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Suchsland &
Woodson (1986)

uses
& Statistics



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:

$$\Delta Q = k \cdot A \cdot \frac{T_2 - T_1}{\rho} \cdot t \text{ (Btu)},$$

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),

ρ = thickness (inches).

The heat loss through 10 ft² 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 52—Production statistics of U.S. hardboard industry (American Hardboard Association)

Imports (1000 ft ²) 1/8-in basis	Year	Area (1000 ft ²) 1/8-in basis					Total service tempered	Total siding	Total special products
		Total industry	Total members	Total standard	Total tempered	Total service			
—	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

*Industrialite.

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.

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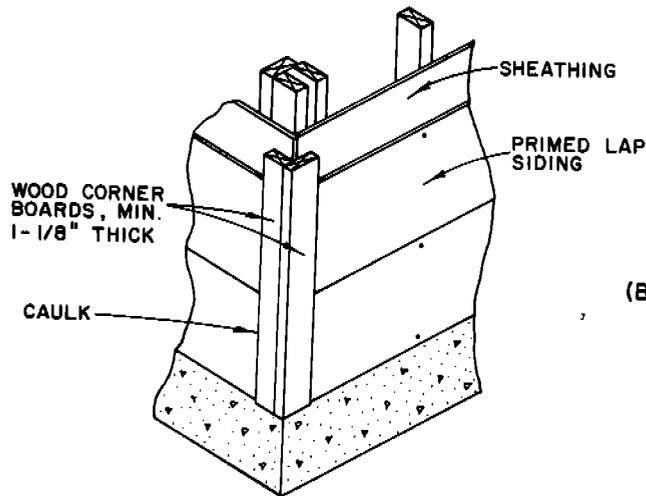
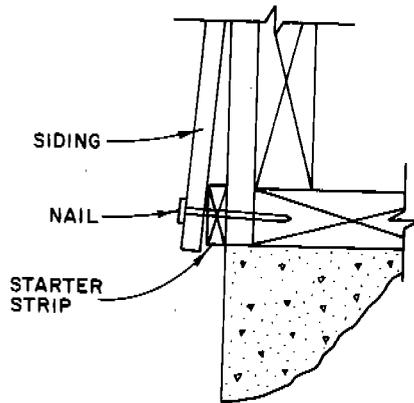


Figure 357 — Details of hardboard lap siding application (American Hardboard Association). Starter strip (A) and outside corner (B).

- 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

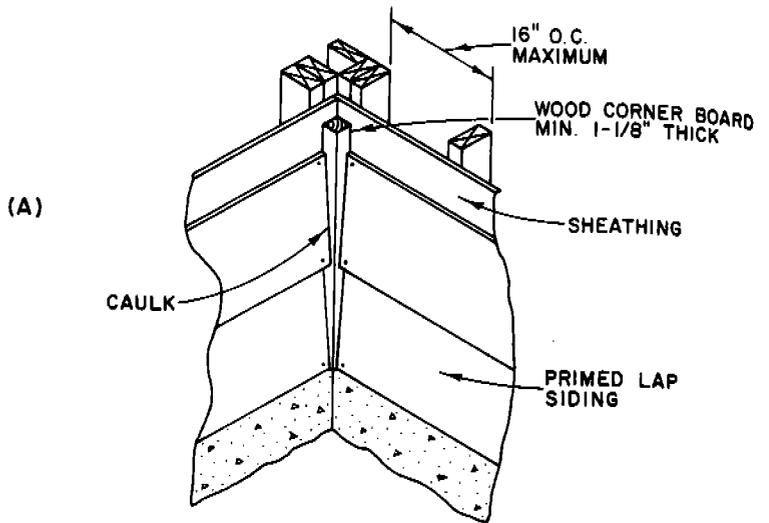


Figure 358—Inside corner details of hardboard lap siding application (American Hardboard Association).

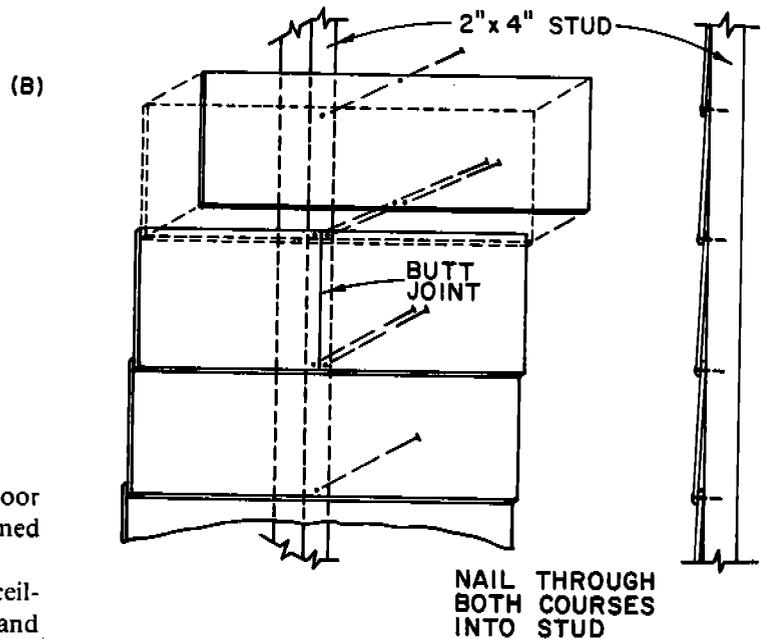


Figure 359—Details of hardboard lap siding application showing joint at stud location (American Hardboard Association).

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 :

$$U = \frac{1}{R_1 + R_2 + R_3 \dots R_n} \left(\frac{\text{Btu} \cdot \text{in}}{\text{h} \cdot \text{ft}^2 \cdot \text{°F}} \right).$$

Example: The total heat loss through 10 ft² 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

Heat transmission, $U = 1/R = 1/5.14$

$$= 0.19 \left(\frac{\text{Btu}}{\text{h} \cdot \text{ft}^2 \cdot \text{°F}} \right)$$

$$\Delta Q = U \times 10.0 \times 50 \times 24 \\ = 2,280 \text{ Btu.}$$

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 ft² 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 347—Close up of face-embossed interior hardboard paneling.

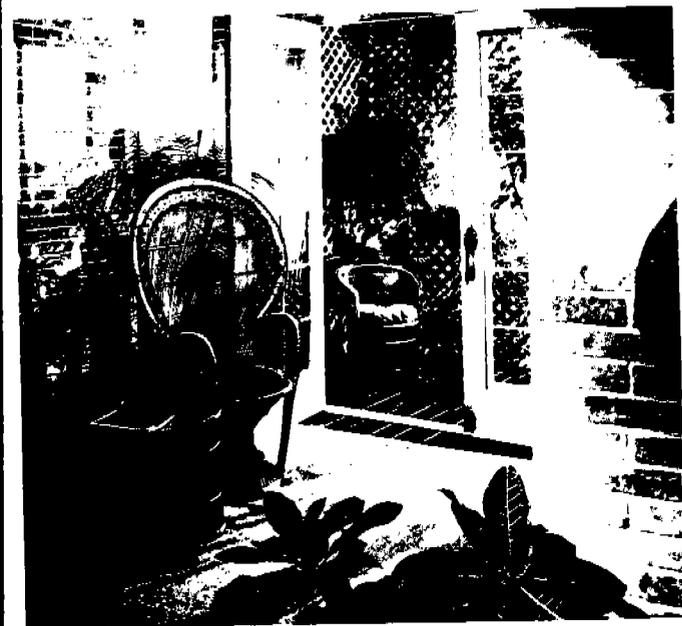


Figure 346—Interior hardboard paneling, simulated brick (Abitibi-Price Corp.).

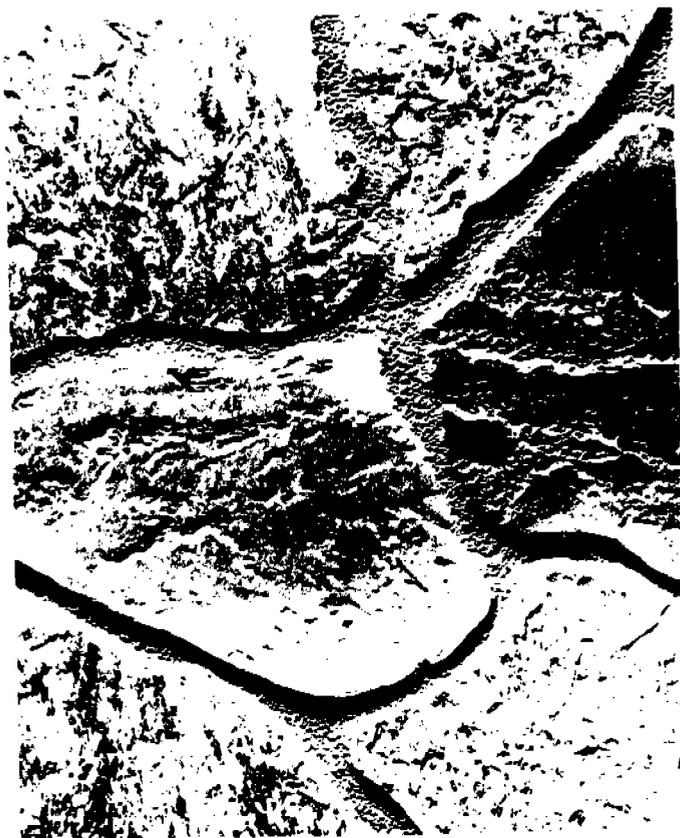


Figure 348—Close up of face-embossed interior hardboard paneling.

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Table 51—Development of interior hardboard paneling market (American Hardboard Association)

Year	Total surface area decorative vinyl, tile, and woodgrain (ft ²)
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.).

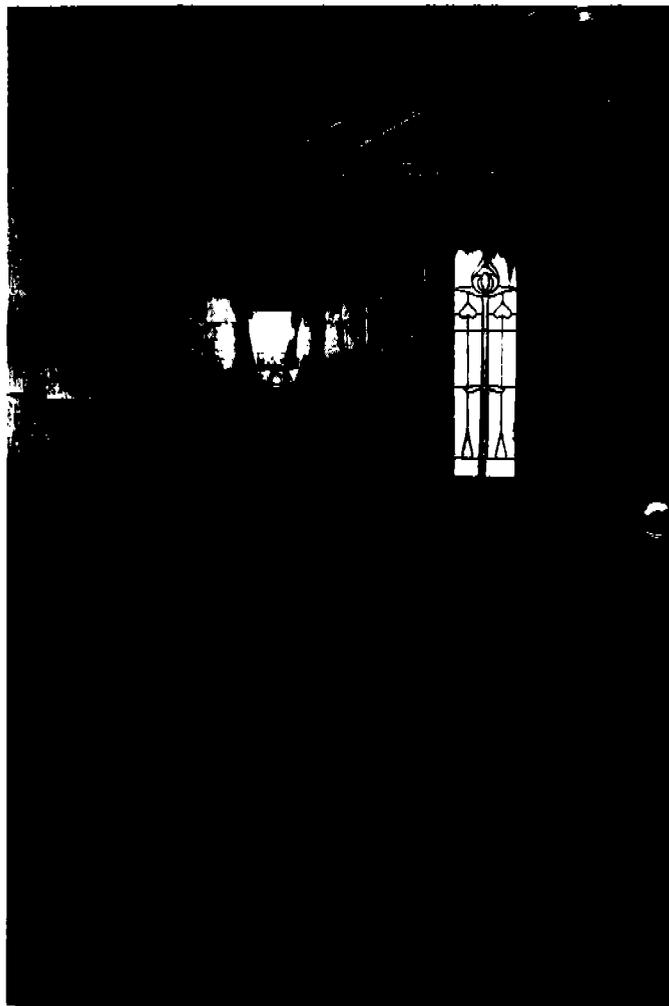


Figure 354—Abitibi shake shingle siding (Abitibi-Price Corp.).

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.



Figure 355—Hardboard panel siding (Abitibi-Price Corp.).

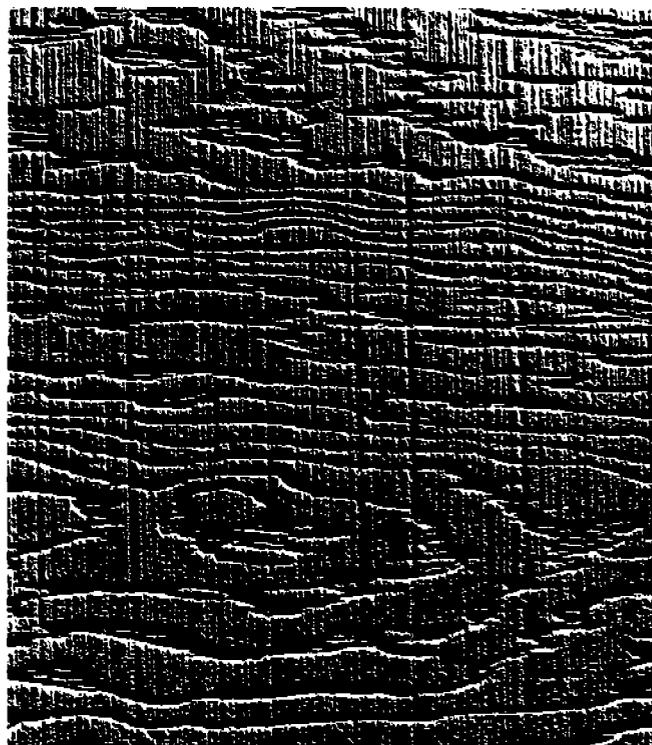


Figure 356—Close up of fiberboard panel siding.

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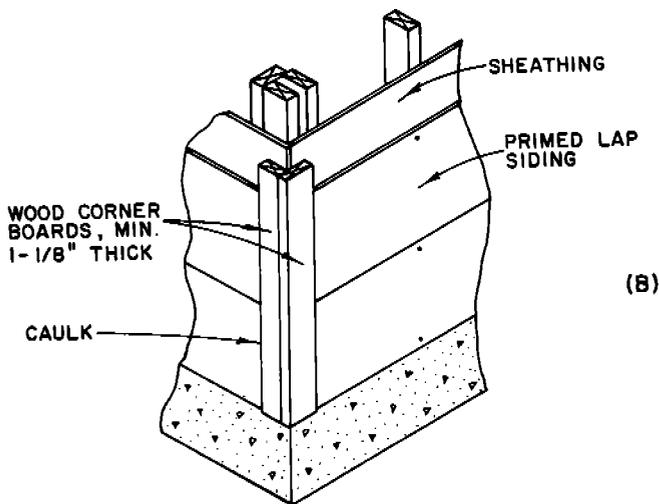
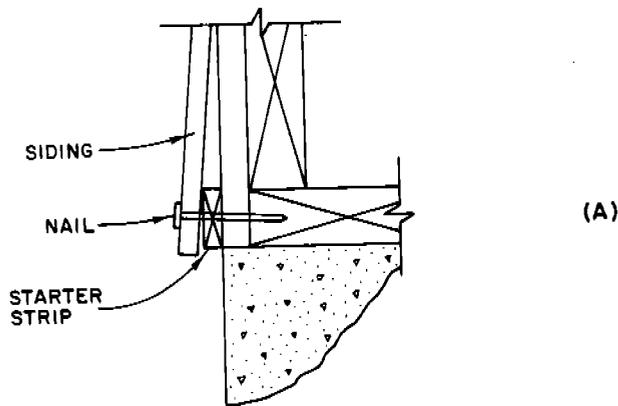


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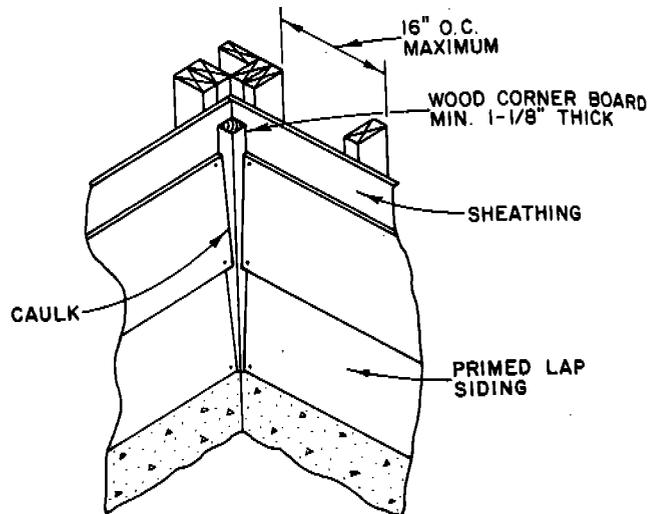


Figure 358—Inside corner details of hardboard lap siding application (American Hardboard Association).

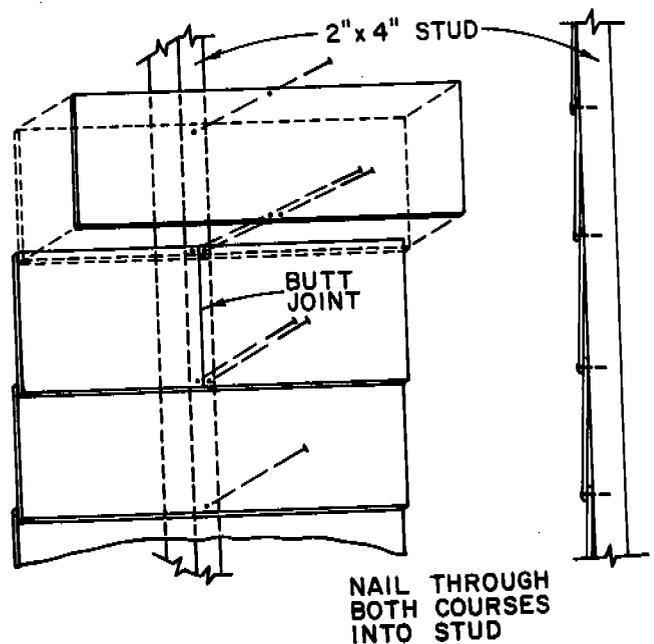


Figure 359—Details of hardboard lap siding application showing joint at stud location (American Hardboard Association).

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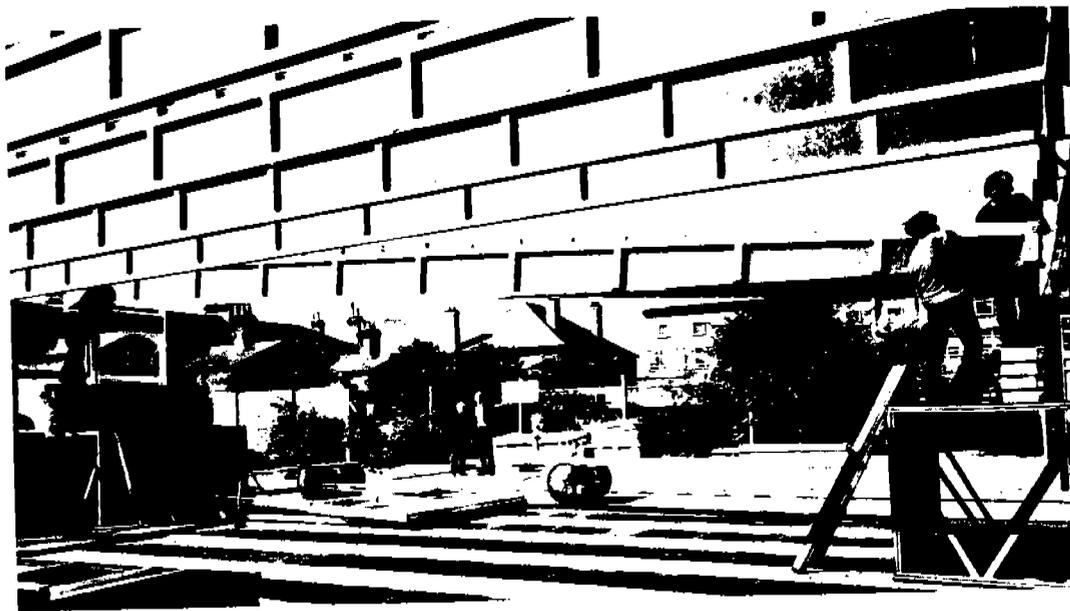


Figure 364—Twelve-meter-span hardboard I-beams for roof of post office mail-sorting office at Southall, London (McNatt 1980).

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 treat-

ment 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

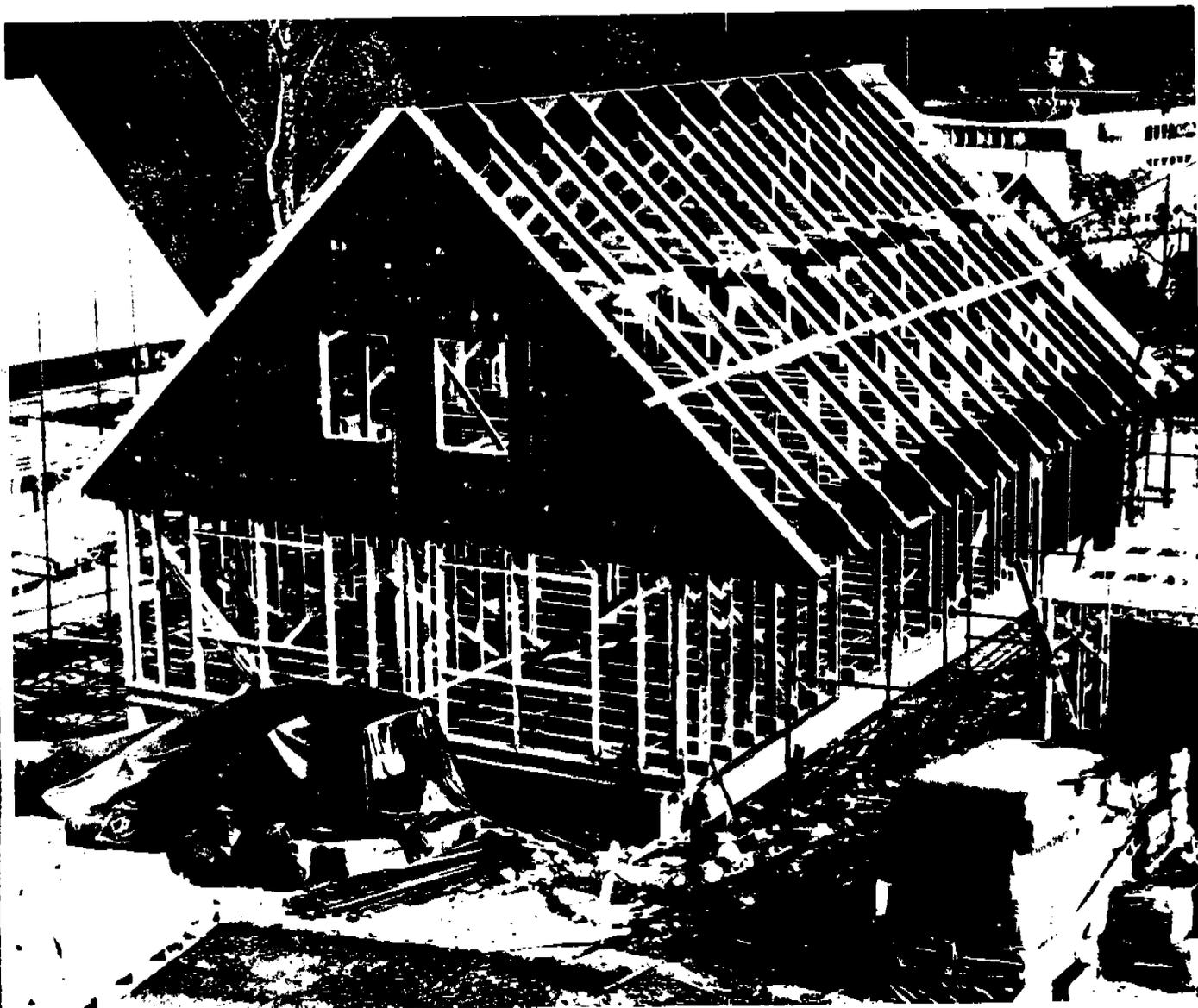


Figure 365—Roof rafter system consisting of hardboard webbed I-beams connected by hardboard gusset plates (McNair 1980).

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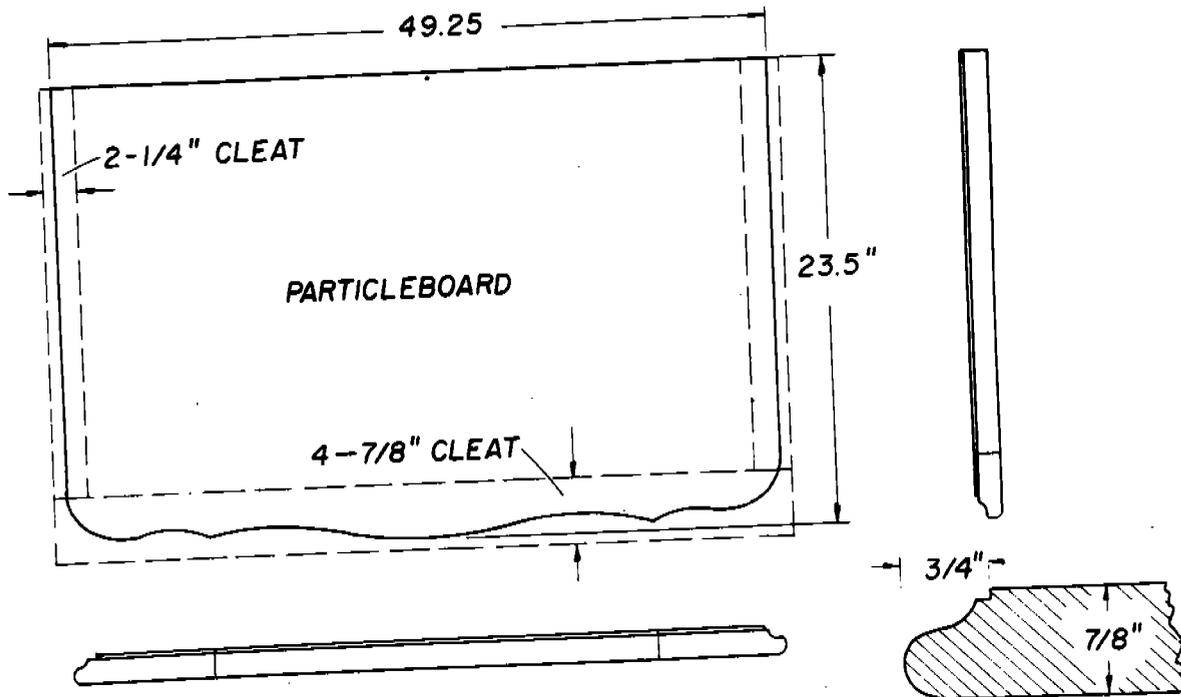


Figure 369—Design and construction of lumber-banded bureau top (Suchsland 1978).

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.).

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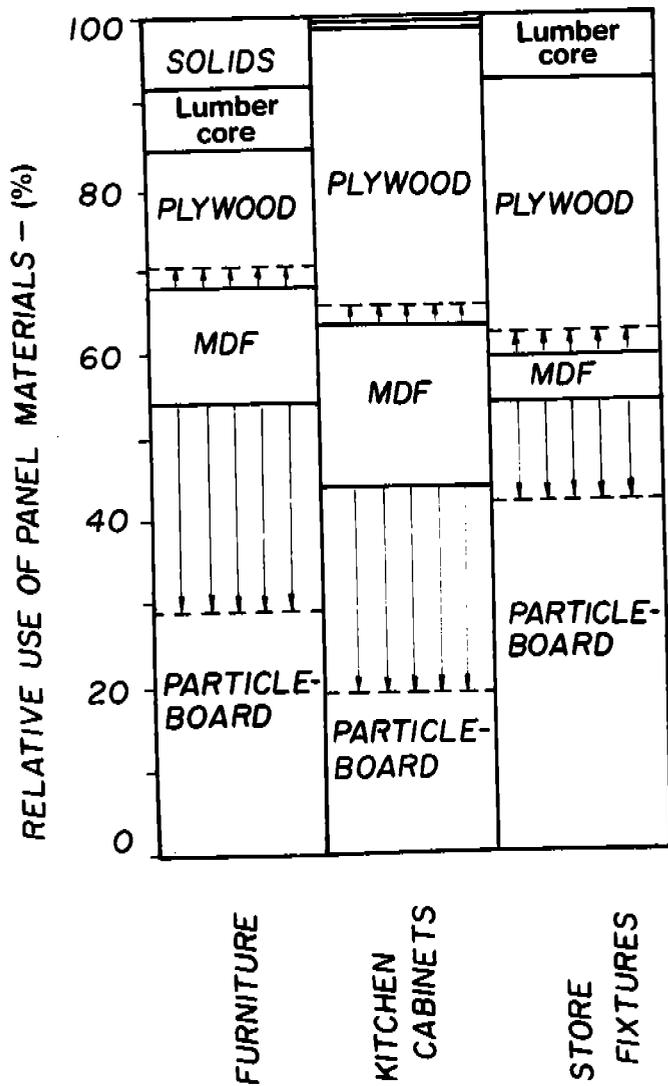


Figure 370—Market position (1977) of medium-density fiberboard (MDF) in industrial market and potential expansion of usage (arrows) on assumption of price equality with particle board (Suchsland 1978).

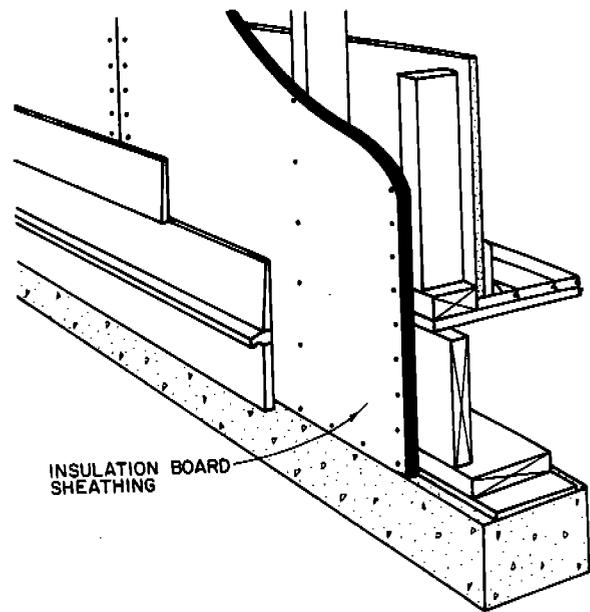


Figure 371—Vertical application of 4-ft-wide insulation board sheathing 25/32 in thick to 2 by 4 framing (Celotex Corp.). All joints must center over framing.

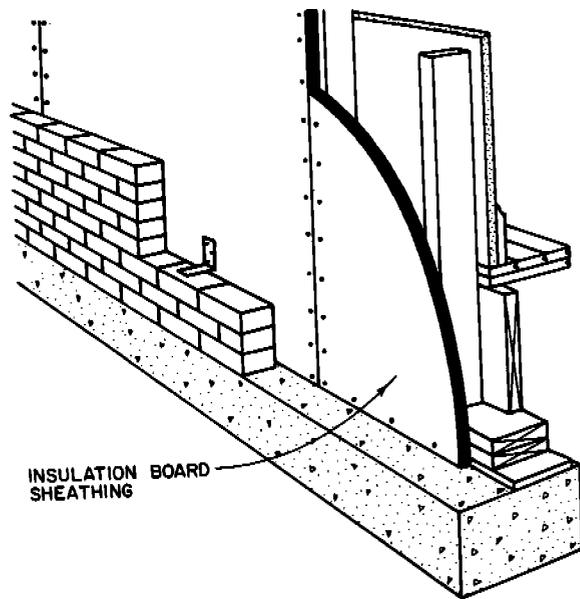


Figure 372—Combination of insulation board sheathing and masonry veneer; 1/2-inch spacing required between face of sheathing and back of masonry veneer (Celotex Corp.). Metal wall ties required at rate of one tie for every 160 to 260 in² of wall area. Ties are nailed through sheathing into studs.

11. Fiberboard Fabricating and Finishing

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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 fabricating and finishing department of an insulation board plant (Dyer 1960). This is a continuous fabrication area designed to produce either single thickness 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 paint line, the boards can go through the resawing and edge fabricating loops, or they may go to the asphalt coating 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 tipples 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 tipples 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, 18). The saws may be mounted with movable saw collars on 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 breakaway 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

Suchsland & Woodson (1986)

Asphalt Coating

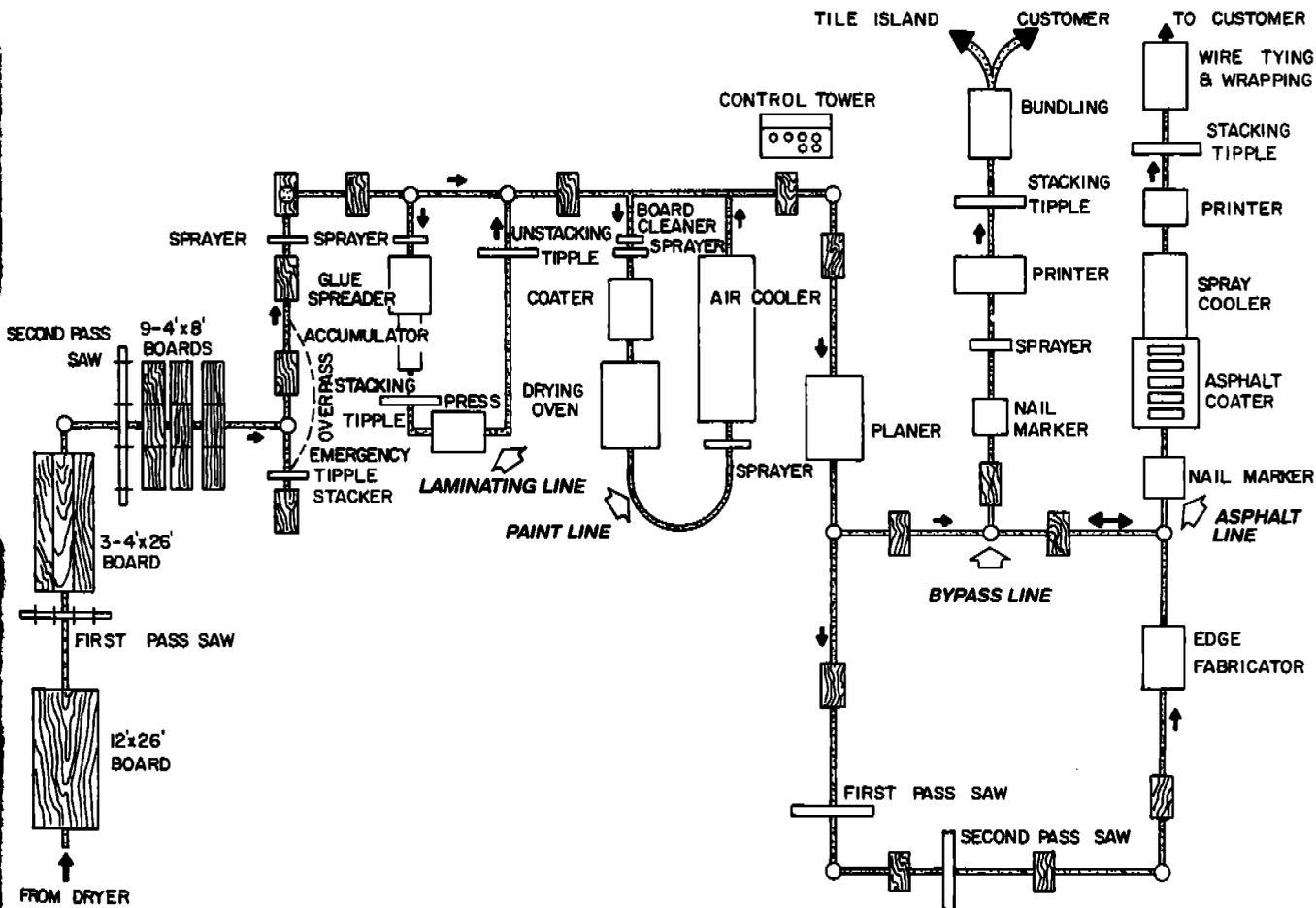


Figure 261—Continuous fabricating area in insulation board plant (Dyer 1960).



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 tippie which builds a 50-in pile of sandwiches; hydraulic press, where the entire stack is compressed for 7 min; and unloading tippie 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 tippie.

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 tippie. 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 tippie and fork-lifted to the separate tile operation. This line is similarly continuous and automatic within itself. The following equipment sequence prevails: unloading tippie; 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-eighths 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

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.

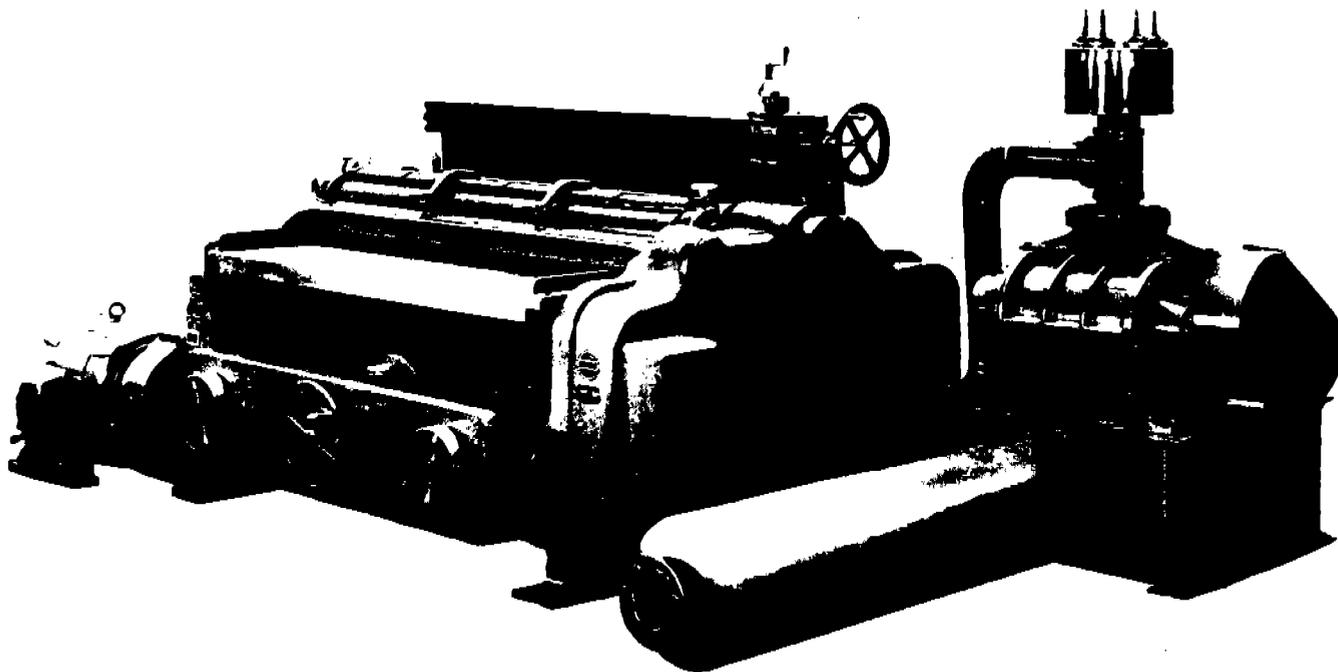


Figure 265—Buss Micro Surfacer. A 52-in-wide single surfacer equipped with carbide knives and vacuum bed (note vacuum pump at right) (Buss).

