.4	4,070	720	17.7	140	44	32	700	95	13.6	3,130	640	20.4
E	680	69	10.2	3,690	360	9.8	250	69	28	695	54	7.7	3,350	350	10.4
J	630	74	11.7	4,000	460	11.3	190	47	25	650	58	9.0	3,109	355	11.5

[1]Tests made according to ASTM D 1037; material at equilibrium at time of test, which average value, standard deviation (SD), and coefficient of variation (CV). Each average based on 100 determinations except modulus of elasticity for ¼-in-thick standard and both ⅛-in-thick boards are for 50 determinations.

[2]Based on secant modulus at 20 percent of the maximum stress.

Table 41—*Elastic and strength properties in shear of commercial hardboard (FPL evaluation) (Werren and McNatt 1975)*[1]

Board type	Interlaminar shear						Edgewise shear					
	Modulus of rigidity[2]			Shear strength			Shear modulus			Shear strength		
	Average (1,000 lb/in²)	SD (1,000 lb/in²)	CV (%)	Average (lb/in²)	SD (lb/in²)	CV (%)	Average (1,000 lb/in²)	SD (1,000 lb/in²)	CV (%)	Average (lb/in²)	SD (lb/in²)	CV (%)
¼-in-thick tempered												
A	78.0	18.0	23	430	81	18.8	295	16	5.3	2,850	175	6.2
B	95.5	21.5	22	490	55	11.2	310	17	5.3	3,200	215	6.8
C	87.5	8.5	10	565	46	8.1	350	16	4.5	2,860	230	8.1
D	200.0	73.0	36	840	115	13.7	335	19	5.6	3,440	290	8.5
E	120.0	22.5	19	485	75	15.3	330	23	7.0	2,860	215	7.6
F	71.0	14.5	20	495	65	13.3	290	16	5.6	2,550	225	8.9
C	96.5	8.0	8	850	30	3.7	350	9	2.7	3,410	215	6.3
H	125.5	14.0	11	540	65	11.9	405	14	3.5	2,880	320	11.2
J	66.0	12.5	19	455	65	14.5	315	21	6.7	2,980	275	9.2
K	130.0	13.5	10	815	40	4.8	295	14	4.9	3,120	95	3.0
L	159.5	22.5	14	705	115	16.2	305	28	9.2	2,860	170	5.9
¼-in-thick standard												
A	71.5[3]	13.0	18	410	73	17.8	240	23	9.4	2,060	235	11.5
E	106.0[3]	17.5	17	440	57	13.0	285	20	7.0	2,440	235	9.7
J	93.0[3]	17.5	19	520	77	14.8	325	18	5.4	2,970	220	7.4
⅛-in-thick tempered[4]												
A	—	—	—	620	178	28.7	320	30	9.5	3,610	410	11.4
E	—	—	—	600	123	20.5	300	19	5.9	3,380	300	8.9
J	—	—	—	510	78	15.3	285	11	3.7	3,180	250	7.9
⅛-in-thick standard[4]												
A	—	—	—	520	132	25.4	245	26	10.6	2,360	315	13.4
E	—	—	—	500	84	16.8	260	15	5.7	2,610	215	8.3
J	—	—	—	490	115	23.5	245	16	6.5	2,590	230	8.8

[1]Tests made according to ASTM D 1037 or ASTM D 3044; material in equilibrium at time of test. SD = standard deviation, CV = coefficient of variation. Each average value based on 50 determinations unless otherwise noted.

[2]Based on secant modulus at 20 % of maximum stress.

[3]Based on 30 tests.

[4]Due to the extremely small deformations, elastic values could not be determined for interlaminar shear.

Table 42—*Linear expansion and thickness swelling of ¼-in-thick tempered commercial hardboard (Werren and McNatt 1975)*[1]

Material and specimen	2-h soak			4-h soak			28-h soak			76-h soak			94-h soak			158-h soak			264-h soak		
No.	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS
A-1	10.5	0.42	6.3	14.5	0.53	12.3	22.9	0.66	18.6	32.0	0.67	19.8	34.5	0.69	20.2	38.4	0.66	21.4	41.0	0.72	22.5
A-2	9.8	.40	5.1	13.3	.50	9.3	21.5	.62	15.6	30.0	.65	17.3	32.1	.66	16.9	34.8	.68	20.7	37.5	.66	19.8
Avg.	10.2	.41	5.7	13.9	.52	10.8	22.2	.64	17.1	31.0	.66	18.6	33.3	.68	18.6	36.6	.67	21.1	39.3	.69	21.2
C-1	11.7	.32	11.7	20.0	.52	17.7	31.6	.58	22.1	47.0	.59	23.3	49.6	.79	23.7	52.2	.62	24.9	55.5	.73	24.9
C-2	11.4	.31	11.5	19.7	.43	18.1	30.8	.58	22.2	43.0	.52	23.5	47.1	.60	23.5	49.9	.58	24.3	53.3	.71	25.1
Avg.	11.6	.32	11.6	19.9	.48	17.9	31.2	.58	22.2	45.0	.56	23.4	48.4	.69	23.6	51.1	.60	24.6	54.4	.72	25.0
E-1	8.2	.39	4.5	9.7	.47	7.0	14.4	.58	9.9	20.6	.70	10.7	22.0	.65	11.1	24.4	.62	12.4	27.8	.69	13.2
E-2	8.3	.45	5.0	9.7	.53	6.6	14.0	.63	10.0	20.2	.64	10.8	20.0	.73	10.8	24.1	.66	12.0	27.8	.70	13.3
Avg.	8.3	.42	4.8	9.7	.50	6.8	14.2	.61	10.0	20.4	.68	10.8	21.5	.69	11.0	24.3	.64	12.2	27.8	.70	13.3
G-1	9.4	.42	5.5	12.3	.51	9.3	20.5	.68	15.6	28.9	.67	18.2	30.7	.68	18.6	35.0	.68	19.8	38.6	.73	22.0
G-2	9.4	.47	6.2	12.0	.55	8.7	20.9	.68	15.8	29.0	.70	17.5	31.9	.74	18.3	35.3	.82	19.6	40.4	.78	21.7
Avg.	9.4	.45	5.9	12.2	.53	9.0	20.7	.68	15.7	29.0	.69	17.9	31.3	.71	18.5	35.2	.75	19.7	39.5	.76	21.9
J-1	11.5	.54	8.8	14.5	.63	13.9	25.6	.82	22.7	35.6	.78	24.8	39.0	.81	25.2	44.4	.82	26.5	49.3	.81	28.6
J-2	11.2	.59	9.6	14.0	.67	12.5	25.0	.81	21.3	35.4	.88	23.3	39.5	.96	24.2	44.1	.91	25.8	49.8	.94	27.5
Avg.	11.4	.47	9.2	14.3	.65	13.2	25.3	.82	22.0	35.5	.83	24.1	39.3	.89	24.7	44.3	.87	26.2	49.6	.88	28.1
L-1	10.0	.47	8.0	12.6	.63	13.5	22.4	.77	24.4	32.7	.77	26.9	37.0	.85	27.3	44.0	.83	28.6	48.4	.87	30.3
L-2	10.3	.45	7.9	13.0	.51	12.1	23.0	.69	22.2	33.2	.73	23.9	38.7	.85	23.9	44.4	.91	25.5	47.8	.84	26.8
Avg.	10.2	.46	8.0	12.8	.57	12.8	22.7	.73	23.2	33.0	.75	25.4	37.9	.85	25.6	44.2	.87	27.1	48.1	.86	28.6

[1]Values are expressed as a percentage of the calculated ovendry measurements determined from dimensions and weights of matched specimens 3 and 4 (table 47). MC = moisture content, LE = linear expansion, TS = thickness swelling.

Table 43—*Linear expansion and thickness swelling of ¼-in-thick tempered commercial hardboard (Werren and McNatt 1975)*[1]

Material and specimen No.	30% RH			64% RH			80% RH			90% RH			97% RH			Soaked in water for 11 days		
	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS	MC	LE	TS
A-3	3.7	0.18	2.0	7.1	0.32	4.3	—	—	—	12.8	0.45	10.6	22.1	0.66	21.7	34.8	0.66	22.1
A-4	—	—	—	—	—	—	10.0	0.36	6.7	—	—	—	26.5	.62	19.8	40.0	.61	19.8
Avg.	—	—	—	—	—	—	—	—	—	—	—	—	24.3	.64	20.8	37.4	.64	20.9
C-3	2.8	.10	1.2	5.4	.20	3.3	—	—	—	10.6	.33	10.3	25.0	0.68	24.3	49.8	.69	24.3
C-4	—	—	—	—	—	—	8.3	.30	6.8	—	—	—	31.4	.68	24.0	55.4	.69	24.8
Avg.	—	—	—	—	—	—	—	—	—	—	—	—	28.2	.68	24.2	52.6	.69	24.5
E-3	2.9	.16	.8	5.6	.32	2.9	—	—	—	9.7	.48	7.5	15.2	.64	13.3	24.1	.65	13.8
E-4	—	—	—	—	—	—	8.0	.35	5.8	—	—	—	19.3	.60	14.1	29.4	.61	14.5
Avg.	—	—	—	—	—	—	—	—	—	—	—	—	17.2	.62	13.7	26.8	.63	14.1
G-3	3.3	.18	.8	6.2	.33	3.3	—	—	—	11.4	.49	9.2	22.5	.69	21.4	35.1	.72	22.2
G-4	—	—	—	—	—	—	9.1	.39	6.3	—	—	—	25.6	.65	21.4	40.1	.68	22.7
Avg.	—	—	—	—	—	—	—	—	—	—	—	—	24.1	.67	21.4	37.6	.70	22.4
J-3	3.9	.25	1.3	7.5	.45	4.2	—	—	—	13.5	.63	11.7	28.2	.85	28.0	47.0	.85	28.9
J-4	—	—	—	—	—	—	10.8	.53	8.0	—	—	—	35.8	.82	28.6	54.6	.82	29.0
Avg.	—	—	—	—	—	—	—	—	—	—	—	—	32.0	.84	28.3	50.8	.84	29.0
L-3	3.8	.20	1.7	7.1	.35	3.8	—	—	—	13.2	.52	11.7	31.8	.84	29.3	44.6	.86	29.3
L-4	—	—	—	—	—	—	10.8	.53	8.0	—	—	—	33.1	.86	31.8	52.7	.88	32.7
Avg.	—	—	—	—	—	—	—	—	—	—	—	—	32.5	.85	30.6	48.6	.87	31.0

[1]Values are expressed as a percentage of the ovendry value. MC = moisture content, LE = linear expansion, TS = thickness swelling.

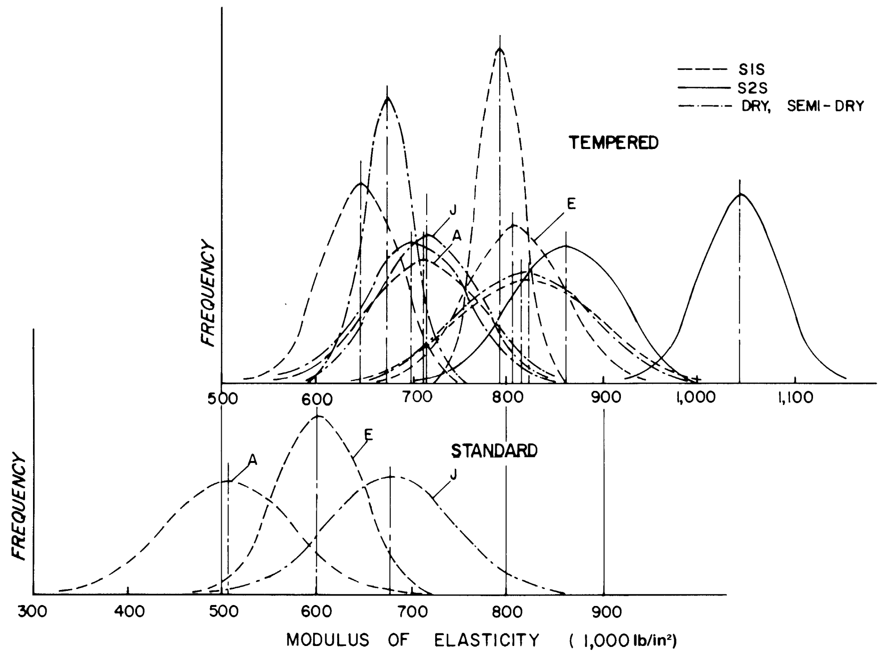


Figure 326—*Modulus of elasticity in bending of ¼-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

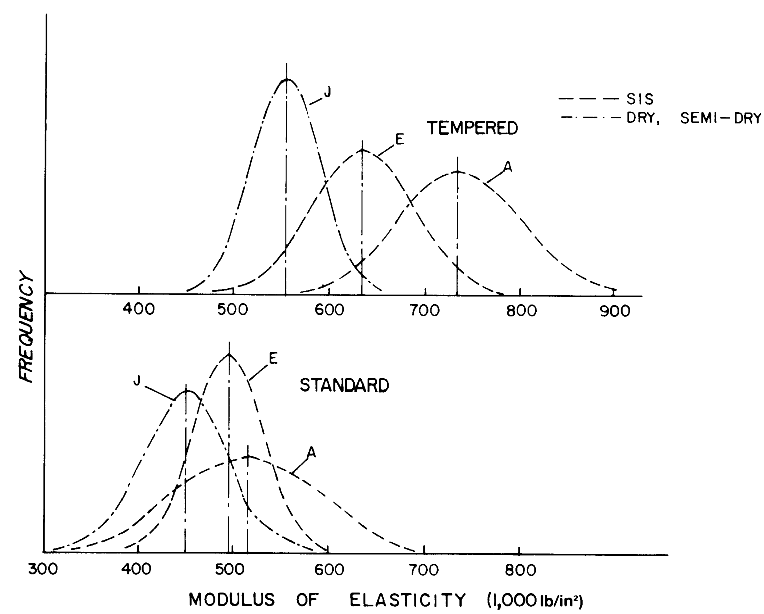


Figure 327—*Modulus of elasticity in bending of 1/8-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

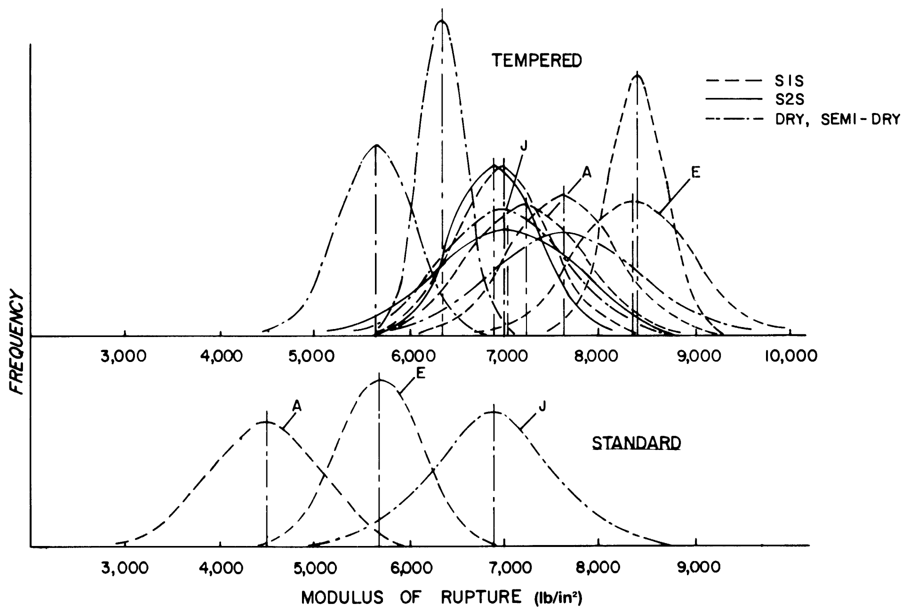


Figure 328—*Modulus of rupture of ¼-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