Suchsland &
Woodson (1986)

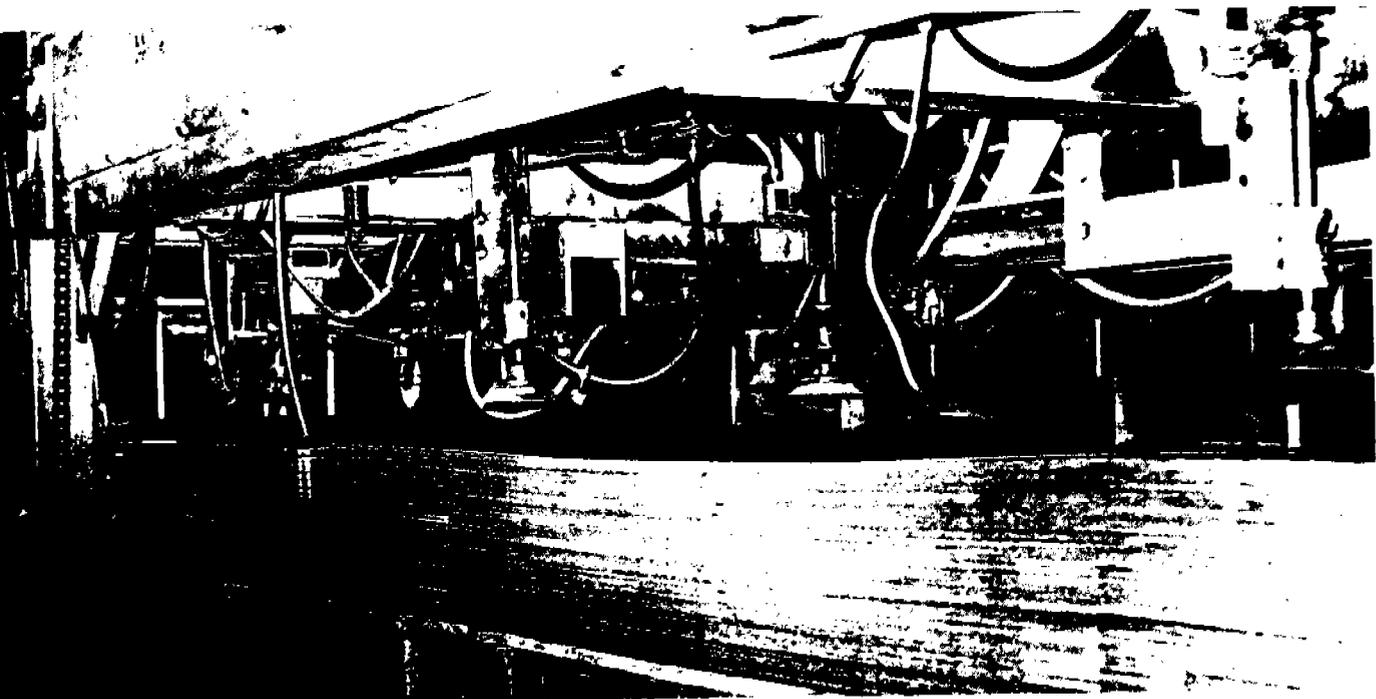


Figure 266—Vacuum feed loading of hardboard into first pass of double trimmer.

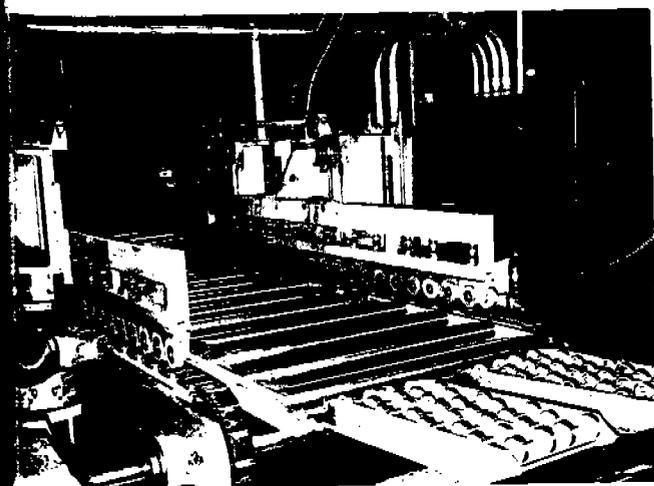


Figure 267—Outfeed end of edge trimmer. Note feed chains and hold-down rolls.

These high-speed cutterheads (6 to 12 in diam, 7200 rpm 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 ma-

chined 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 $\pm 1/64$ in/linear ft. For a 4- by 8-ft board, the length and width tolerances would thus be $\pm 1/8$ in and $\pm 1/16$ in,

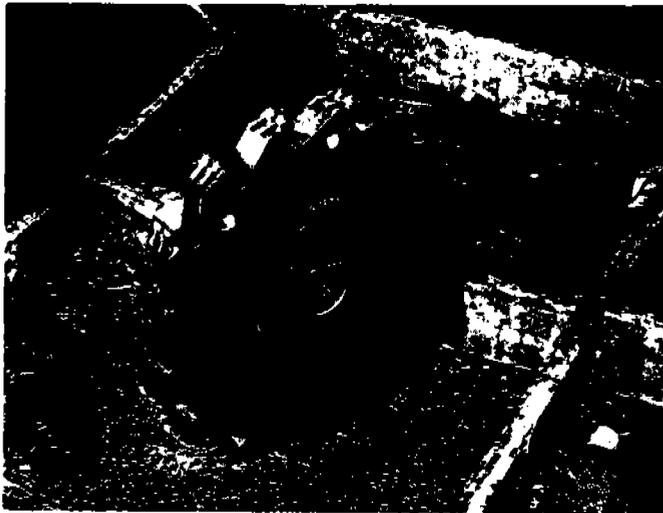


Figure 268—Carbide-tipped cutterhead for rounding hardboard edges.

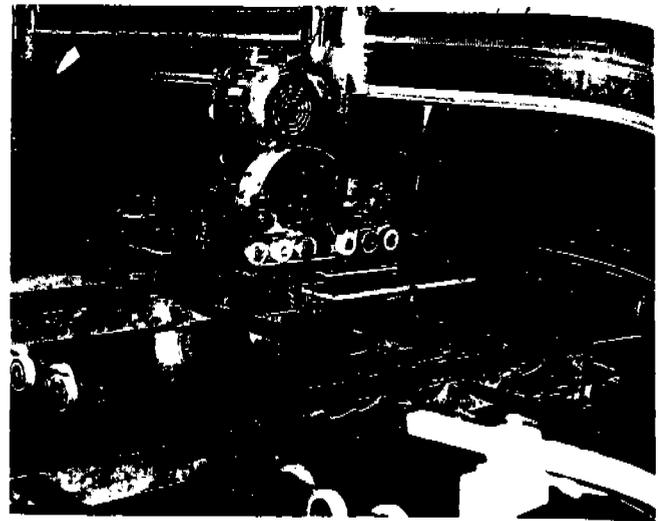


Figure 270—Cross trimmer saw unit with individual drive for easy positioning along overhead beam.

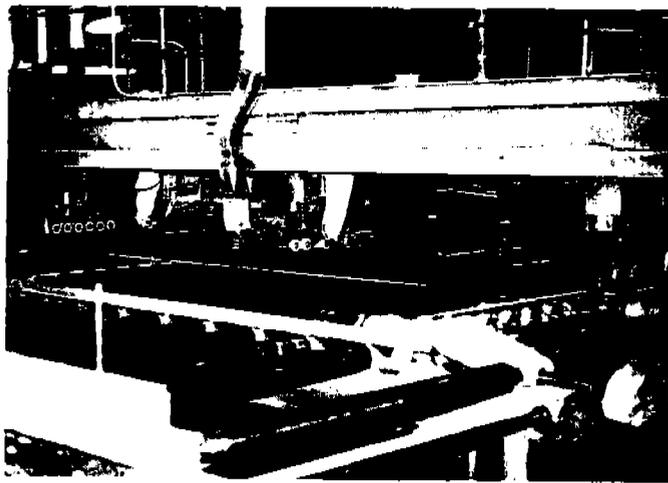


Figure 269—Outfeed end of cross trimmer. Note feed lugs on infeed side.

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 frequent 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 paneling 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 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

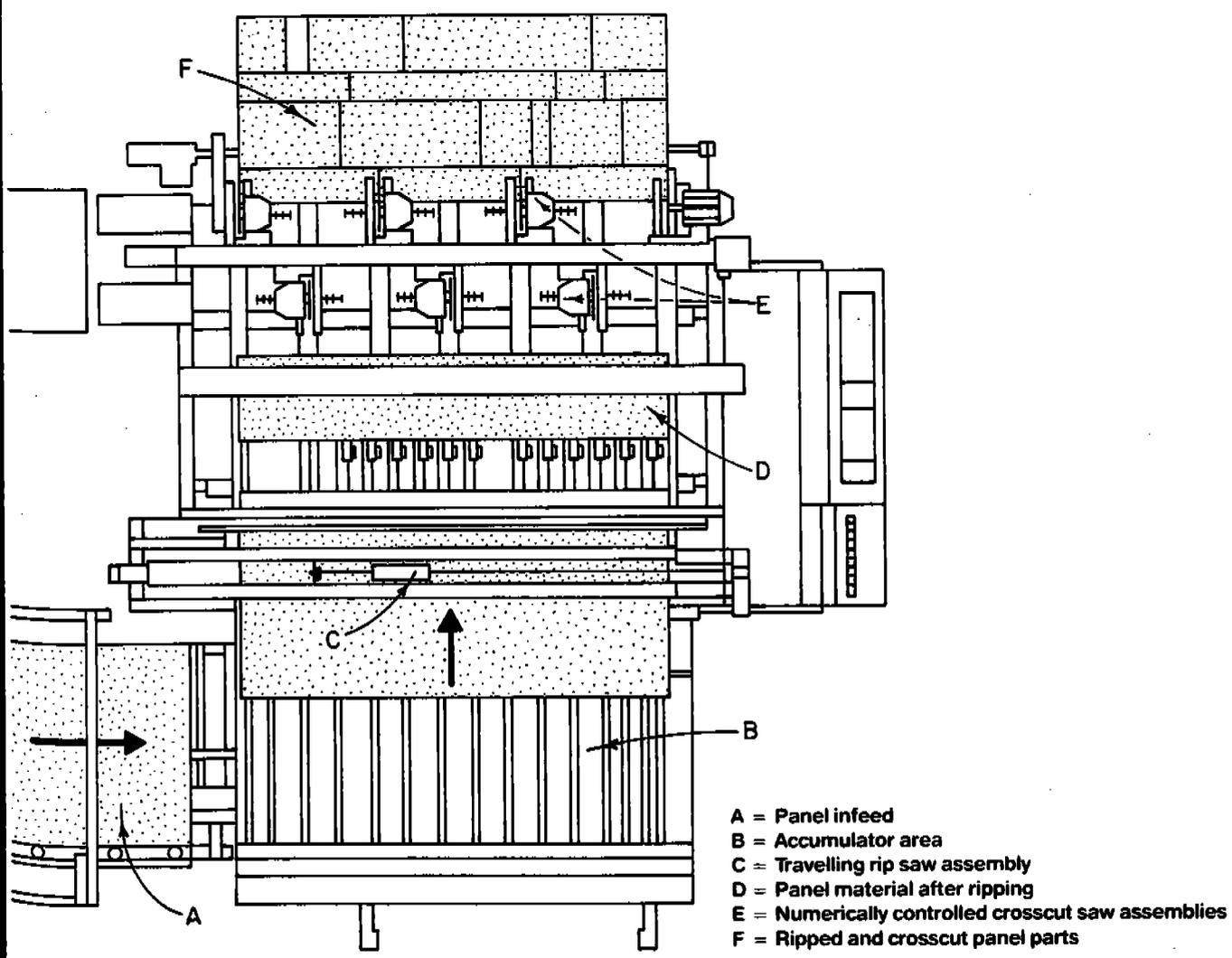


Figure 271—Schematic drawing of panel-sizing machine (McMillin 1982).

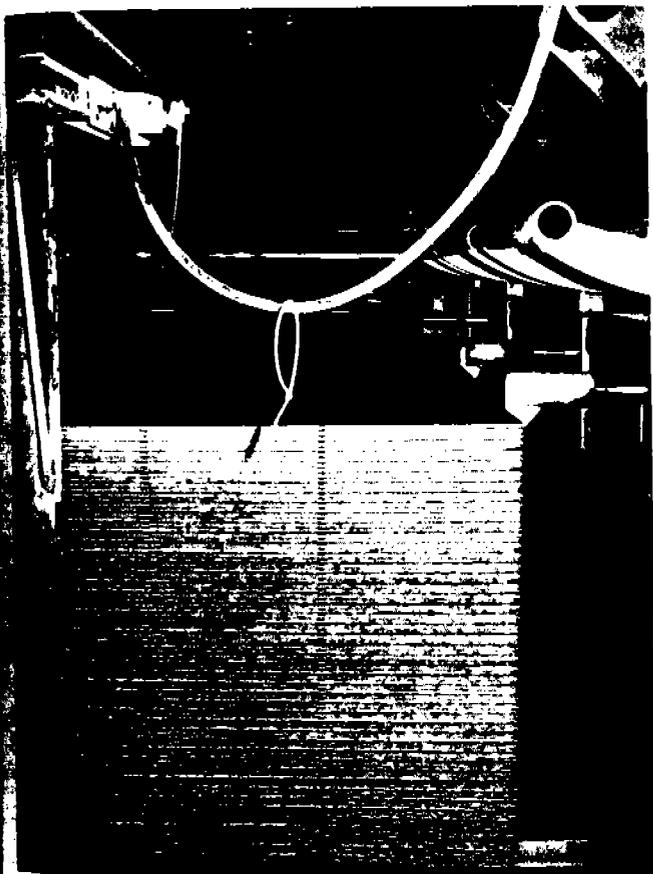


Figure 275—Stack of hardboard panels scored with fixed knives.

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

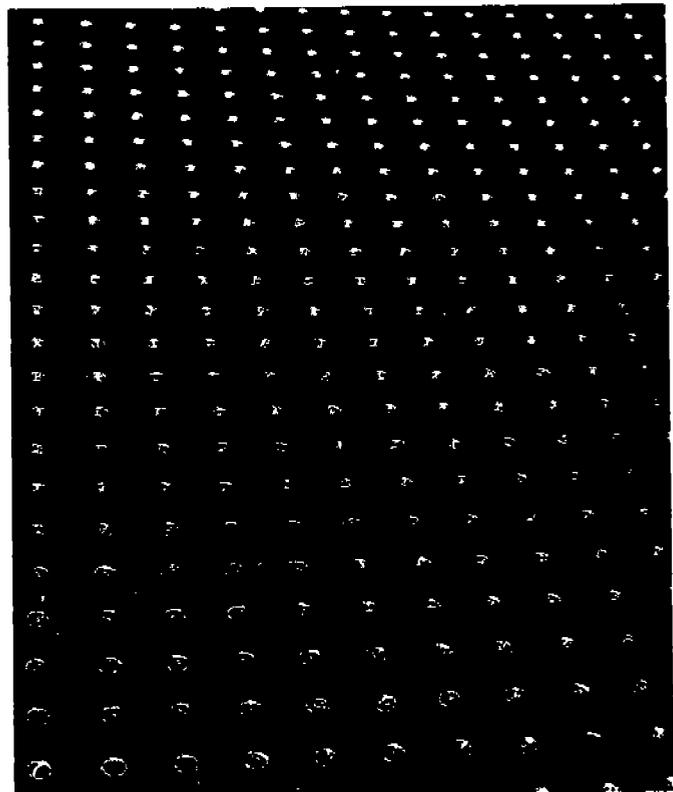


Figure 276—Pegboard.

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

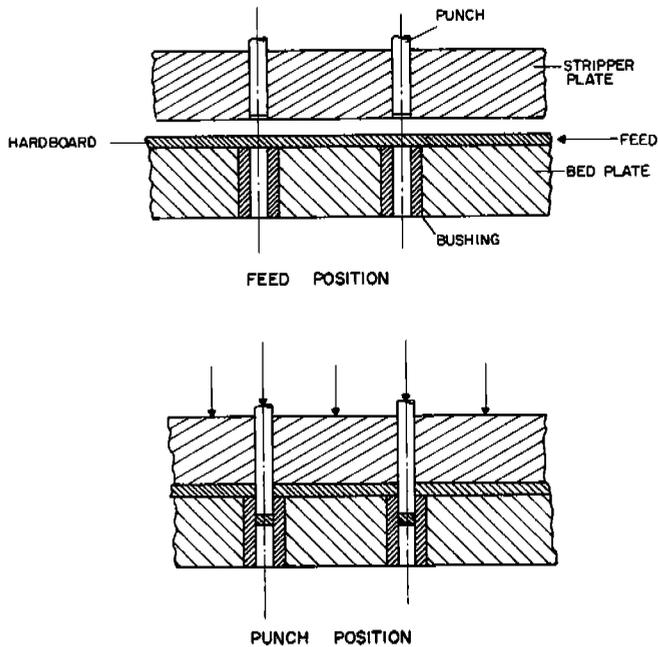


Figure 277—Principle of operation of punch press in the manufacture of pegboard.



Figure 278—Closeup of punch press showing bed plate and raised head with stripper plate. Advancement of panel and operation of punch proceed automatically.

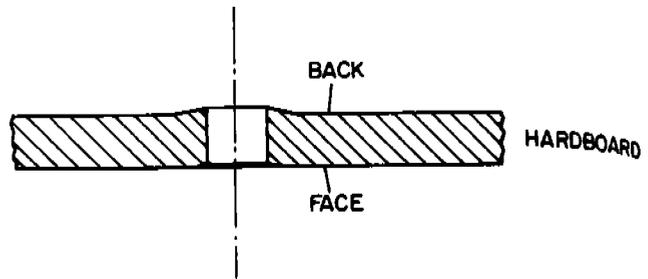


Figure 279—Schematic illustration of possible distortion of pegboard surface (volcano).



Figure 280—Hardboard banding machine.



Figure 281—Stack of profiled cauls for the manufacture of embossed hardboard panels.

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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 simulate weathered wood grain, for instance, have included contoured planer blades. Limited quantities of one 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 implies the limitation that the depth of the profile can be only a fraction of the total board thickness. Male-female forming 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/ft³. At greater densities, blisters occur in these areas and, in SIS boards, blisters are pressed into the carrying screens. The low-density areas should have a density of about 40 to 45 lb/ft³ 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

weathered wood or a fieldstone wall. The photograph is enlarged if necessary 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).

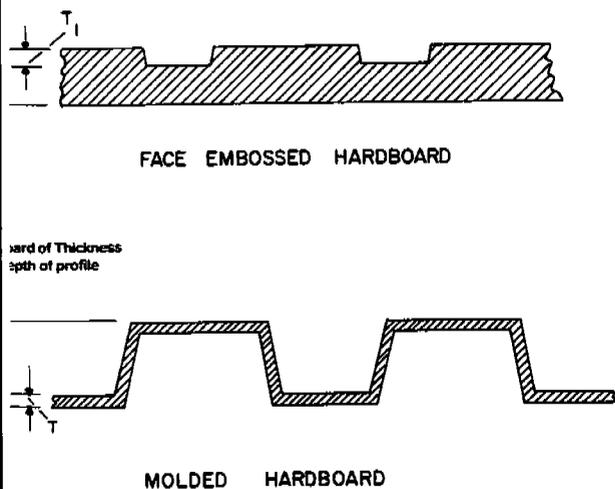


Fig. 282 — Illustration of basic difference between face-embossed and molded hardboard. In face-embossed boards, T_1 is always smaller than T .

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Agriculture

Forest
Service

Agriculture
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Fiberboard Manufacturing Practices in the United States

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Otto Suchsland and
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Contents

	Page		Page
1. Introduction	1	8. Wet-Process Fiberboard Manufacture	98
Concepts	1	General	98
Definitions	4	Forming Machines	98
References	4	The Wet Press	108
2. The Fiberboard Industry	5	Trimming of Wet Fiber Mat	111
Historical Background	5	Hotpressing and Drying	112
Industry Statistics	7	References	134
References	11	9. Dry-Process Fiberboard Manufacture	136
3. Some Chemical Aspects of Fiberboard		General	136
Manufacture	13	Manufacture of Dry-Process High- and	
General	13	Medium-Density Hardboard	137
The Structure and Chemistry of Wood Cells	13	Manufacture of Medium-Density Fiberboard	151
Chemical Reactions in Fiberboard Manufacture	22	Manufacture of Dry-Process Fiberboard by the	
Chemistry of the Adhesive Bond	24	Continuous Mende Process	160
References	25	Manufacture of Board With Oriented Fibers	163
4. Raw Materials	28	References	165
General	28	10. Heat Treatment, Tempering, and Humidification	168
The Importance of Fiber Characteristics	28	General	168
Softwoods Versus Hardwoods	31	Improvement of Board Properties	168
Individual Species and Mixtures	32	Industrial Practices	171
Wood Chips	34	References	178
Wood Residues	35	11. Fiberboard Fabricating and Finishing	180
Nonwood Raw Materials	37	General	180
References	37	Fabricating and Finishing of Insulation Board	180
5. Preparation of Raw Material	39	Fabricating of Hardboard	182
General	39	Finishing of Hardboard	192
The Millyard	39	References	205
Raw Material Measurement	41	12. Water Use and Treatment	206
Manufacture of Pulp Chips	44	General	206
The Handling of Chips	53	The Water Problem	206
Deterioration of Wood Chips During Storage	55	Treatment Methods	208
The Cleaning of Whole-Tree Chips	56	References	217
References	58	13. Board Properties and Markets	219
6. Pulping Processes	59	General	219
General	59	Properties of Commercial Hardboard	219
The Freeness of Pulp	59	Properties of Dry-Process Mende-Board	221
The Masonite Pulping Process	62	Properties of Commercial Medium-Density	
Disk Refining	65	Fiberboard	232
Pulp Washers and Screw Presses	80	Viscoelastic Behavior of Fiberboard	233
The Pulping of Bagasse	80	Insulation Board Property Requirements	235
Process Control	82	Application of Hardboard Products	244
References	87	Application of Medium-Density Fiberboard	252
7. Chemical Additives	88	Application of Insulation Board Products	253
General	88	References	255
The Sizing of Fiberboard	88	Index	258
Fiberboard Binders	90		
Fire Retardant and Preservative Treatments	91		
Industrial Practices	92		
References	97		

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 fiber-

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.

board. 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 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 Tung oil Tall oil	Flax seed Seed of tung tree Byproduct of sulfate pulping of softwoods
Thermoplastic resins	Soybean oil Vinsol Gilsolite	Soybean Pine rosin 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.

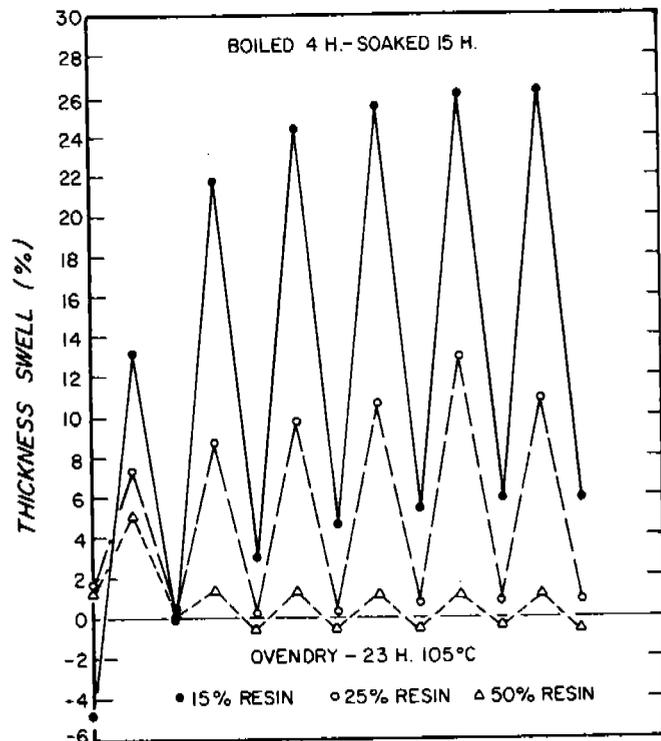


Figure 126—Dimensional stabilization of dry-formed hardboard as a result of treatment with three levels of impregnating resins (Brown and others 1966).

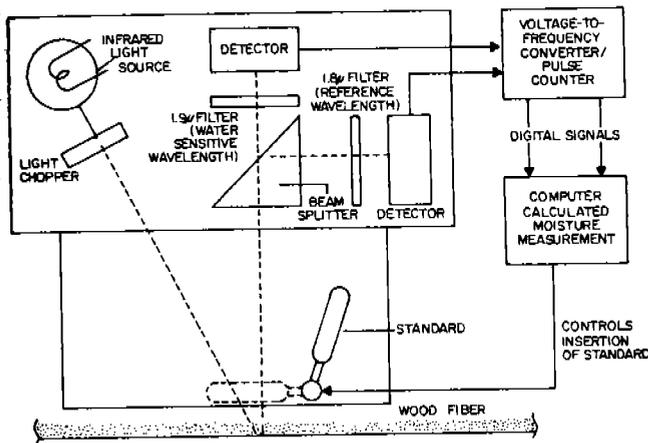


Figure 211—Principle of Measurex moisture sensor (Betzner and Wallace 1980).

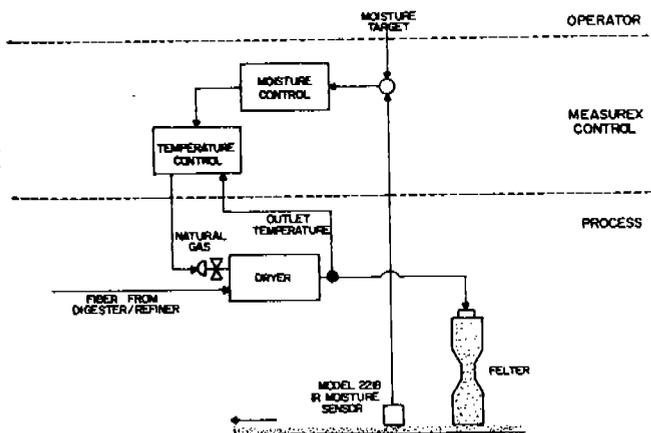


Figure 212—Principle of Measurex mat moisture measurement and control (Betzner and Wallace 1980).

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/ft³ or less), which develops good resin bonding during compression to normal board density (45 to 50 lb/ft³). 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/ft³ is in-

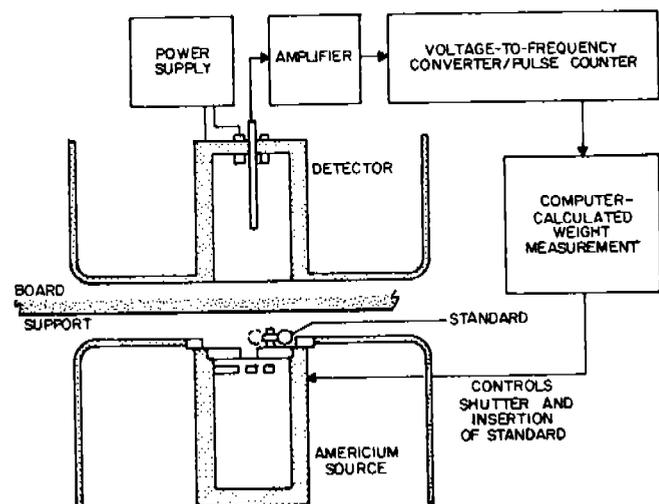


Figure 213—Principle of Measurex weight sensor (Betzner and Wallace 1980).

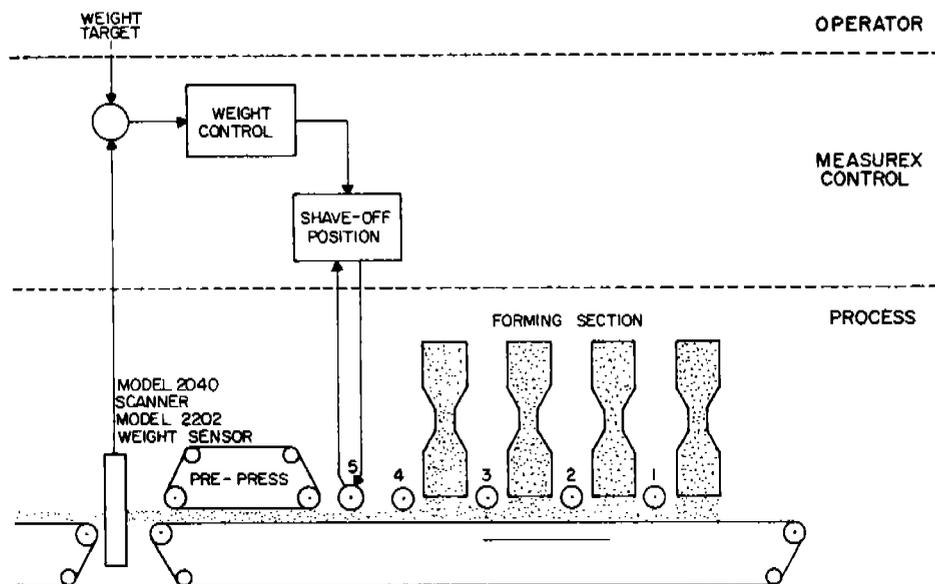


Figure 214—Principle of Measurex weight measurement and control (Betzner and Wallace 1980).

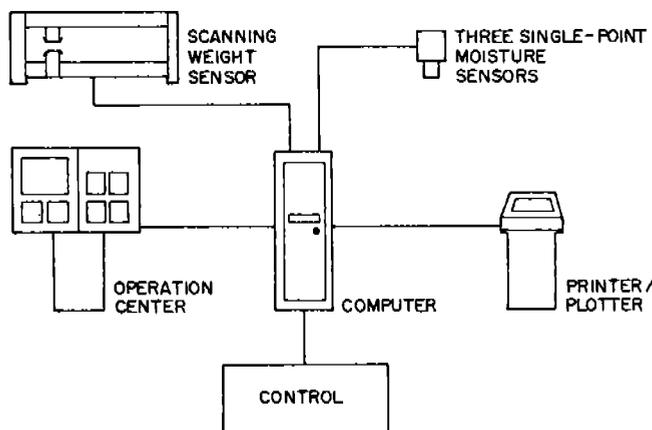


Figure 215—Overview of Measurex mat density control system (Betzner and Wallace 1980).

indicated 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

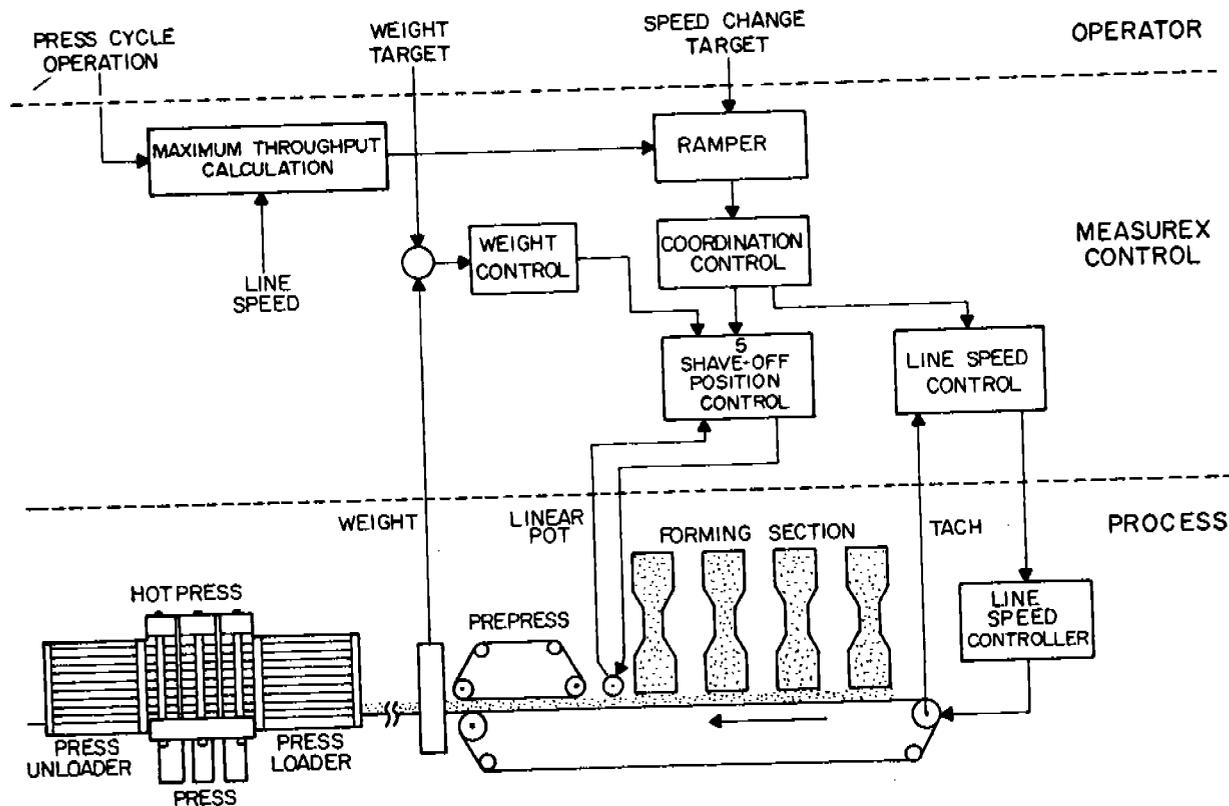


Figure 216—Measurex speed change control and throughput maximization control (Betzner and Wallace 1980).

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

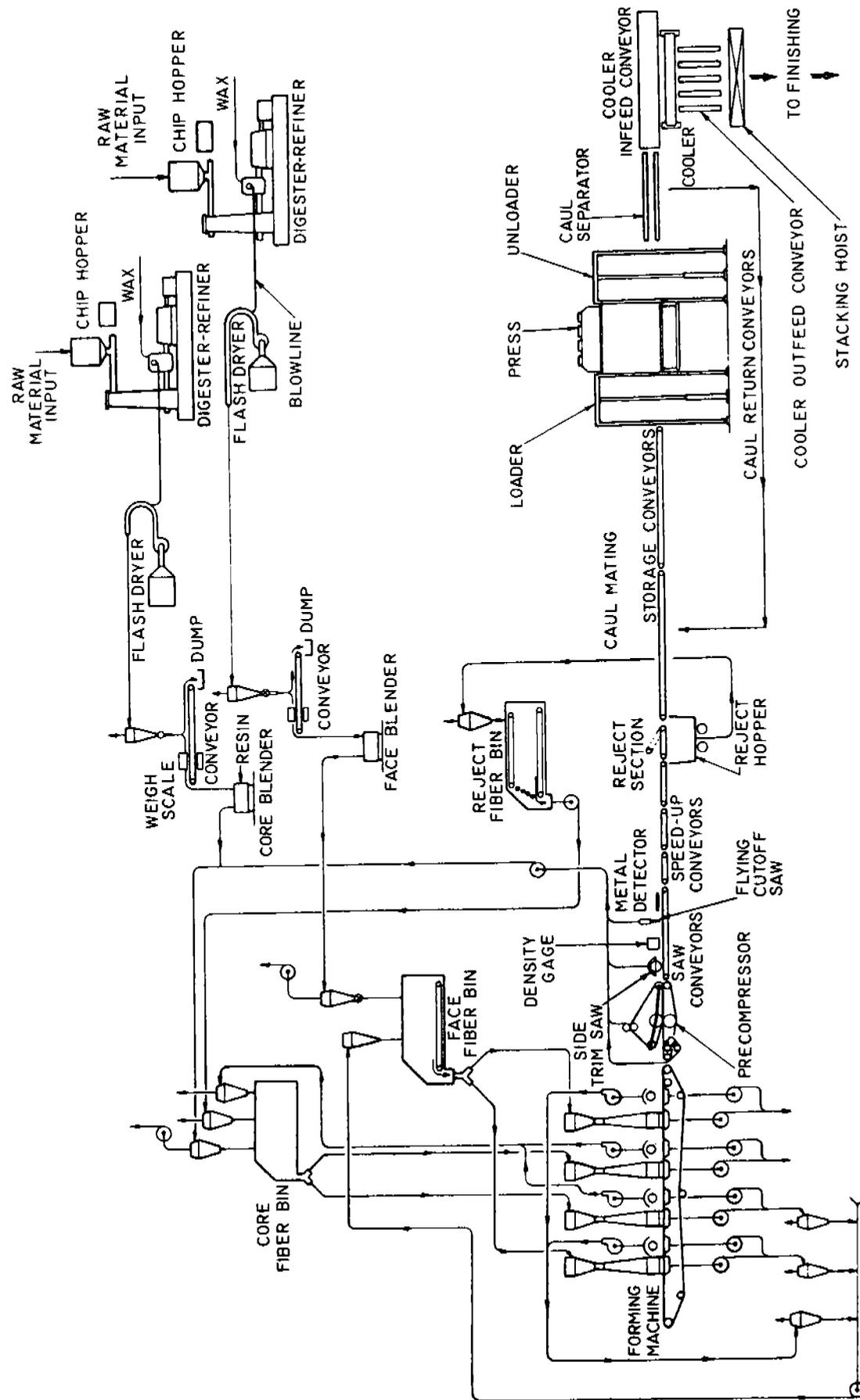


Figure 217—Typical process flow chart of medium-density fiberboard plant (Chrysi and Rudman 1979).

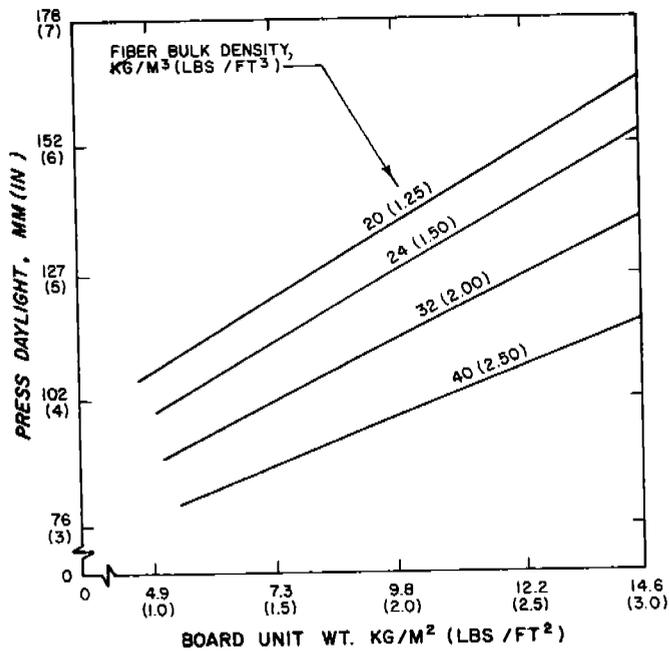
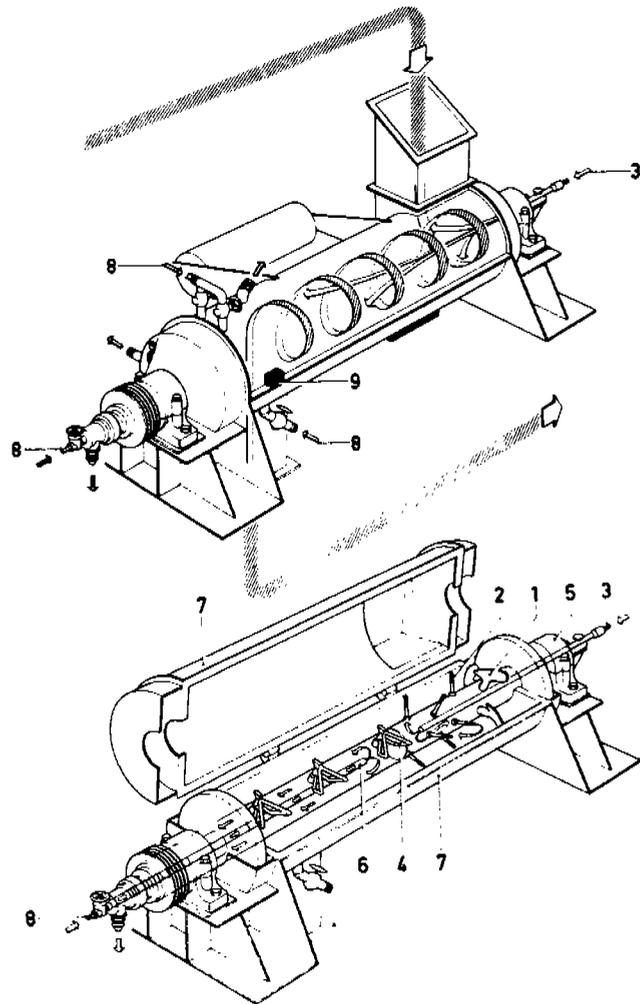


Figure 218—Press daylight required for fiberboards for various fiber bulk densities (Chryst and Rudman 1979). "Daylight" is the clearance between adjacent press platens when press is fully opened.

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

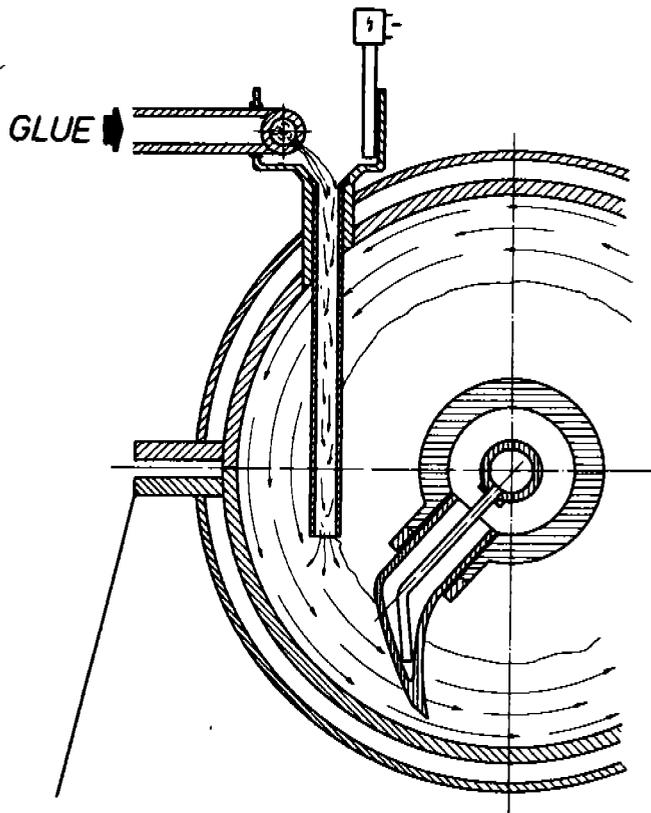


Figure 220—Injection of liquid resin through external feeding pipes into ring of rotating furnace (Engels 1978).

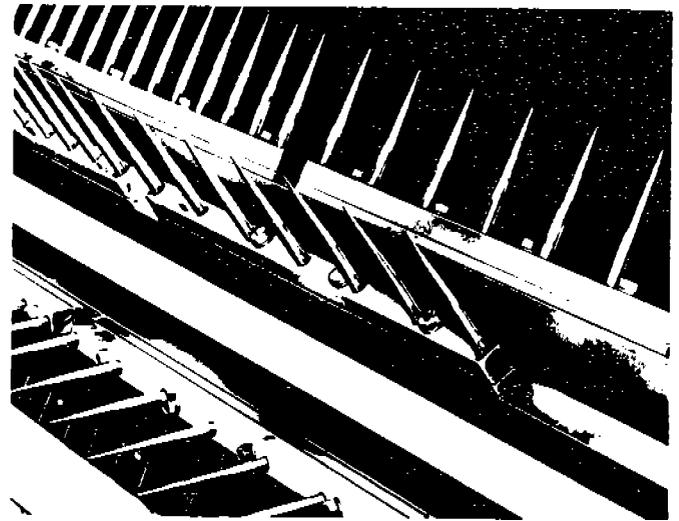


Figure 221—Ring mixer for fiber furnish equipped with needle-type agitator arms (Engels 1978).

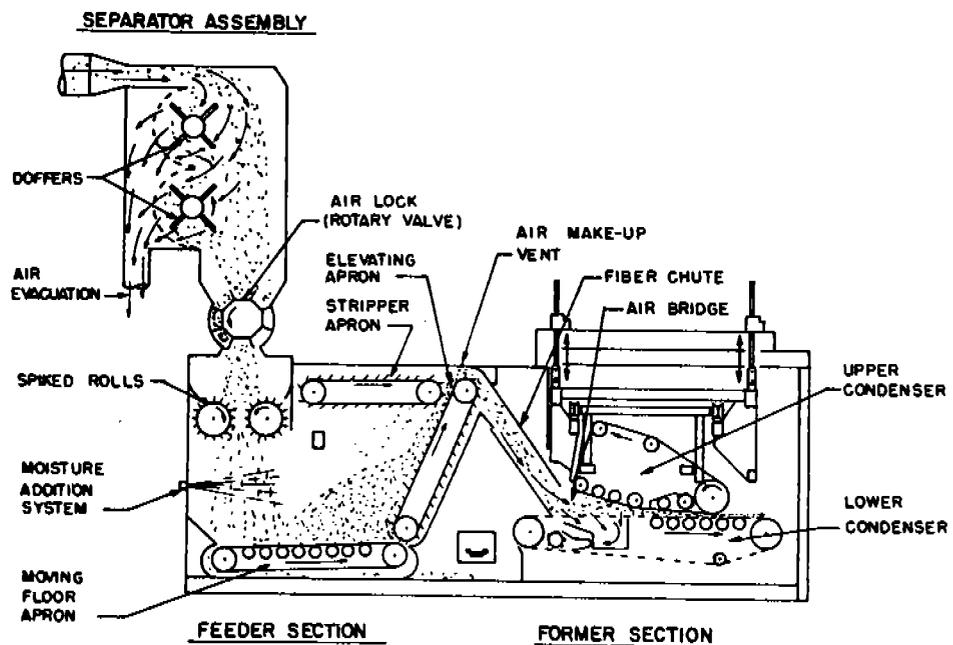
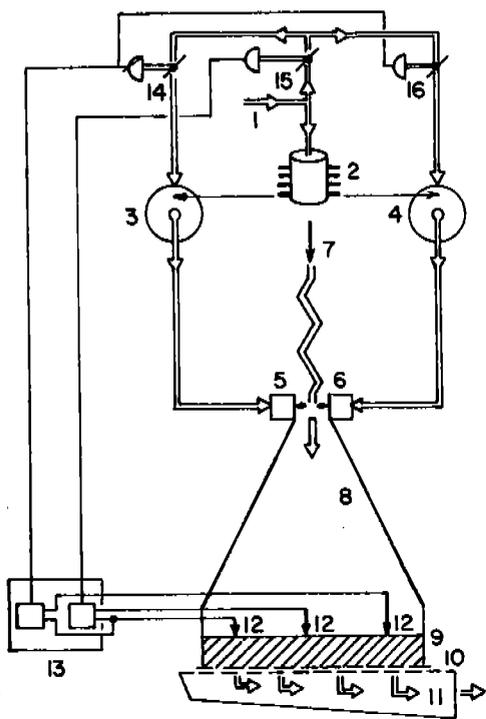


Figure 222—Schematic drawing of Rando-Wood Former Mark II (Wood 1976).



- 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).

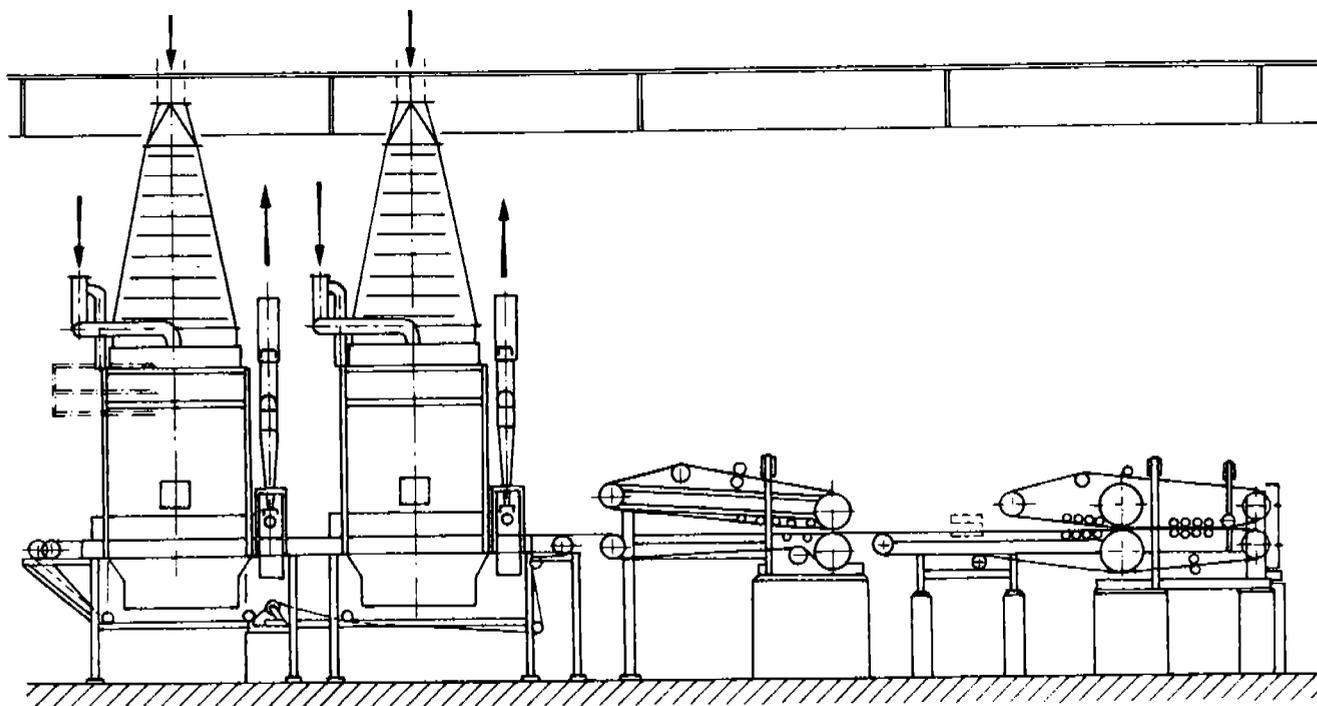


Figure 224—Pendistor forming station. Two Pendistor formers are followed by a two-stage band-prepress. First stage is low pressure, second is high pressure (Carlson 1978).

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

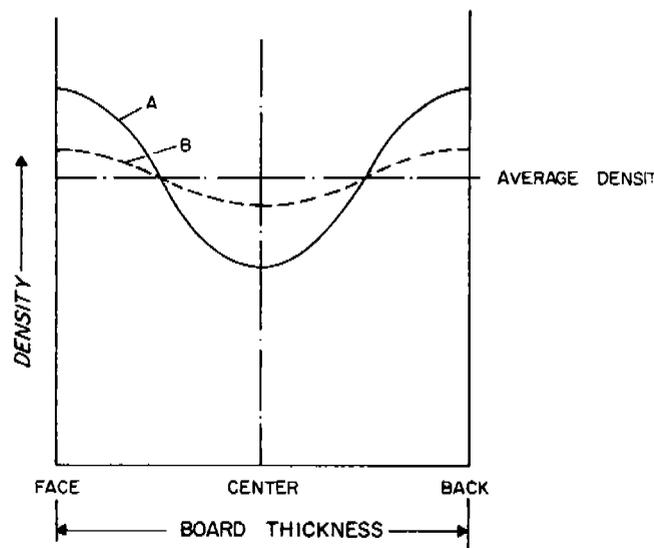


Figure 225—Examples of density distributions over board cross section at constant average board density.

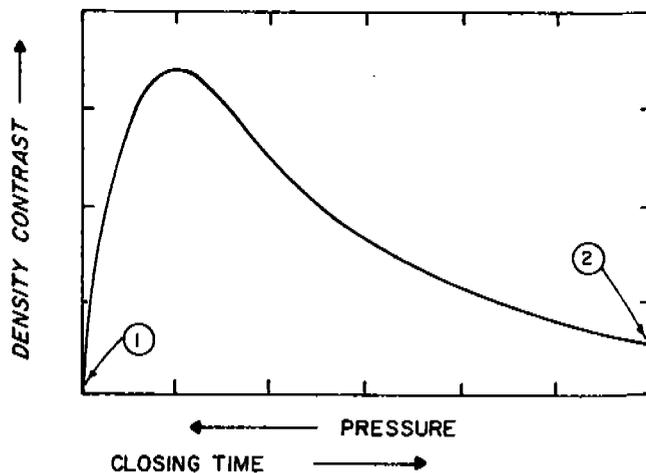


Figure 226—Schematic illustration of relationship between pressure or closing time and density contrast over cross section of medium-density fiberboard (Suchsland and Woodson 1974).

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

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 3/4-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 3/4 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

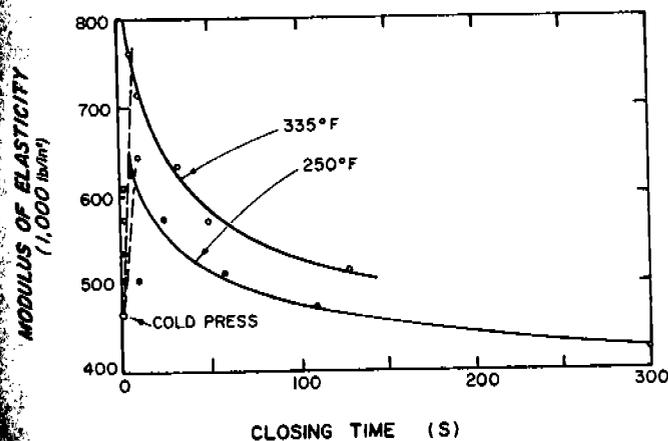
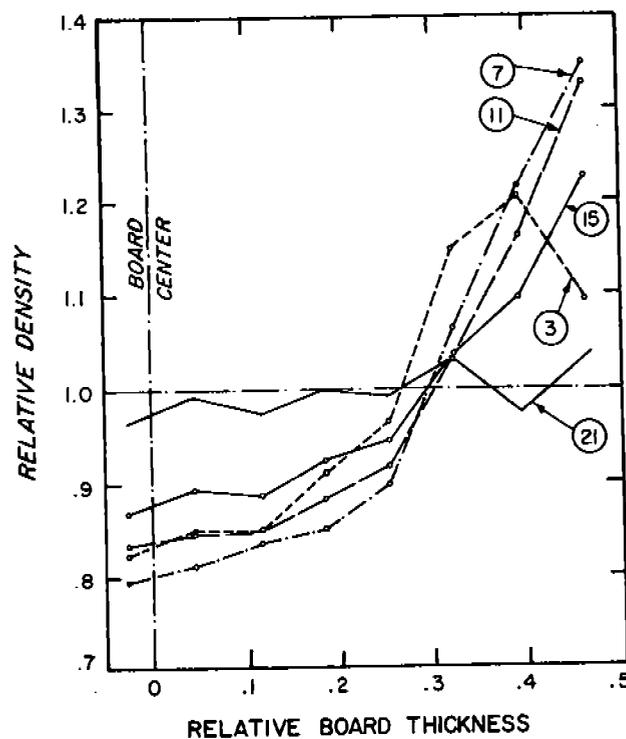


Figure 227—Relationship between press closing time and modulus of elasticity in bending of experimental medium-density fiberboard pressed at two different platen temperatures (Suchsland and Woodson 1974).

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



No.	Prepressure (lb/in ²)	Pressure (lb/in ²)	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 3/4-in experimental medium-density fiberboards pressed at a platen temperature of 335 °F. (Suchsland and Woodson 1974).

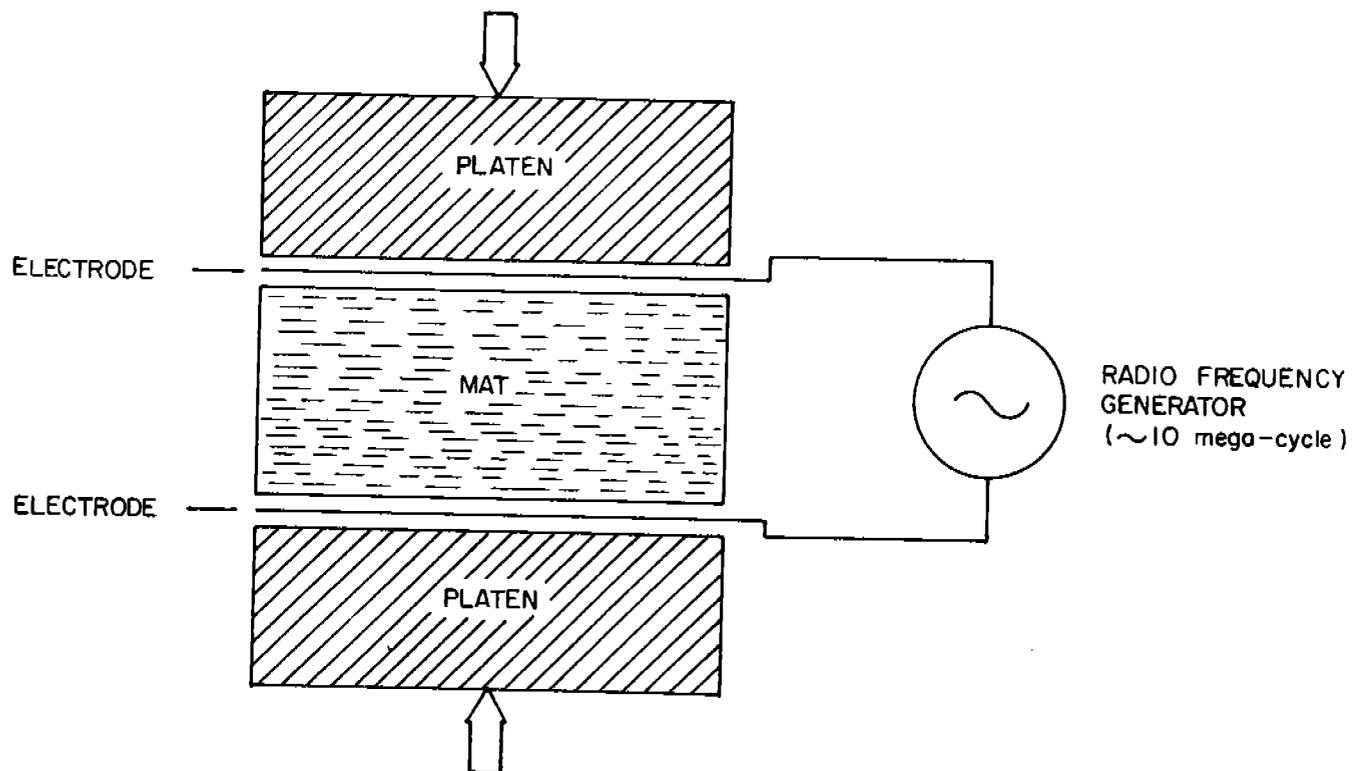


Figure 229—Principle of radio frequency board press (Suchsland 1978).

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 thicknesses.

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.

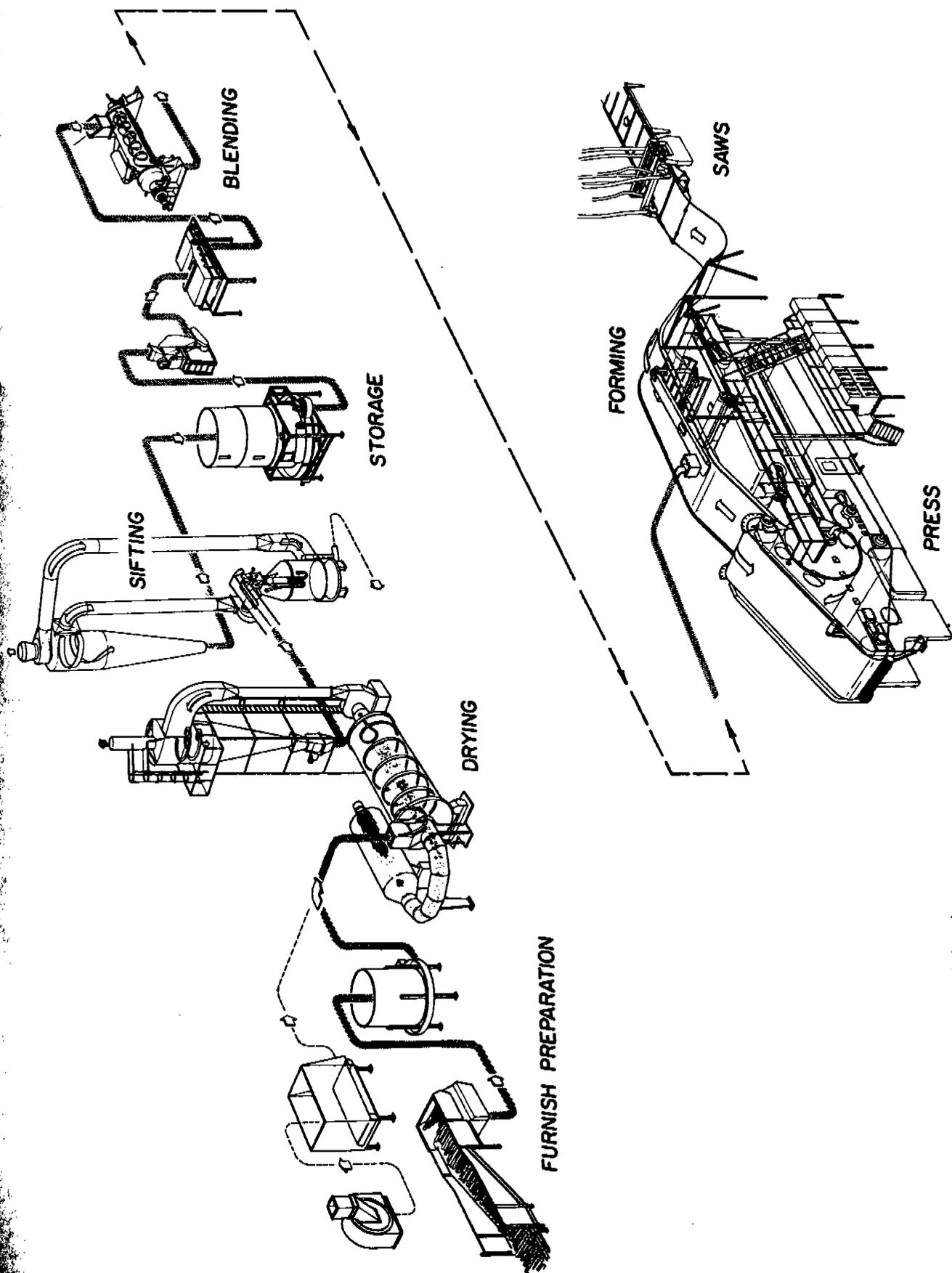


Figure 230—Schematic flow chart of Mende board plant (Bison Werke).

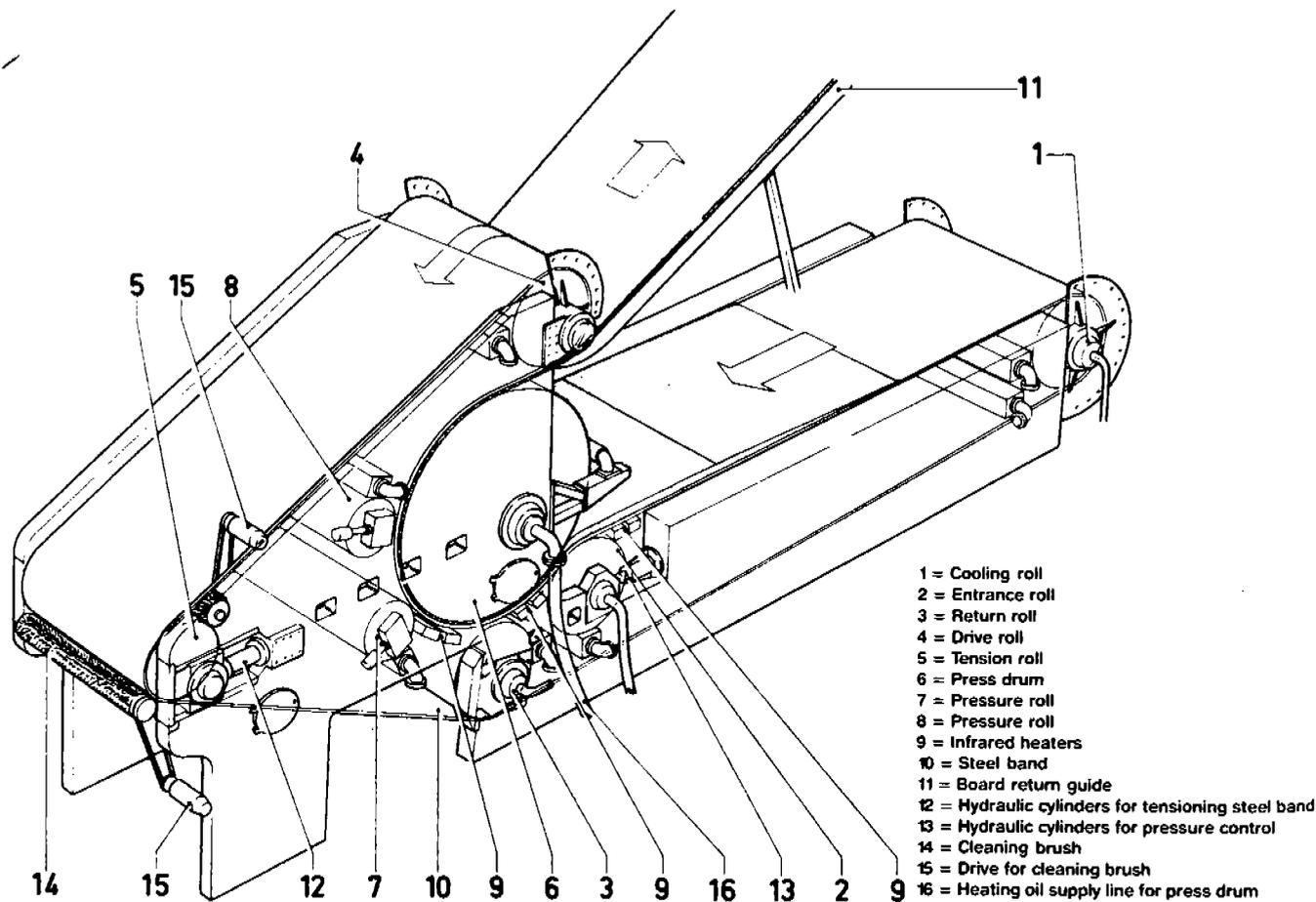


Figure 231—Continuous Mende press (Bison Werke).

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 fiber-board 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

Suchsland &
Woodson (1986)

Contents

	Page		Page
1. Introduction	1	8. Wet-Process Fiberboard Manufacture	98
Concepts	1	General	98
Definitions	4	Forming Machines	98
References	4	The Wet Press	108
2. The Fiberboard Industry	5	Trimming of Wet Fiber Mat	111
Historical Background	5	Hotpressing and Drying	112
Industry Statistics	7	References	134
References	11	9. Dry-Process Fiberboard Manufacture	136
3. Some Chemical Aspects of Fiberboard		General	136
Manufacture	13	Manufacture of Dry-Process High- and	
General	13	Medium-Density Hardboard	137
The Structure and Chemistry of Wood Cells	13	Manufacture of Medium-Density Fiberboard	151
Chemical Reactions in Fiberboard Manufacture	22	Manufacture of Dry-Process Fiberboard by the	
Chemistry of the Adhesive Bond	24	Continuous Mende Process	160
References	25	Manufacture of Board With Oriented Fibers	163
4. Raw Materials	28	References	165
General	28	10. Heat Treatment, Tempering, and Humidification	168
The Importance of Fiber Characteristics	28	General	168
Softwoods Versus Hardwoods	31	Improvement of Board Properties	168
Individual Species and Mixtures	32	Industrial Practices	171
Wood Chips	34	References	178
Wood Residues	35	11. Fiberboard Fabricating and Finishing	180
Nonwood Raw Materials	37	General	180
References	37	Fabricating and Finishing of Insulation Board	180
5. Preparation of Raw Material	39	Fabricating of Hardboard	182
General	39	Finishing of Hardboard	192
The Millyard	39	References	205
Raw Material Measurement	41	12. Water Use and Treatment	206
Manufacture of Pulp Chips	44	General	206
The Handling of Chips	53	The Water Problem	206
Deterioration of Wood Chips During Storage	55	Treatment Methods	208
The Cleaning of Whole-Tree Chips	56	References	217
References	58	13. Board Properties and Markets	219
6. Pulping Processes	59	General	219
General	59	Properties of Commercial Hardboard	219
The Freeness of Pulp	59	Properties of Dry-Process Mende-Board	221
The Masonite Pulping Process	62	Properties of Commercial Medium-Density	
Disk Refining	65	Fiberboard	232
Pulp Washers and Screw Presses	80	Viscoelastic Behavior of Fiberboard	233
The Pulping of Bagasse	80	Insulation Board Property Requirements	235
Process Control	82	Application of Hardboard Products	244
References	87	Application of Medium-Density Fiberboard	252
7. Chemical Additives	88	Application of Insulation Board Products	253
General	88	References	255
The Sizing of Fiberboard	88	Index	258
Fiberboard Binders	90		
Fire Retardant and Preservative Treatments	91		
Industrial Practices	92		
References	97		

9. Dry-Process Fiberboard Manufacture

Suchsland & Woodson (1986)

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 SIS 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/ft³ and in the high-density range, over 55 lb/ft³. 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.

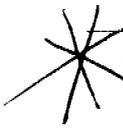
Although it was initially believed that the dry process would become the dominant fiberboard process in North America, air pollution abatement regulation resulted in increased power requirements and capital costs for the dry process. Increases in oil prices have substantially raised fiber drying and 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

The term "raffinator" is interchangeable with "refiner."

The largest dry-process hardboard plant in the country (Masonite at Towanda, PA) uses an Asplund defibrator and raffinator 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.

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.



**General
Density Hardboard
Manufacture of Dry-Process High- and Medium-**

In addition to conventional thick and thin, medium- and high-density dry-process fiberboards, a unique continuous board process, the so-called Mendé 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 1/4 in, it is in direct competition with conventional dry- and wet-process hardboard. One of the attractive features of the Mendé process is its capability to produce hardboard economically on a small scale.

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.

For the wet process than for the dry process. 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.

• 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.

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).

Plant Capital Cost (thousands of dollars)	Wet-process plants	Dry-process plants
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	800	800
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	1,730	2,400
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	4,570	4,780
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	2,880	1,560
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	650	650
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	2,050	1,620
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	1,410	1,330
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	14,090	13,140
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	4,200	3,260
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	2,000	750
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	3,850	2,950
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	250	250
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	1,110	1,050
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	2,500	2,100
Wet process: press size, 2438 by 5486 mm — 26 openings; production capacity, 200 tons/day (3 mm) or 222 tons/day (11 mm).	2,700	2,700
Wet process: press size, 1524 by 5486 mm — 24 openings; production capacity, 185 tons/day (3 mm) or 277 tons/day (11 mm).	30,700	26,200

Costs (thousands of dollars)

Wet-process Dry-process plants

26—Plant capital costs estimates for wet- and dry-process hardboard (adapted from Anon, 1976)

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.

Costs wet- vs. dry-process fiberboard

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 ft³/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 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 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 pre-dryer 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 pre-dryer but also to allow accurate control of board density and 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 explosion.

Table 27—Manufacturing costs estimates for wet- and dry-process hardboard (Anon. 1976)

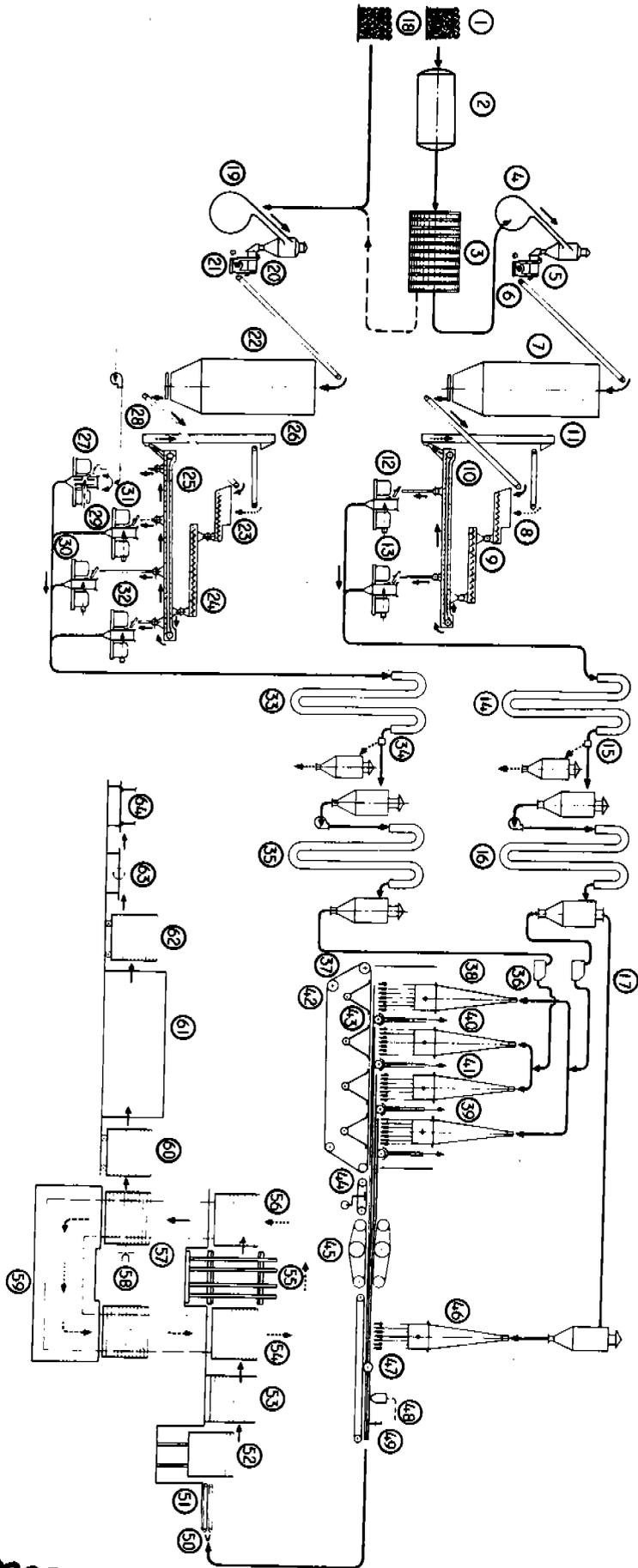
Item	Wet process	Dry process
Panel thickness (mm)	3.2	3.2
Product (type)	board	siding
Production capacity (tons/a) ¹	65,000	72,000
Manufacturing cost (dollars/ton)		
Wood	29.40	29.20
Resin	2.10	7.70
Wax	3.30	3.30
Alum	1.17	1.17
Power	5.75	5.75
Fuel	8.08	8.08
Labor	18.46	16.67
Operating and maintenance supplies	11.73	11.74
Administration and overhead	7.04	6.21
Taxes and insurance	5.46	5.30
Cutting, priming, & packaging costs	—	26.23
Total manufacturing cost ² (dollars/ton)	92.49	121.35
Depreciation ³ (dollars/ton)	28.72	28.43
Total cost (dollars/ton)	121.21	149.78
Wood	28.52	29.15
Resin	33.60	15.40
Wax	3.15	3.30
Alum	—	—
Power	5.25	5.25
Fuel	8.51	8.72
Labor	12.00	18.00
Operating and maintenance supplies	8.57	11.08
Administration and overhead	5.14	7.65
Taxes and insurance	3.74	5.00
Cutting, priming, & packaging costs	26.23	—
Total manufacturing cost ² (dollars/ton)	134.71	103.55
Depreciation ³ (dollars/ton)	19.41	26.11
Total cost (dollars/ton)	154.12	129.66

¹a = annum = 325 days.
²Excluding interest & depreciation.
³15-year straight line.

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Drying

D

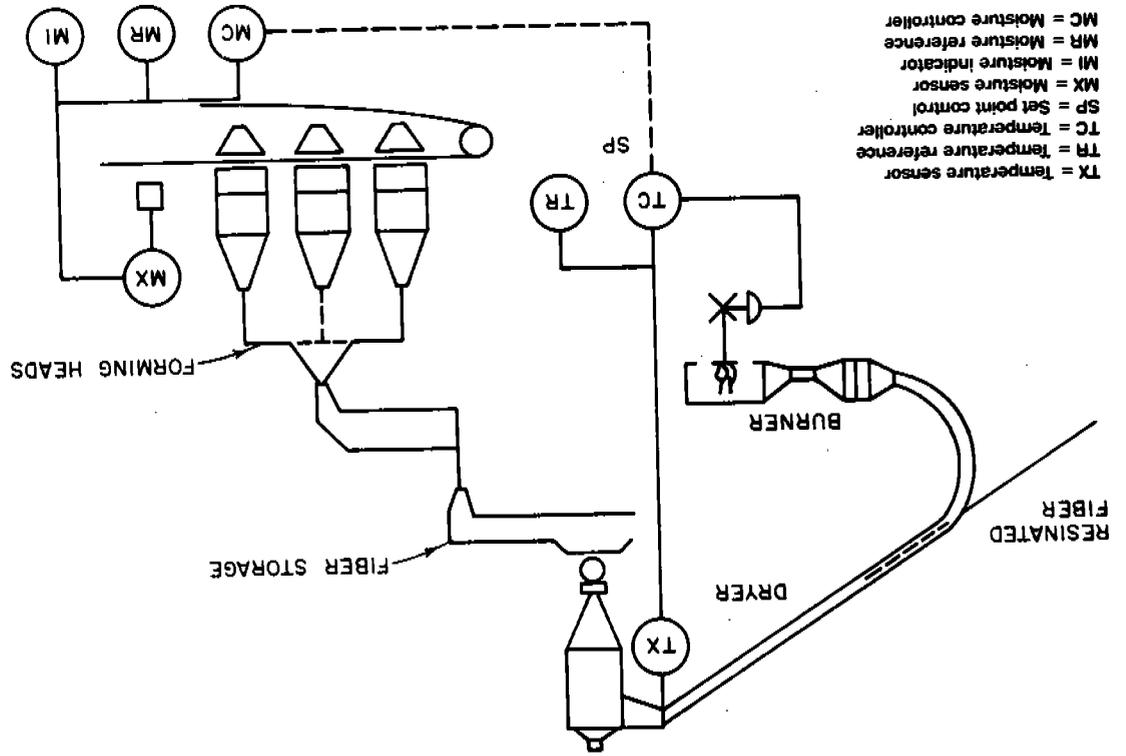


- 1 = Raw material for surface layers
- 2 = Steaming drum
- 3 = Drum debarker
- 4, 19 = Chippers
- 5, 20 = Screens
- 6, 21 = Secondary mills
- 7, 22 = Chip silos
- 8, 23 = Metering devices
- 9, 24 = Digesters
- 10, 25 = Conveyors
- 11, 26 = Conveyors for return of excess material
- 12, 13, 27, 30, 31, 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 hardwood manufacturing plant in the United States (Switzerland 1953)

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EXC HEIL OIL GAS HEIL OIL GAS



TX = Temperature sensor
 TR = Temperature reference
 TC = Temperature controller
 SP = Set point control
 MX = Moisture sensor
 MI = Moisture indicator
 MR = Moisture reference
 MC = Moisture controller

193—Single-stage (A) and double-stage (B)
 ders (Bulkat 1971).