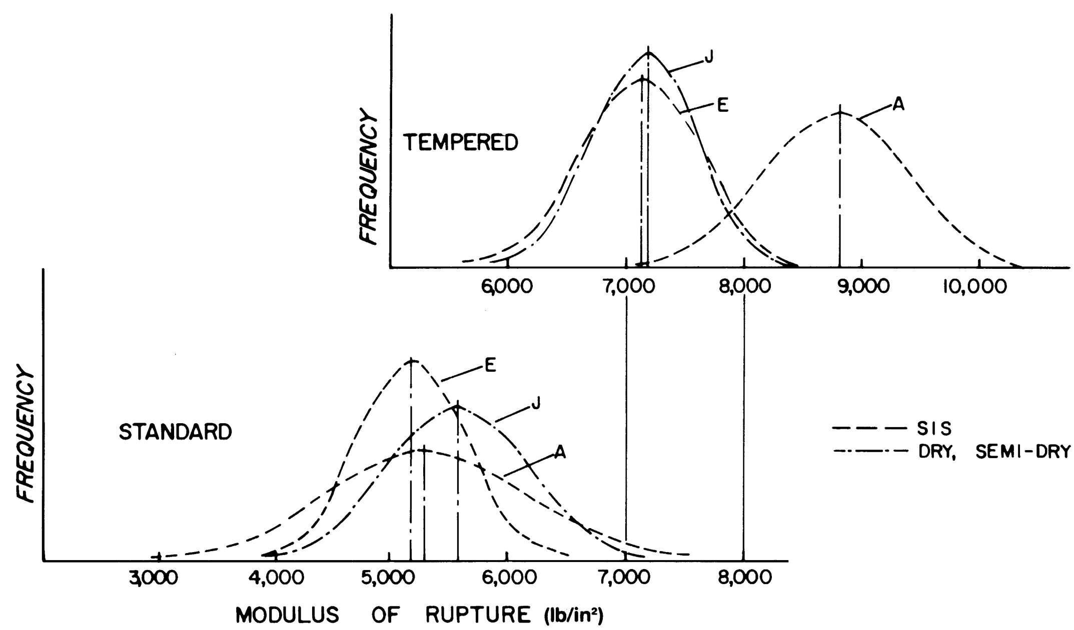


Figure 329—*Modulus of rupture of 1/8-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

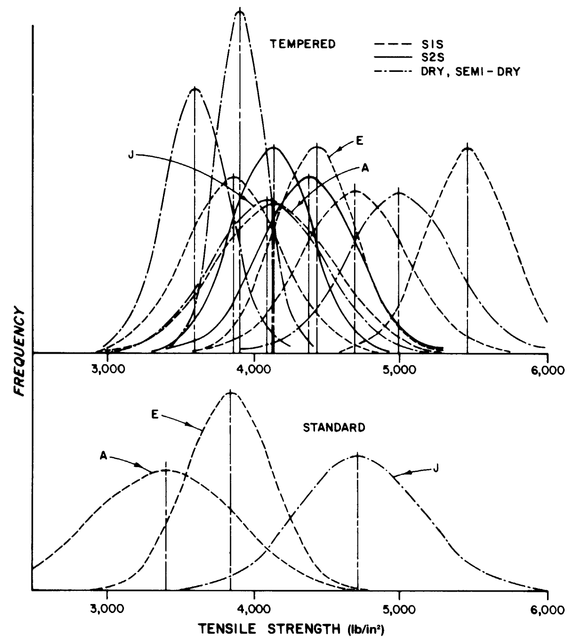


Figure 330—*Tensile strength parallel to surface of ¼-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

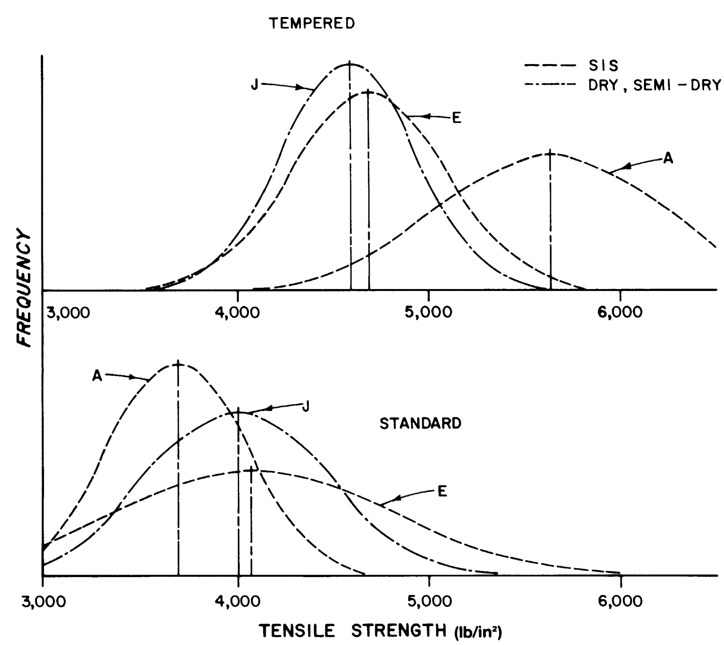


Figure 331—*Tensile strength parallel to surface of 1/8-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

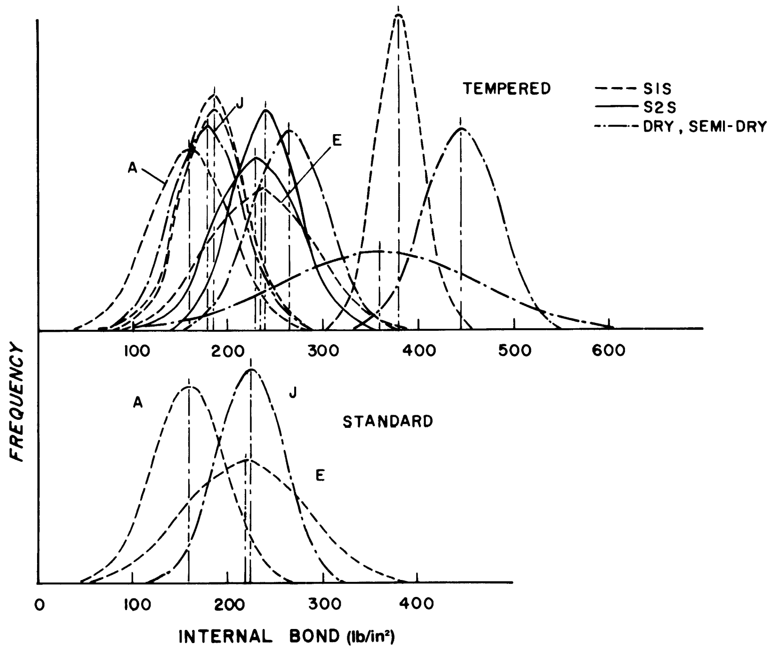


Figure 332—*Tensile strength perpendicular to surface (internal bond) of ¼-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

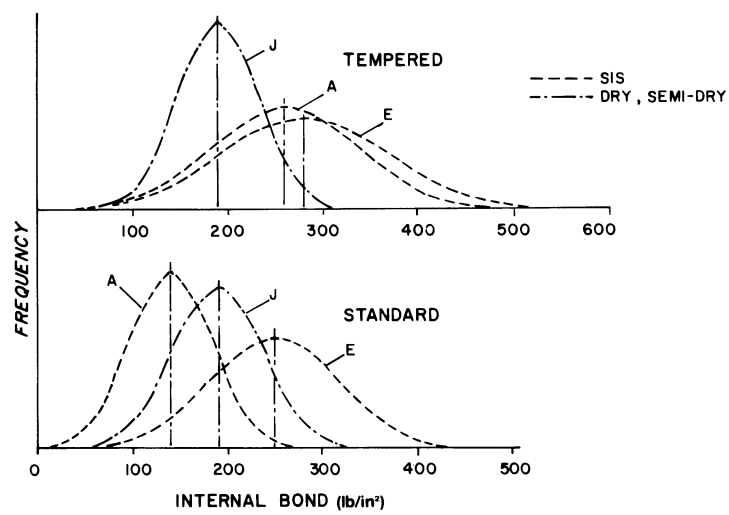


Figure 333—*Tensile strength perpendicular to surface (internal bond) of 1/8-inch hardboard types commercially manufactured in the United States (drawn from data by Werren and McNatt 1975). Letters refer to specific manufacturing plants.*

Table 44—*Properties of commercial Mende-boards (Suchsland 1977)*

Manufacturer	Thickness (in)	Internal bond (lb/in²)	Tensile strength (lb/in²)	Modulus of rupture (lb/in²)	Modulus of elasticity (1,000 lb/in²)	Linear expansion (%)	Water absorption by weight (%)	Water absorption by volume (%)	Thickness swelling (%)	Specific gravity	Moisture content (%)	Board type
A	0.155	228	1,296	3,126	409	0.786	17.1	13.8	8.3	0.742	8.8	Particles, homogeneous
	3/16	209	1,231	2,775	385	.688	13.6	10.7	5.4	.711	9.3	
B	3/16	156	778	1,876	220	.621	52.4	36.4	12.2	.633	9.2	
C	3/16	218	1,112	2,753	331	.481	57.4	43.1	12.4	.664	9.2	
D	1/4	123	1,569	3,397	236	.540	15.7	12.0	4.7	.712	6.8	Fibers, homogeneous
	1/8	141	1,856	4,409	316	.577	23.6	8.6	6.9	.775	7.2	
E	1/4	156	1,347	3,569	392	.439	8.5	6.3	2.8	.707	9.4	Particles three-layer
	3/16	198	1,862	3,536	370	.399	36.0	27.4	9.7	.699	8.8	
	5/32	272	1,382	3,306	385	.566	28.0	21.2	11.1	.719	8.8	
	1/8	248	1,331	3,039	308	.533	33.8	25.6	14.5	.698	8.8	

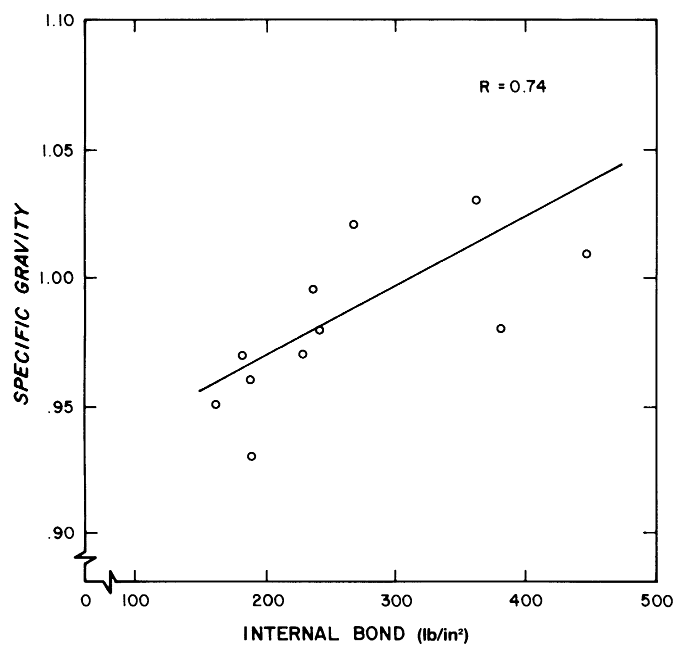


Figure 334—*Correlation between board specific gravity and internal bond of ¼-inch tempered commercial hardboard (drawn from data by Werren and McNatt 1975).*

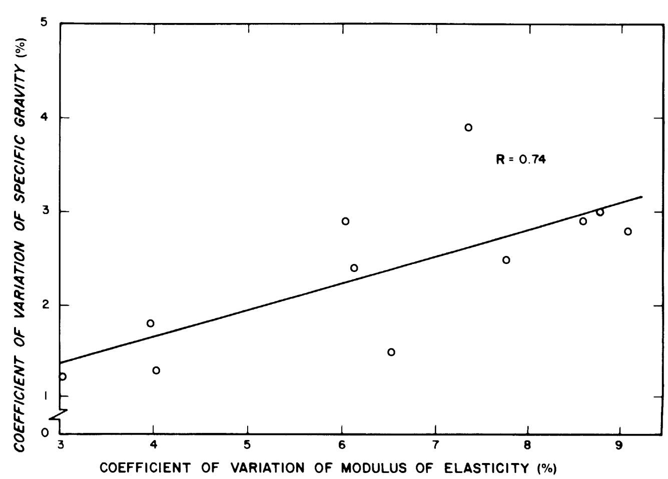


Figure 335—*Correlation between the coefficients of variation of board specific gravity and of modulus of elasticity in bending of ¼-inch tempered commercial hardboard (drawn from data by Werren and McNatt 1975).*

be expected through greater densification aided by preheating of the mat, better selection of particle geometry and other furnish characteristics, and improved particle or fiber alignment.

Properties of Commercial Medium-Density Fiberboard

The major property requirements of thick medium-density fiberboard (MDF) are listed in table 45, which is taken from the standard for "Medium Density Fiberboard for Interior Use," cosponsored by the American Hardboard Association and the National Particleboard Association (USDC NBS 1980).

Table 46 is the result of a comprehensive evaluation of commercial medium-density fiberboards from 8 of a total of 11 manufacturers operating in 1975. See also the results of an earlier study made by the USDA Forest Service, Forest Products Laboratory (Superfesky and Lewis 1974). Board densities varied over a wide range (fig. 336) and most boards possessed a considerable density gradient (density variation over cross section), which enhanced the modulus of elasticity. This is illustrated in figure 337, in which modulus of elasticity is plotted over

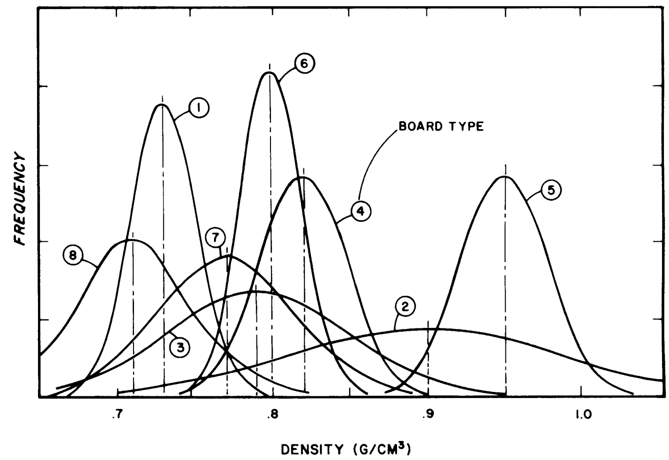


Figure 336—*Normal distribution curves for board densities of eight commercially manufactured medium-density fiberboards (Suchsland and others 1979).*

Table 45—*Property requirements of thick medium-density fiberboard (USDC NBS 1980)*

Nominal thickness (in)	Modulus of rupture (lb/in²)	Modulus of elasticity (lb/in²)	Internal bond (tensile strength perpendicular to surface) (lb/in²)	Linear expansion (%)	Screw-holding capacity (lb)	
					Face	Edge
$\leq$ 13/16	3,000	300,000	90	0.30[1]	325	275
$\geq$ 7/8	2,800	250,000	80	.30	300	225

[1]For boards having nominal thicknesses of 3/8 inch or less, the linear expansion value is 0.35%.