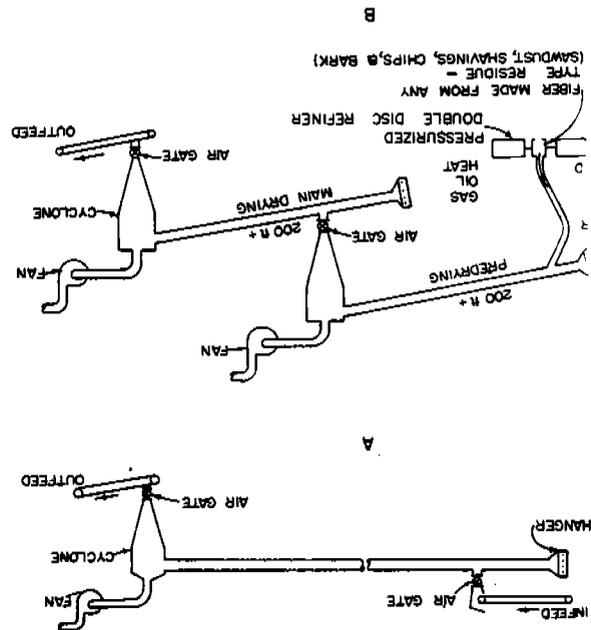
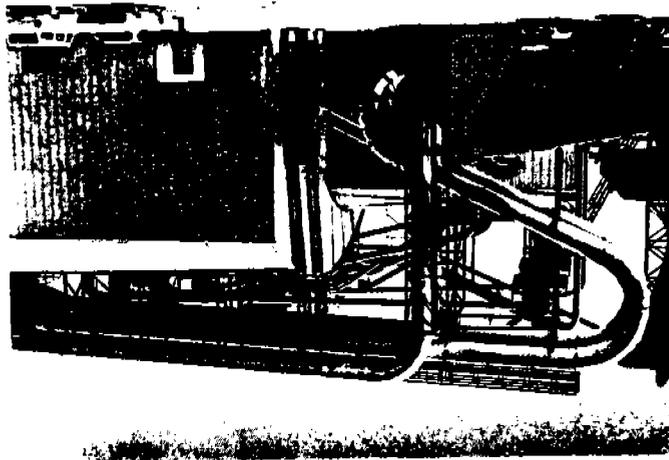


Figure 194 - Suspension tube flash-dryer in me-
 dum-density fiberboard plant (M-E-C Co.)



chamber (Evans 1958, Robinson 1959). The fibers then fibers and creates a "snowstorm effect" in the felting box and above a high-speed rotor, which agitates the spout that distributes the fibers across the width of the forming belt. The furnish enters the box through a swing is a box, the so-called felting box, situated above the This line does not use a dryer. The forming machine itself schematic picture of the process is shown in figure 197. patented by the Plywood Research Foundation. A gravity forming machine that was developed and plant in the United States, at Anacortes, WA, employs a The first dry process (actually semidry) fiberboard also combinations of these principles.

Most of these devices deposit the furnish by gravity, or filter the fibers out of the fiber-air suspension. There are Sandermann and Kunne Meyer 1957, Swiderski 1963). density from such difficult furnish (Lampert 1967, answers to the challenge of producing a mat of uniform The technical and patent literature offers a variety of "cultation" in the wet-forming process (fig. 135).

certain limit values. This phenomenon is similar to "floc- the concentration of the fiber-in-air suspension exceeds its tendency to congregate and to form lumps as soon as Another important characteristic of dry fiber furnish is horizontal support.

- A fiber-air suspension does not flow laterally on a or "classify" when the air flow slows down.
- Fibers remain in suspension in air only at considerable air velocities and will promptly settle out

derive directly from two facts:
 characteristic difficulties of the dry-forming process or between wet- and dry-forming processes results from the much lower density of the air. Some of the The basic difference between water- and air-forming Forming

of the high temperature of the exhaust gases.

of this system is the higher energy input required because dryer combustion chamber (fig. 196). The disadvantage native is complete recirculation of exhaust gases to the ty and efficiency would be severely limited. The alter- if dryer temperatures were lowered, but dryer producti- more difficult. This evaporation could be greatly reduced "blue haze" caused by the evaporation of volatiles is tion of cyclones, filters, and scrubbers. The control of the Emission of larger particles such as fibers and fiber frac- detection and control devices are therefore imperative. materials evaporated from the furnish. Sensitive fire and small volatile condensation particles of volatile solid particles resulting from the combustion process, and the emission from the dryer of fibers, fiber fractions,

A forming machine that filters the furnish from fiber-air suspension is illustrated in figure 201. metered furnish is supplied to one or more vert- chutes, which are suspended above a moving scre- These felting heads are maintained under a slight posi- air pressure. Rotating brushes inside the heads agitate furnish and discharge an air-furnish stream through perforated plate forming the bottom of the felt he- The air stream is drawn by vacuum through the travel screen, which filters out the furnish and builds up mat. This vacuum-type forming machine is used by Weyerhaeuser Corporation in the dry-process sid- plant at Klamath Falls, OR. A schematic of this plan- shown in figure 202.

boards. Figure 200 shows a schematic of the entire op- capability of the dry process for producing multilaye- tion of the top surface layer. This demonstrates is controlled by means of an equalizer roll before appli- ried forward and placed on top of the mat. Mat thickn- forming the bottom surface layer. The other half is c- material to be deposited ahead of the main stream, th- from the falling furnish and allows half of this fi- creates a crosscurrent of air that deflects the fine mate- As the furnish falls to the cauls, a suction dev- loose uniform mat.

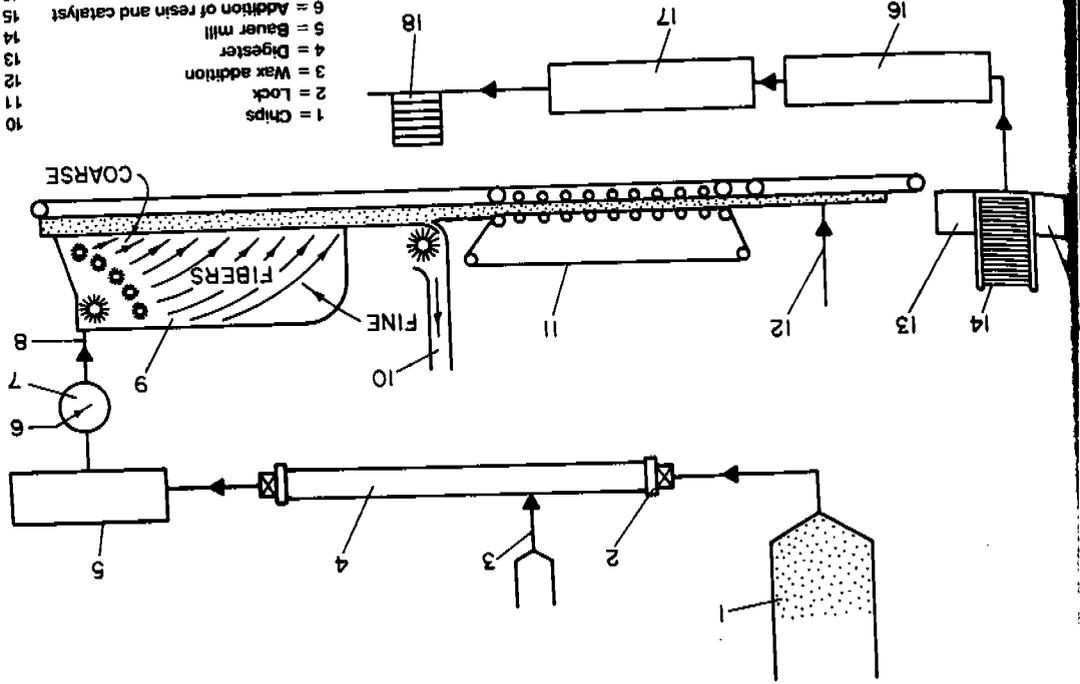
disks prevents congregation of the furnish and deposi- machine by a conveyor belt. The action of the rota- through the slots to moving cauls carried through chute and transfers the furnish from the chute disks projects partially into slots at the bottom of screw conveyors. A series of closely spaced sawblade- forming machine by means of a number of horizon- ing device supplies the furnish to a vertical chute with which it is distributed laterally across the width of Corporation's board plant at Lebanon, OR, is illustra- by the patent drawing in figure 199. A volumetric me-

Champion International in the former Cascades Plywo- therefore critical. ity, pulping conditions, moisture content, etc., characteristics that affect bulk density, such as air vel- does not fluctuate. Close control of all prod- board thickness only if the bulk density of the furn- metering results in uniform board density or unifor- the mat by controlling its thickness. This volume- uniform thickness; that is, it controls the uniformity- An equalizer or shaving roll reduces the ma- depending on the final thickness of the board (fig. 19- of a density of about 2 lb/ft³, and 4 to 12 in the- gently settle down on the moving belt and build up a

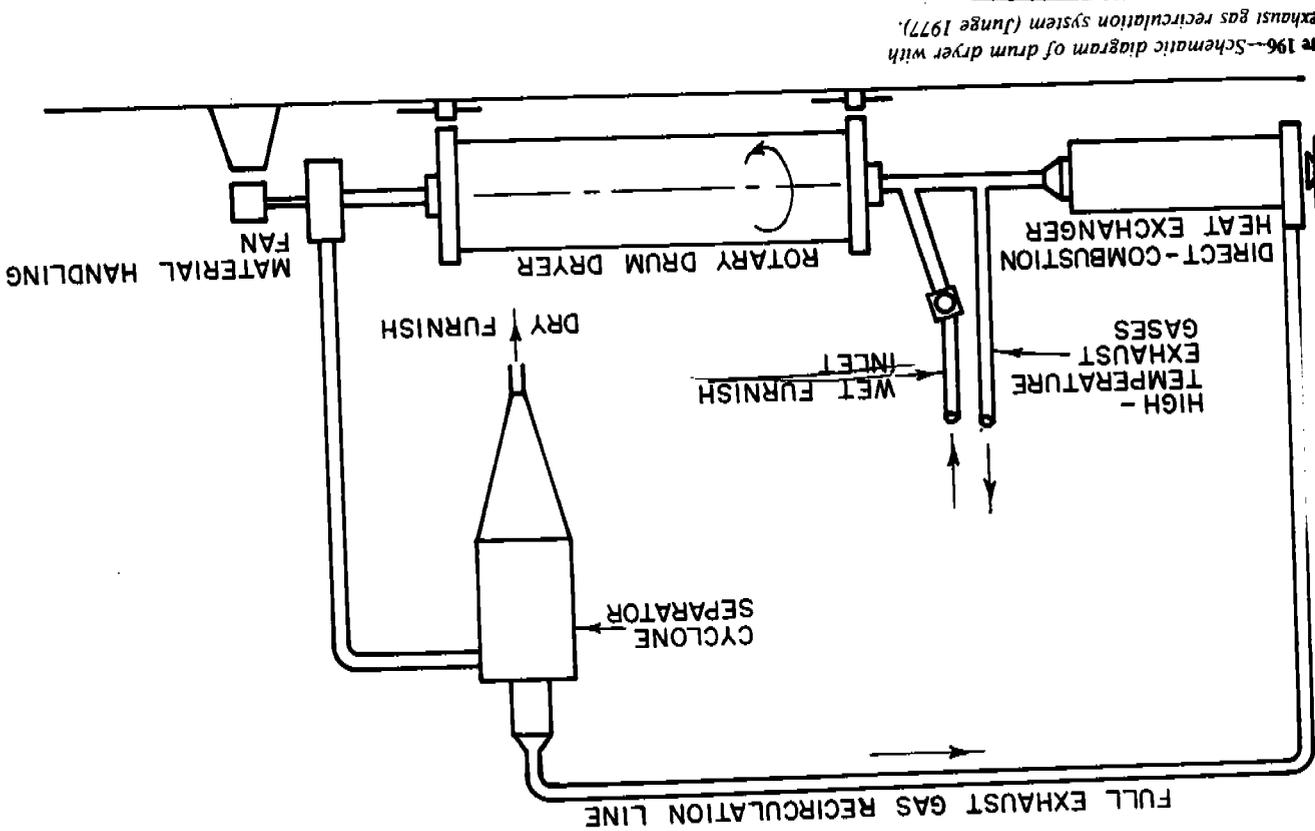
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 Forming

- 10 = Equalizing roller
- 11 = Re-press
- 12 = Saws
- 13 = Press loader
- 14 = Hot press
- 15 = Press unloader
- 16 = Humidifier
- 17 = Saws
- 18 = Storage and shipping

- 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



197—Schematic chart of semidry hardboard process according to Plywood Research Foundation and Kunemeyer 1957).



196—Schematic diagram of drum dryer with exhaust gas recirculation system (Junge 1977).

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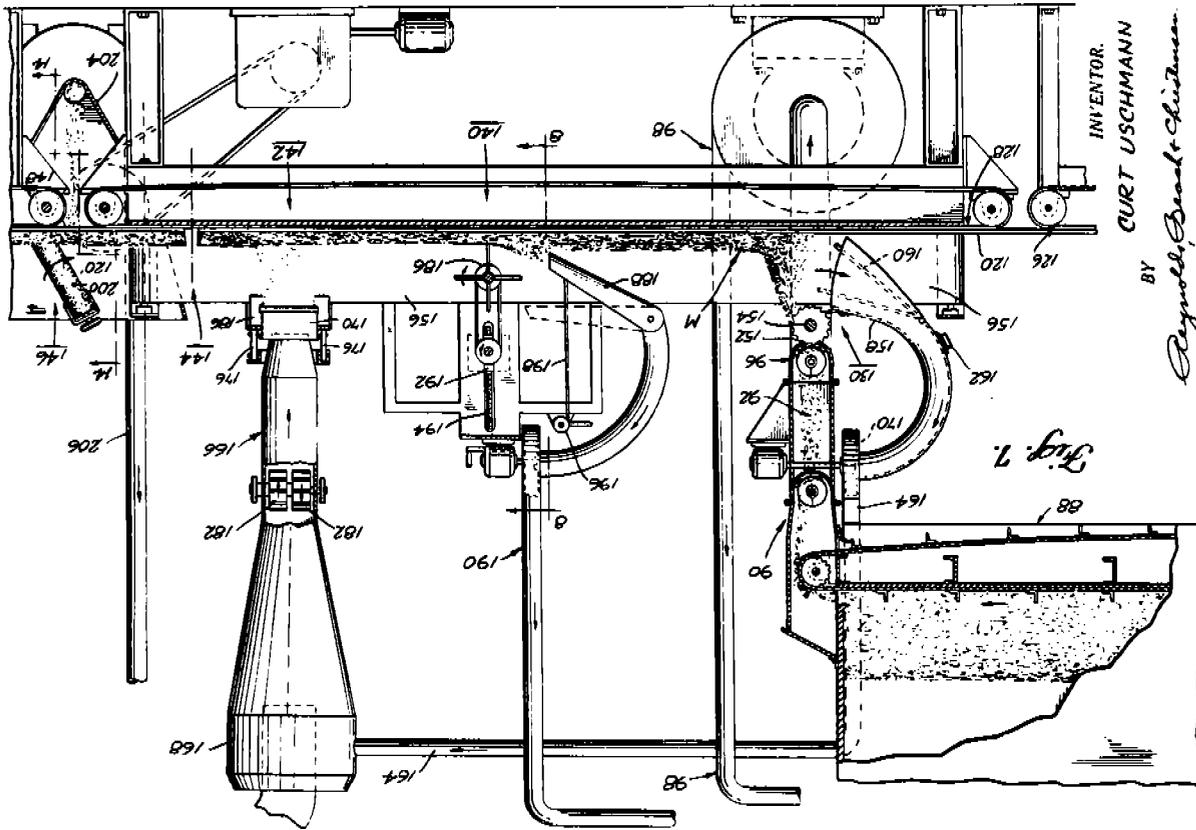


Figure 199—Patent drawing of forming machine used in Cascade Plywood Corporation board plant at Lebanon, OR (now Champion International) (Ushmann 1956).

INVENTOR.
 CURT USCHMANN
 BY
 Reynolds, Brandt & Christman
 ATTORNEYS

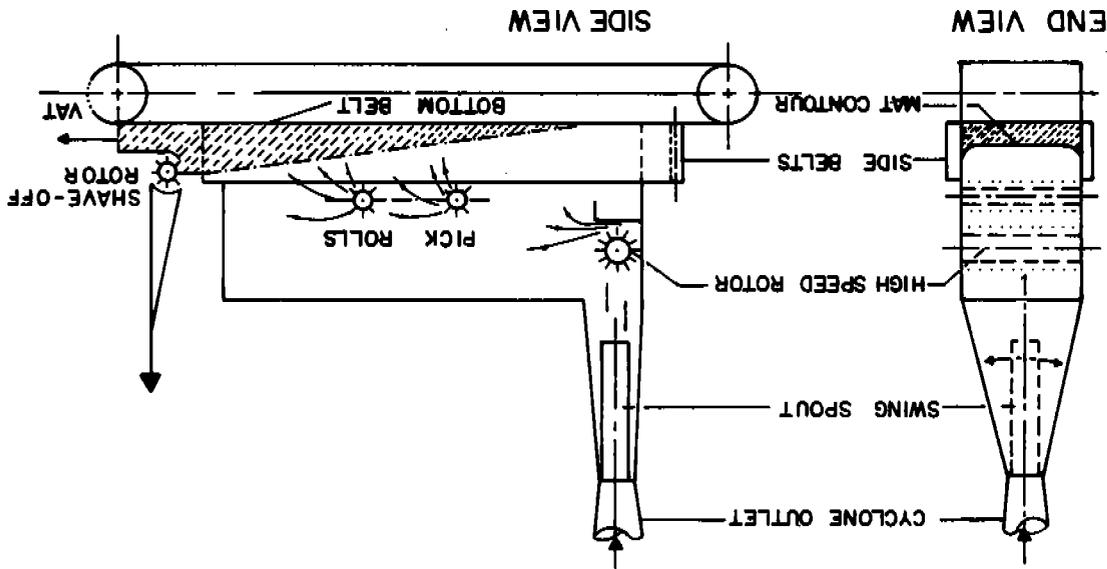


Figure 198—Snowfall-type feltier (Plywood Research Foundation) (Robinson 1959).

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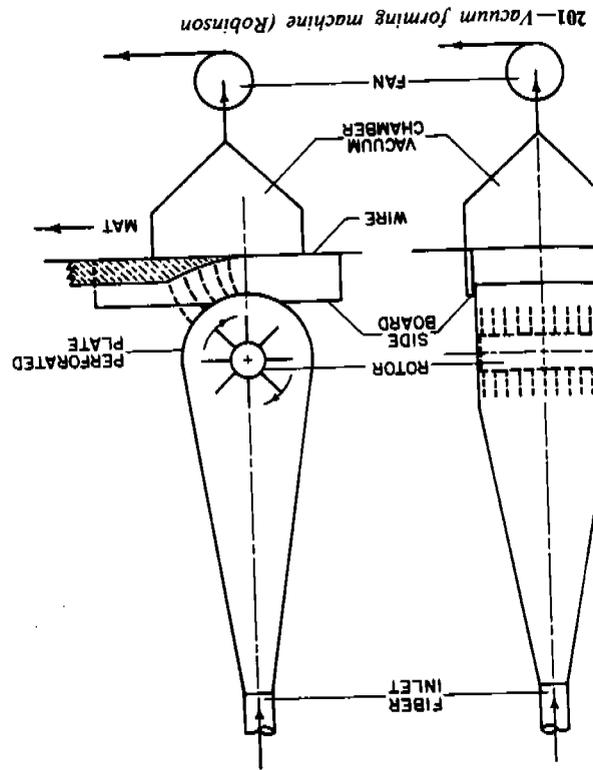
The dry-formed mat has a very low density. The mat requirements and closing times in the hotpress, and to improve handling quality of the mat and surface quality of the finished board, the mat is pressed in a continuous band press. Roll pressures are about 1,000 lb/in. The mat density is thereby doubled 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 caulk plates for the pressing

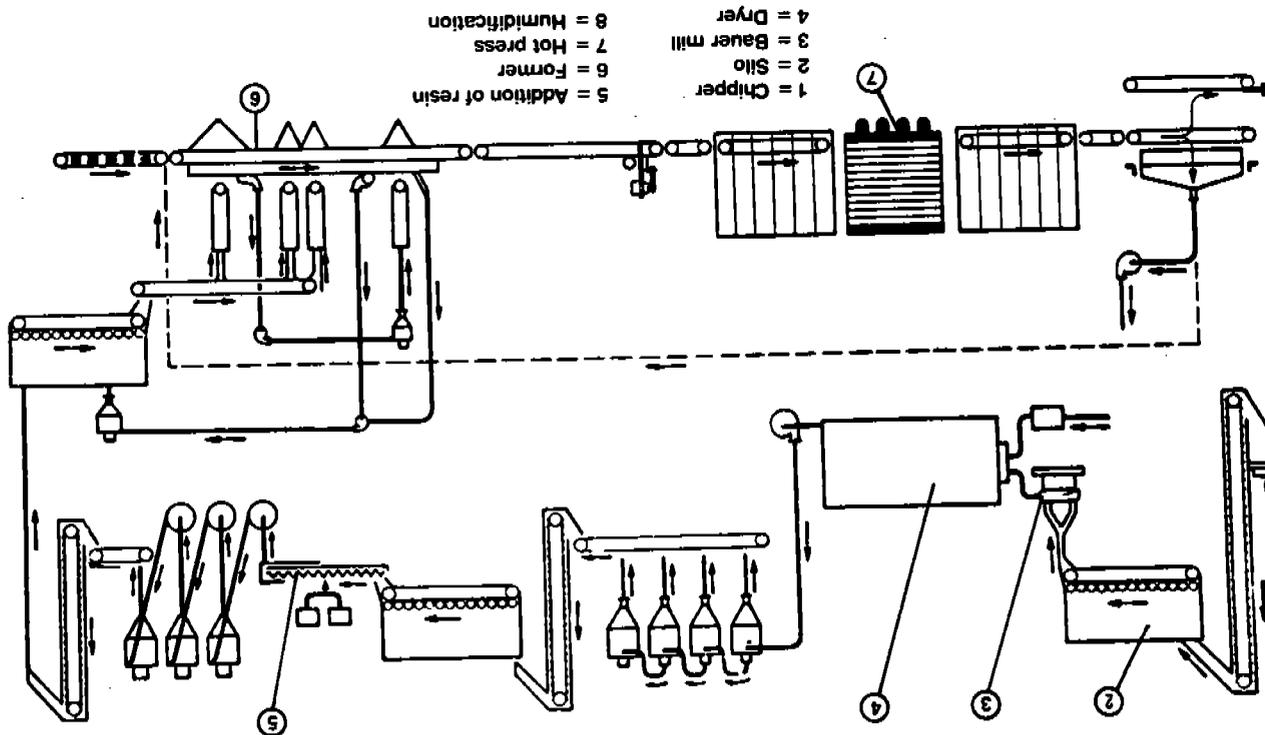


Pressing

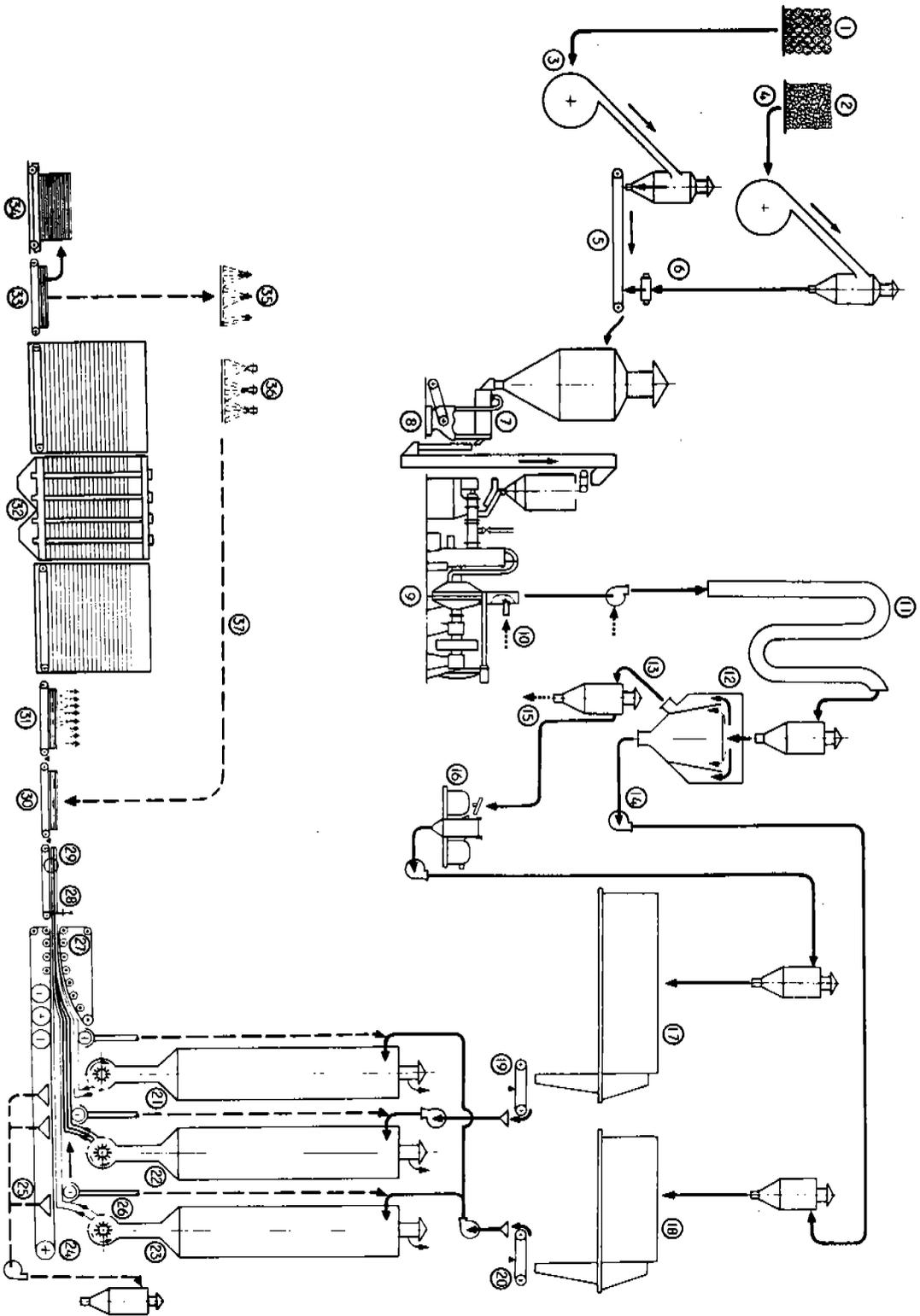
Vacuum felters provide greater mat uniformity and have become the standard dry-process forming device. However, the maintenance of the vacuum requires considerable electric power. A more recent four-stage vacuum former is shown in figure 203. The furnish is distributed across the machine width by means 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.



201—Vacuum forming machine (Robinson)
Schematic chart of dry-process hard-
plant of Cascade Plywood Company in
, OR (now Champion International)
mann and Kunne Meyer 1957).



Suchsland & Woodson (1986)
Pressing
fiber board



- 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

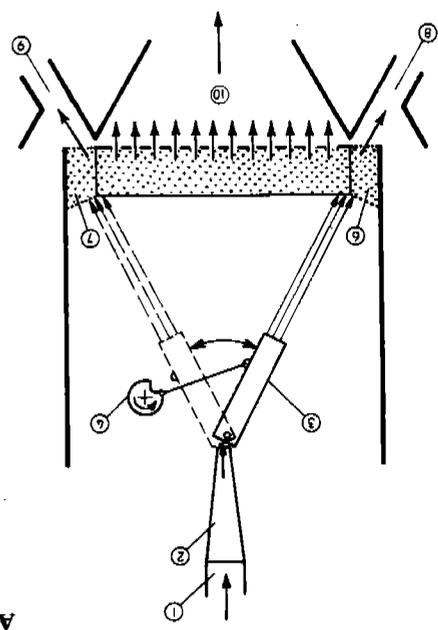
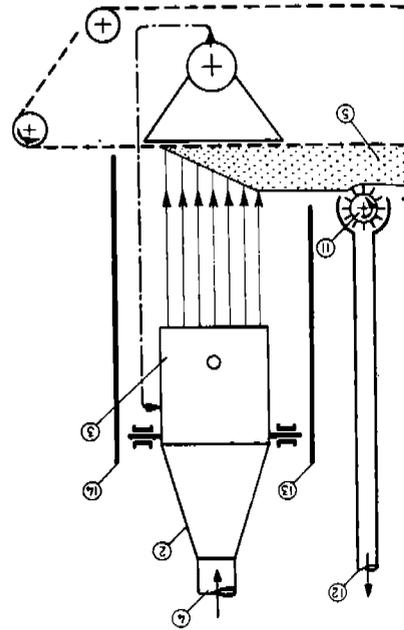
Suchsland & Woodson (1986)

Figure 202—Schematic chart of Weyerhaeuser semidry plant in Klamath Falls, OR. This plant now

Suchsland & Woodson (1986)

wood 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

ation. Dry-formed board is hotpressed in multi-
 ning presses very similar to those used for wet-formed
 board. Presses must have rapid, simultaneous clos-
 Platen temperatures are high (400 °F); press cycles
 short. At low mat moisture contents (5 percent),
 de-phase press cycles are used (fig. 205). Higher
 moisture contents require two or three phases (fig. 206).
 de-phase press cycles work particularly well with hard-



- 1 = Fiber supply
- 2 = Inlet funnel
- 3 = Swing spout
- 4 = Drive
- 5 = Forming screen
- 6, 7 = Fiber excess along edges of mat
- 8, 9 = Vacuum ducts
- 10 = Vacuum
- 11 = Shave-off roll
- 12 = Furnish return
- 13, 14 = Walls of forming chamber

- 1 = Forming screen
- 2 = Vacuum
- 3 = Formers for surface layers
- 4 = Formers for core
- 5 = Former for fine surface layer
- 6 = Shave-off rolls
- 7 = Automatic mat scale
- 8 = Prepress
- 9 = Fiber inlet tunnel

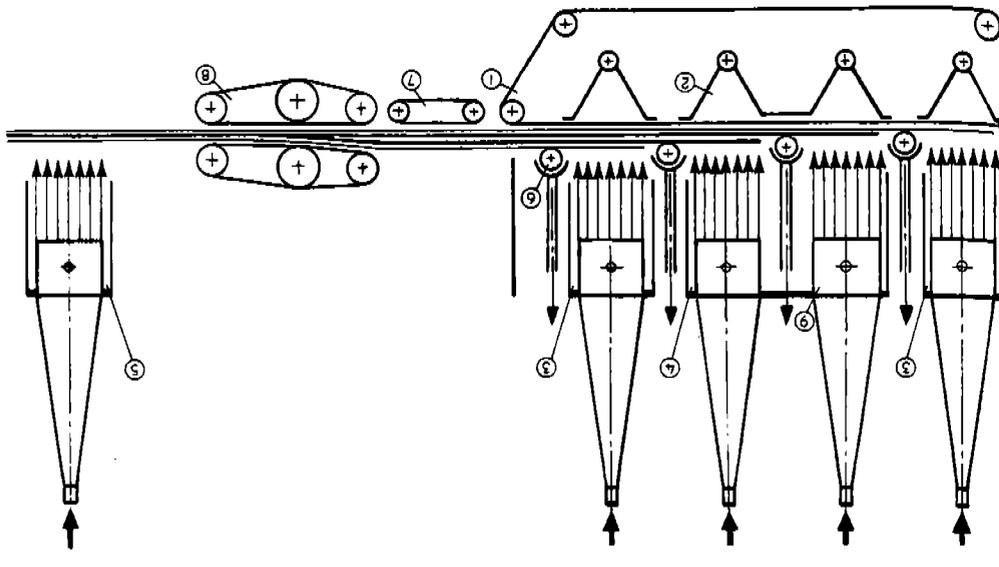


fig. 203—Vacuum former with swing spouts
 (Imperi 1967). A—Schematic of swing spout
 element. B—Four-stage vacuum former
 element for forming fine surface layer.

Suchsland & Woodson (1986)

MDF manuf.

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/ft³ or less), which develops good resin bonding during compression to normal board density (45 to 50 lb/ft³). 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/ft³ is in-

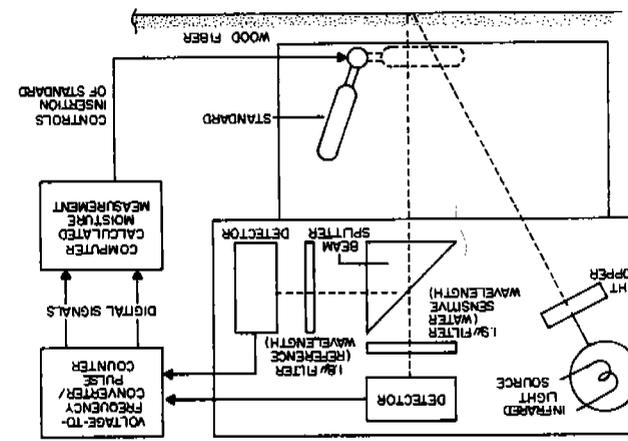


Figure 211—Principle of Measurax moisture sensor (Beitzner and Wallace 1980).

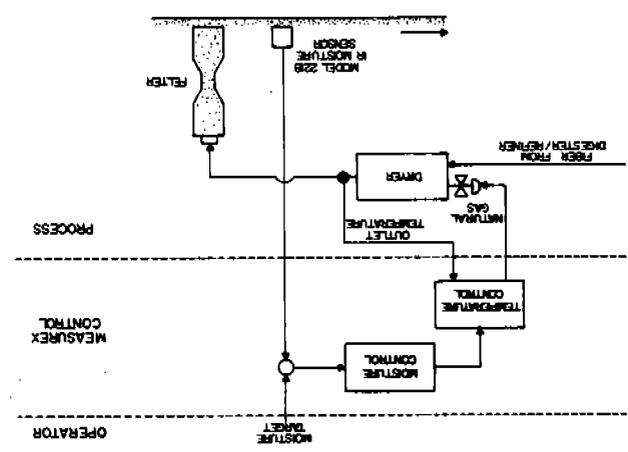


Figure 212—Principle of Measurax mat moisture measurement and control (Beitzner and Wallace 1980).

and moves down to a normal operating range, the line is ramped back to the optimum speed as computed by the throughout maximization control.

Manufacture of Medium-Density Fiberboard

Medium-density fiberboard (MDF), according to the common usage of the term, refers to the thick (3/8 to 1 inch) medium-density fiberboard that is generally sold in the industrial core stock market in direct competition with particle board. Its properties, such as bending length, modulus of elasticity, internal bond, machinability, and screw holding power, meet the levels required for these applications.

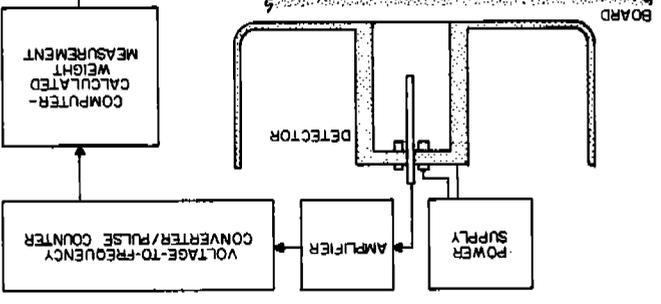


Figure 213—Principle of Measurax weight sensor (Beitzner and Wallace 1980).

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

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

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).

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.

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.

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

precompression they are much thicker (9 to 24 in.) sized to accommodate mats after precompression. Before daylight. It should be noted that these press openings are ing by loader trays that require an additional 3 in of the precompressed mat is transported into the press open- dicated in figure 218. When caul-less systems are used,

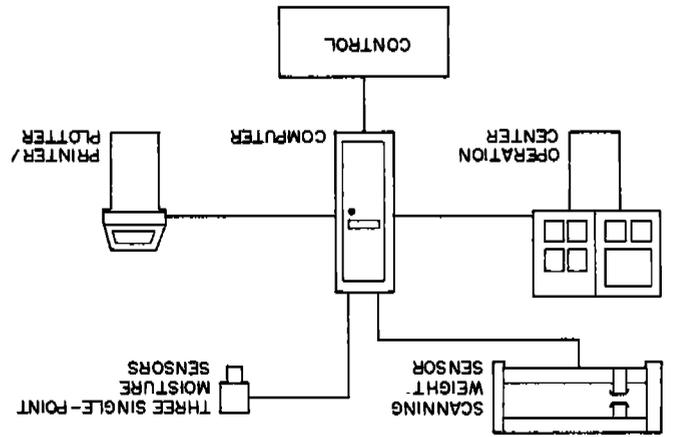
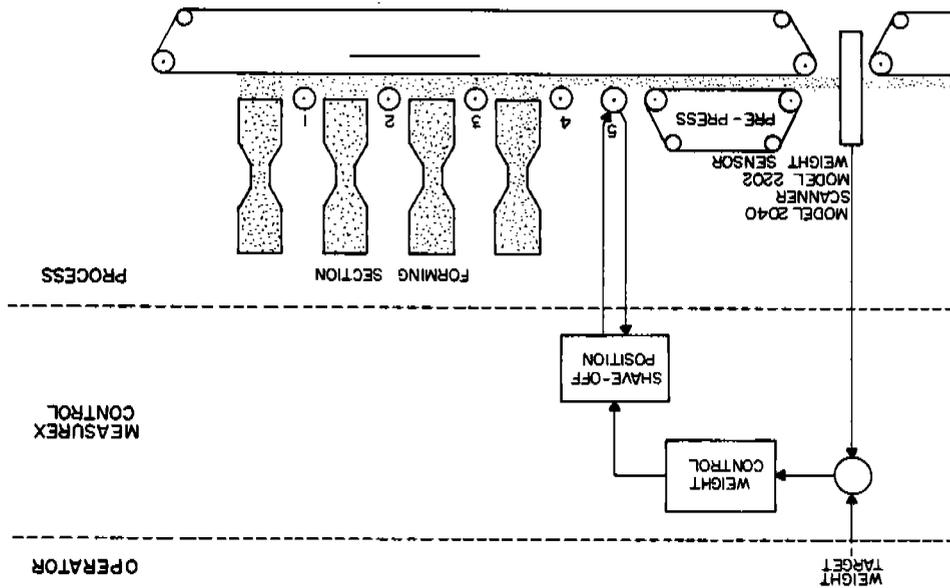


Figure 214—Principle of Measurx weight measurement and control (Betzner and Wallace 1980).