Table 46—*Summary of physical and mechanical properties of eight commercial medium-density fiberboards (Suchsland 1979)*[1]

Mill No.	Density (g/cm³)	1,000 lb/in²			Screw-holding capacity (lb)		Thickness swelling, 47-93% RH (%)	Residual thickness swelling (%)	Linear expansion, 47-93% RH (%)
		MOR	MOE	IB	Edge	Face			
1	0.73	4,837	466	125	257	326	9.59	4.36	0.360
2	.90	4,932	576	136	325	407	6.32	1.61	.391
3	.79	3,366	432	282	330	445	6.26	2.48	.611
4	.82	5,703	635	121	252	326	8.88	2.83	.346
5	.95	3,565	517	133	405	509	11.44	5.45	.577
6	.80	5,278	578	103	315	404	10.49	4.52	.376
7	.77	5,421	572	179	360	464	8.74	3.18	.440
8	.71	5,107	858	158	324	416	8.17	3.03	.413

[1]MOR = modulus of rupture, MOE = modulus of elasticity, IB = internal bond, RH = relative humidity.

board density. The density of each board type is represented by a horizontal line at the level of its modulus of elasticity. The length of each line indicates the difference in density between the face (right end of line) and the core (left end of line). The average board density is indicated by the location of the numbered small circle between the extremes. The face density dominates the relationship with the modulus of elasticity, as demonstrated by its strong correlation with this modulus. No similar

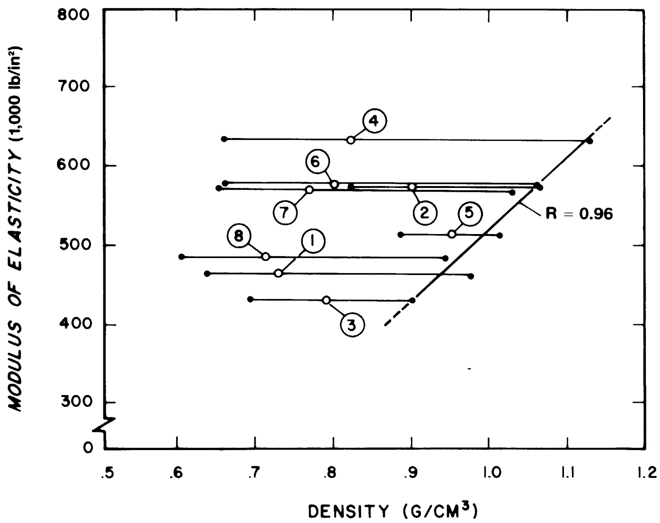


Figure 337—*Modulus of elasticity in bending as related to density of commercially manufactured medium-density fiberboard types. Horizontal lines indicate density gradient from board surface (right end of line) to board center (left end) (Suchsland and others 1979).*

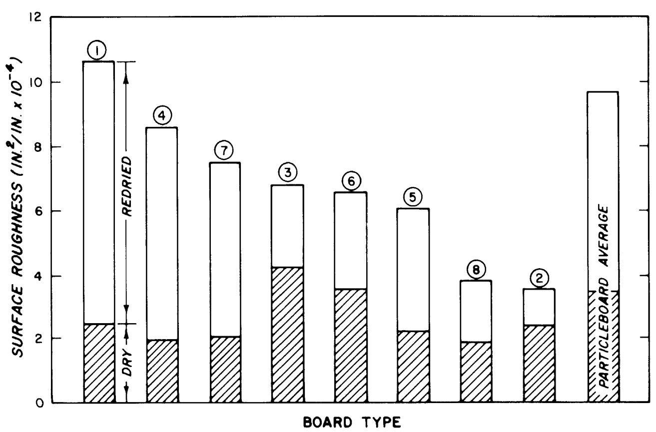


Figure 338—*Surface roughness at dry condition and at redried condition after 24-h water soak of commercially manufactured medium-density fiberboard types compared with average of nine commercial particle board types (Suchsland and others 1979).*

relationship between overall or core density and internal bond (tension perpendicular to board surface) could be found. This contrasts with data for hardboard, where internal bond was strongly affected by board density. The linear expansion values of all commercial board types tested exceeded the maximum value allowed by the standard, perhaps because of procedural differences.

Other important properties are not included in the standard because they cannot be conveniently tested or are not equally important in all applications. In those cases, the user selects on the basis of his own experiments or experience with various types of board. Surface smoothness and its stability in service is one such important characteristic that is difficult to express in quantitative terms. Figure 338 shows the results of an attempt to evaluate this characteristic by measuring the surface smoothness of the board dry and redried after it was soaked in water. The surface "roughness" is expressed in terms of the integral of the profilometer trace (in^2/in). Figure 338 shows the superiority of medium-density fiberboard over conventional particle board in this test.

Viscoelastic Behavior of Fiberboard

In the design of most structures involving wood as structural members, the assumption is made that wood is an elastic material and that the deformation response to stresses is linear and completely reversible. For most practical purposes and at relatively low stress levels this assumption is justified, although solid wood cannot be classified as a purely elastic material. Instead, wood and particularly wood-derived composition board such as particle board and fiberboard possess **plastic response** components that significantly alter their behavior under stress. Materials that possess such plastic components are called **viscoelastic materials.**

Viscoelastic characteristics are not recognized by the standards. However, an appreciation of this behavior is very helpful in properly applying hardboard in structural situations and in many other applications.

Figure 339 shows typical response curves of completely elastic and viscoelastic materials. In the **elastic material** there is no time dependent deformation after application of the constant load, and the elastic response disappears instantly and completely upon load removal. Viscoelastic material, after the initial and immediate elastic response, continues to deform under the constant load (creep). Upon load removal, only the elastic deformation component is recovered immediately. The **creep** portion is recovered gradually and incompletely, leaving a permanent deformation **(plastic flow).**

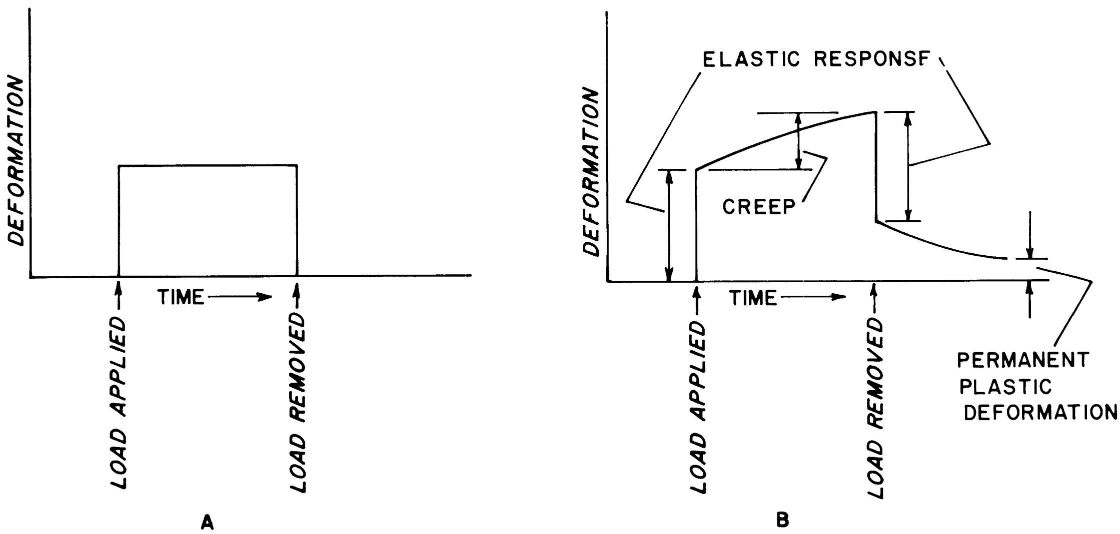


Figure 339—*Deformation response curve to constant load of elastic* **(A)** *and viscoelastic material* **(B).**

This behavior can be visualized better by considering a simplified model consisting of purely elastic springs and purely plastic dashpots (cylinders filled with viscous fluid and containing a disk-shaped piston with enough clearance to allow the piston to move when load is applied) (fig. 340). The elastic spring will respond instantly to an applied load and will return instantly to its original length upon load removal. The dashpot will not respond immediately but will extend with time. Upon removal of the load, the dashpot will remain in the extended condition.

The viscoelastic behavior, as shown in figure 339, could be simulated by a combination of springs and dashpots, as shown in figure 341. Element A would respond instantly (elastic response component). Elements B and C cannot respond instantly because of the "sluggishness" of the dashpots. They both will deflect, however, with time (creep). Upon load removal, element B will slowly but completely contract to its original condition because of the restoring force of the spring. Element C will remain extended (permanent plastic deformation).

By combining, in series and in parallel, a large number of springs with various spring constants and dashpots with various viscosities, the viscoelastic behavior of any material, including hardboard, could be quite accurately described (Moslemi 1964).

It is clear that pronounced viscoelastic behavior would require that special attention be given to structural applications of such materials. Long-term bending moments, for instance, would cause considerable sag with time far beyond the predictable elastic response. The situation is made more complicated by the fact that the plastic element is greatly affected by moisture content and temperature. This may be illustrated by an experiment involving the linear expansion of hardboard under restraint.

Figure 342 shows an apparatus used for the measurement of swelling stresses and swelling deformations of narrow hardboard strips. The strip is clamped at both ends and is completely restrained from expansion in the direction of its long dimension. Upon raising the relative humidity of the surrounding air, the **restrained swelling** will be transformed into compression deformation and **buckling** of the strip. The resulting stresses are measured by a load cell and the buckling deformation by dial indicators.

Figure 343 shows the results of cyclic exposure of this arrangement to high and low relative humidity. The solid curve indicates the development of axial stresses as measured by the load cell. The broken curves indicate the lateral deflection (buckling) of the strip at midpoint as measured by the dial micrometer.

As moisture content of the strip increases, compressive stresses build up quickly without lateral deflection until the **critical buckling stress** is reached, at which point the lateral deflection increases rapidly. The axial stresses, however, diminish to zero as the strip equalizes at the high relative humidity. This means that the compressive stress has **relaxed** and that the clamps could be released at this point without causing the bowing of the strip to disappear.

Upon reversal of the cycle (drying of the clamped strip), tensile stresses develop, while at the same time the lateral deflection disappears again. This means that the strip must be stretched to straighten it out. In subsequent cycles, the lateral deflection occurs again without the recurrence of compressive stresses. Even if the strip was initially clamped in the wet condition, buckling could not be entirely avoided (fig. 344). The results of the experiment allow the following general conclusions (Suchsland 1965):

- In restrained expansion and shrinkage of hardboard, compressive stresses are associated with expansion and increase with increasing moisture content. Tensile stresses are associated with shrinkage and increase with decreasing moisture content. The combination of these two characteristics and the fact that **stress relaxation** and creep increase with increasing moisture content favors the development of tensile stresses and the suppression of compressive stresses.
- Although the buckling of hardboard is a result of compressive stresses, under certain conditions the buckling deformation is "frozen" in by stress relaxation and will recur every time the axial stresses approach the level to which the compressive stresses had relaxed initially.
- When transverse deflections are objectionable, higher initial moisture contents might be considered. The buckling deformation will be reduced, but the tensile stresses will increase. However these tensile stresses, if not properly balanced, might cause even more severe distortions in addition to applying a considerable load to the frame member.

A thorough understanding of this behavior of hardboard will go a long way in preventing problems associated with its hygroscopic expansion and shrinkage. At the same time, the reduction or elimination of the plastic component of the stress response ought to be a challenging research goal.

Insulation Board Property Requirements

The Voluntary Product standard PS 57-73 (U.S. Department of Commerce, National Bureau of Standards 1973), "Cellulosic fiber insulating board," covers the property requirements and test methods for insula-

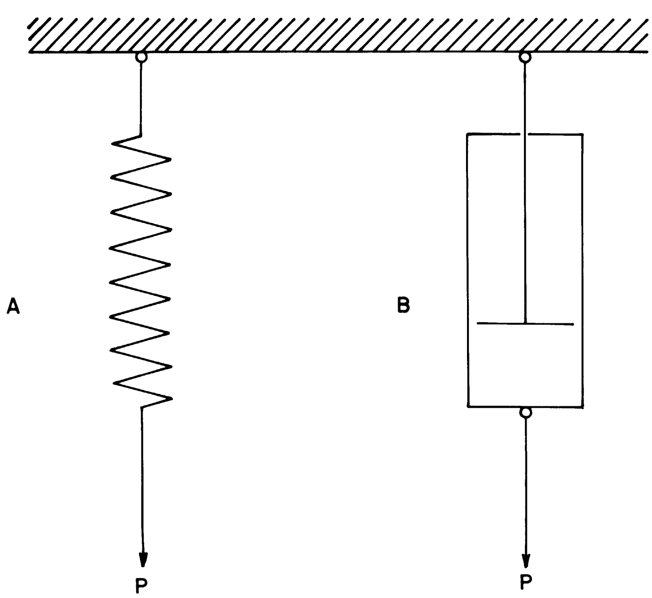


Figure 340—*Models symbolizing response characteristic of materials: elastic spring, symbolizing perfectly elastic behavior* **(A)** *and dashpot, symbolizing perfectly plastic behavior* **(B)**.

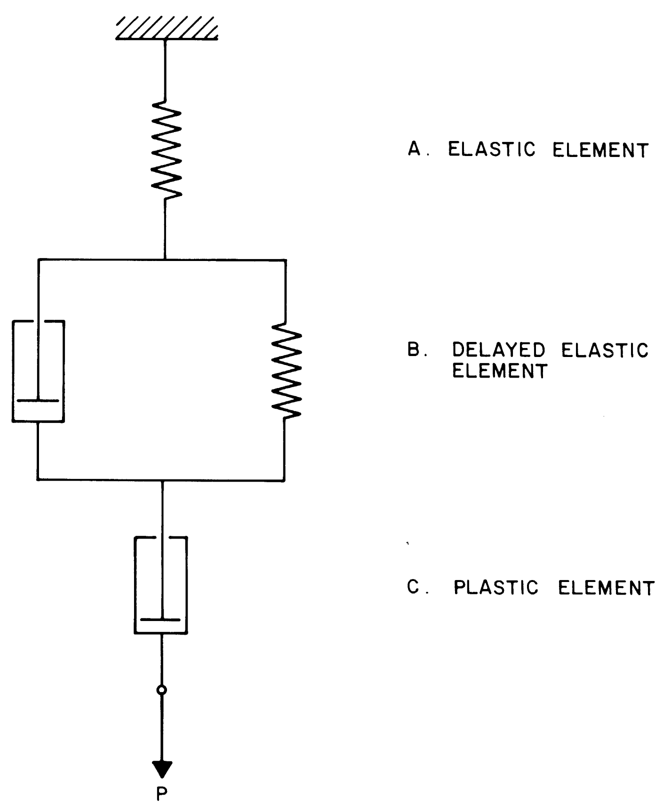


Figure 341—*Simplified model of viscoelastic material.*

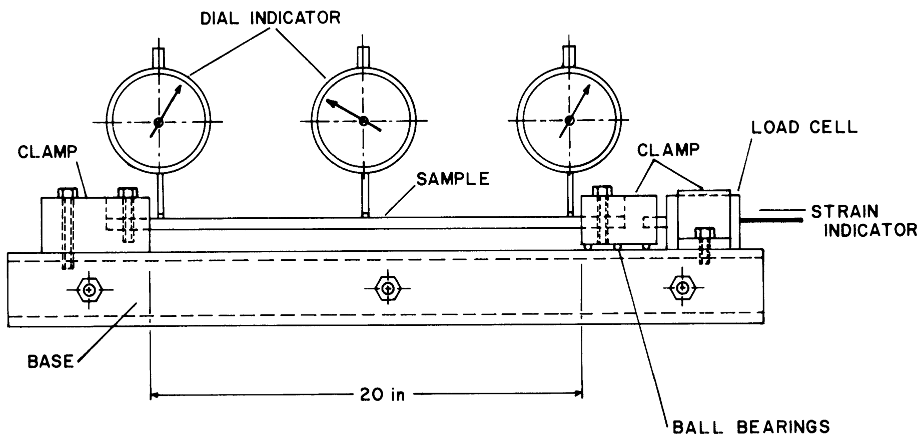


Figure 342—*Apparatus for measuring swelling stress and swelling deformation of hardboard strips (Suchsland 1965).*