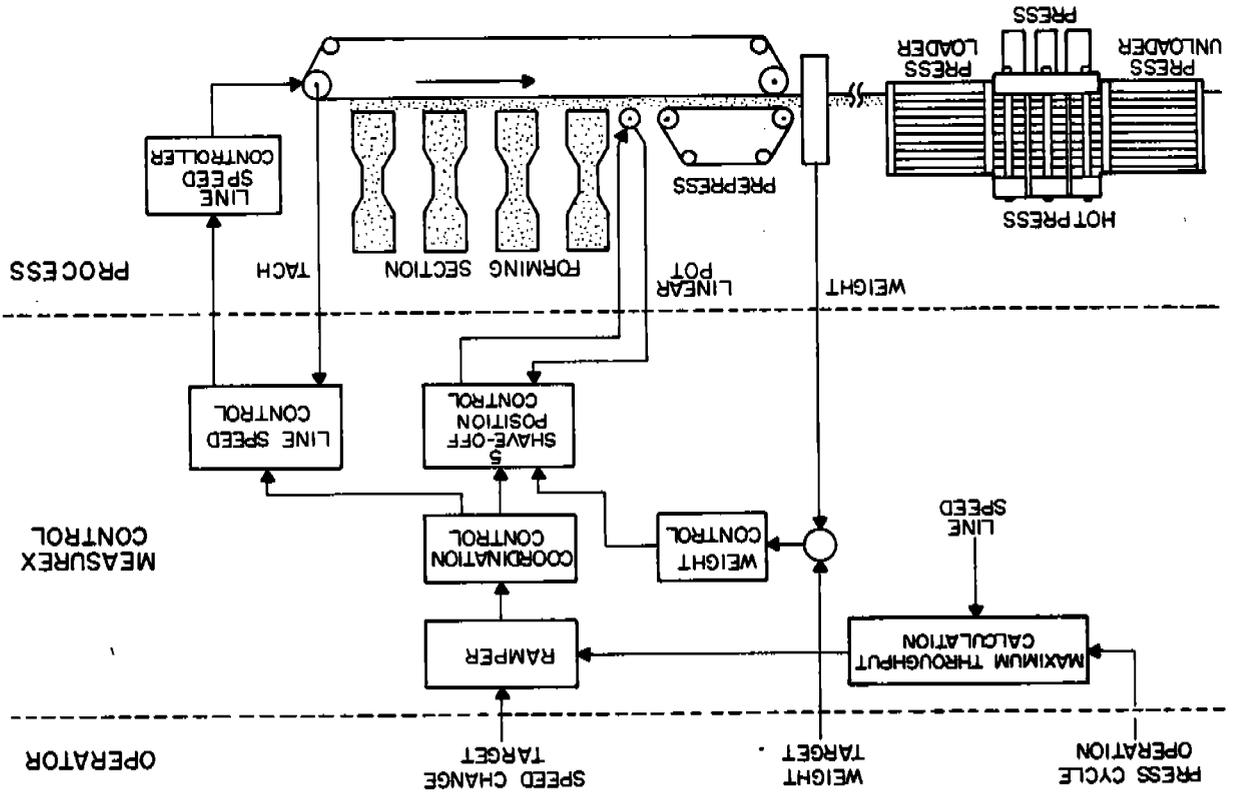


Suchsland & Woodson (1986)

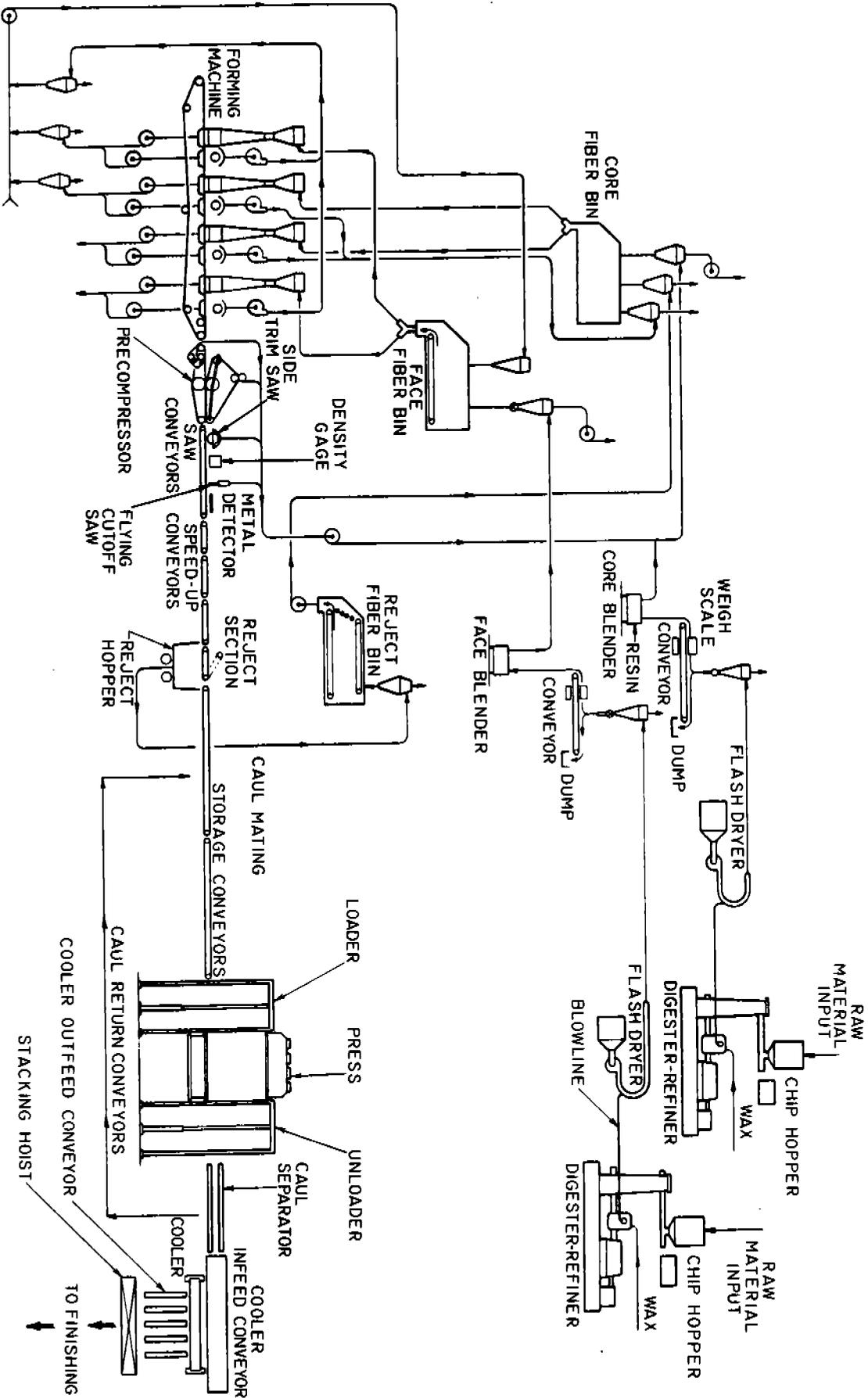
injection into the rotating ring of furnish (fig. 220). Retention times are only a few seconds. Mixers of this type have been equipped with agitators especially suited for handling fiber furnish (fig. 221). These machines, when applied to fiber furnish, sometimes develop resin spots visible on the finished 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

ing, 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 presented a significant advance from the conventional application in large low-velocity trough-type mixers (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 fiber to another during rapid agitation of the furnish. Spray nozzles have been replaced by liquid adhesive delivery through shaft and rotating paddles or trough

Figure 216—Measures speed change control and throughput maximization control (Beizner and Wallace 1980).



Suchsland & Woodson (1986)



Suchsland & Woodson (1986)

Figure 217 — Typical process flow chart of medium-density fiberboard plant (Christ and Rudman 1979).

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

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 cleared 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.

Wood (1976).
 The entire mat thickness simultaneously, is described by Wood-MDF former (fig. 222), which attempts to form a more sophisticated forming machine, the Rando-whether or not its upper layers benefit from the vacuum. The mat thickness is much greater, it may be questionable mats. The vacuum former is the standard device. Because

Figure 219—Short retention mixer for particle furnish. Speed: 600 to 1,000 r/min (Bison Werke).

- 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

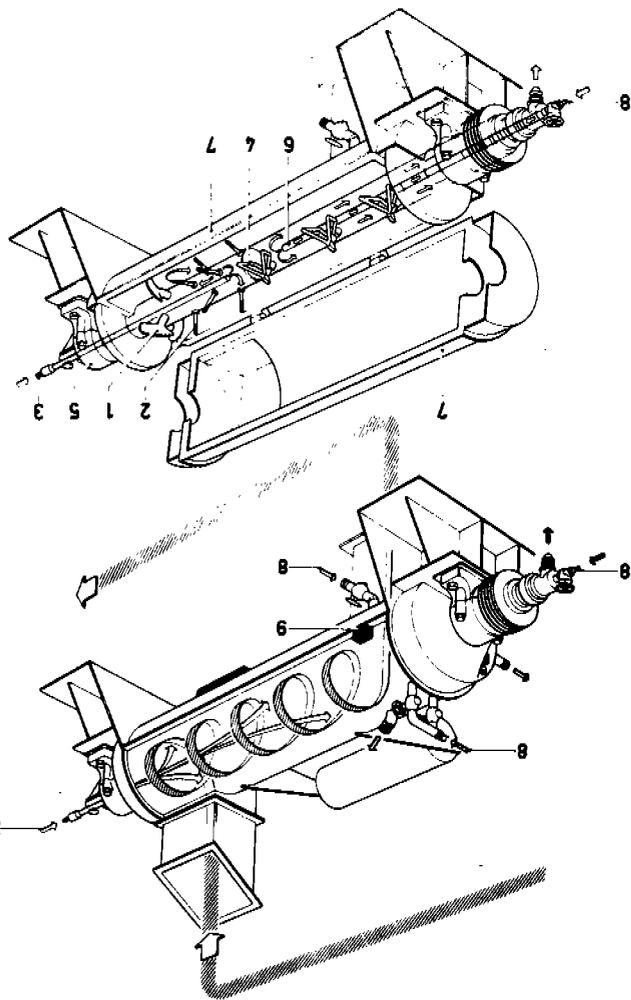
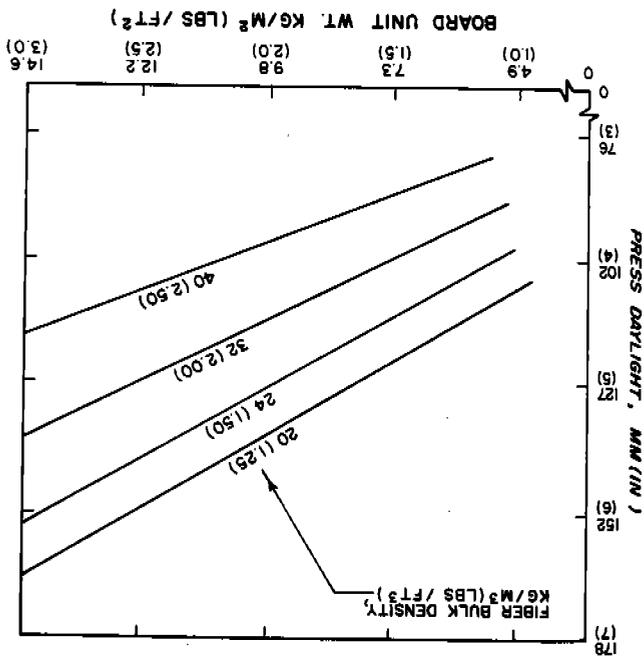


Figure 218—Press daylight required for fiberboards for various fiber bulk densities (Chrysi and Rudman 1979). "Daylight" is the clearance between adjacent press platens when press is fully opened.



Suchsland & Woodson (1986)

Figure 217—Typical process flow chart of medium-density fiberboard plant (Chrysi and Rudman 1979).

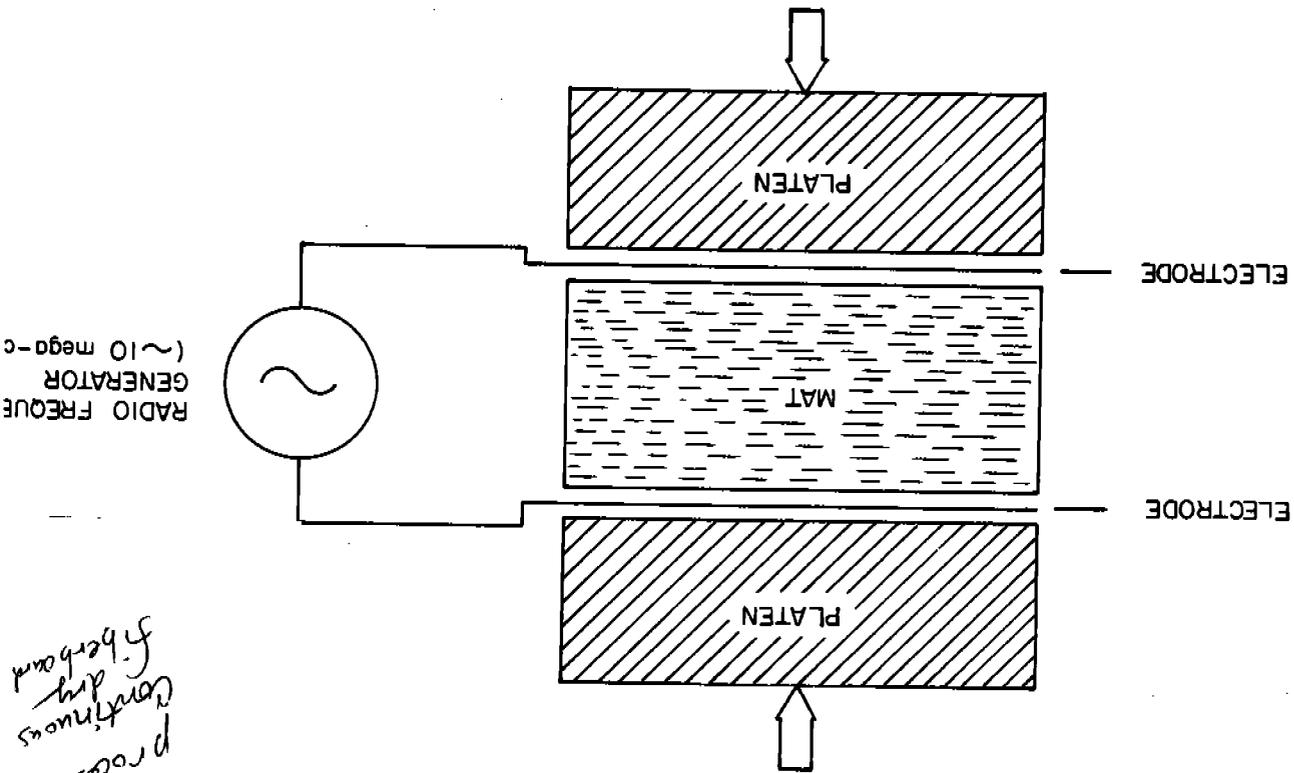
The heart of the Mende process is the continuous press, which consists of a large-diameter (10 ft) heated and rotating drum against which the mat is pressed by a steel band. After less than one full revolution of the drum the continuous board leaves the press and is cut to size.

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.

Manufacture of Dry-Process Fiberboard by the Continuous Mende Process

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.

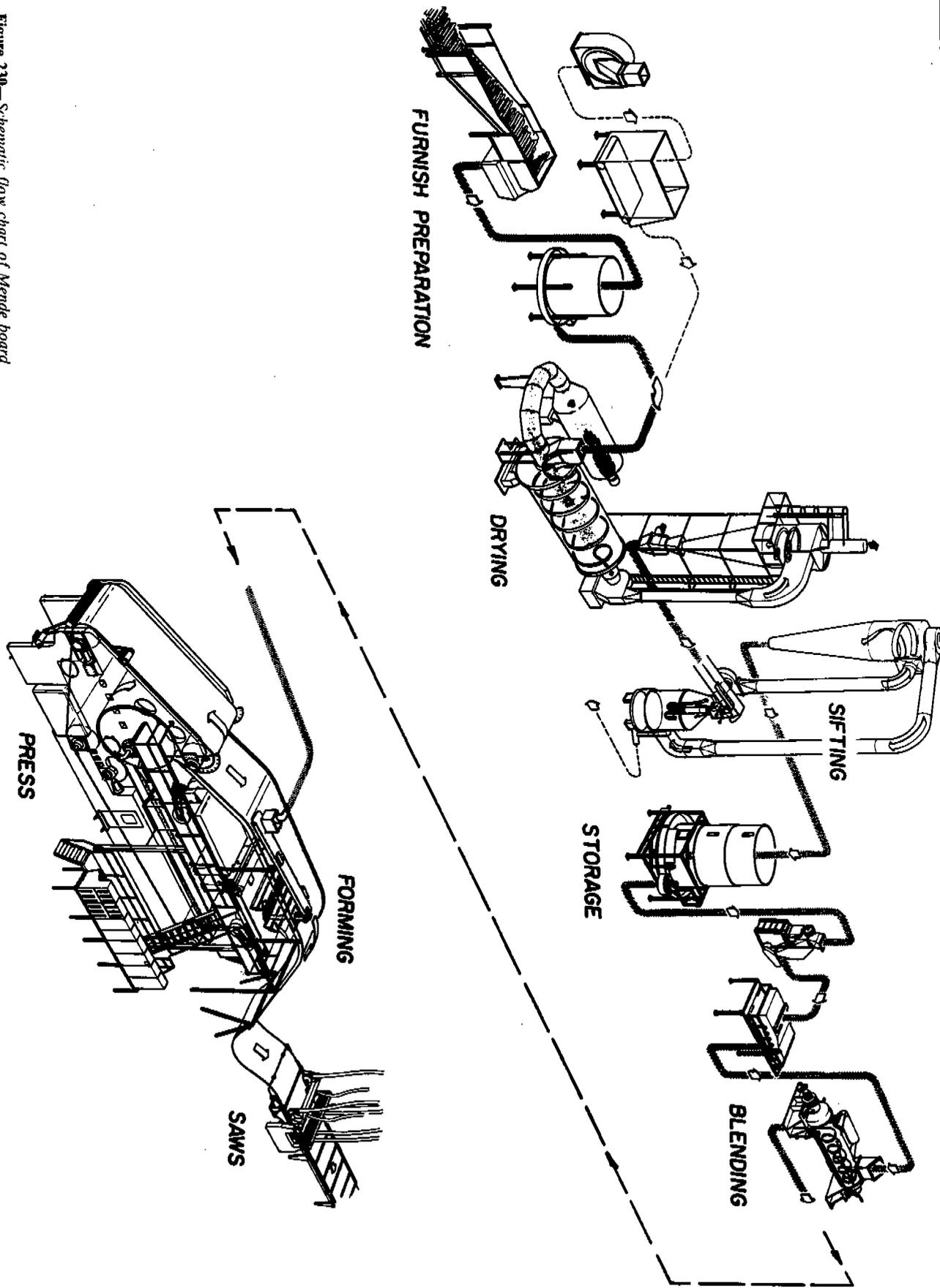
Figure 229—Principle of radio frequency board press (Suchsland 1978).



Suchsland & Woodson (1986)

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 lamps which elevate the temperature of the steel band to 250 °F. Pressure is first applied as the mat passes between entrance roll and press drum (fig. 232). Both elements are oil heated to a temperature of 355 °F. 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 two unheated pressure rolls, which press the mat to final board thicknesses. As the band turns around the drive roll, the board is fully cured and is returned in the reverse direction to the forming station. The temperature of the board leaves the heating drum is 230 °F.

Figure 230—Schematic flow chart of Mende board plant (Bison Werke).



Suchsland & Woodson (1986)

replacement of the steel band by a wire screen, and the board requires the installation of a vacuum former, the To modify the process for manufacture of fiber- various board thicknesses.

duces 4 to 8 million Btu. Table 28 shows the line speed for each drum can be controlled separately. The boiler pro- it is heated either by gas or other fuels. Temperature of The heating oil recirculates through the boiler, where before the mat enters the press section.

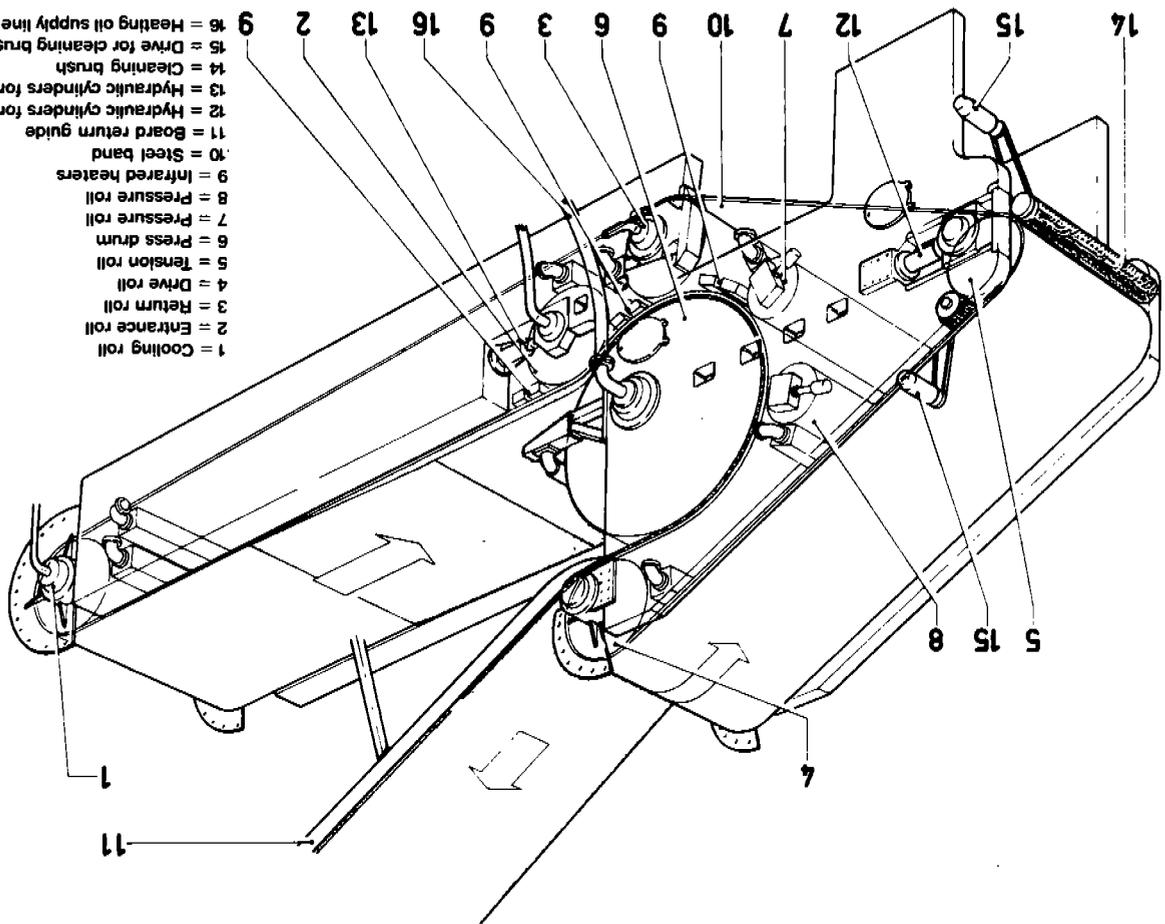
160 °F. This is necessary to prevent the resin from curing cooled roll, which reduces its temperature to about 150 to The steel band returns to the forming station via a water. Several rotating brushes clean both drum and steel band. of the drum surface from scoring is very important. the mat and therefore forms the surface, the protection Because the heating drum is in direct contact with

Board thickness	mm	in	m/min	ft/min
3.0	0.118	15.0	49.2	15.0
3.2	.126	14.0	45.9	14.0
4.2	.165	10.7	35.1	10.7
4.8	.189	9.4	30.8	9.4
5.6	.220	8.0	26.2	8.0
6.3	.248	7.0	22.9	7.0

Table 28—Relationship between board thickness and speed of Mende continuous board process (Bison Wer

dry processes (fig. 233). addition of a band prepress. Handling, drying, blending equipment would be similar to that used in o

Figure 231—Continuous Mende press (Bison Werke).



Suchsland & Woodson (1986)

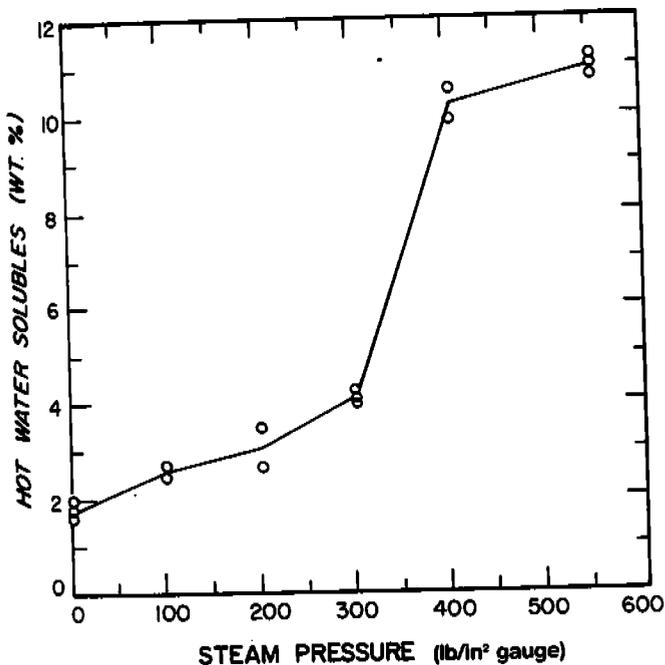


Figure 83—Hot-water extractability of wood chips as a function of saturated steam pressure used in the preheat segment of the digesting operation (Spalt 1977).

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.

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,

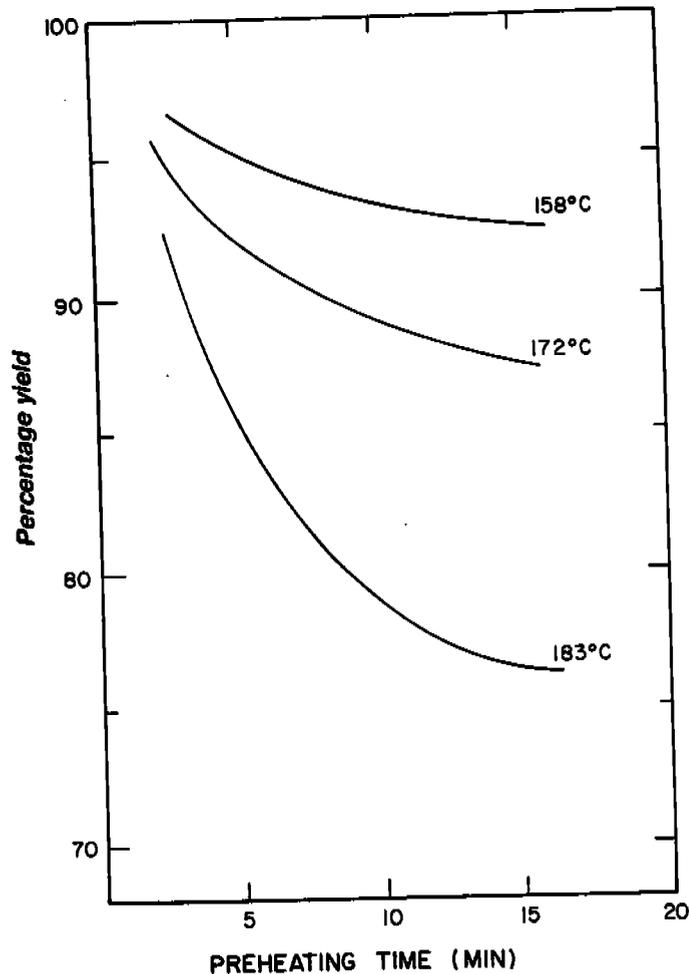


Figure 84—Effect of preheating time and temperature on pulp yield (EPA 1973).

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).

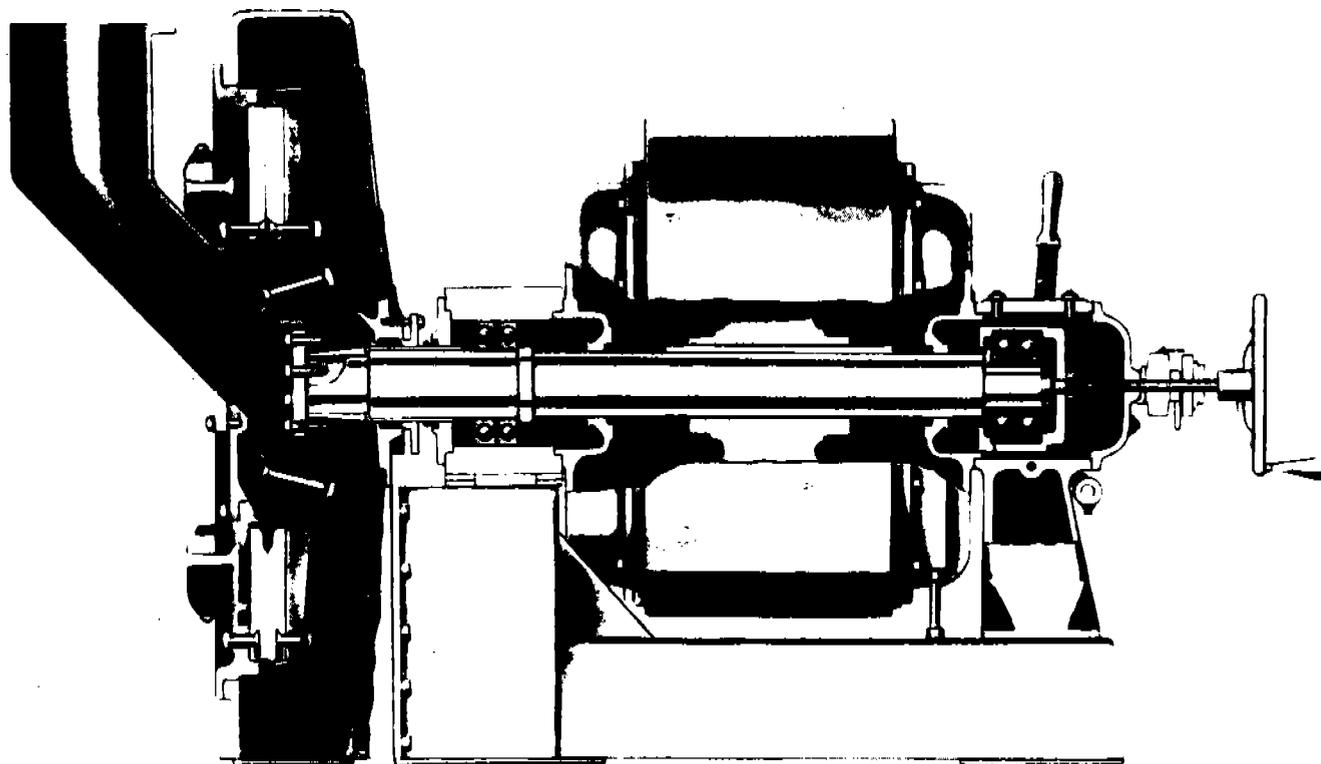


Figure 85—Cutaway view of a single-revolving-disk mill (Bauer).



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 $3\frac{1}{2}$ 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 $3\frac{1}{2}$ 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, degeneration for starch, feather curling, etc.

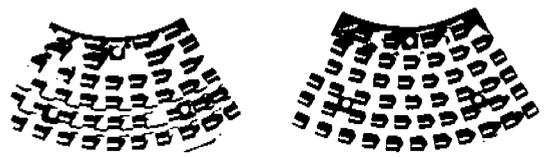
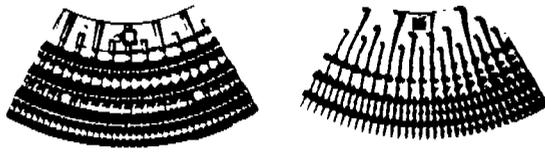
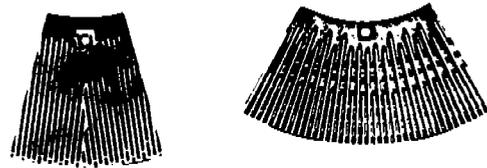
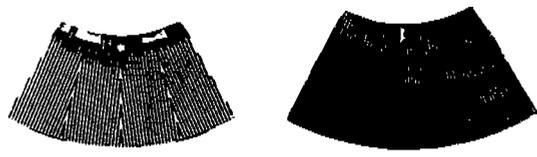


Figure 87—General classification of Bauer refining plates (Bauer).

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/in².

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 ft³ of chips, designed for pressures up to 300 lb/in². 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/in², 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 **dwel 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 admit-

Before
refining

ted 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 losses, 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/in ² steam pressure; 2-min treating time
S1S	50:50 oak-birch	150 lb/in ² 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 short-falls. 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-

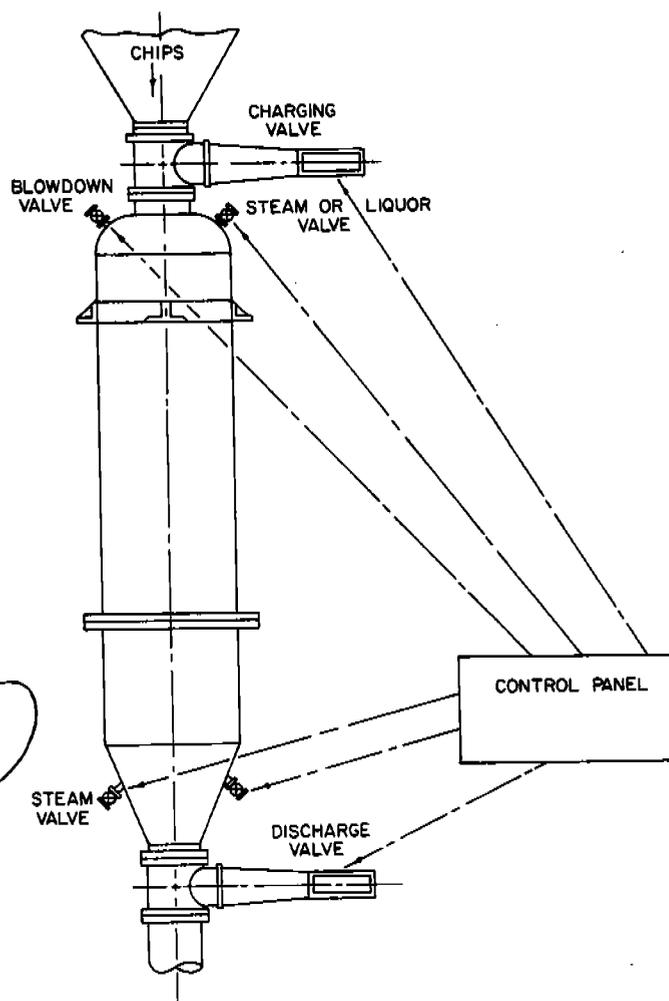


Figure 88—Automatic Bauer rapid cycle digester (Texas 1958).

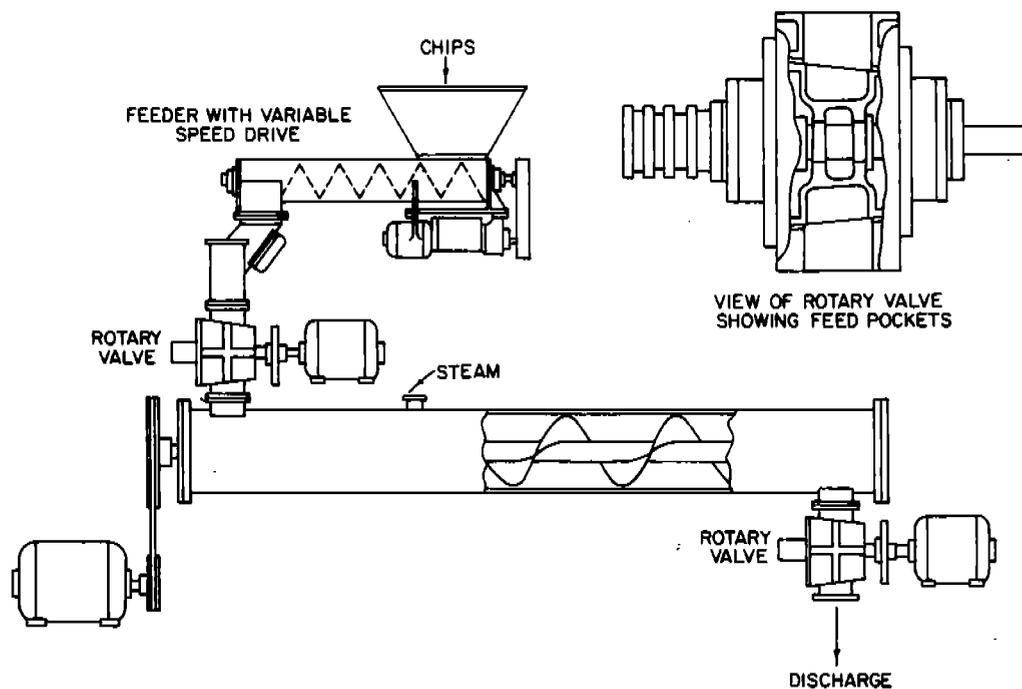


Figure 89—Greco continuous digester (Atchison and Agronin 1958).

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.

See p. 79

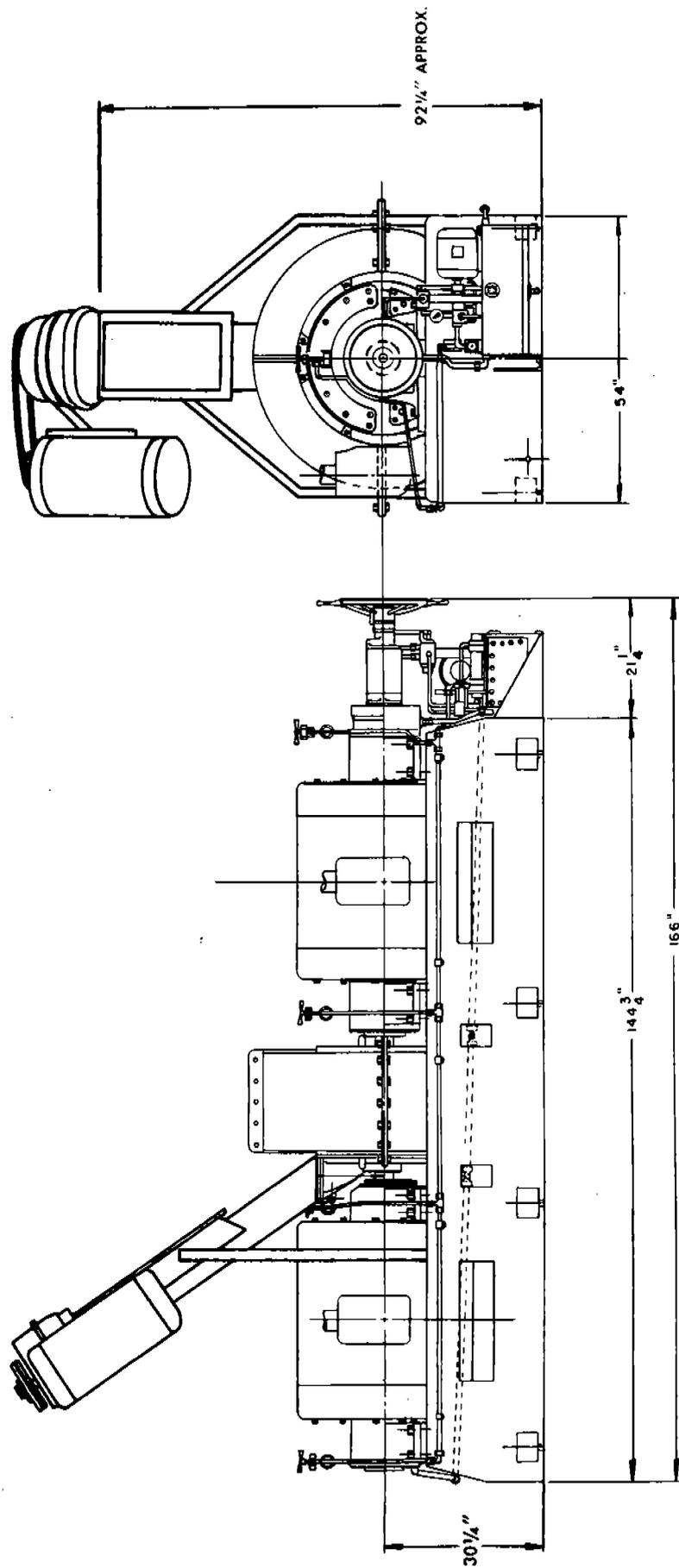


Figure 90—Bauer refiner with twin-screw feeder (Bauer).

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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.

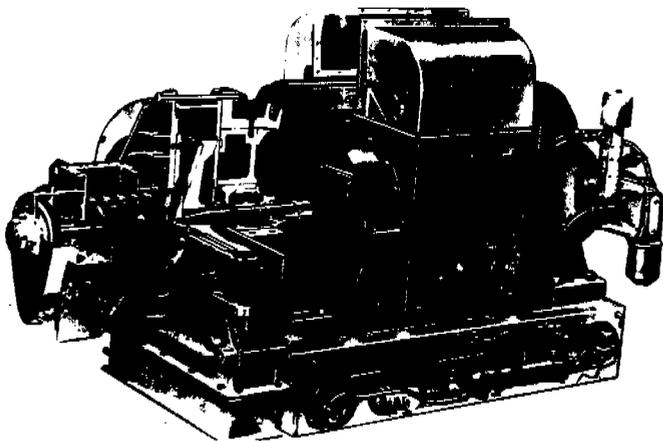


Figure 91—Sprout-Waldron refiner with coaxial feeder (Sprout-Waldron).

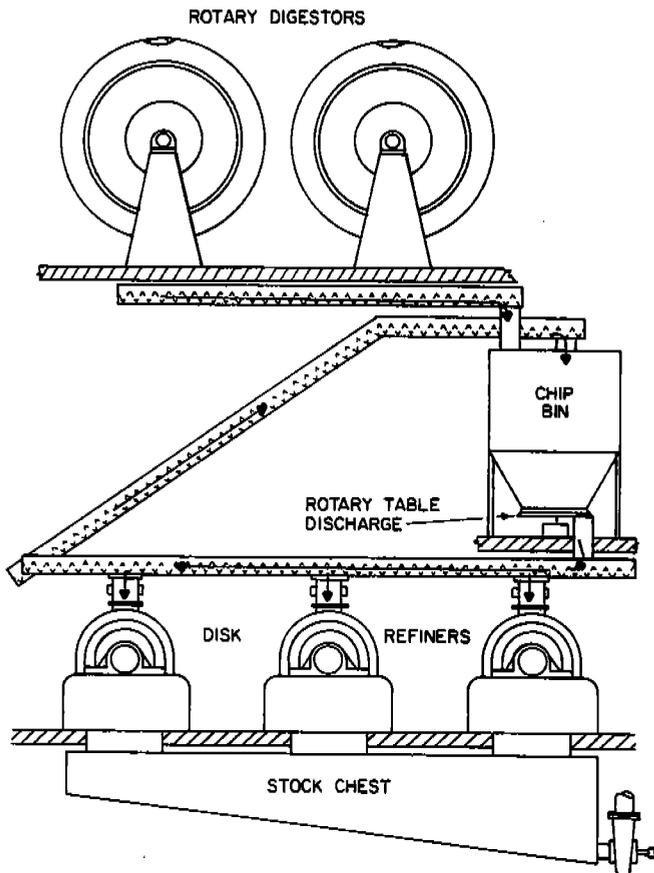


Figure 92—Flow sheet of system for pretreating and refining wood chips (Textor 1948).