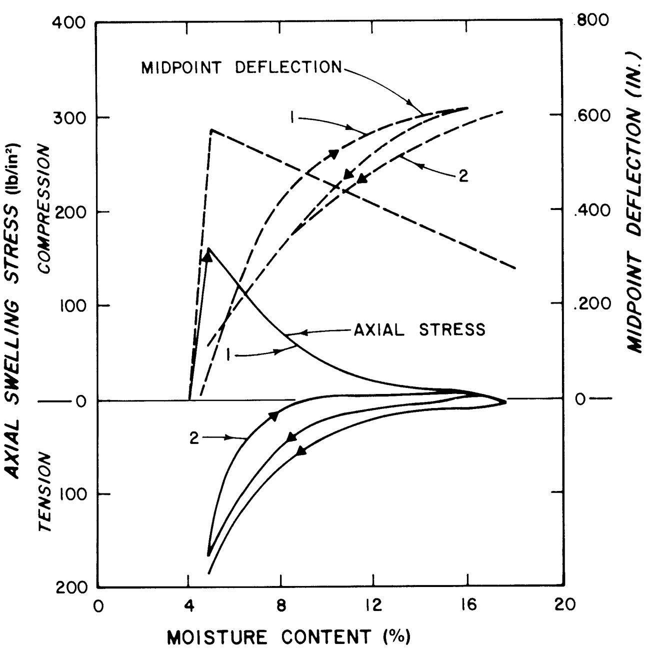


Figure 343—*Axial stresses and midpoint deflection of axially restrained hardboard strips as functions of moisture content (clamped dry) (Suchsland 1965). Numbers 1 and 2 indicate sequence of cycles. Dashed line represents theoretical stresses (assumption of elasticity).*

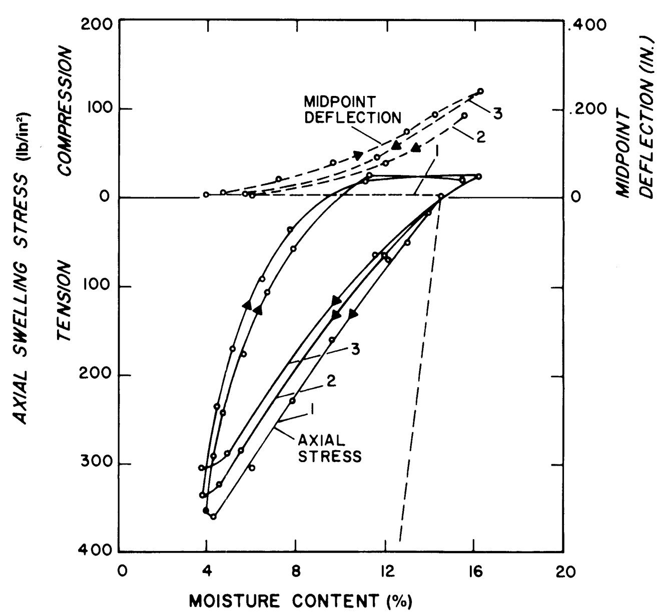


Figure 344—*Axial stresses and midpoint deflection of axially restrained hardboard strips as functions of moisture content (clamped wet) (Suchsland 1965). Numbers 1, 2, and 3 indicate sequence of exposure cycles. Dashed line represents theoretical stresses (assumption of elasticity).*

tion board. This standard defines insulation board as fiberboard in the density range of 10 to 31 lb/ft³ (specific gravity: 0.16 to 0.50) and establishes 12 types according to application, as shown in table 47.

Table 48 lists properties and the appropriate ASTM test methods for their evaluation. Property requirements are listed in table 49.

Actual properties of commercial insulation board are not available.

Of the properties listed, the thermal conductivity, k, is probably the most significant. Below is a brief discussion of heat transfer through building material and the

Table 47—*Types, classes, and intended uses of insulation board (USDC NBS 1973)*

Type	Class	Name	Intended use
I		Sound deadening board	In wall assemblies to control sound transmission
II		Building board	As a base for interior finishes
III		Insulating formboard	As a permanent form for poured-in-place reinforced gypsum or lightweight concrete aggregate roof construction
IV		Sheathing	
	1	Regular-density	As wall sheathing in frame construction where method of application and/or thickness determines adequacy of racking resistance
	2	Intermediate-density	As wall sheathing where usual method of application provides adequate racking resistance
	3	Nail-base	As wall sheathing where usual method of application provides adequate racking resistance; in addition, exterior siding materials, such as wood or asbestos shingles, can be directly applied with special nails
V		Shingle backer	As an undercoursing for wood or asbestos cement shingles
VI		Roof insulating board	As above-deck insulation under built-up roofing
VII		Ceiling tiles and panels	
	1	Nonacoustical	As decorative wall and ceiling coverings
	2	Acoustical	As decorative, sound absorbing wall and ceiling coverings
VIII		Insulating roof deck	As roof decking for flat, pitched, or shed-type open-beamed, ceiling-roof construction
IX		Insulating wallboard	As a general-purpose product used for decorative wall and ceiling covering

use of thermal conductivity in the calculation of heat losses.

Heat (Q) is measured in Btu (British thermal units); 1 Btu is the amount of heat needed to raise the temperature of 1 lb of water from 63 to 64 °F. The amount of heat transferred through a material depends on its thermal conductivity (a material characteristic), its thickness, the surface temperature difference, and time:

$$\Delta Q = k \cdot A \cdot \frac{T_2 - T_1}{\ell} \cdot t \text{ (Btu)},$$

where k = thermal conductivity $\left(\frac{\text{Btu} \cdot \text{in}}{\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}}\right)$,

A = area (square feet),
T_1, T_2 = surface temperatures (°F),
t = time (hours),
ℓ = thickness (inches).

The heat loss through 10 ft^2 of pine lumber ($k = 0.80$), 3/4 in thick, over a time period of 24 h, and for a temperature difference of 50 °F is:

$$\Delta Q = 0.80 \times 10.0 \times (50/0.75) \times 24 = 12{,}792 \text{ Btu}.$$

For many materials, the thermal conductivity per inch of thickness is meaningless because the material is not homogeneous (hollow cement block) or it is of a given unique thickness (asbestos cement shingles or asphalt roll roofing).

In these cases, the thermal conductivity for the entire material thickness is listed and is called thermal conductance, C. The above heat loss equation is then written

$$\Delta Q = C \cdot A \cdot (T_2 - T_1) \cdot t \text{ (Btu)}.$$

Table 48—*Test methods for insulation board (USDC NBS 1973)*

Property or dimension	Test method	Comment or exception
Certain properties of type VIII insulating board only		
Thermal conductance Modulus of rupture (dry and after accelerated aging) Modulus of elasticity Deflection span ratio Vapor permeance	ASTM D 2164-65. *Standard Methods of Test for Structural Insulating Roof Deck*	For strength parameters use equivalent Uniform Load
All other properties		
Thickness Thermal conductivity Transverse strength (dry and wet) Modulus of rupture (dry and wet) Deflection at specified min. load (dry and wet) Tensile strength parallel to the surface Tensile strength perpendicular to the surface Water absorption (except for type IV class 2 and class 3 boards) Direct nail withdrawal resistance (dry and soaked)	ASTM C 209-72, *Standard Methods of Testing Structural Insulating Board Made from Vegetable Fibers*	(1) *Transverse strength*—Wet value for type III board obtained after conditioning as follows: one side of board shall be submerged for 24 hours under ¼ in of water which is at a temperature of 70 ± 5 °F. Edges shall be sealed when soaking and the soaked side of the specimen shall be in compression when testing. (2) *Modulus of rupture*—(a) Values computed from transverse strength test data using the formula: $MOR = \frac{(6P)}{t^2}$, where MOR = modulus of rupture, P = transverse load, t = thickness. (b) Wet value for type III board obtained as described in (1) above. (3) *Deflection at specified min. load*—Wet value for type III board obtained as described in (1) above. (4) *Tensile strength parallel to surface*—Value for type VIII board pertains to individual plies making up the board (see 3.3) no larger than 1-in thick. (5) *Direct nail withdrawal resistance*—A 0.100-in-diameter aluminum wire nail at least 1⅜-in long with 20 sharp rings per in measuring 0.116-in max outside diameter shall be used. Testing speed shall be 1.0 in/min ± 50%.

Flame spread index	ASTM E 84–70, *Standard Method of Test for Surface Burning Characteristics of Building Materials*	
Racking load (dry and wet)	ASTM E 72–68, *Standard Methods of Conducting Strength Tests of Panels for Building Construction.* In conjunction with Federal Housing Administration Technical Circular No. 12, *A Standard for Testing Sheathing Materials for Resistance to Racking.*	Specimens shall be fastened 6 in apart to intermediate framing and 3 in apart around edges. Specimens shall be in a vertical position when tested. Studs shall be placed 16 in on center. Specimens shall be nailed with 1½-in galvanized roofing nails or 6d common nails or 16-gauge staples 1⅛-in long with a minimum crown of 7/16 in for ½-in sheathing. 25/32-in sheathing shall be nailed with 1¾-in galvanized nails or 8d common nails or 16-gauge staples 1½-in long with a minimum crown of 7/16 in.
Vapor permeance	ASTM C 355-64, *Standard Methods of Test for Water Vapor Transmission of Thick Materials*	
Width Length		
Linear expansion	ASTM D 1037–64, *Standard Method of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials*	
Water absorption (for type IV, class 2 and class 3 boards only)		
Thermal conductance	ASTM C 177-63, *Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate*	

Table 49—*Insulation board property requirements (USDC NBS 1973)*[1]

Property	Type I	Type II	Type III	Type IV, Class 1, ½ in thick	Type IV, Class 1, 25/32 in thick	Type IV, Class 2	Type IV, Class 3	Type V, 3/8 in thick	Type V, 5/16 in thick	Type VI, ½ in thick	Type VII	Type VIII	Type IX
Thermal conductivity (k) avg. max. (Btu in/h, ft², deg. at 75 ± 5 °F)	0.38	0.38	0.40	0.40	0.40	0.44	0.48	0.40	0.40		0.38	0.40	0.40
Transverse strength either direction, avg. min. (H)													
Dry	12	12	37	14	25	17	25	6	6	7	10	NR	6
Wet	NR	NR	18	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Modulus of rupture, avg. min. (lb/in²)													
Dry	240	240	190	275	200	340	500	200	240	140	200	225	200
Wet	NR	NR	95	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
After accelerated aging	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	50%[2]	NR
Modulus of elasticity, avg. min. (lb/in² × 10)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	40	NR
Deflection span ratio, avg. max.	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1:240	NR
Deflection at specified min. load, avg. max. (in)													
Dry	0.85	0.85	0.16	0.75	0.56	0.75	0.65	1.18	1.18	1.25	NR	NR	NR
Wet	NR	NR	0.11	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Tensile strength parallel to surface, avg. min. (lb/in²)	150	150	150	150	150	200	300	150	150	50	150	150	150

Tensile strength perpendicular to surface, avg. min. (lb/in²)	600	600	600	600	600	800	1000	600	600	500	600	600	600
Water absorption by volume, avg. max. (%)	7	7	10	7	7	15	12	7	7	10	NR	10	15
Linear expansion, 50–90% RH, avg. max. (%)	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Vapor permeance, avg. min. (grains/h, ft², in Hg pressure differential)	NR	NR	5	5	5	5	5	5	5	NR	NR	0.5[3]	NR
Direct nail withdrawal resistance, avg. min. (lb/nail)													
Dry	NR	NR	NR	NR	NR	NR	40	NR	NR	NR	NR	NR	NR
Soaked	NR	NR	NR	NR	NR	NR	25	NR	NR	NR	NR	NR	NR
Racking load, avg. min. (lb)													
Dry	NR	NR	NR	NR	5,200	5,200	5,200	NR	NR	NR	NR	NR	NR
Wet	NR	NR	NR	NR	4,000	4,000	4,000	NR	NR	NR	NR	NR	NR
Flame spread index, finish surface, max.[4]	NR	200	NR	NR	NR	NR	NR	NR	NR	NR	200	200	200

[1]NR = Not required for this product, max. = maximum, min. = minimum.
[2]Percent of dry value; for example, if the dry modulus of rupture (MOR) is found to be 300 lb/in², then the MOR after accelerated aging must not be less than 150 lb/in².
[3]Average maximum; for products without a vapor barrier, there is no requirement for vapor permeance.
[4]The physical properties listed for acoustical material, except for flame spread, apply to the base material before punching, drilling, perforating, or embossing.

Table 50—*Conductivities (k) and conductances (C) for calculating heat loss coefficients (Insulation Board Institute 1963)*

Material	Description	Constants (Btu/hr/ft²/°F diff.) k	C	Resistance R per inch thickness $1/k$	per thickness listed $1/C$
Air spaces	Vertical		1.03		0.97
¾ in or more in width and bounded by	Horizontal—heat flow down		.80		1.25
ordinary materials	Horizontal—heat flow up		1.18		.85
Air surfaces	Vertical		1.46		.68
Still air	Horizontal—heat flow down		1.08		.92
	Horizontal—heat flow up		1.63		.61
	Outside surface (15 mi/h wind)		6.00		.17
Exterior finishes (frame walls)					
Asbestos cement siding	¼ in lapped		4.76		.21
Asphalt insulating siding			.69		1.45
Brick veener	4 in face brick	9.0		0.11	.44
Hardboard	¼ in		5.60		.18
Plywood	⅜ in		1.59		.59
Stucco	1 in	5.0		.20	.20
Wood shingles	16 in, 7½ in exposure		1.15		.87
Wood shingles and insulation backer board			.71		1.40
Wood siding, bevel	½ × 8 in, lapped		1.23		.81
Insulating materials					
Batts or blankets	Mineral wool, glass (2–4 lb density)	.27		3.70	
	Wood fiber (2 lb density)	.25		4.00	
Boards	Wood or cane interior finish	.35		2.86	
	Wood or cane sheathing	.38		2.63	
	Wood or cane roof deck, 1½ in		.24		4.17
	Wood or cane roof deck, 2 in		.18		5.56
	Wood or cane roof deck, 3 in		.12		8.33
	Cellular glass	.40		2.50	
	Corkboard (without binder)	.27		3.70	
	Plastic (foamed)	.29		3.45	
	Wood shredded (cemented in slabs)	.55		1.82	
Loose fill	Mineral wool (rock, glass, slag)	.30		3.33	
	Perlite (expanded)[3]	.38		2.63	
	Vermiculite (expanded)	.48		2.08	
	Wood fiber	.30		3.33	
Roof insulation	½ in		.72		1.39
Preformed above deck (all types)	1 in		.36		2.78
Approximate thicknesses	1½ in		.24		4.17

Roof insulation	2 in		.19		5.26
Preformed above deck (all types)	2½ in		.15		6.67
Approximate thicknesses	3 in		.12		8.33
Insulating roof deck	1½ in		.24		4.17
Approximate thicknesses	2 in		.18		5.56
	3 in		.12		3.33
Interior finishes					
Gypsum board	½ in		2.25		.45
Gypsum lath and plaster	3/8 in lath and ½ in plaster		2.44		.41
Insulation board (plain or perforated)	½ in	.35		2.86	1.43
Metal lath and plaster	¾ in		7.70		.13
Plywood	3/8 in		2.12		.47
Plywood	½ in		1.60		.63
Masonry materials					
Brick	Common	5.0		.20	
Brick	Face	9.0		.11	
Gypsum fiber concrete	87½% gypsum-12½% wood chips	1.66		.60	
Light weight aggregate concrete	Density 30 lb/ft^3	.90		1.11	
Concrete-sand and gravel aggregate		12.0		.08	
Cinder block	8 in hollow		.58		1.72
Concrete block	8 in hollow		.90		1.11
Stucco				.20	
Roofing materials					
Asbestos cement shingles			4.76		.21
Asphalt shingles			2.27		.44
Built-up roofing	Assumed thickness, 3/8 in		3.00		.33
Asphalt roll roofing			6.50		.15
Slate			20.00		.05
Wood shingles			1.06		.94
Sheathings					
Gypsum (½ in)			2.25		.45
Insulation board (½ in regular density)			.76		1.32
Insulation board (25/32 in)			.49		2.06
Insulation board (½ in intermediate)			.82		1.22
Insulation board (½ in nail-base)			.88		1.14
Plywood (3/8 in)			2.12		.47
Wood (25/32 in)	Fir or pine		1.02		.98
Woods					
Maple, oak, and similar hardwoods		1.10		.91	
Fir, pine, and similar softwoods		.80		1.25	
Wood subfloor	25/32 in		1.02		.98
Wood, hardwood finish floor	¾ in		1.47		.68

The heat loss through 10 ft of 8-in hollow cement blocks ($C = 0.58$) over a time period of 24 h, and for a temperature difference of 50 °F is:

$$\Delta Q = 0.58 \times 10.0 \times 50 \times 24 = 6{,}960 \text{ Btu}.$$

This is equal to the heat loss through pine boards of a thickness of 1.38 in, under the same assumptions.

The reciprocal of k or C is called the thermal resistivity or thermal resistance, R:

$$R = 1/k \text{ or } 1/C.$$

To determine the heat transmission through a composite wall or a sequence of materials, the resistances of all layers are added. The reciprocal of that sum is the total heat transmission, U:

$$U = \frac{1}{R_1 + R_2 + R_3 \ldots R_n} \left(\frac{\text{Btu} \cdot \text{in}}{\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}}\right).$$

Example: The total heat loss through 10 ft^2 of stud space of a frame wall consisting of wood siding, 25/32-in insulation board sheathing and 3/8-in gypsum lath and plaster over a time period of 24 hours, and for a temperature difference of 50 °F is calculated as follows (see table 50 (Insulation Board Institute 1963)):

	Resistance (R)
Outside surface[4]	0.17
Wood siding	0.85
25/32-in insulation board sheathing	2.06
Air space	0.97
3/8-in gypsum lath and plaster	0.41
Inside surface [4]	0.68
Overall resistance, R	5.14

$$\text{Heat transmission, } U = 1/R = 1/5.14 = 0.19\left(\frac{\text{Btu}}{\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}}\right)$$

$$\Delta Q = U \times 10.0 \times 50 \times 24 = 2{,}280 \text{ Btu}.$$

[4] Thin layers of air cling to solid surfaces and act as insulators. They must, therefore, be included in the calculation.

Replacing the insulation board with 3/8-in sheathing plywood (R = 0.47) would increase the daily heat loss to 5,640 Btu.

Application of Hardboard Products

Interior wall paneling and decorative boards

Not too many years ago most hardboard was sold as a 4- by 8-ft sheet with minimal fabricating and no finishing added. After World War II, importation of thin plywood panels made from large low density logs from Southeast Asia stimulated development of a market for prefinished wall paneling in the United States. The unique suitability of hardboard as substrate for simulated wood and other finishing systems, and their development to artistic perfection, opened this market to hardboard.

Finishing lines added to existing mills produced prefinished paneling that was shipped complete with matching moldings and fasteners, ready for installation by the home owner. This market reached around 650 million ft^2 annually in 1974 but has since declined (table 51). Most of this board is 1/4 in thick and can be applied directly to a stud wall. Thinner sheets (1/8 in) must be applied over gypsum board. Figures 345 through 348 illustrate interior hardboard panel applications. Application instructions (figs. 349 through 352) are those recommended by the Masonite Corporation. Of particular significance are the durability of the finishes used on such paneling and the substantial warranties protecting the consumer.

Ninety percent of the interior hardboard paneling is installed in existing homes. The interior hardboard paneling market is about 20 percent of the total, the rest being supplied by plywood panels.

Hardboard siding

The success of hardboard siding is the big story in the fiberboard industry (figs. 353–356). This product line has shown dramatic growth since 1960 (table 52).

Keys to this success include high-quality durable finishes, efficient installation techniques, and competitive prices. On the other hand, the siding market is tied directly to new housing construction and is sensitive to the ups and downs of this market. Efforts are, therefore, being made to develop re-siding systems for use over old siding on existing homes.

Hardboard siding products come in a great variety of finishes and textures (smooth or embossed) and in different sizes. For application purposes, the sidings can be

Figure 345—*Interior hardboard paneling, simulated pegged planks (Abitibi-Price Corp.).*

Figure 346—*Interior hardboard paneling, simulated brick (Abitibi-Price Corp.).*

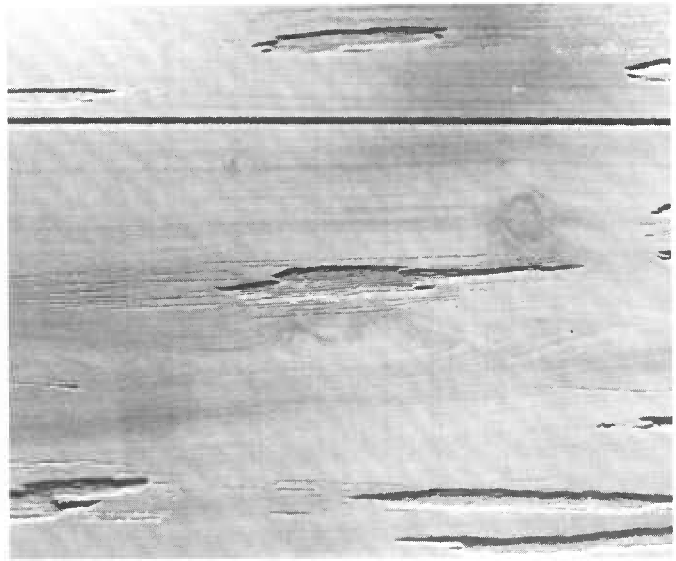


Figure 347—*Close up of face-embossed interior hardboard paneling.*

Figure 348—*Close up of face-embossed interior hardboard paneling.*

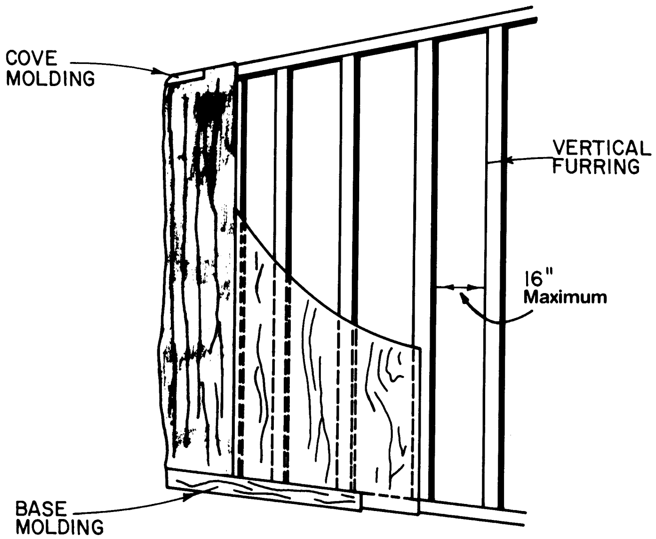


Figure 349—*Application of wall paneling over vertical furring strips, 16 in on center. All panel edges must be supported (Masonite Corp.).*

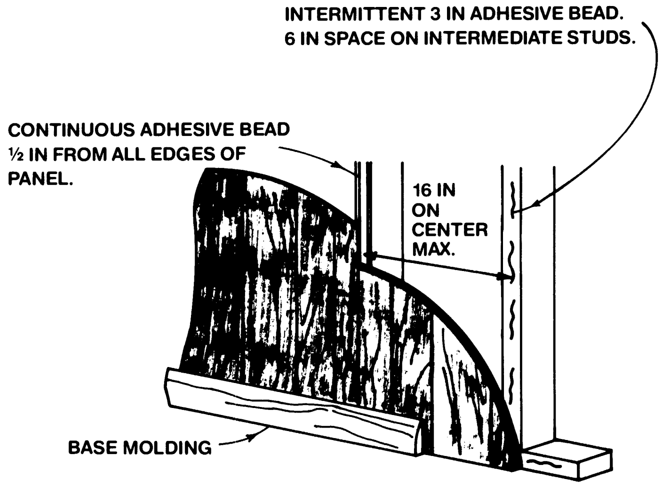


Figure 351—*Application of wall paneling to open framing; studs spaced 16 in on center (Masonite Corp.).*

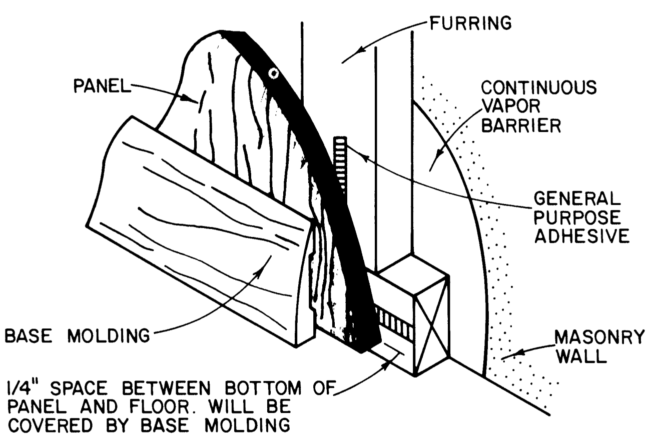


Figure 350—*Application of wall paneling to exterior walls or masonry walls, either above or below grade. Note that vapor barrier such as polyethylene film is recommended here (Masonite Corp.).*

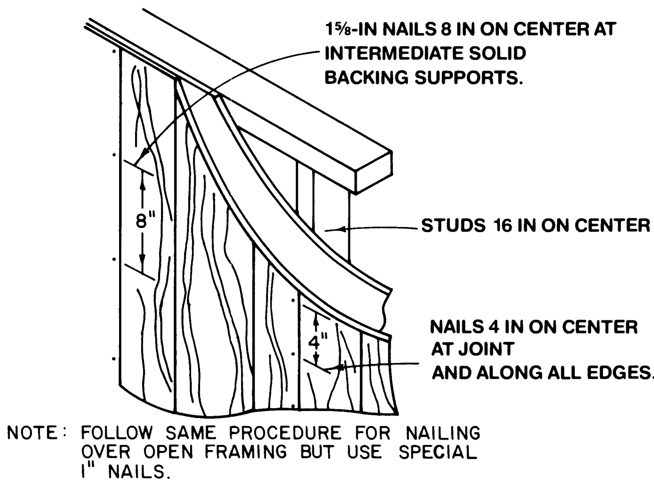


Figure 352—*Application of wall paneling over solid backing, such as plaster or gypsum board (Masonite Corp.).*

Table 51—*Development of interior hardboard paneling market (American Hardboard Association)*

Year	Total surface area decorative vinyl, tile, and woodgrain (ft²)
1964	162,949,503
1965	170,563,185
1966	212,603,079
1967	215,805,013
1968	251,424,443
1969	267,325,908
1970	323,603,805
1971	383,971,062
1972	431,388,367
1973	522,548,087
1974	645,242,891
1975	537,384,234
1976	549,899,047
1977	584,956,305
1978	368,361,543
1979	438,221,265
1980	402,631,613
1981	352,028,137

classified into three basic types (American Hardboard Association):

1) Lap siding: boards applied horizontally, with each board overlapping the board below it.
2) Square edge panels: intended for vertical application in full sheets.
3) Shiplap edge panel siding: intended for vertical application, with the long edges incorporating shiplap joints.

The type of panel dictates the application method. Figures 357 through 361 are from installation recommendations by the American Hardboard Association.

A variety of special fastener systems have been developed. An example is the System 25 (patented by the Abitibi-Price Corporation) for the application of Random Shake Lap Siding (figs. 362, 363). The patented plastic clip snaps quickly and securely onto the back of the siding (fig. 363). The clip automatically aligns each siding course and also secures the bottom of each siding section to the course below. Only the top of the siding is nailed at stud locations. The overlapping course conceals the nail heads. The ends are shiplapped and weathertight.

Long-term satisfactory performance of hardboard siding requires proper moisture control before and after application and proper installation techniques. If the