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

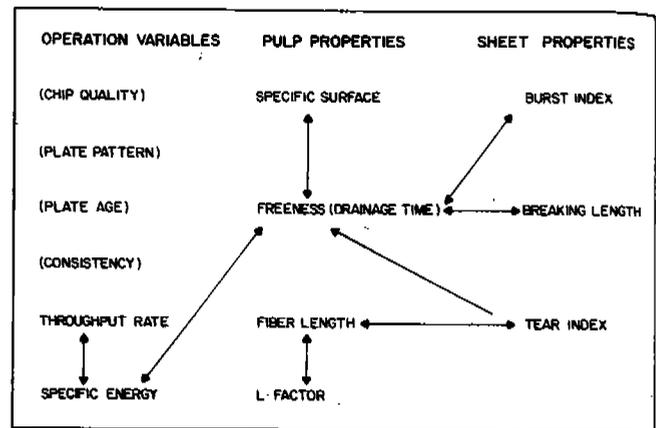


Figure 93—Schematic illustration of interrelationships between specific pulping energy and various pulp and sheet properties (Johnson and El-Hosseiny 1978). (© 1978 TAPPI. Reprinted from Tappi Journal, December 1978, with permission.)

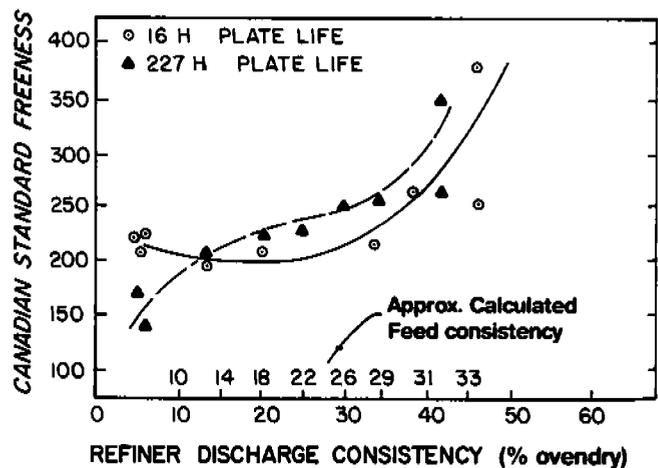


Figure 94—Effect of refining consistency on freeness of unscreened pulp (after Mihelich 1972). OD = ovendry.

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CANADIAN STANDARD FREENESS

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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

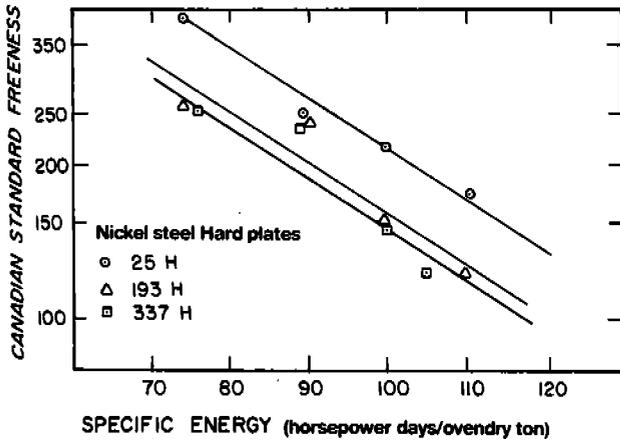


Figure 95 — Effect of plate wear on freeness (after Mihelich 1972).



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

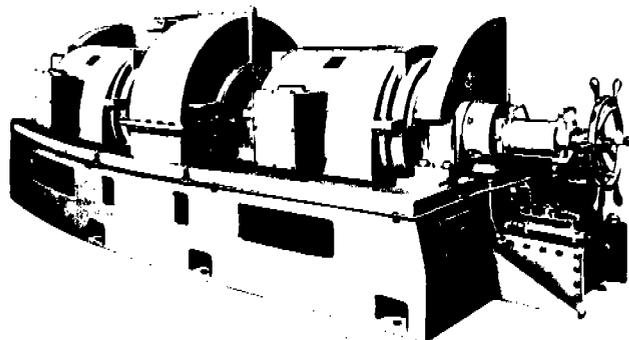


Figure 97—Bauer 411 double-disk refiner (Bauer).

figure 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-

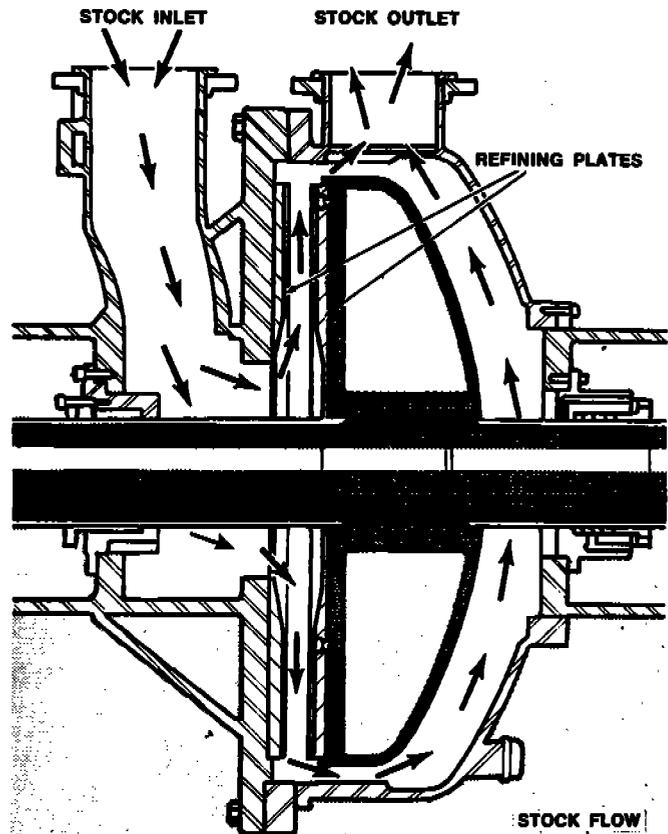


Figure 98—Bauer pump-through refiner (Bauer).

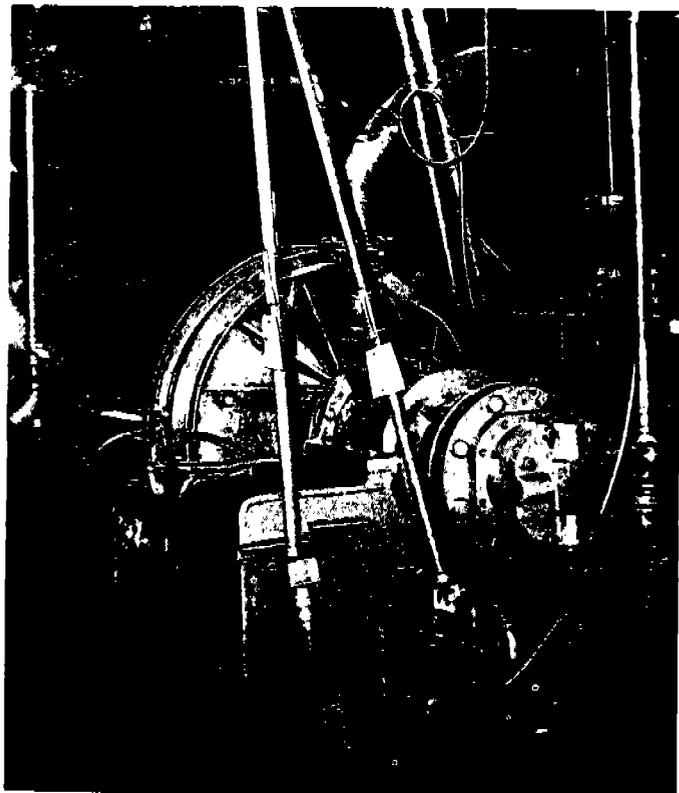
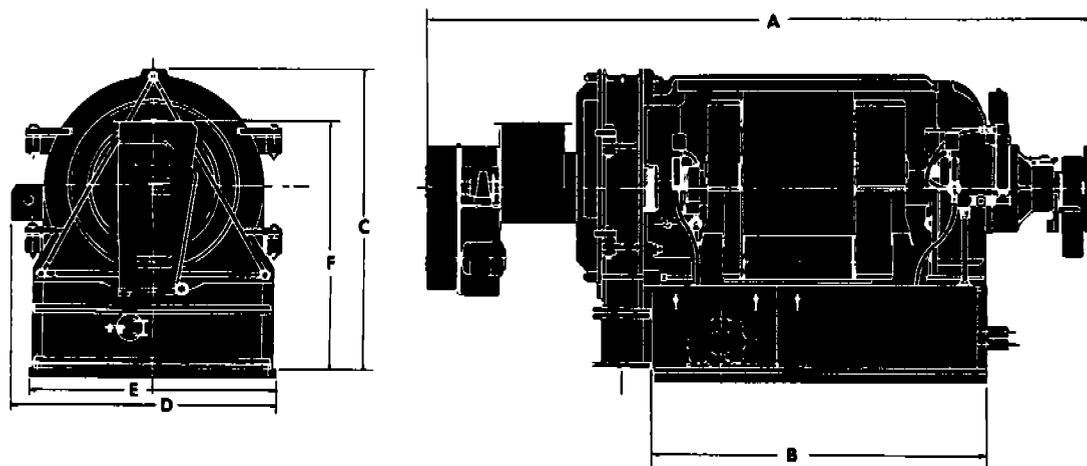


Figure 99—Bauer 442 refiner.

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	1500/1800 rpm	12'-11"	6'-8"	6'	5'-4"	5'	5'	26,500 lbs.	27,500 lbs.
42-1B	1250-2500 hp	1500/1800 rpm	13'-4"	6'-8"	6'	5'-4"	5'	5'	29,000 lbs.	30,000 lbs.

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

POWER CONSUMPTION (KWH/T)

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 un-

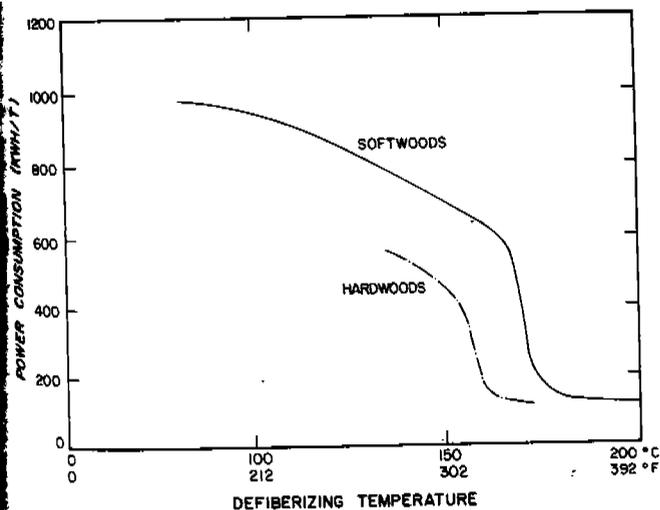


Figure 101—Relationship between power consumption and defiberizing temperature.

damaged 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.

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

dry only?

Table 18—Asplund defibrator specifications (Sunds Defibrator)

Machine type	Disk diameter		Max. motor size		Capacity (ton/day)
	mm	in	kW	hp	
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)

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

Data are approximate.

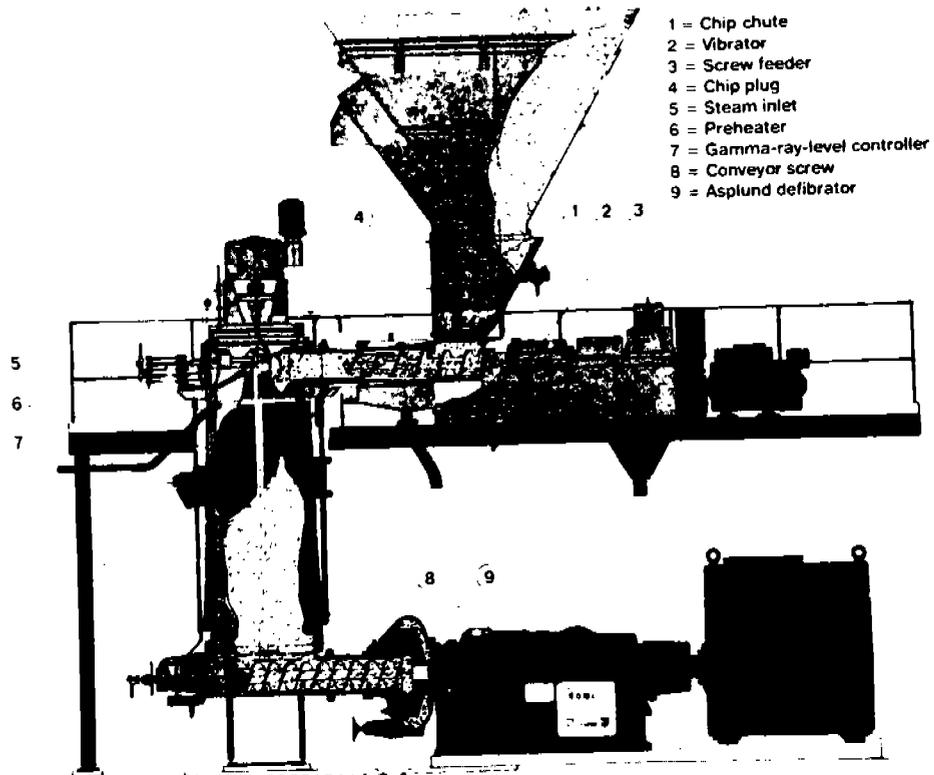


Figure 102—Asplund defibrator pulping plant (Sunds Defibrator).

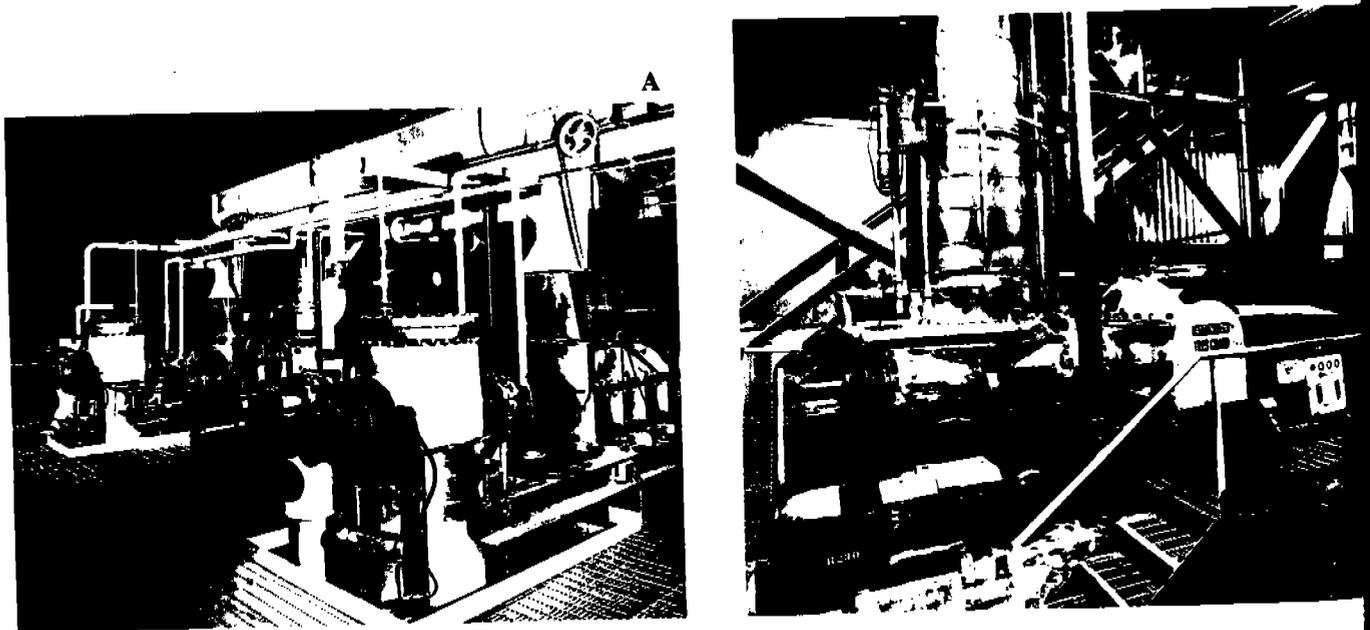
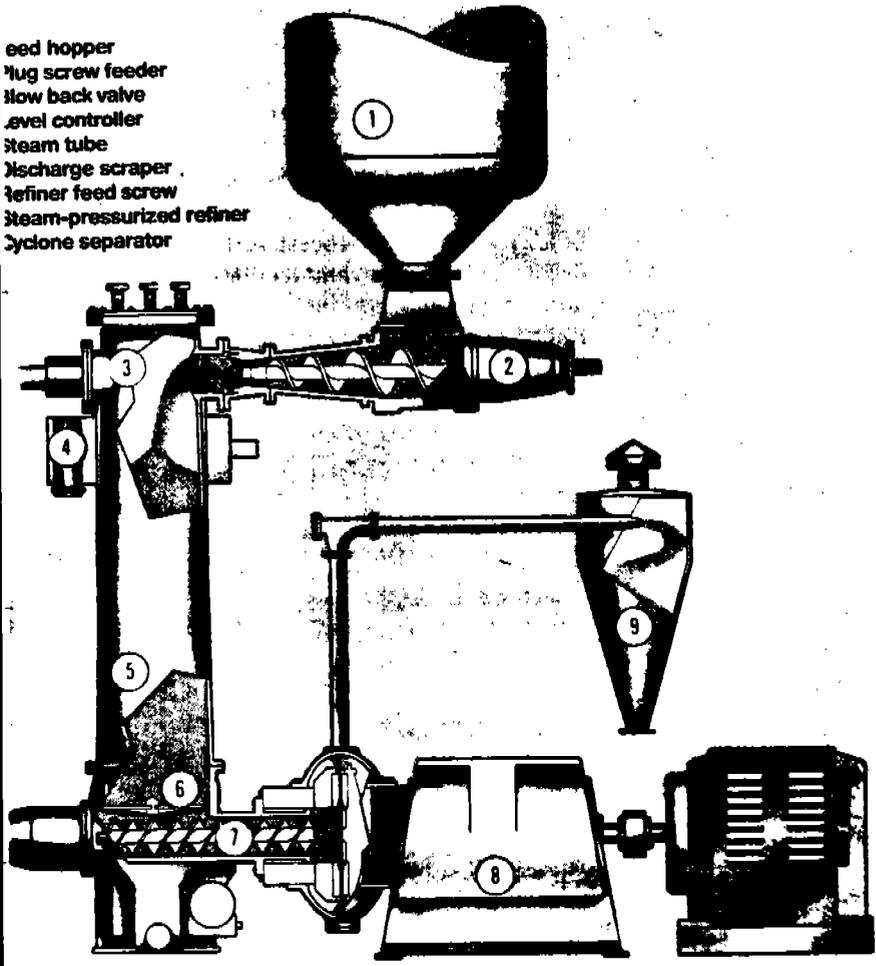
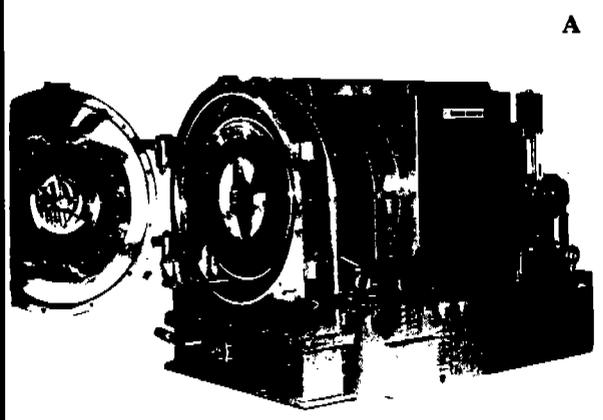


Figure 103—Installation of Type 42 defibrator in fiberboard mill (Sunds Defibrator). **A**—Chip chute and top of preheater. **B**—Lower part of preheater feed screw drive and defibrator.

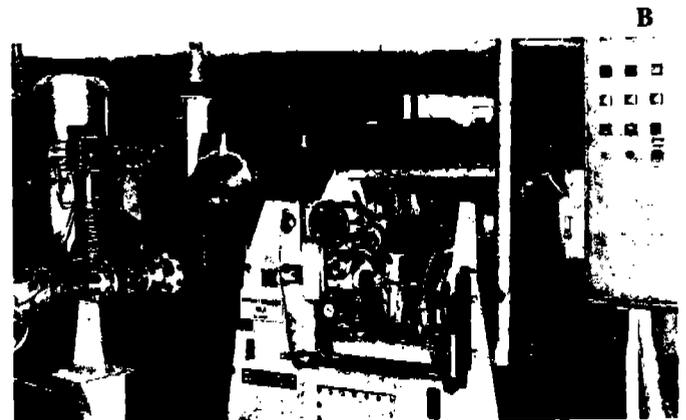
Feed hopper
 Plug screw feeder
 Flow back valve
 Level controller
 Steam tube
 Discharge scraper
 Refiner feed screw
 Steam-pressurized refiner
 Cyclone separator



104—Sprout-Waldron pressurized refining (Sprout-Waldron).



105A—Sprout-Waldron pressurized refiner housing opened to show disk



B—Sprout-Waldron 42-in pressurized in hardboard mill.

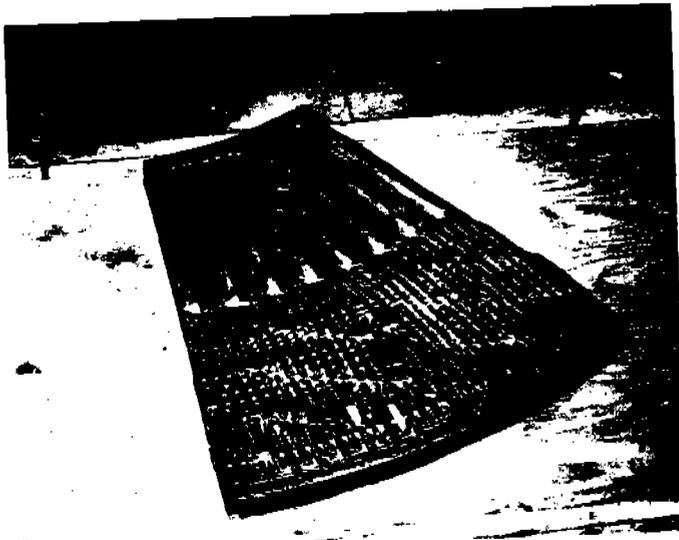


Figure 106—Plate segment of Sprout-Waldron 42-in pressurized refiner.

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 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.

Bauer?

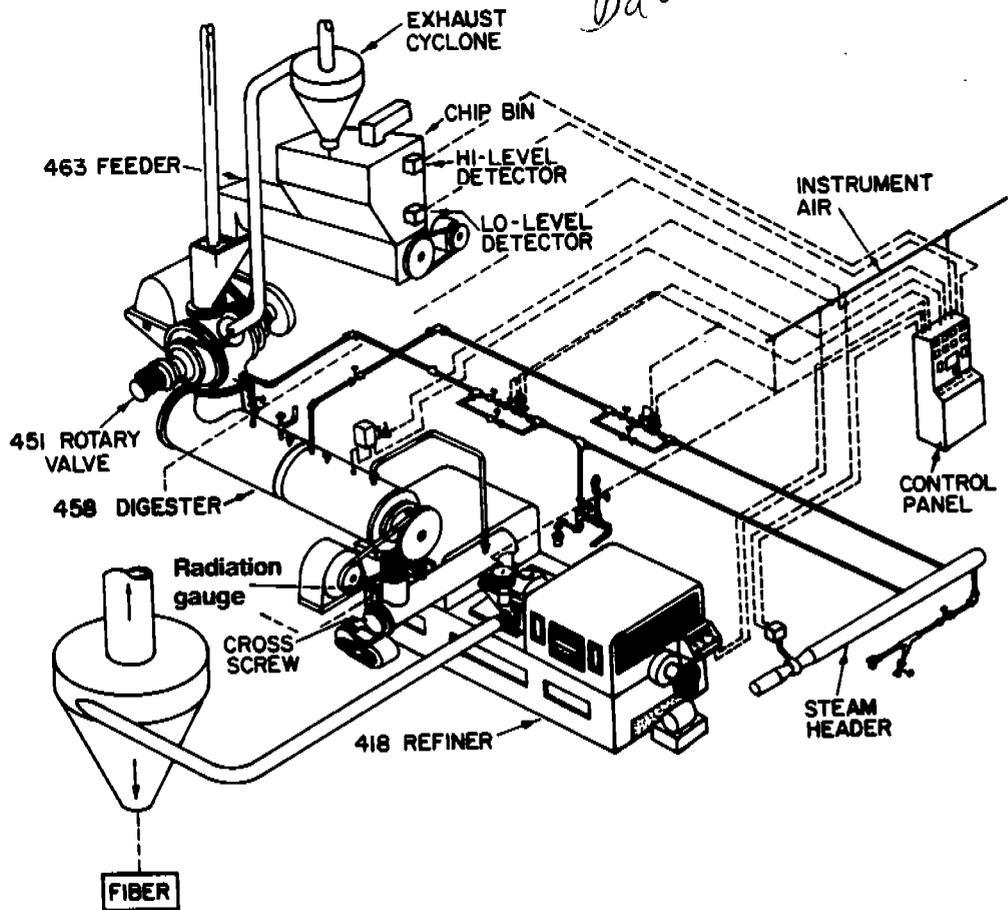


Figure 107—Bauer 418 pressurized refining system (Bauer).

In producing dry pulp, one important pulp characteristic—freeness—can be disregarded. Strength-developing characteristics such as fines content, particle size distribution, and bulk 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.

BAUER 18 x 20 x 33 INLET ROTARY VALVE (MODEL 71)

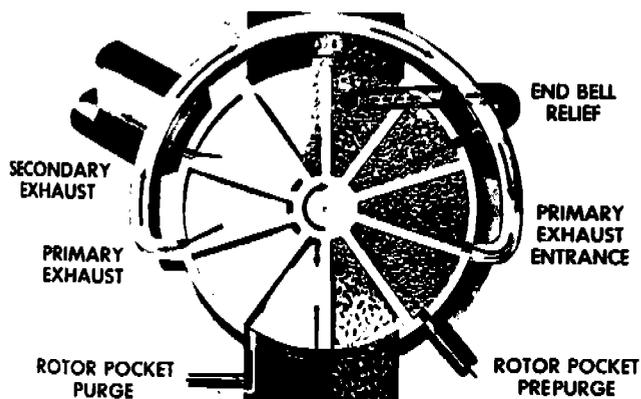


Figure 108—Bauer inlet rotary valve model 71 (Bauer).

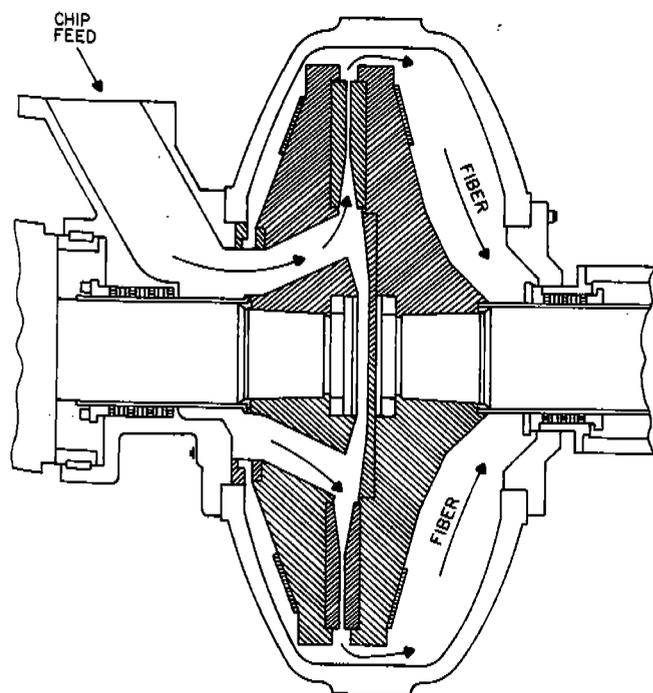


Figure 109—Cross section of Bauer pressurized refiner showing stock flow (Bauer).

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/ft³ 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

C-E Bauer 36" and 40" Medium Plates

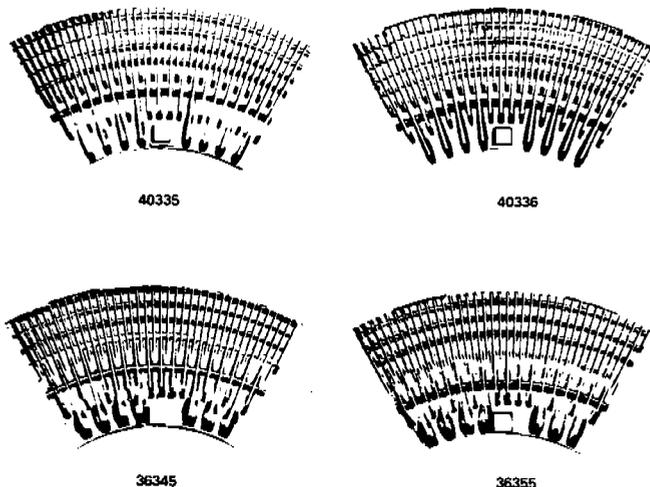


Figure 110—Medium-type plate segments as used in Bauer 418 pressurized refiner (Bauer).

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 leg¹ applies vacuum 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/in² 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 Claffin 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.

¹A 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.

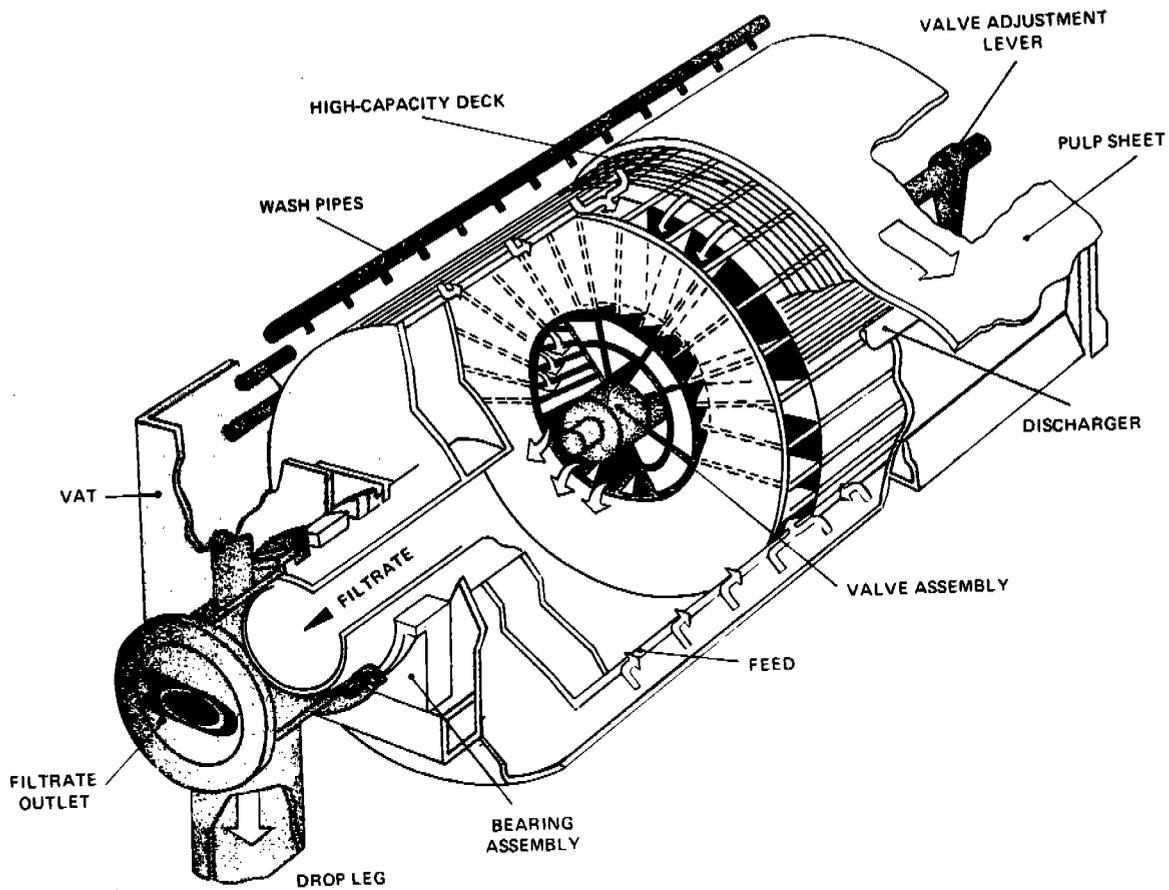


Figure 111—Principle of vacuum pulp washer (Dorr-Oliver).

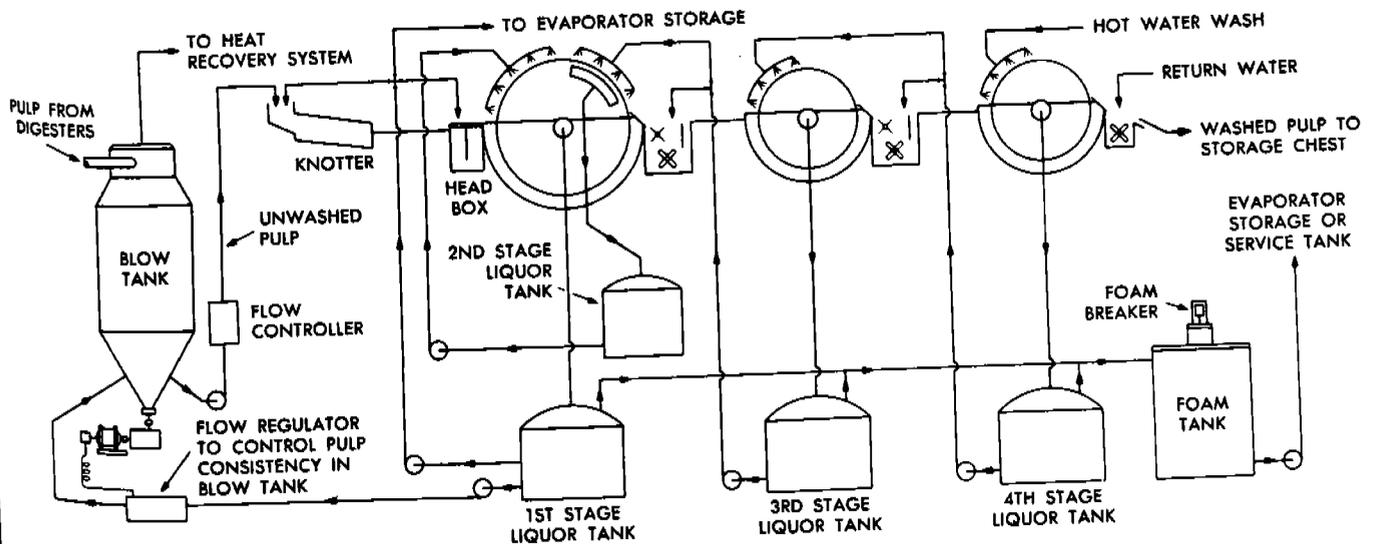


Figure 112—Principle of four-stage Oliver washing system with three washers (Dorr-Oliver).

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.

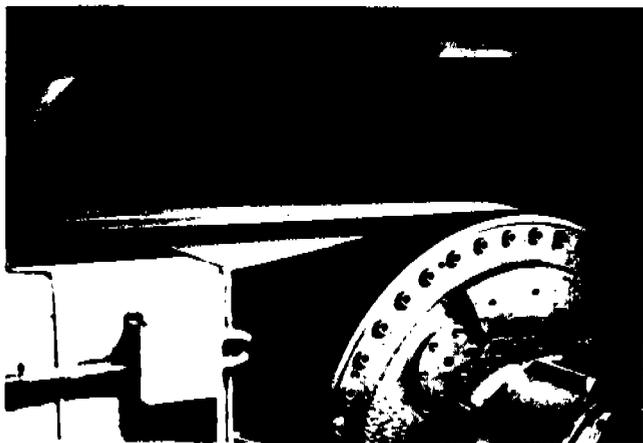


Figure 232—Mat on steel band entering nip between entrance roll and press drum (Bison Werke).

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 develops a torque tending to rotate the fiber to a position with its axis parallel to the electric field. The torque is largest at $\theta = 45^\circ$. 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).

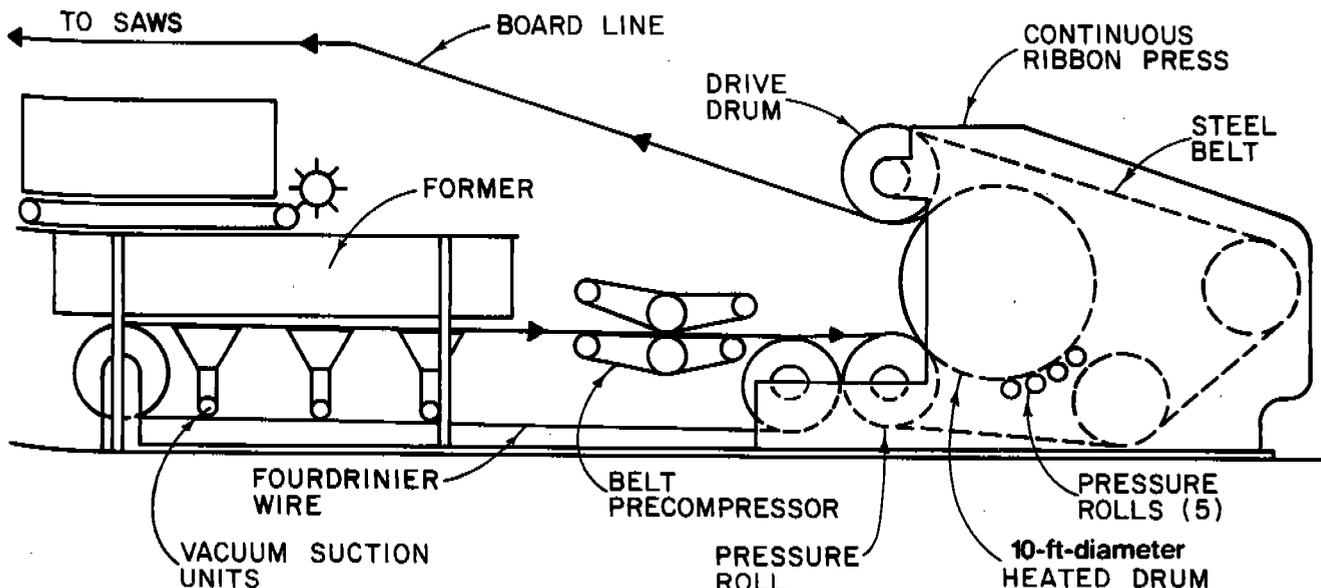


Figure 233—Mende continuous press set up to press fiber mat (Wentworth 1971). Mat formed in former travels from left to right through precompressor and is then forced around heated drum by steel belt and pressure rolls.

234

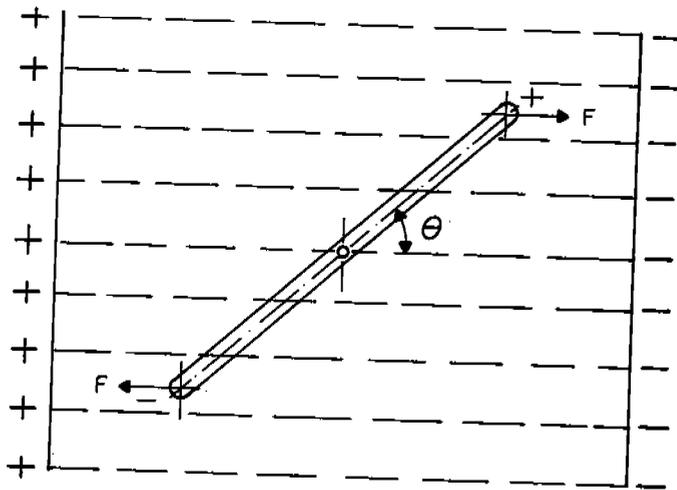
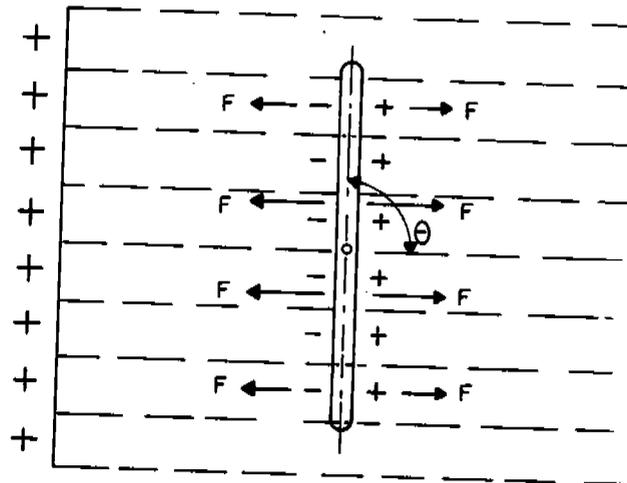
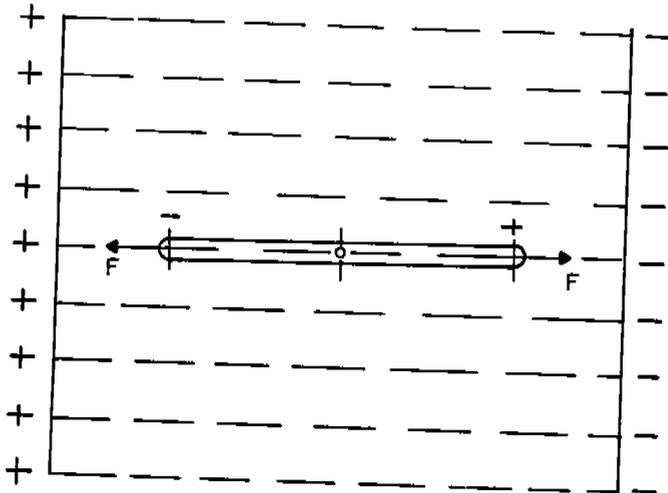


Figure 234—Forces on dipole in electric field. Change shown on dipole end is net result of charge separations occurring throughout the dipole.

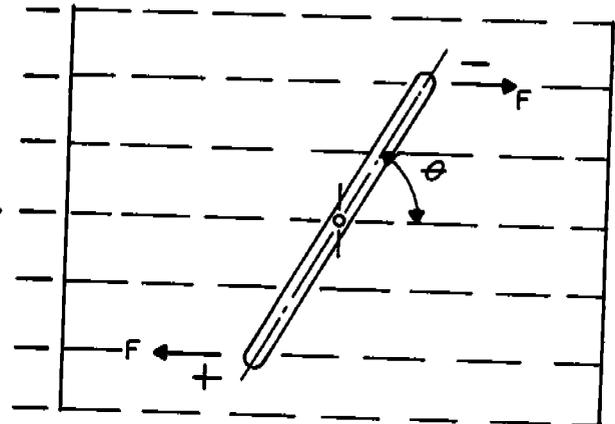
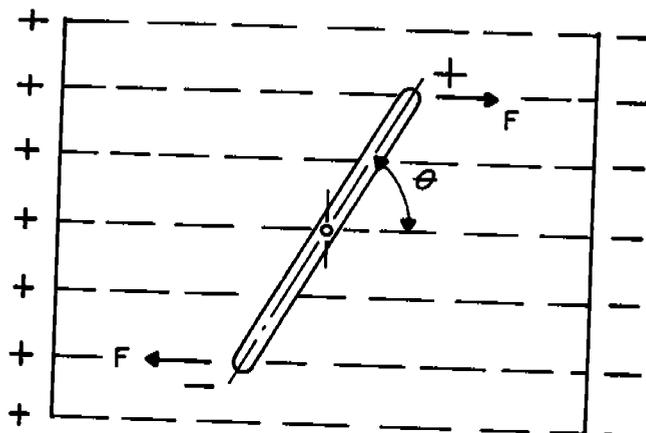
Figure 235—Absence of torque on dipole at $\theta = 0^\circ$ and $\theta = 90^\circ$.

Figure 236—Dipole in AC electric field. The alternating direction of the field between reversal of polarity of field allows reversal of charge separation on dipole so that aligning forces always point in the same direction.

235



236



An alternating field has a similar aligning effect as the frequency is low enough to allow a reversal of charge separation, before the polarity of the field reverses 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 s/s are most effective. Other important variables are 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). Unsized fibers, having a moisture content of 9 to 10 percent, fall through a series of closely spaced vibrating strings to enter the 60-cycle electric field of the forming chamber. The air-fiber mixture moves through the forming chamber at about 50 to 100 ft/min. At the bottom of the forming chamber 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 long products (reduced linear expansion in the long direction of the product) and might encourage the use of fiberboard in structural applications.

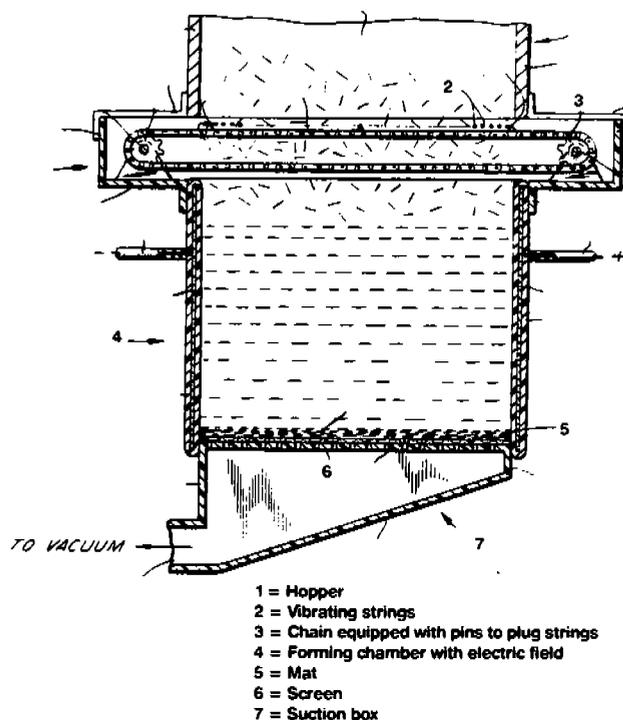


Figure 238—Patent drawing of forming machine providing parallel alignment of fibers in mat (Talbott and Logan 1974).

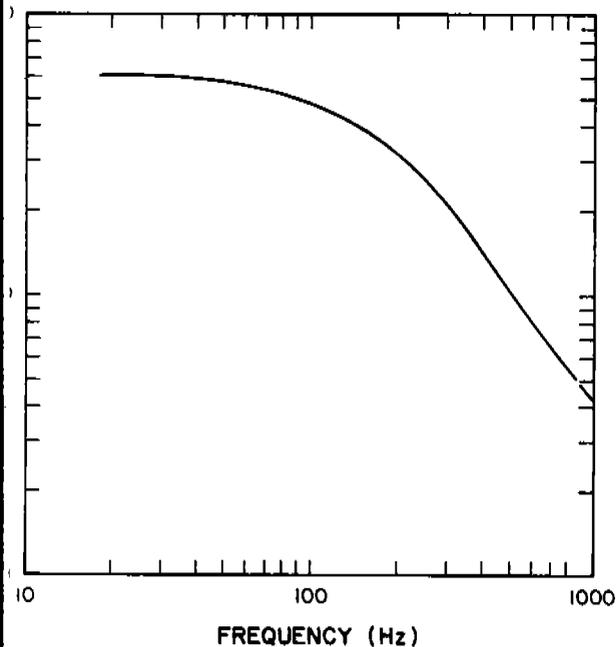
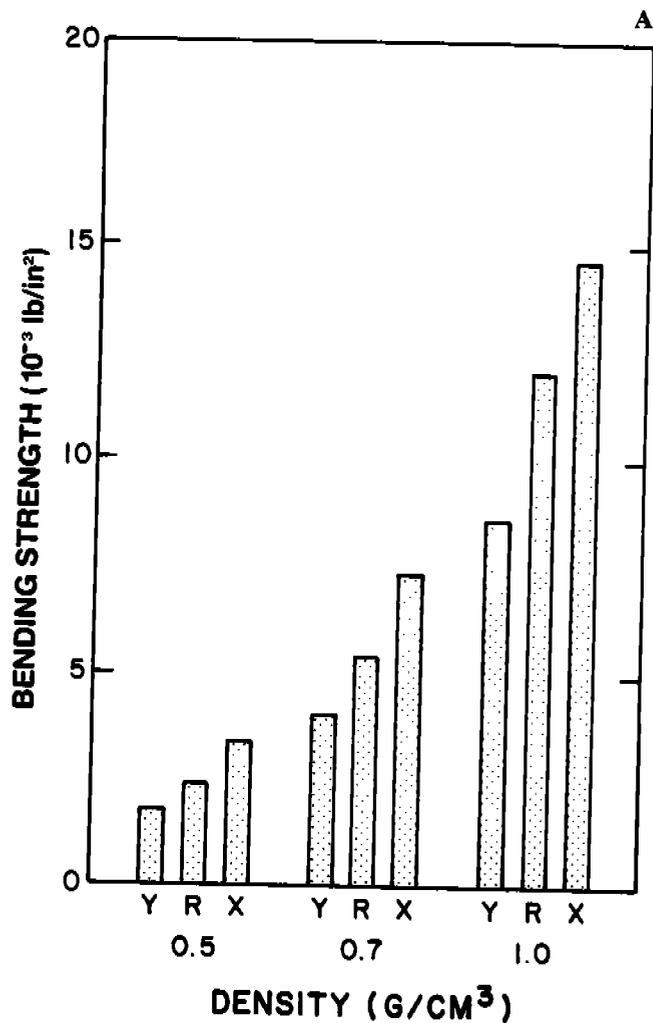


Figure 237—Frequency response of torque on a particle (Talbott and Stefanakos 1972).

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R = Boards with unaligned fibers
 X = Tests in the direction of alignment
 Y = Tests at right angle to alignment

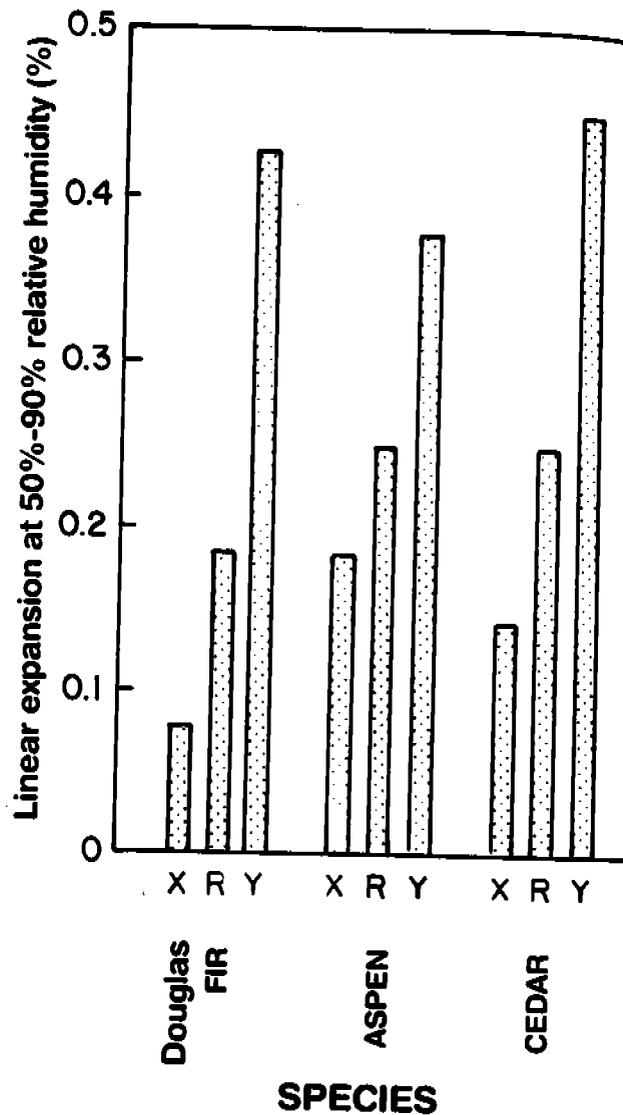


Figure 239A—Effect of fiber alignment on bending strength of fiberboard at three density levels (three species averaged) (Talbot 1974). B—Effect of fiber alignment on linear expansion of fiberboard made from three different species (Talbot 1974).

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Suchsland & Woodson (1986)

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

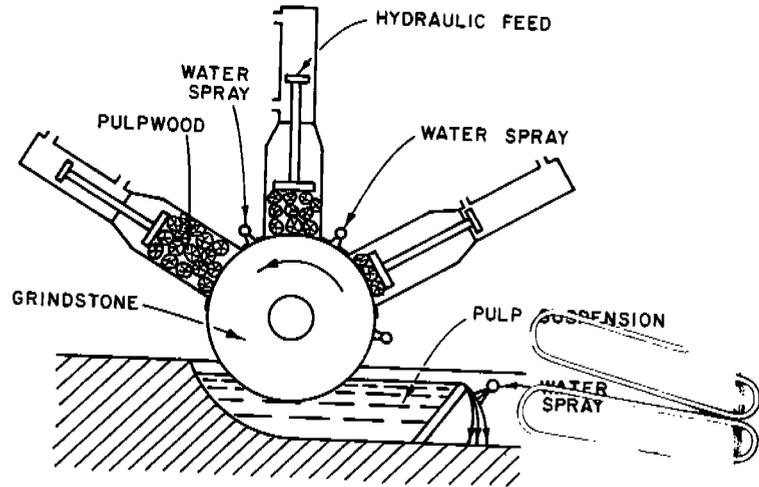


Figure 74—Multipocket pulpwood grinder (Rydholm 1965).

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,

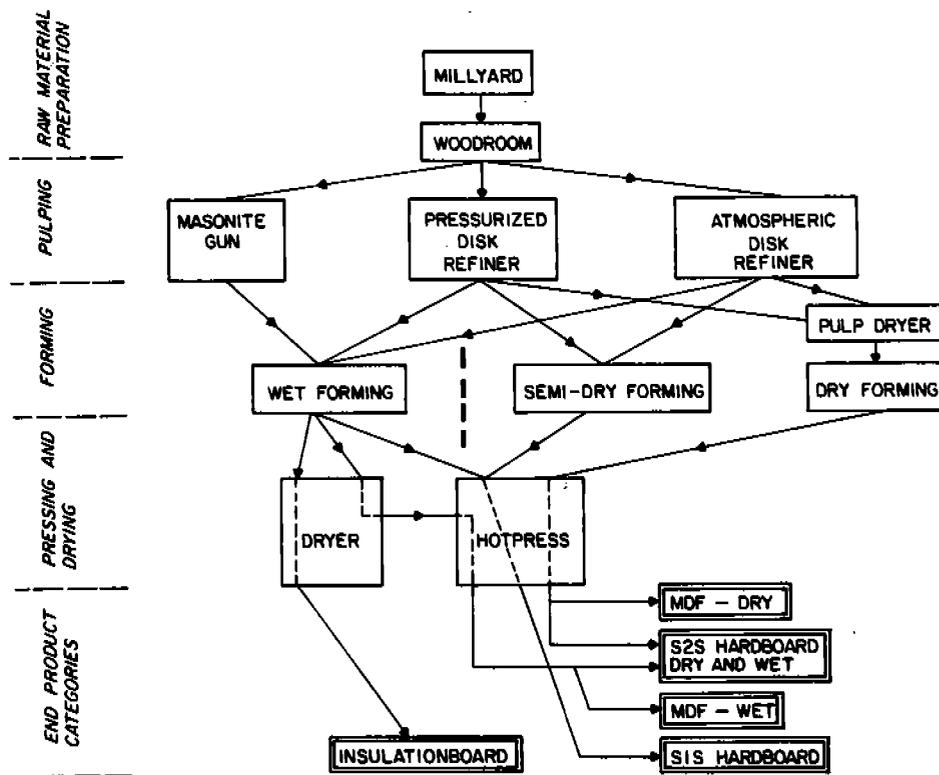


Figure 75—Summary schematic of fiberboard processing. (Suchsland and Woodson, 1986)

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

Freeness testers are of two types:

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

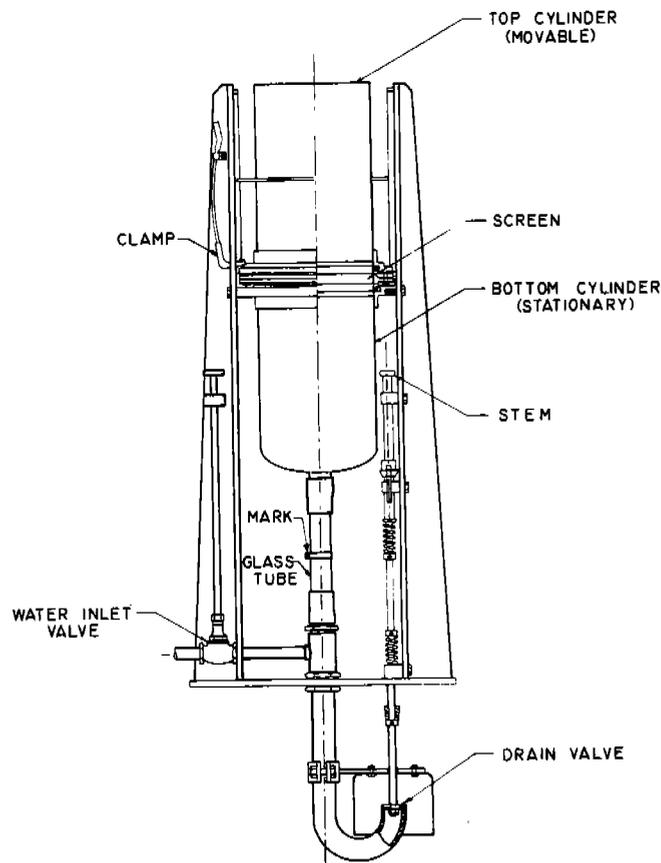


Figure 78—Defibrator pulp freeness tester (Sunds Defibrator).

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 ft³, (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/in²—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/in², 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

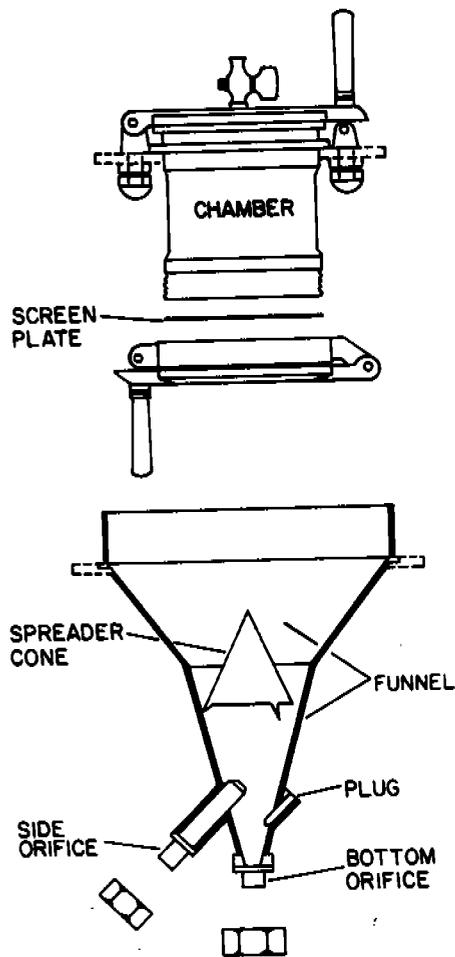


Figure 76—The Canadian Standard freeness tester (Tasman 1969) (exploded view).

b—the higher the number, the slower the pulp. Drainage time for water is 1.5 s; for SIS 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

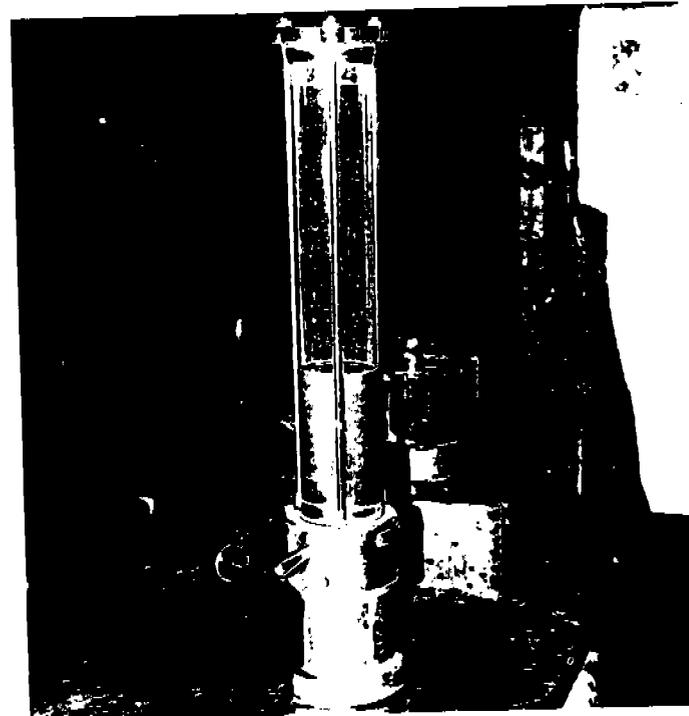
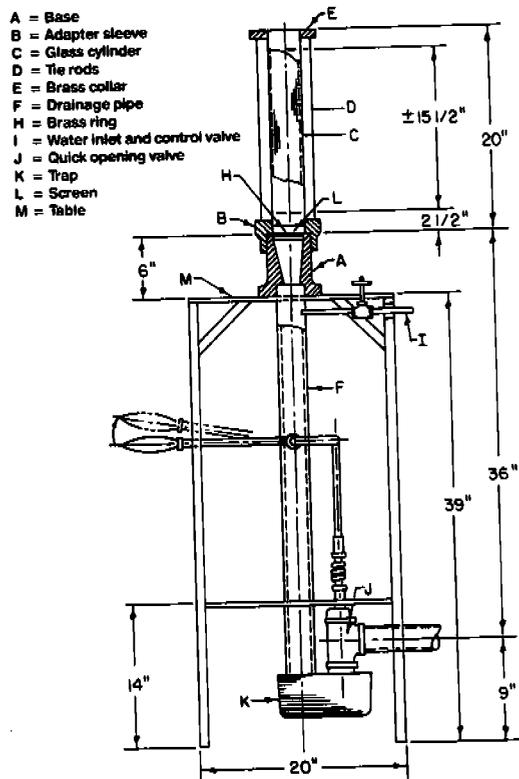


Figure 77A — Tappi Standard SFMC Drainage Tester (TAPPI 1951). (© 1960 TAPPI. Reprinted from TAPPI Useful Method 1006 Sm-60, with permission.) B — Tappi Standard SFMC Drainage Tester.

7. Chemical Additives

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Woodson (1986)

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. After the precipitant lowers the pH, causing the size to precipitate, 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 also 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 directly 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 rosin (a hydrolytic process) through adding sodium hydroxide or sodium carbonate. The size is emulsified and 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 added in fiberboard, is aluminum sulfate, $Al_2(SO_4)_3$, or alum. Alum 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 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 particles, 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

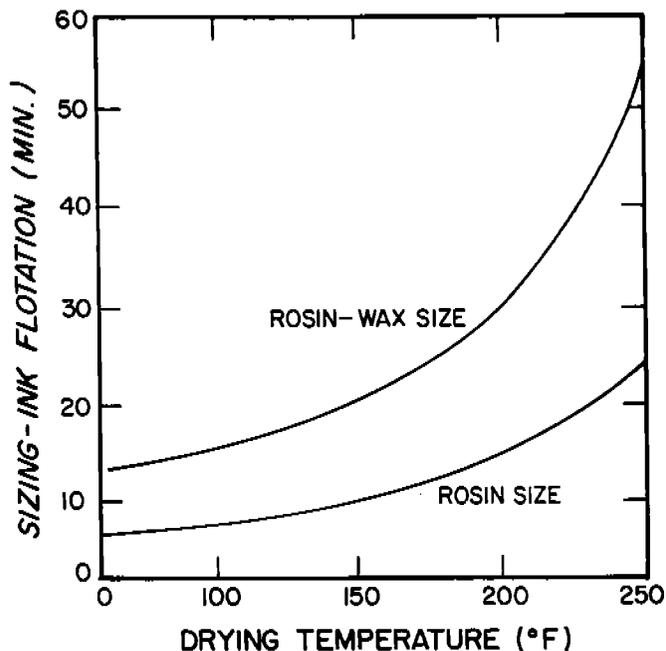


Figure 125—Effect of drying temperature on the effectiveness of sizing as measured by the ink flotation test (longer time = better sizing) (Cobb and Swanson 1971). (© 1971 TAPPI. Swanson, T. W. Internal Sizing of Paper and Paperboard.)

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 fiber-

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.

board. The establishment of S1S hardboard mills in West in the 1940's was substantially aided by availability of water-soluble, highly condensed phenolic resins of high pH that could be precipitated on the surface, had a high degree of retention, and could form satisfactory fiber bond in the hotpress (Keaton 1950).

Dry-formed hardboard and dry medium-density fiberboards must, of course, rely entirely on 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 must pass through a severe drying cycle before hotpressing. Phenolic resins would cure in the dryer and could contribute to fiber bonding after densification in hotpress. 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 for fiberboard or are mentioned in various patents as suitable additives promoting fiber bonding (Wilke 1942); among them are starch, casein, animal glue, latex, tannins. Of these, only starch has industrial importance today. Starch is added as a secondary binder to insulation board (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

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	Thermoplastic 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 Tung oil Tall oil	Flax seed Seed of tung tree Byproduct of sulfate pulping of softwoods
	Soybean oil	Soybean
Thermoplastic resins	Vinsol Gilsonite	Pine rosin 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 andorption 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, joists, 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 prescribed 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.

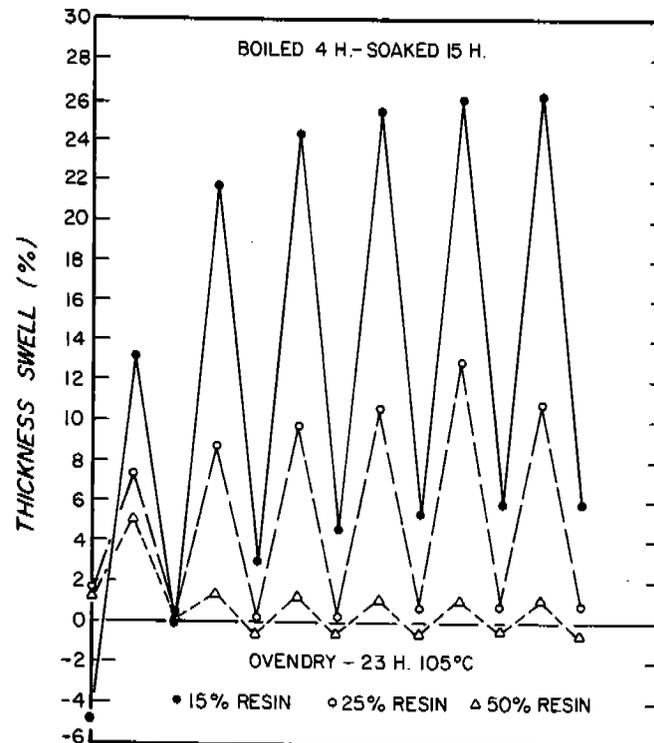


Figure 126—Dimensional stabilization of dry-formed hardboard as a result of treatment with three levels of impregnating resins (Brown and others 1966).

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 non-burning inorganic chemicals.

→ The only commercial treatment of fiberboard with fire retardant chemicals is one patented by the Masonite Corporation (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 of sealant. In addition, pentachlorophenol 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

Suchsland & Woodson (1986)

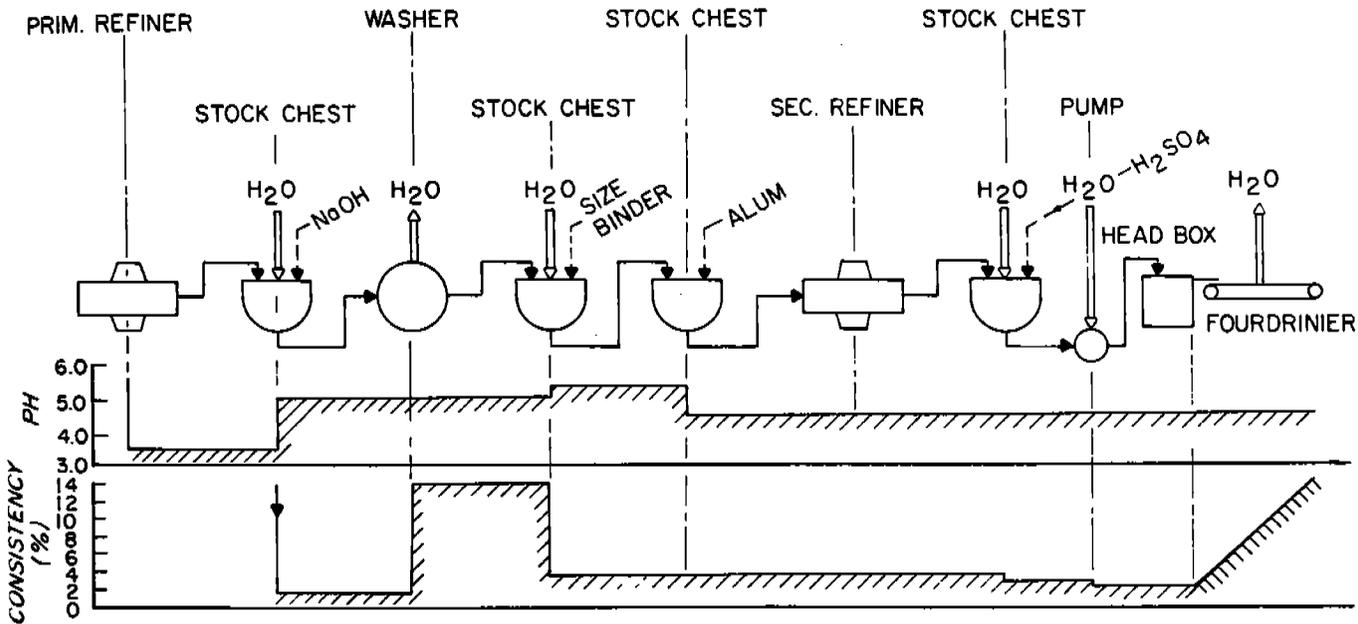


Figure 127—Schematic of stock flow in wet-process fiberboard plant, showing pH, stock consistency, and introduction of additives.

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

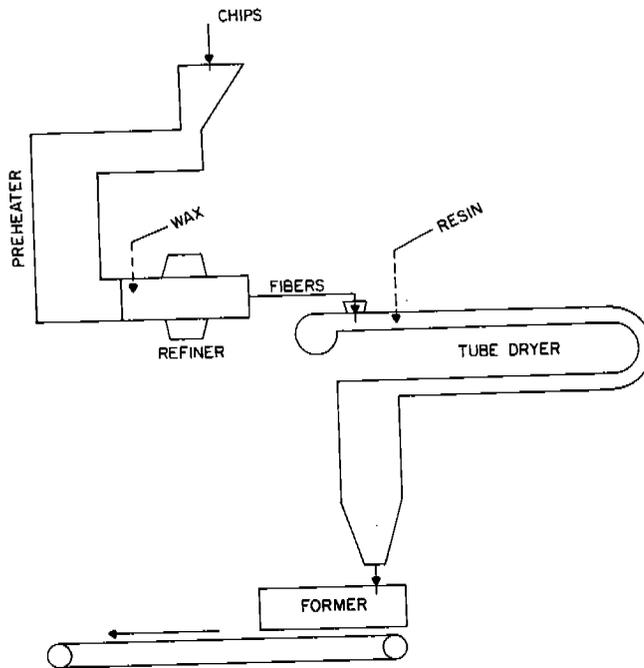


Figure 128—Schematic of furnish preparation in dry-process hardboard plant, showing addition of phenolic resin prior to drying of fiber in tube dryer.

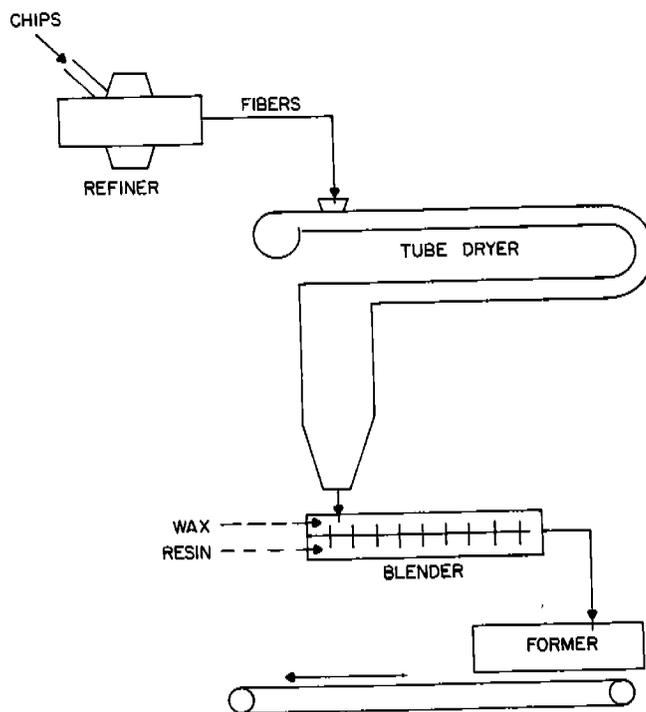


Figure 129—Schematic of furnish preparation in dry medium-density fiberboard plant, showing addition of urea resin in short retention blender after drying of fiber in tube dryer.

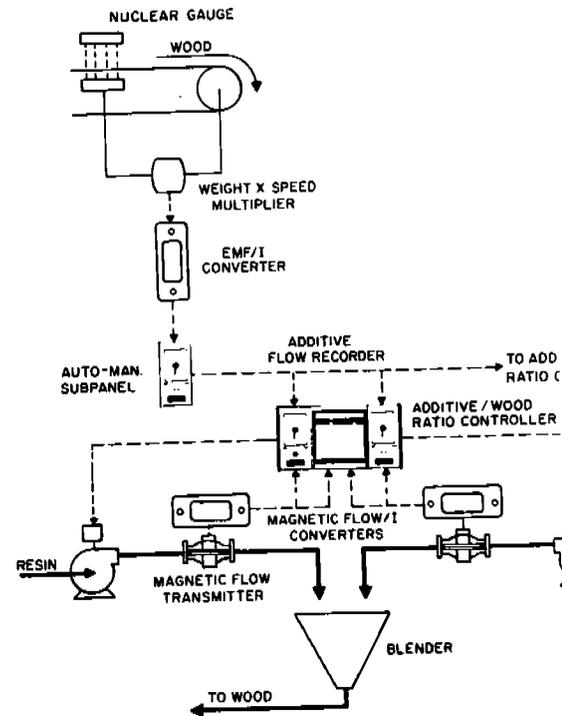


Figure 130—Electronic wood/resin/wax ratio control system for process fiberboard plant (Ballard and Schlavin 1969).

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

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

Part of the wax evaporates in the dryer and is condensed, 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 a 1/2" sized insulation board. Most insulation boards require an addition of between 0.75 and 1.25 percent dry weight 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 weight. Asphalt was first used in insulation board

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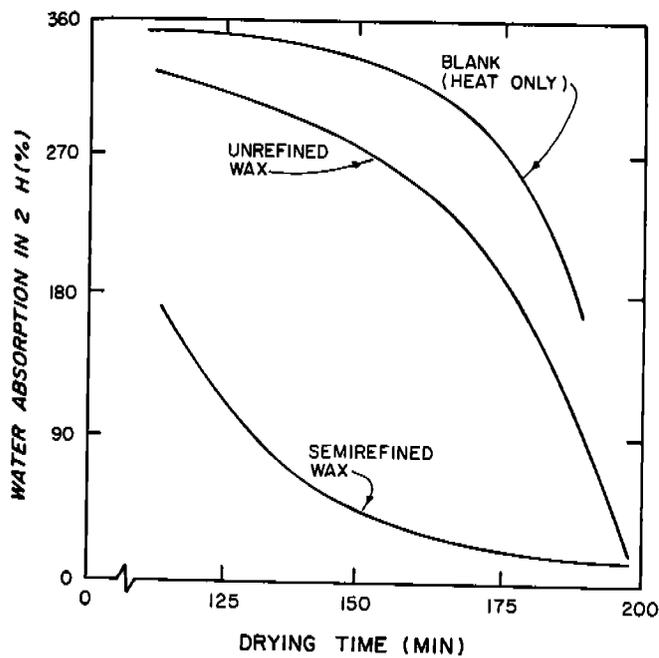


Figure 131 — Effect of drying time on water absorption by insulation board (Porter 1971). (© 1971 TAPPI. Swanson, T.W. Internal Sizing of Paper and Paperboard.)

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).

SIS board

The standard additives in the manufacture of SIS 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, SIS 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 SIS 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

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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/ft³, 0.75 percent oil; for 50 to 55 lb/ft³, 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 added.

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

Boise Cascade (Insulite) at International Falls 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 a precipitant. Gilsonite is used at the rate of 5 percent.

A thermoplastic resin derived from pine rosin (rosin) is used in Abitibi's siding, which is made by the same 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 used 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 the furnish is that the binder often has enough tack to 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 process called in situ resin, a combination melamine-formaldehyde resin of low molecular weight, low tackiness, and low viscosity. Later, standard urea resin with low tack were used as well. These resin binders are applied in short retention blenders like the Gresco 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 content

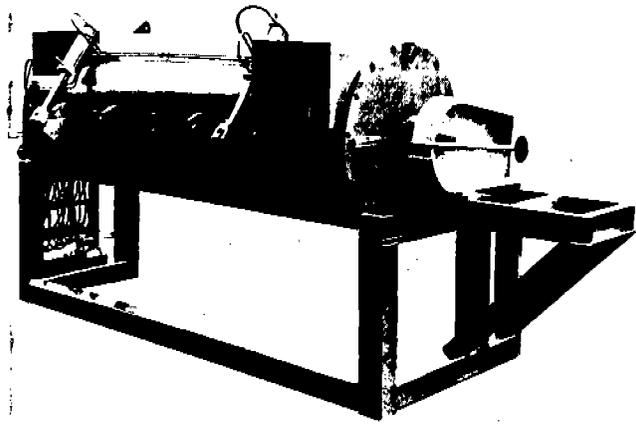


Figure 132—Grenco short retention blender for dry furnish (Suchsland 1978).

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).