Figure 353—*Example of hardboard siding installation (Abitibi-Price Corp.).*

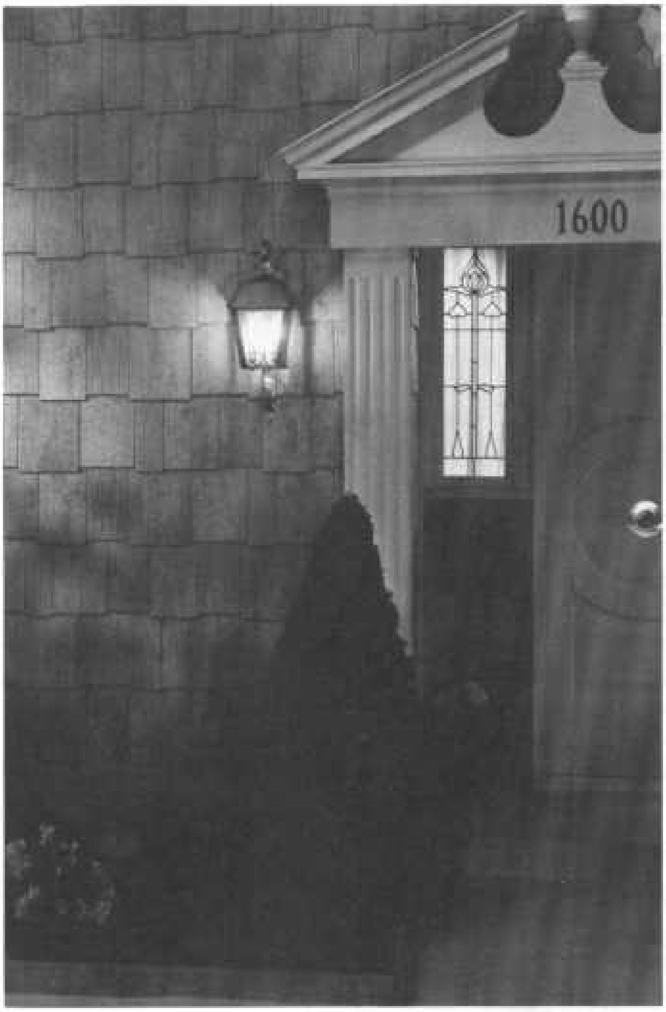


Figure 354—*Abitibi shake shingle siding (Abitibi-Price Corp.).*

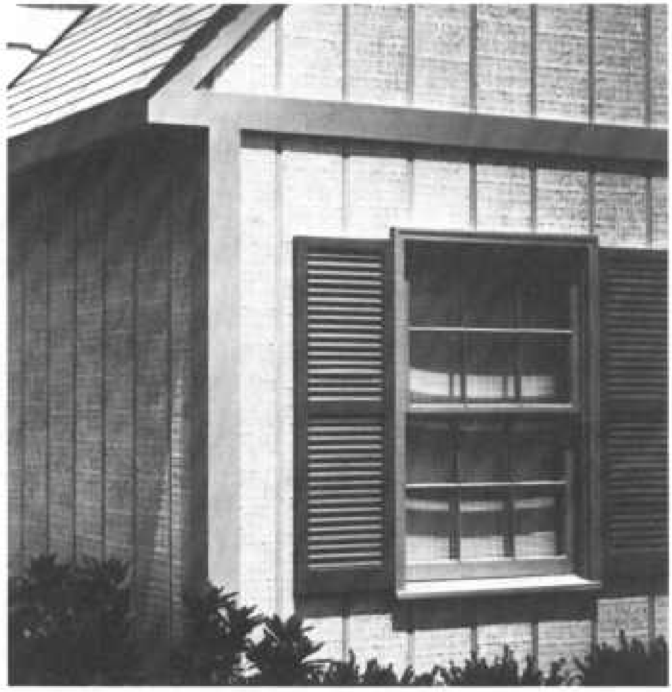


Figure 355—*Hardboard panel siding (Abitibi-Price Corp.).*

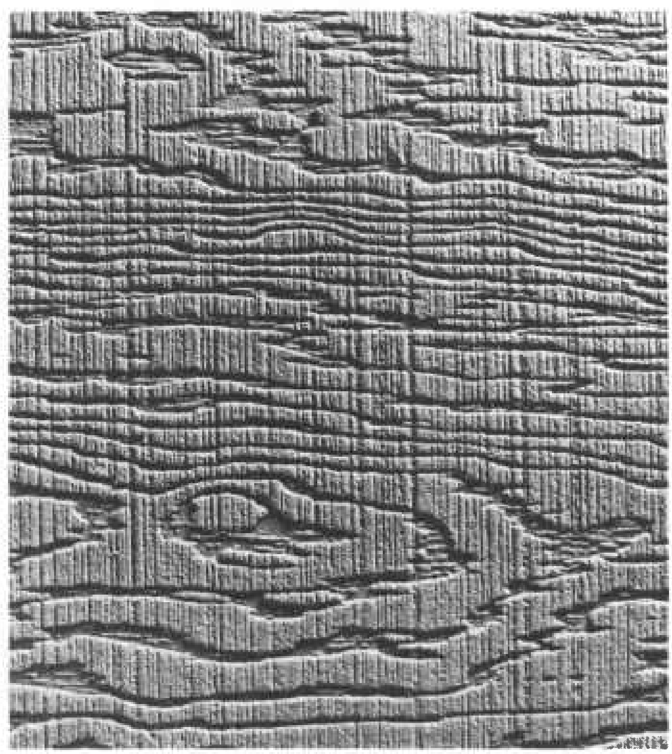


Figure 356—*Close up of fiberboard panel siding.*

manufacturers' recommendations are followed, however, various warranties apply. The Random Shake Clip System described above is warranted for a period of 25 years against peeling, blistering, or cracking.

Other structural applications of hardboard

It may be debated whether or not hardboard siding is a structural element. The term "structural" implies engineering qualities or an element that significantly contributes to the structural integrity of the building.

Such structural applications of hardboard are being considered now, as large structural lumber becomes scarcer and where lumber of such dimensions has never been plentiful.

Table 52—*Production statistics of U.S. hardboard industry (American Hardboard Association)*

Imports (1000 ft²) 1/8-in basis	Year	Area (1000 ft²) 1/8-in basis							
		Total industry	Total members	Total standard	Total tempered	Total service	Total service tempered	Total siding	Total special products
—	1960	1,930,434	1,911,323	706,823	750,692	413,320	—	—	—
—	1961	2,222,408	2,034,699	703,834	722,692	446,045	—	—	—
—	1962	2,426,479	2,255,766	1,056,885	714,758	439,241	—	—	—
—	1963	2,432,149	2,398,790	932,471	645,062	477,933	19,115	—	—
—	1964	2,688,820	2,558,820	1,134,149	542,290	447,051	94,371	—	—
—	1965	2,921,102	2,813,262	1,049,365	514,271	483,638	122,339	—	—
443	1966	3,083,444	2,971,387	1,324,624	549,066	501,367	134,985	—	—
430	1967	3,037,952	2,808,921	1,154,157	448,852	470,151	168,434	525,924	41,403*
650	1968	3,710,471	3,367,754	1,434,400	453,241	522,354	203,250	644,133	110,376*
710	1969	4,246,760	3,963,251	1,511,187	490,413	725,876	253,657	961,356	20,762*
460	1970	4,384,081	4,189,354	1,534,588	429,638	681,210	258,194	1,186,875	98,849*
634	1971	5,224,789	4,963,315	1,698,877	471,568	661,477	271,516	1,793,463	66,414*
1070	1972	5,798,376	5,511,298	1,847,220	500,903	528,598	270,259	2,235,000	129,318*
1039	1973	6,475,387	5,396,769	1,463,249	538,001	558,904	291,369	2,114,667	430,579*
751	1974	6,056,542	5,036,081	1,376,565	510,764	465,750	285,433	1,986,911	410,658*
277	1975	6,237,906	5,352,387	742,199	463,014	782,701	377,080	2,422,331	556,522*
494	1976	7,066,022	6,047,746	898,469	513,164	663,149	400,513	2,979,071	581,183*
627	1977	7,714,265	6,750,485	888,391	479,421	773,527	484,866	4,105,706	18,574
—	1978	7,824,967	6,867,827	863,597	456,708	642,033	477,019	4,393,031	35,439
786	1979	7,687,798	6,414,520	1,099,467	545,856	759,136	480,397	3,505,624	24,040
515	1980	6,140,128	5,700,826	1,102,348	437,162	359,765	505,568	3,281,309	14,674
	1981	6,104,829	5,775,748	1,371,631	420,224	144,801	372,435	3,415,846	49,811

*Industralite.

The composite I-beam is a good example. Plywood webbed I-beams have been used in this country for some time, but there are no published design values available for hardboard that would allow the introduction of hardboard webs (McNatt 1980). Such standards do exist in England, Sweden, Germany, and other countries where hardboard webbed I-beams are being used successfully (figs. 364, 365). Research is in progress at the USDA Forest Service Forest Products Laboratory to develop long-term performance characteristics of different hardboard webbed beam designs under various exposure conditions (Superfesky and Ramaker 1978).

Industrial uses of hardboard

Over 25 percent of all hardboard produced goes into the industrial markets, where it finds applications in many fields and becomes part of many consumer products. The following is but a partial list:

- Furnishings: kitchen cabinets, wardrobe closets, desks, appliances, tables, cribs, hampers, chests, trays, chair seats, playpens, dust proofing, mirror backings, case ends and backs, and shelving.
- Transportation and shipping: domestic crating, boxes, containers, decking, cab liners, trailers, trucks, cars, railroad cars, mobile homes, and boats.
- Merchandising and display: easels, models, display booths, product containers, signs, rack displays, carrying cases, and card racks.
- Education, recreation: games, jigsaw puzzles, sleds, toys, wagons, blackboards, car carrier platforms, instrument cases, luggage, desks, and activity tools for children.
- Appliances and machinery: radio and TV backs, housings, guards, templates, conveyors, louvers, cabinet backs, bins, and pallets.
- Garage door panels: flush doors, commercial panels, special designs, and multi-paneled sectional doors.

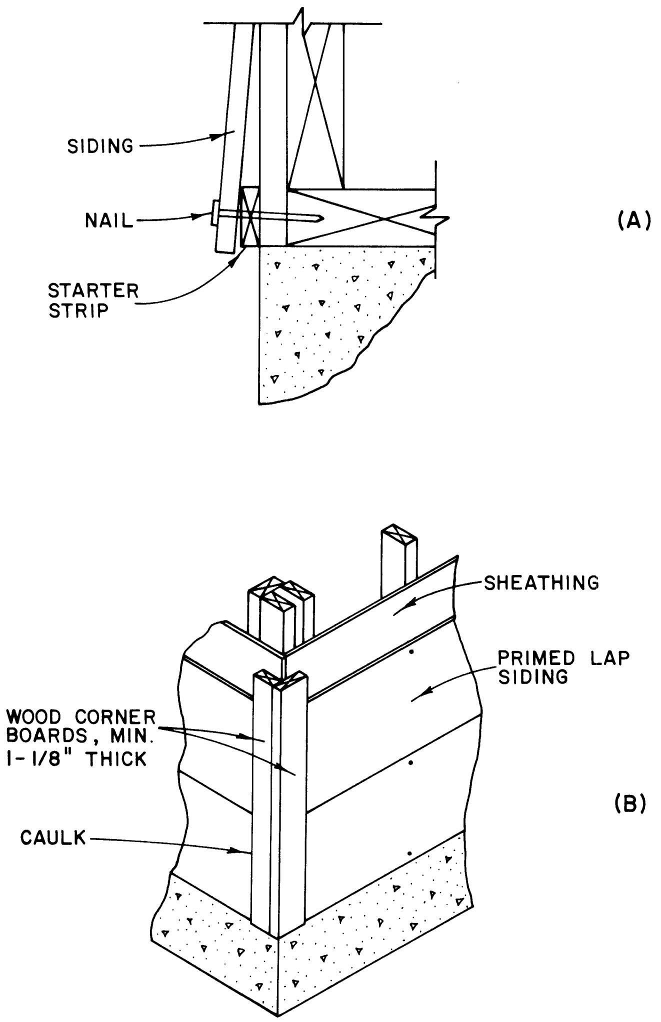


Figure 357 — *Details of hardboard lap siding application (American Hardboard Association). Starter strip* **(A)** and outside corner **(B)**.

- Office equipment: desks, file cabinets, chair floor pads, clipboards, aisle runners, chutes, framed picture backing, and casebacks.
- Mobile homes and prefab housing: shelving, ceiling and locker liners, soffits, underlayment, and stair treads.
- Automobiles: headliners, shelf panels, arm rests, seat sides, door panels, instrument panels, and package trays—perforated, die cut, and formed.

General comments

Hardboard is sold for $4 to $30 per 4- by 8-ft sheet. At the highest price levels it competes with ceramic tile (bathroom wall paneling), at the lowest with Mende-type

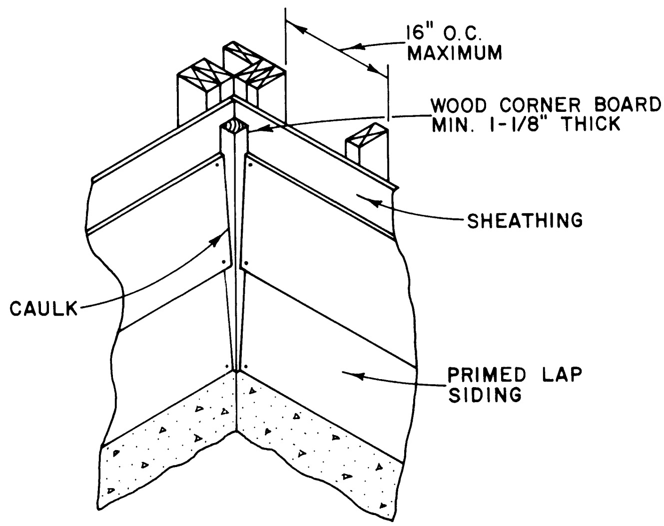


Figure 358—*Inside corner details of hardboard lap siding application (American Hardboard Association).*

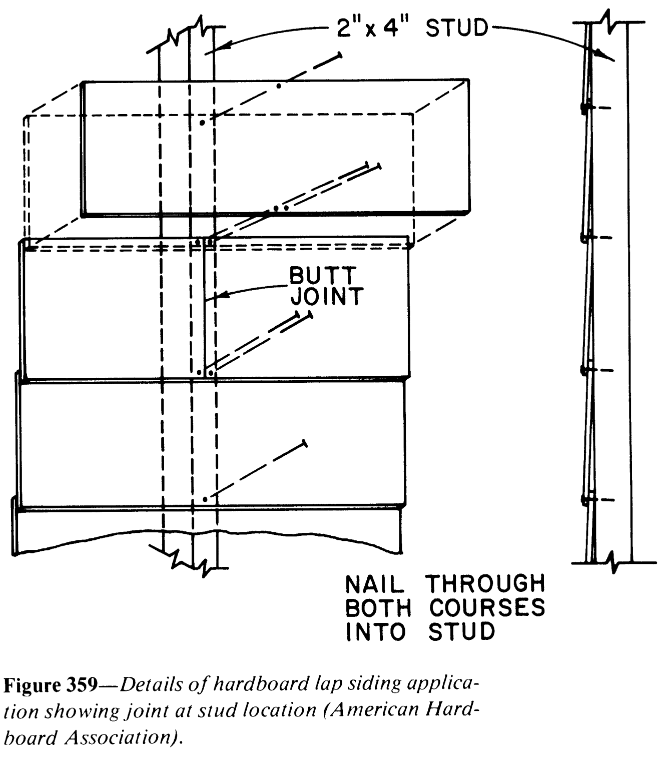


Figure 359—*Details of hardboard lap siding application showing joint at stud location (American Hardboard Association).*

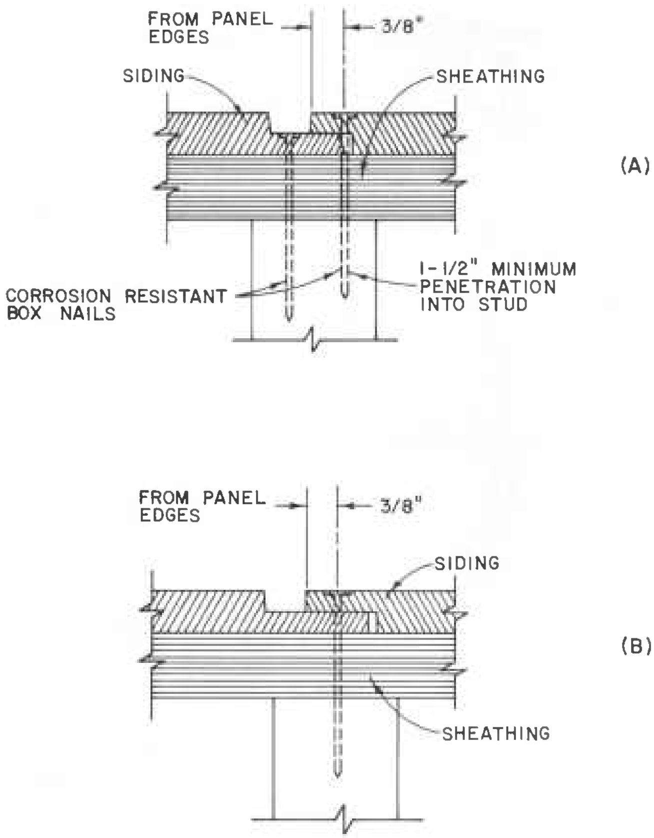


Figure 360—*Details of 3/8-in shiplap* (**A**) *¾-in shiplap* (**B**) *joints in shiplap edge panel siding (American Hardboard Association).*

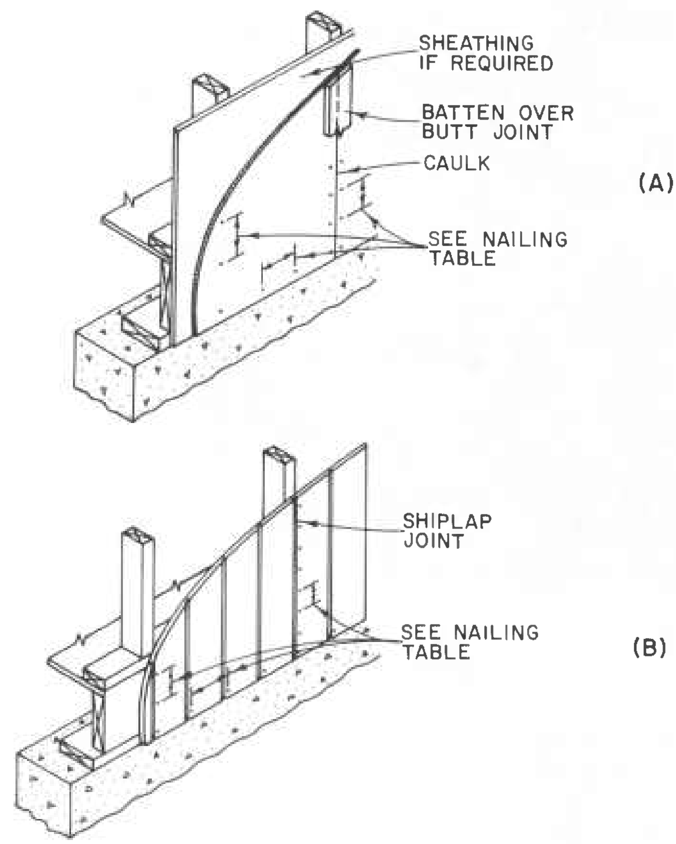


Figure 361—*Panel siding application (American Hardboard Association) applied over sheathing* (**A**) *and to unsheathed stud wall* (**B**).

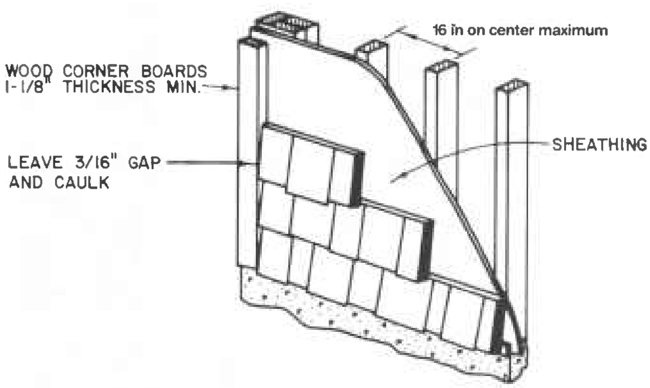


Figure 362—*Detail of Abitibi Random Shake Shingle Siding (Abitibi-Price Corp.).*

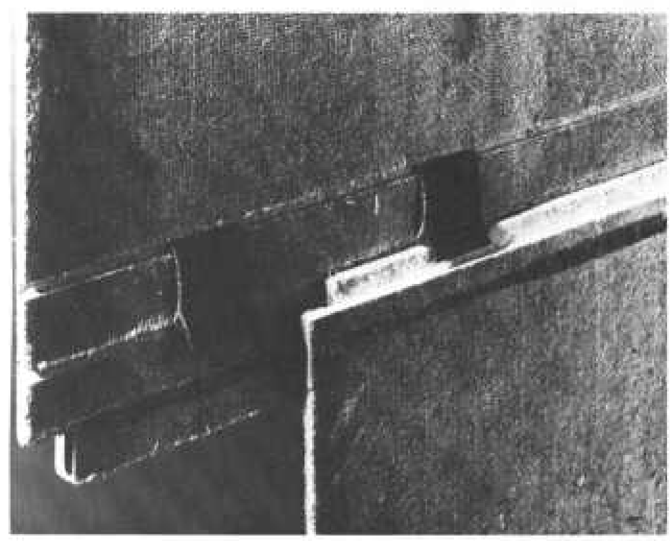


Figure 363—*Abitibi Random Shake Shingle Siding, System 25 clip (Abitibi-Price Corp.).*

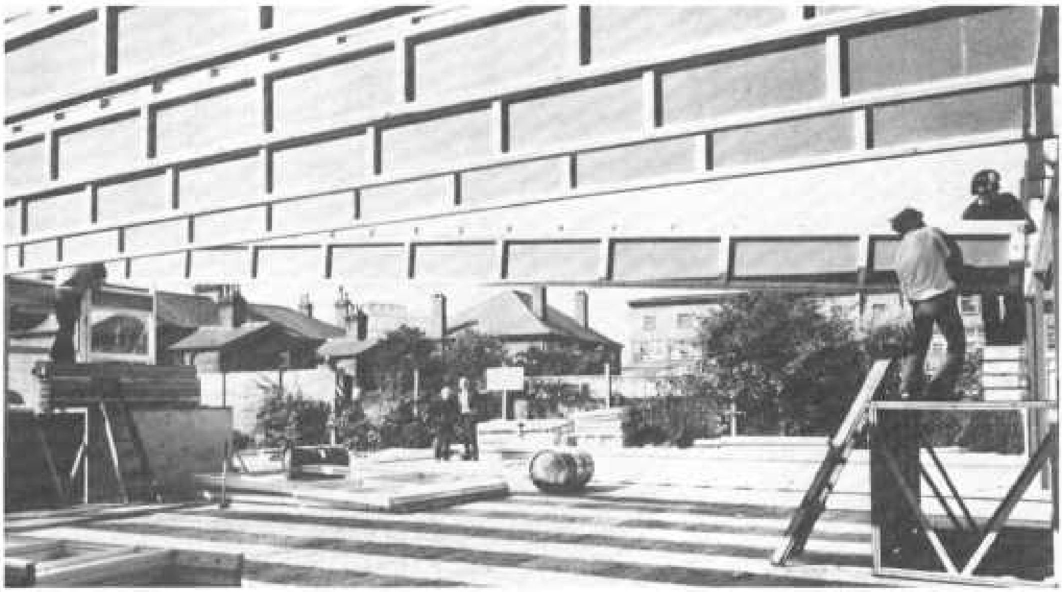


Figure 364—*Twelve-meter-span hardboard I-beams for roof of post office mail-sorting office at Southall, London (McNatt 1980).*

particle board (furniture backs, drawer bottoms, etc.). As siding, it competes successfully with aluminum, vinyl, brick, and solid wood. In the interior panel market ($10 to $14 per sheet) and in many industrial markets, it competes with hard wood plywood at almost the same price level. These low plywood prices are due to abundant veneer log supplies from Southeast Asia and to very efficient and competitive manufacturing facilities in Korea, Taiwan, and Japan. Gradual depletion of these log supplies and possible revisions of log export policies might have very significant effects on the competitive position of imported hardwood plywood in the United States relative to domestically produced hardboard paneling.

Other forces affecting hardboard prices and marketing position are related to the increasing cost of water treatment in wet-process plants. This might reduce the competitiveness of hardboard or it may lead to process modifications, which may eventually greatly reduce the use of process water.

Applications of Medium-Density Fiberboard

Only the markets for the thicker (1/2- to 3/4-in) medium-density fiberboards are considered here, for siding of this class was described in the previous section.

The major use of thick medium-density fiberboard is as core material in furniture panels. Conventional furniture panel construction is based on an edge-glued lumber core overlaid with crossband veneers as stiffeners and as base for high quality but thin face veneers. This construction is illustrated in figure 366.

Over the last 20 years, particle board has replaced much of the lumber core in furniture panels. Particle board has a more stable surface and equal stiffness in all directions in the plane of the board, thus allowing 3-ply construction and the elimination of crossband veneers. Only in cases where the panel edges are profiled and/or curved must lumber banding be used to assure smooth machining and finishing of the edge profile, which requires 5-ply construction to prevent the lumber band-particle board joint from telegraphing through the thin face veneer (fig. 367).

One of the important characteristics of medium-density fiberboard is that its smooth, solid edge is easily machined and finished. If used as a furniture panel core, it allows the elimination of the lumber band and the crossband veneer in the manufacture of edge-profiled panels (fig. 368).

Although medium-density fiberboard is more expensive than particle board, the cost of the finished medium-density fiberboard panel could be much less. This advantage has secured a solid position in the furniture market for medium-density fiberboard. Table 53 is a cost comparison—not including finishing—for two constructions, one using particle board and the other using medium-density fiberboard, in the manufacture of a bureau top (fig. 369).

If medium-density fiberboard could be produced at the same cost as particle board, its market position would improve substantially, as shown in figure 370 which is a projection based on a market survey conducted in 1977.

Application of Insulation Board Products

The insulation board industry is in a transition phase. Thermal insulation and sound insulation are as important as ever and so are energy costs and water treatment cost in the manufacture of insulation board. These factors, and the fact that value added by fabricating and finishing is far less than in the case of hardboard, have caused a shift in certain product lines within the industry from wood fibers as raw material to mineral fibers and plastics. Insulation board products made from mineral fibers or plastics are often directly substituted for wood-fiber-based materials. In other cases, special consideration must be given to structural requirements. Plastic foam insulation board, for instance, has much lower

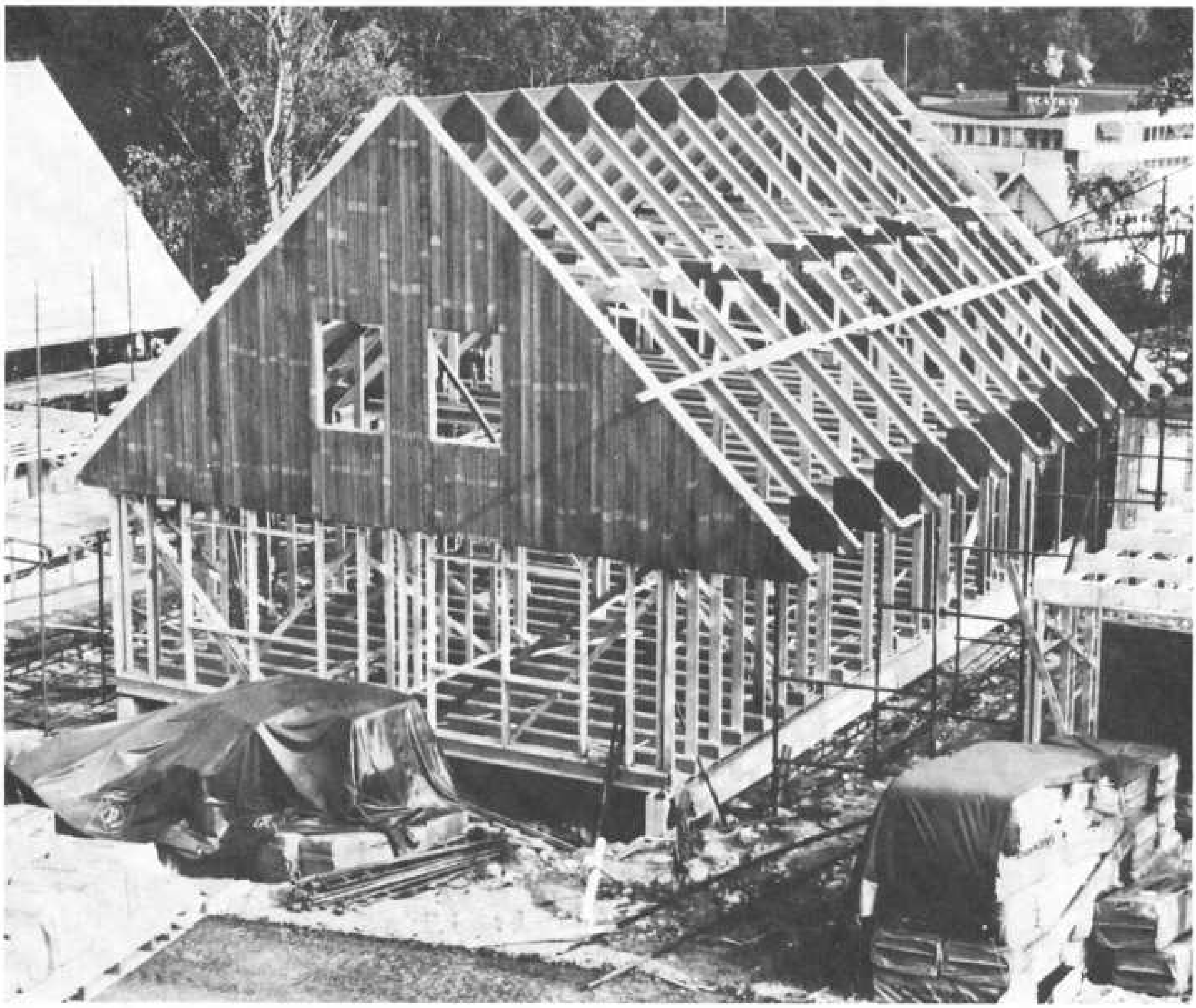


Figure 365—*Roof rafter system consisting of hardboard webbed I-beams connected by hardboard gusset plates (McNatt 1980).*

Table 53—*Cost breakdown for manufacture of bureau top with particle board core and medium-density fiberboard core (see fig. 371) (Suchsland 1978)*

	Particle board, solid banding	Medium-density fiberboard, no banding
Material		
Lumber	$1.97	$ —
Board	1.66	2.49
Veneer face	.87	.87
Veneer back and edge	.55	.53
Cross bands	1.22	—
Glue	.35	.18
Total material	$6.62	$4.07
Labor & burden		
Yard and kiln	$ .50	$ —
Veneer	5.75	2.55
Rough mill	1.42	—
Intermediate machining	1.54	.26
Total labor & burden	$9.21	$2.81
Total factory cost	$15.83	$6.88

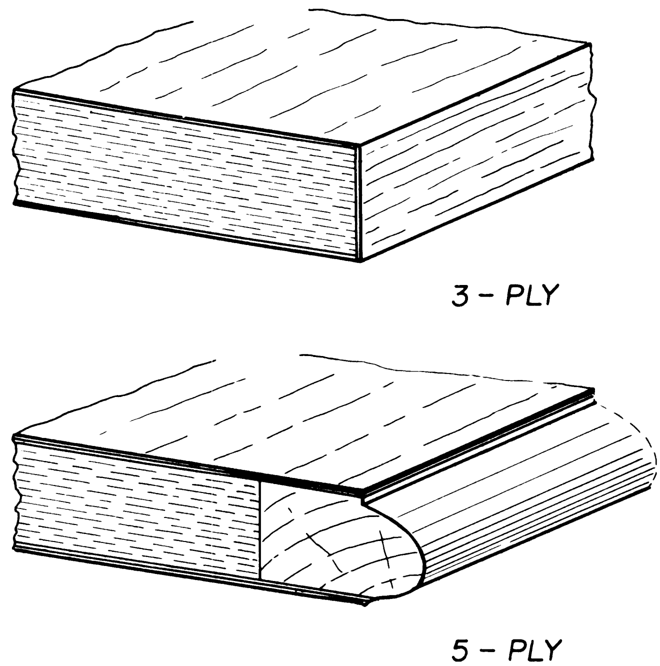


Figure 367—*Construction of particle board furniture panels (Suchsland 1978).*

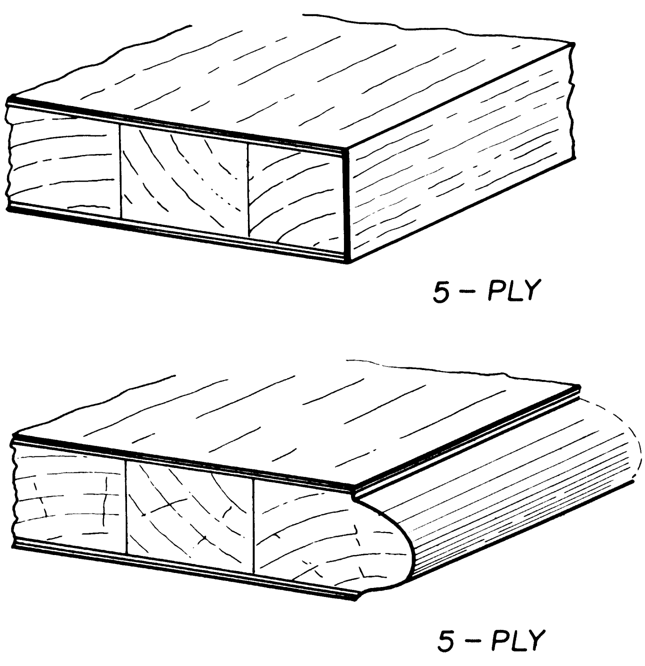


Figure 366—*Construction of 5-ply lumber core furniture panels (Suchsland 1978).*

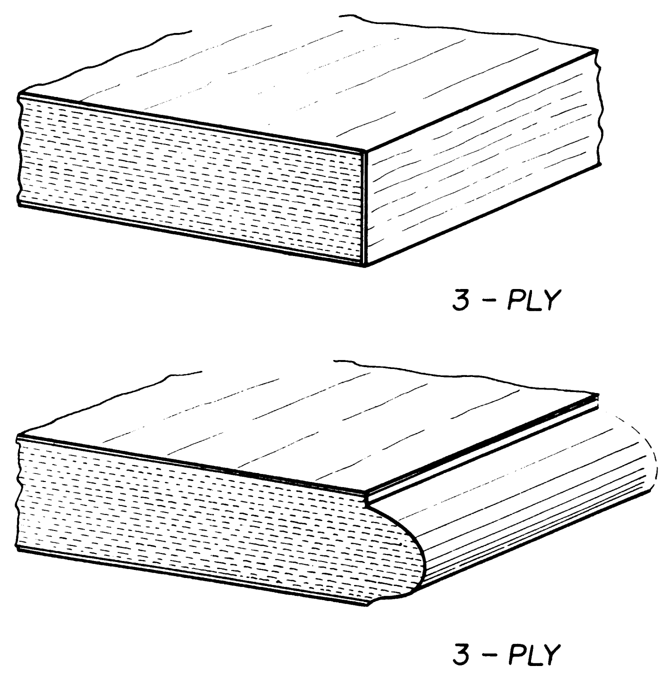


Figure 368—*Construction of 3-ply medium-density fiberboard furniture panels (Suchsland 1978).*

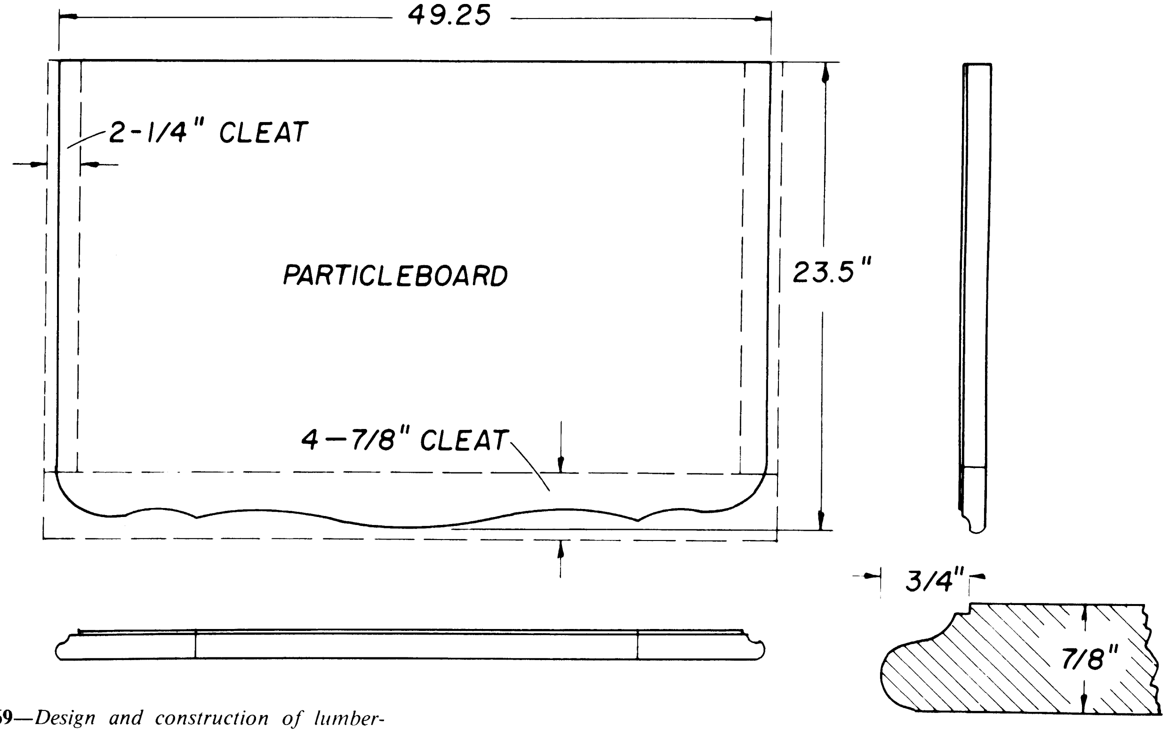


Figure 369—*Design and construction of lumber-banded bureau top (Suchsland 1978).*

structural properties than wood-fiber-based insulation board.

A listing of wood-fiber-based insulation board products manufactured by one prominent company includes these product categories (Celotex Corp.):

- Sound deadening board
- Building board
- Insulating sheathing
- Concrete joint filler
- Shingle backer
- Aluminum siding backer
- Gypsum lath
- Acoustical tile
- Ceiling tile
- Lay-in panel for suspended ceiling systems.

Figures 371 and 372 show specific examples of the application of insulating sheathing board (Celotex Corp.).

References

Abitibi-Price Corporation. Troy, MI.

American Hardboard Association. Palatine, IL.

American Society for Testing Materials. Standard methods for evaluating the properties of wood-base fiber and particle panel materials: ASTM 1037. Philadelphia: 1983.

Celotex Corporation. Promotional literature. Tampa, FL.

Chow, P.; Reiss, W.L. Hardboard has good impact resistance. Illinois Research. 16(3): 14–15; 1974.

Currier, R.A. Effect of cyclic humidification on dimensional stability of commercial hardboard. Forest Products Journal. 7: 85–100; 1957.

Insulation Board Institute. Fundamentals of building insulation. Chicago; 1963. 42 p.

Keylwerth, R. Untersuchungen uber die Gleichmassigkeit von Spanplatten und Faserplatten. Holz als Roh- und Werkstoff. 13(3): 216–221; 1955.

Kumar, V.B. Untersuchungen uber die Dickenschwankungen bei Holzfaserplatten. Holz als Roh- und Werkstoff. 16(10): 371–377; 1958.

Law, K.N.; Balatinecz, J.J.; Garceau, J.J. Density-strength development in oriented and random fiber sheets. Forest Products Journal. 25(6): 28–29; 1975.

Lundgren, A. Die hygroskopischen Eigenschaften von Holzfaserplatten. Holz als Roh- und Werkstoff. 16(4): 122–127; 1958.

Masonite Corporation. Promotional literature. Chicago, IL.

McNatt, J.D. Design stresses for hardboard—effect of rate, duration, and repeated loading. Forest Products Journal. 20(1): 53-60; 1970.

McNatt, J.D. Effects of equilibrium moisture content changes on hardboard properties. Forest Products Journal. 24(2): 29–35; 1974.

McNatt, J.D. Hardboard-webbed beams: research and application. Forest Products Journal. 30(10): 57-64; 1980.

Moslemi, A.A. Some aspects of the viscoelastic behavior of hardboard. Michigan State University; 1964. Ph.D. thesis.

Ruffin, E.T. Exterior durability of hardboard. Forest Products Journal. 10: 336-341; 1960.

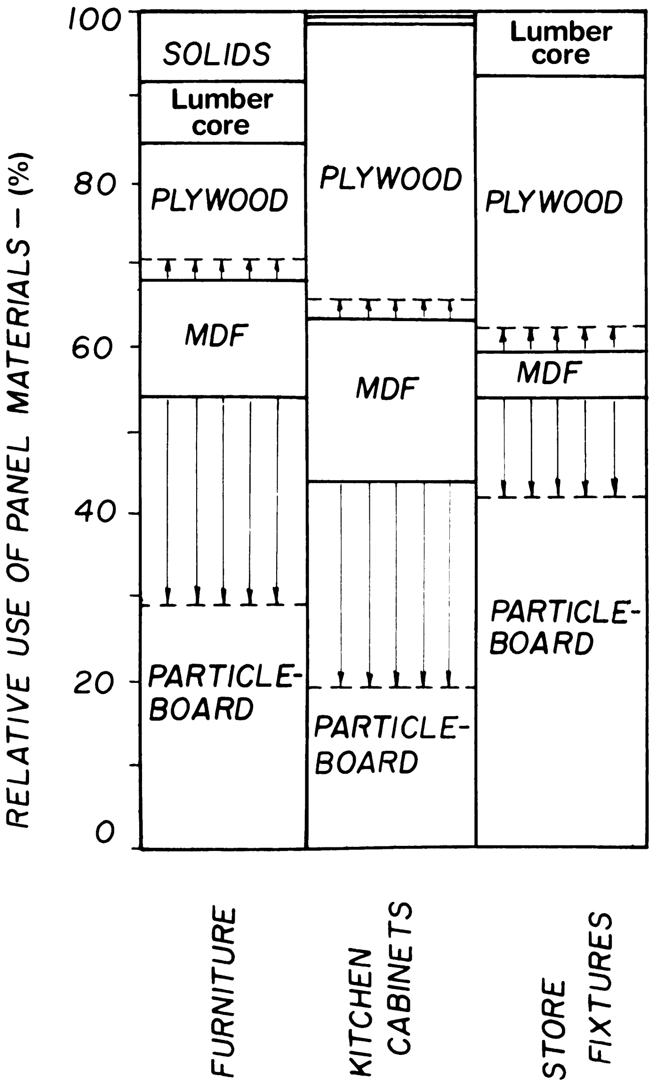


Figure 370—*Market position (1977) of medium-density fiberboard (MDF) in industrial market and potential expansion of usage (arrows) on assumption of price equality with particle board (Suchsland 1978).*

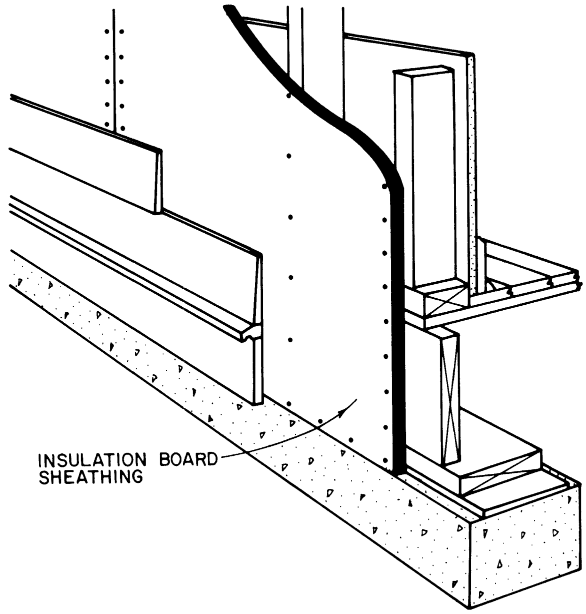


Figure 371—*Vertical application of 4-ft-wide insulation board sheathing 25/32 in thick to 2 by 4 framing (Celotex Corp.). All joints must center over framing.*

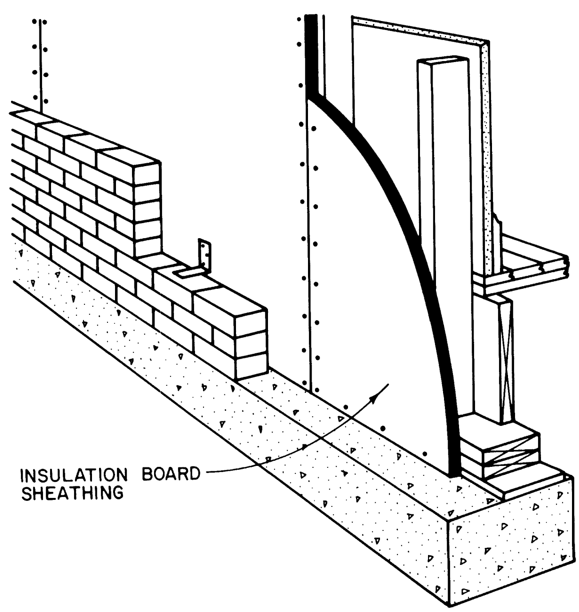


Figure 372—*Combination of insulation board sheathing and masonry veneer; ½-inch spacing required between face of sheathing and back of masonry veneer (Celotex Corp.). Metal wall ties required at rate of one tie for every 160 to 260 in² of wall area. Ties are nailed through sheathing into studs.*

Shen, K.C. Torsion-shear and twisting-shear strengths of hardboard and their relation to tensile strength perpendicular to surface. Report OPX42E. Ottawa; Department of the Environment, Canadian Forestry Service, Eastern Forest Products Laboratory; 1974. 19 p.

Steinmetz, P.E.; Fahey, D.J. Effect of manufacturing variables on stability and strength of wet-formed hardboards. Res. Paper FPL-142; Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1971. 8 p.

Stillinger, J.R.; Coggan, W.G. Relationship of moisture content and flexural properties in 25 commercial hardboards. Forest Products Journal. 6(5): 179–186; 1956.

Suchsland, O. Swelling stresses and swelling deformations in hardboard. Michigan State University Agricultural Experiment Station, Quarterly Bulletin. 47(4); 591–605; 1965.

Suchsland, O. The manufacture, properties and uses of thin particle board. Unpublished manuscript prepared for the Tennessee Valley Authority. East Lansing, MI: with permission of the Tennessee Valley Authority; 1977: 54 p.

Suchsland, O. Markets and applications of medium-density fiberboard. In: McMillin, C.W., ed. Complete tree utilization of southern pine. Madison, WI: Forest Products Research Society; 1978: 473–481.

Suchsland, O.; Lyon, D.E.; Short, P.E. Selected properties of commercial medium-density fiberboards. Forest Products Journal. 29(9): 45–49; 1979.

Superfesky, M.J.; Lewis, W.C. Basic properties of three medium-density hardboards. Res. Paper FPL-238; Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1974. 4 p.

Superfesky, M.J.; Ramaker, T.J. Hardboard-webbed I-beams: effect of long term loading and loading environment. Res. Paper FPL-306; Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1978. 12 p.

Turner, H.D.; Hohf, J.P.; Schwartz, S.L. Effect of some manufacturing variables on the properties of fiberboard prepared from milled Douglas-fir. In: Proceedings, Forest Products Research Society Annual Meeting; 1948; Madison, WI: Forest Products Research Society; 1948: 100–112; Vol. 2.

U.S. Department of Commerce, National Bureau of Standards. American National Standard ANSI/AHA A 135.4-1982: basic hardboard. Washington, DC; 1982a. 4 p.

U.S. Department of Commerce, National Bureau of Standards. American National Standard ANSI/AHA A 135.5-1982: prefinished hardboard paneling. Washington, DC; 1982b. 5 p.

U.S. Department of Commerce, National Bureau of Standards. American National Standard ANSI/AHA A 136-1983: hardboard siding. Washington, DC; 1983. 5 p.

U.S. Department of Commerce, National Bureau of Standards. American National Standard ANSI A208.2-1980b: medium density fiberboard for interior use. Washington, DC; 1980. 5 p.

U.S. Department of Commerce, National Bureau of Standards. Cellulosic fiber insulating board. Voluntary Product Standard. PS-57-73. Washington, DC; 1973. 6 p.

Werren, F.; McNatt, J.D. Basic properties and their variability in twenty commercial hardboards. Internal report. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1975. 18 p.

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