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Woodson (1986)

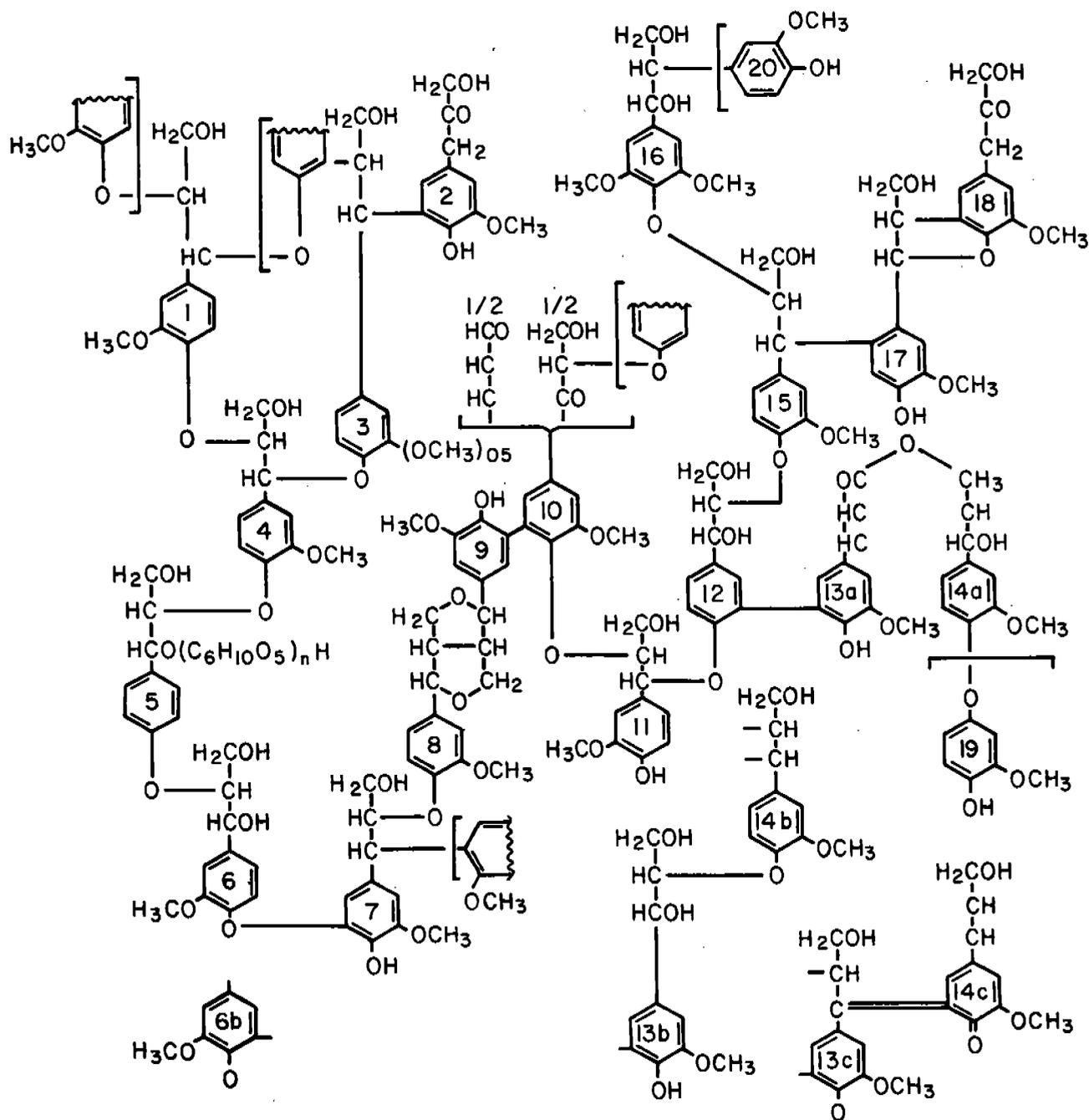


Figure 19— General polymeric structure present in conifer lignins (after Sarkanen 1970).

(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 hot-press. Phenol-formaldehyde resins form waterproof and boilproof glue lines; urea-formaldehyde resins have con-

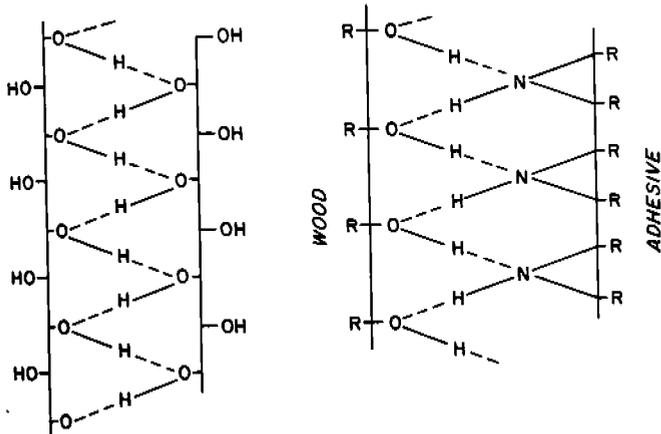


Figure 24A—Hydrogen bonds between two cellulose chains. The bond develops between hydroxyl groups (-OH) of the cellulose molecules and is indicated by dotted lines. B—Hydrogen bonds between adhesive and wood. The vertical lines indicate the wood and adhesive surfaces possessing hydroxyl groups (wood) 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).

siderable 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.

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 hot-press 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

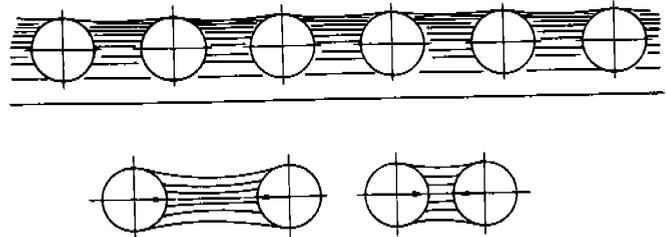


Figure 25—Attractive forces between fibers due to surface tension of evaporating water. In the upper portion of the picture, fibers are shown (in cross section) in suspension in water. The lower portion shows the attraction developing between drying fibers as the water is being removed. This will lead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

in the hotpress with phenolic substances obtained from lignin to form condensation products similar to phenol-formaldehyde resins.

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 entanglement 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.

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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.

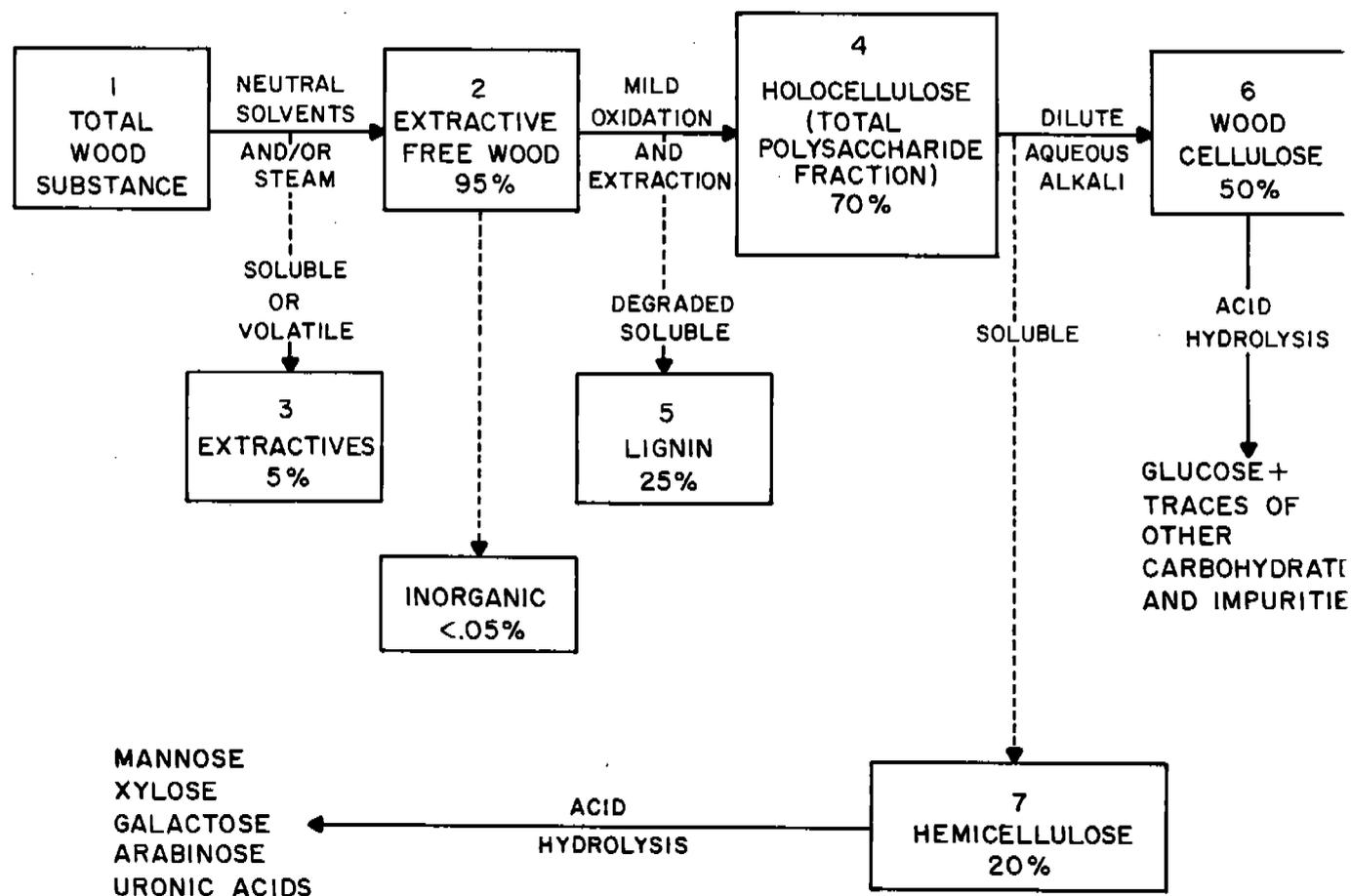


Figure 20—Schematic breakdown of solid wood into its chemical components (EPA 1973).



Suchsland &
Woodson (1986)

Copy 2

Table 52—Production statistics of U.S. hardboard industry (American Hardboard Association)

		Area (1000 ft ²) 1/8-in basis							
Imports (1000 ft ²) 1/8-in basis	Year	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

*Industrialite.

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.

1. Introduction

Suchsland &
Woodson (1986)

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.

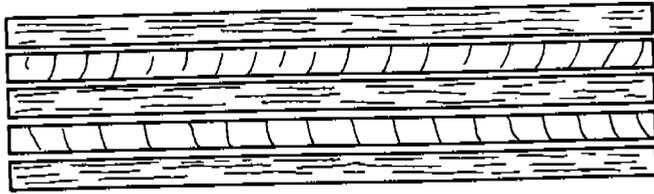
A special effort has been made throughout to illustrate the subject with in-plant photos and to explain important concepts by means of schematic drawings.

Concepts

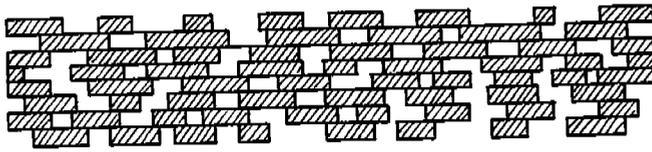
Several concepts provide a basic approach to the book's subject. They are discussed here as a starting point to the succeeding chapters.

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



PLYWOOD



PARTICLE BOARD

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

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

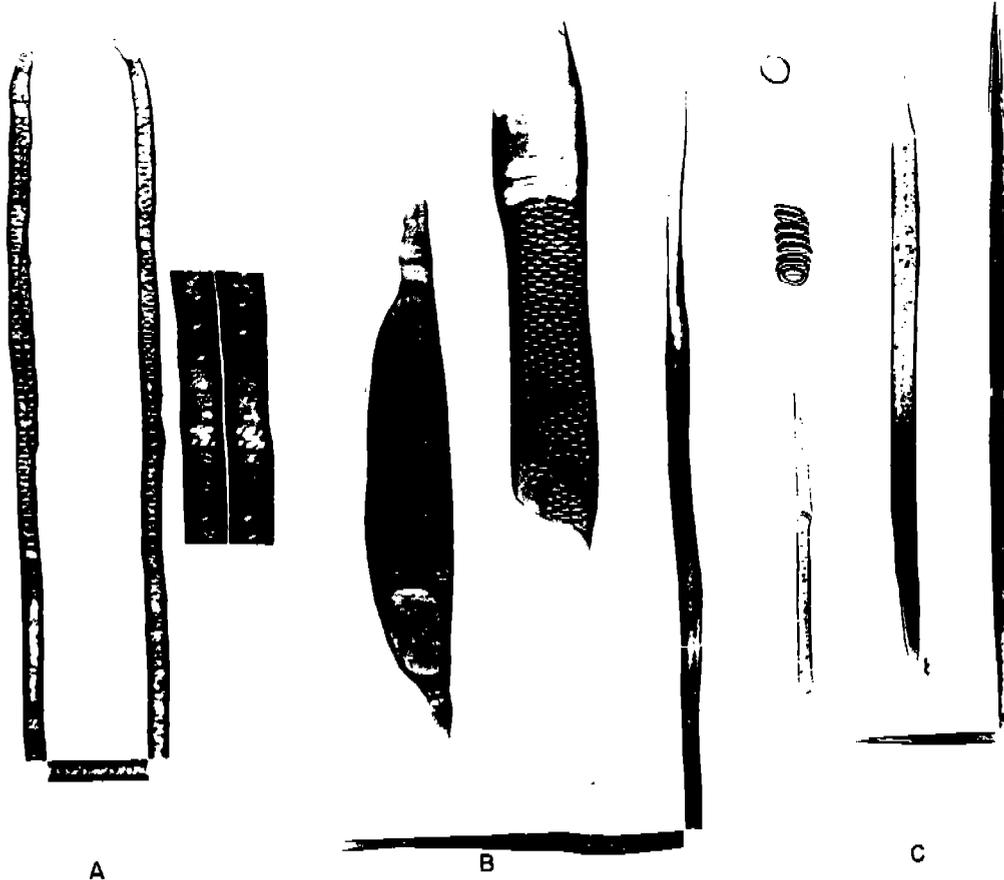


Figure 3—Examples of fibers used in the manufacture of fiberboard (Carpenter and Leney 1952). A—Softwood fibers. B—Hardwood fibers. C—Sugarcane fibers.

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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

is defined by a separate, voluntary product standard (USDC 1973) as a fiberboard ranging in density from 10 to 31 lb/ft³, 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

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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/ft³) 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/ft³) 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/ft³) 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/ft³ (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 de-

finied by a separate, voluntary product standard (USDC 1973) as a fiberboard ranging in density from 10 to 31 lb/ft³, 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.

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.

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

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/ft³). 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 oven-drying.

$$\text{specific gravity} = \frac{\text{weight (oven-dry)}}{\text{test condition} \times 62.4 \text{ (lb)}} / \left[\frac{\text{volume at test condition}}{\text{volume of water}} \right] \text{ (lb/ft}^3\text{)}$$

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/ft³ has a specific gravity of 48/62.4 = 0.77.

Bulk density. This term is used to describe the bulk effect of loose materials such as dry fibers, particles, or chips. It is the density of the uncompressed material. Loose dry particle fiber might have a bulk density of 1 or 2 lb/ft³.

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 slurry.

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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 cm³ 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 cm³ results in different relative volumetric expansion values, depending upon the

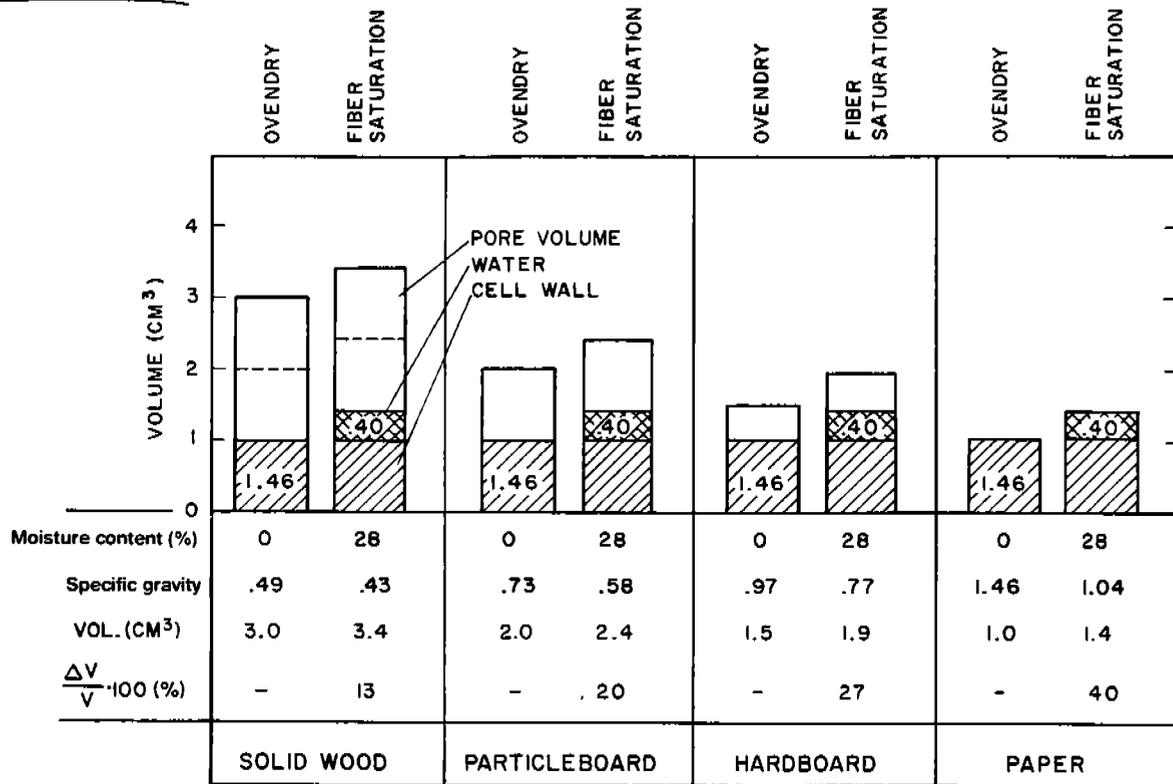


Figure 240— Relationship between specific gravity and volumetric swelling of solid wood and densified wood products.

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 hydroxyl 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

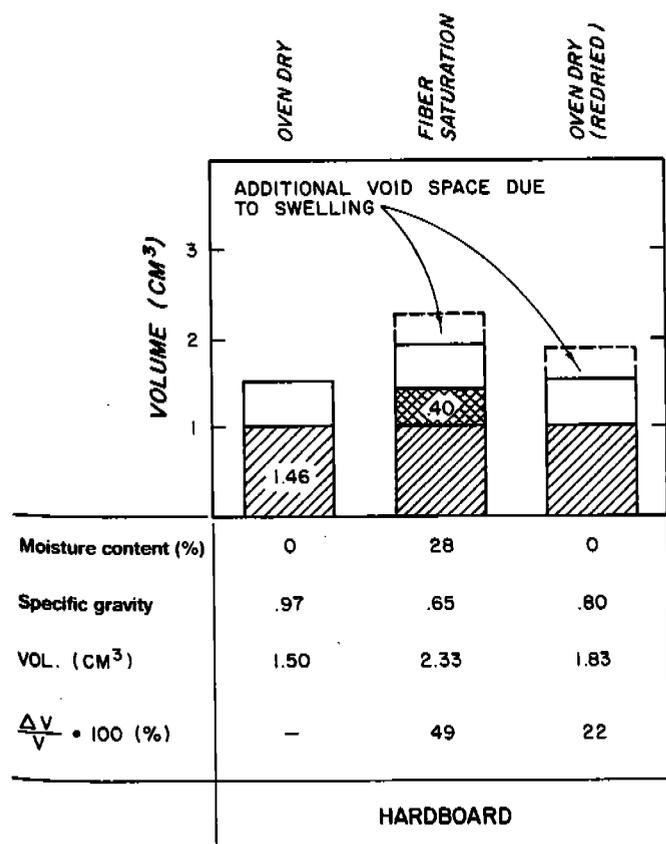


Figure 241—Effect of springback on volumetric swelling of hardboard.

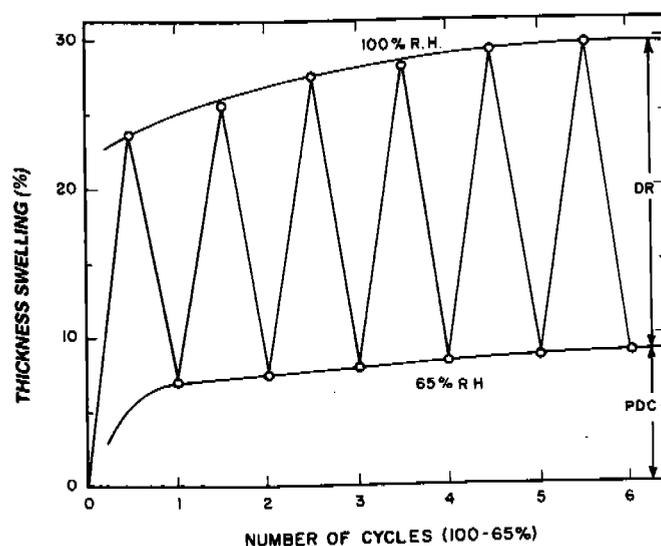


Figure 242—Dimensional range (DR) and permanent dimensional change (PDC) in thickness swelling of wet-formed hardboard during cyclic exposure. PDC is equivalent to springback (Klinga and Back 1964). RH = relative humidity.

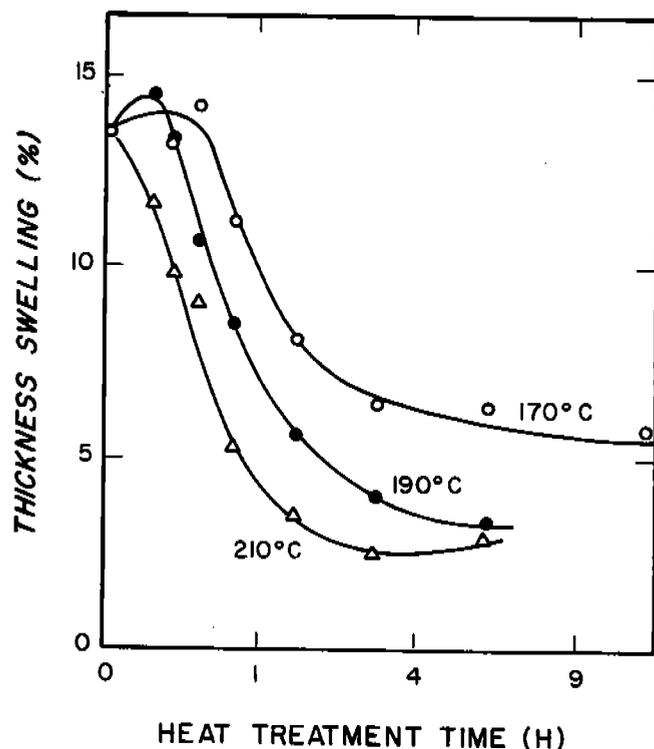


Figure 243—Reduction of permanent thickness swelling after heat treatments at various temperatures (after Braun and Strand 1958).

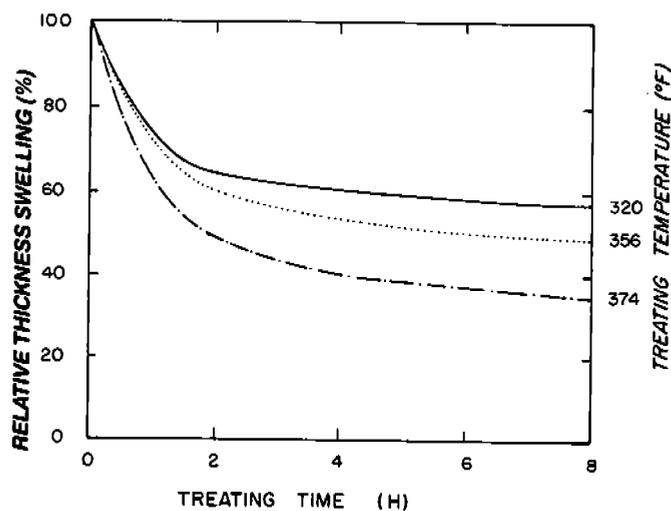


Figure 244—Reduction of thickness swelling of 1/8-in hardboard after heat treatment at various temperatures (after Braun & Strand 1958).

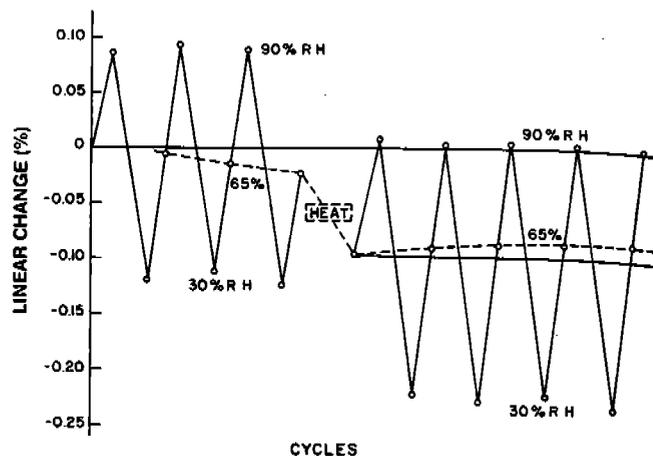


Figure 245—Linear changes in response to cyclic exposure of 1/8-in hardboard before and after heat treatment at 375 °F for 2 1/2 h (Klinga and Back 1964).

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

Chapter 10
Heat treatment
Tempering &
Humidification
Suchsland &
Woodson (1986)

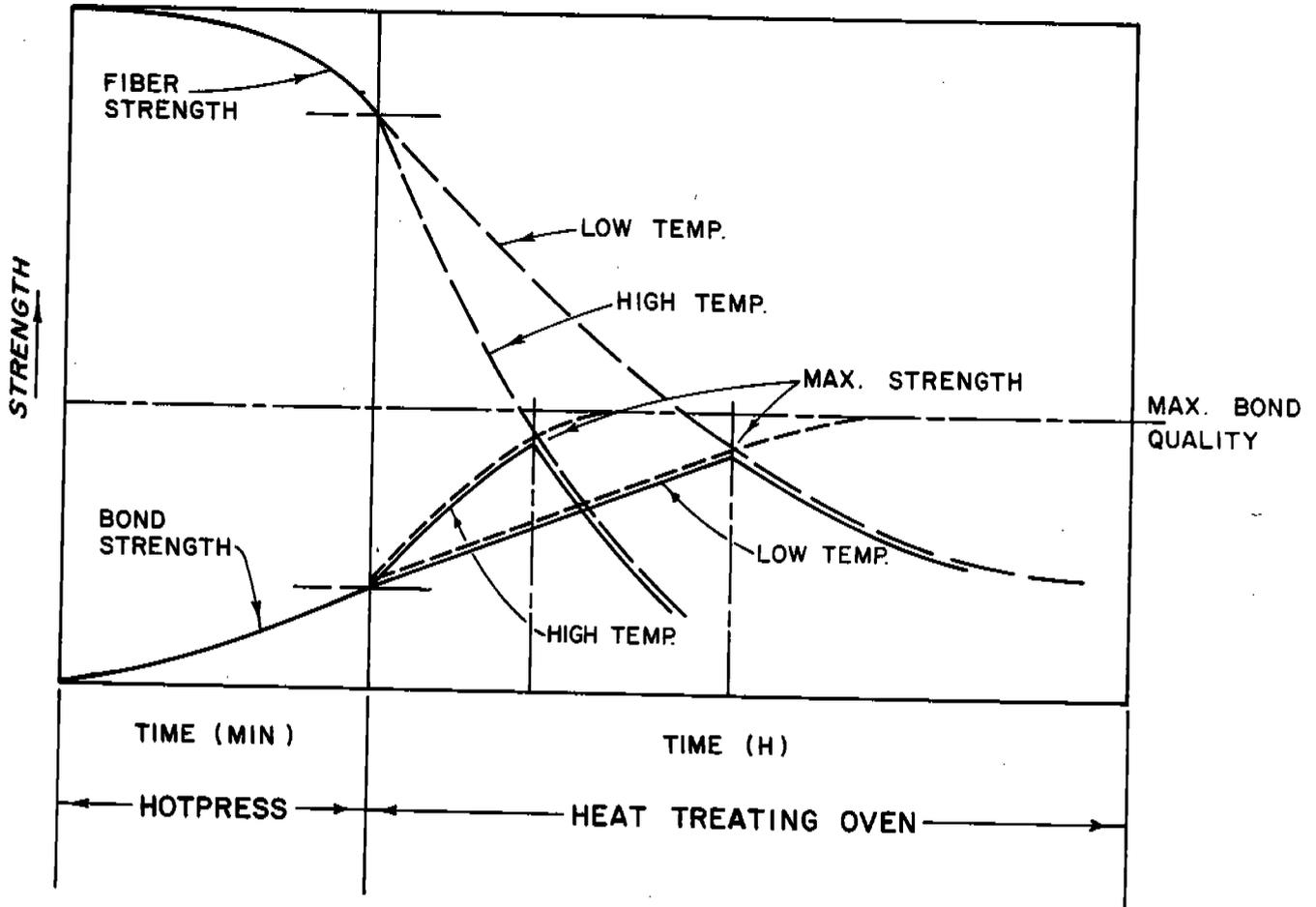


Figure 246—Hypothetical development of board strength as affected by changing bond strength and fiber strength during pressing and heat treating.

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

Suchsland &
Woodson (1986)

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/in ²)	Tensile strength (lb/in ²) (min. av./panel)	
	Water absorption based on wt (%)	Thickness swelling (%)		Parallel to surface	Perpendicular to surface
1—Tempered			6,000	3,000	130
	30	25			
	25	20			
	25	20			
	25	20			
	20	15			
	15	10			
2—Standard	10	9			
			4,500	2,200	90
	40	30			
	35	25			
	35	25			
	35	25			
	25	20			
3—Service-tempered	20	15			
	15	10			
			4,500	2,000	75
	35	30			
	30	30			
4—Service	30	25			
	20	15			
			3,000	1,500	50
	45	35			
	40	35			
	40	30			
	35	25			
	35	25			
	30	20			
	25	20			
	25	20			
	20	15			
	20	15			
5—Industrialite	20	15			
			2,000	1,000	25
	50	30			
	40	25			
	40	25			
	35	25			
	30	20			
	30	20			
	30	20			
	25	20			

Table 29 — continued

Nominal thickness (in)	Water resistance (max. av./panel)		Modulus of rupture (min. av./panel) (lb/in ²)	Tensile strength (lb/in ²) (min. av./panel)	
	Water absorption based on wt (%)	Thickness swelling (%)		Parallel to surface	Perpendicular to surface
Class 5—Industrialite					
13/16	25	20	2,000	1,000	25
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 SIS 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/ft³ 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 1 1/2 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,

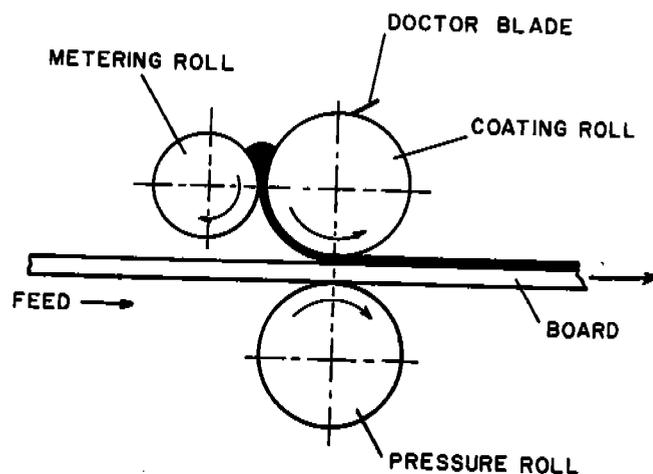


Figure 250—Principle of direct roll coater.



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 mat 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-

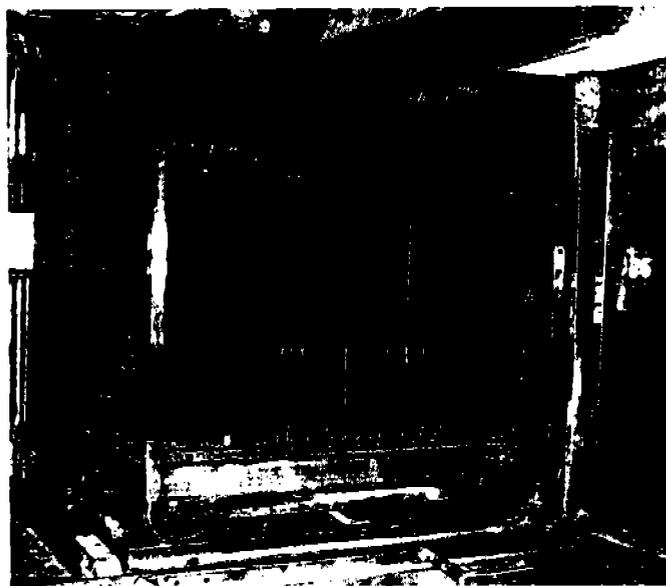


Figure 252—Buggy loaded with hardboard ready to enter heat treating oven. Boards are standing on edge.

intermediate 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 result in 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 pre-conditioning 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 progressive-type chambers following, and often integrated with, the treating oven. In a progressive-type humidifier, the boards coming out of the heat treating 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 stack 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 5 (Vranizan 1968)). Upon leaving the boards, the air is cooled as it passes over steam-heated pipes and reaches point 2 on the chart. Moisture is then added by steam

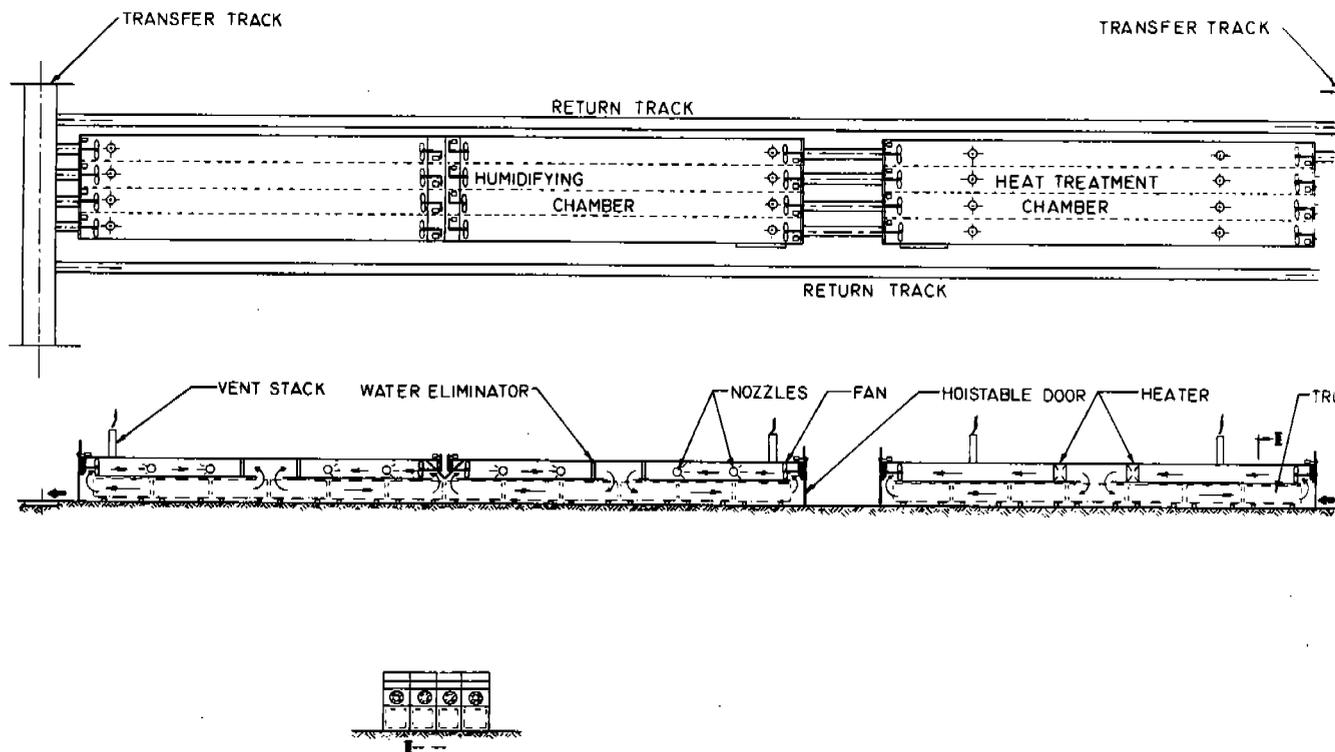


Figure 253—Layout of progressive heat treating chamber and humidifier in hardboard plant (Lofgren 1957).

Suchsland &
Woodson (1986)

Finishing

S2S

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 1/4-in S2S flat board to 1/4-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 a 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 a paneled 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 ft², which corresponds to a specific gravity of about 0.73, or a board density of 45.6 lb/ft³ (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.

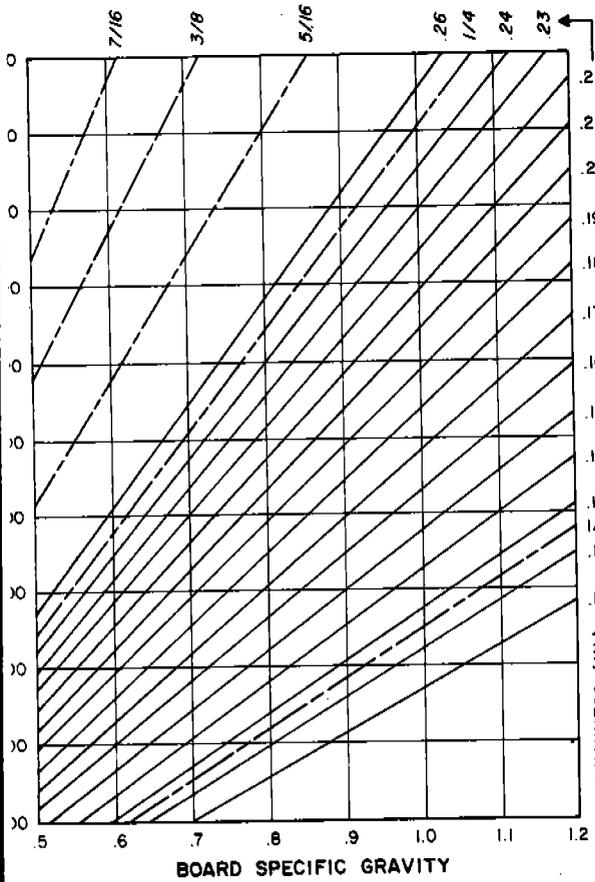
Decorative Board. Paneling boards finished in solid colors or printed with designs other than wood grain and not normally grooved. They include vinyl-overlaid boards featuring a wallpaper look, and tile boards, t

category often used on bathroom walls and as
er enclosures, one of the most demanding applica-
of hardboard.

light solid colors and high gloss surfaces require
high quality substrates and the utmost cleanliness in
finishing operation. S1S substrates are not suitable

30—Weight of prefinished hardboard products of
us thicknesses

Type	Board weight (lb/1,000 ft ²)		
	1/8 in	1/4 in	7/16 in
Paneling	700-750	950	—
	750	925	—
Decorative hardboard	700-750	950	—
S1S	750	925	—
S2S	—	—	1,500
S3S	—	—	1,500



285—Relationship of weight and specific
v of board.

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).

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 ap-
plied 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 im-
perfections 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 com-
monly 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 prop-
erties, 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 in-
to the atmosphere, or may prohibit the release of certain

Suchsland & Woodson (1986)

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,

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
	Automotive primers
Epoxies	Chemically resistant coatings
	Marine coatings
	Can coatings
	Appliance finishes
	Automotive primers
Acrylics	Automotive coatings
	House paints
	Coil coatings
	Appliance finishes
	Machinery finishes
Cellulosics	Paper and paperboard coatings
	Automotive coatings
	Furniture finishes
Vinyl resins	Automotive coatings
	Can coatings
	Tank coatings
	House paints
	Plastic coatings
	Coatings for flexible substrates (plastics)
Urethanes	Wood furniture and fixture coatings
	Automotive coatings
	Paper and paperboard coatings
	Sealers
Rubber-base products	Swimming pool paints
	Marine coatings

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.

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
Tetrachloroisindolinone 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,
Clay	viscosity, and/or
Mica	other properties
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

Suchsland & Woodson (1986)

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

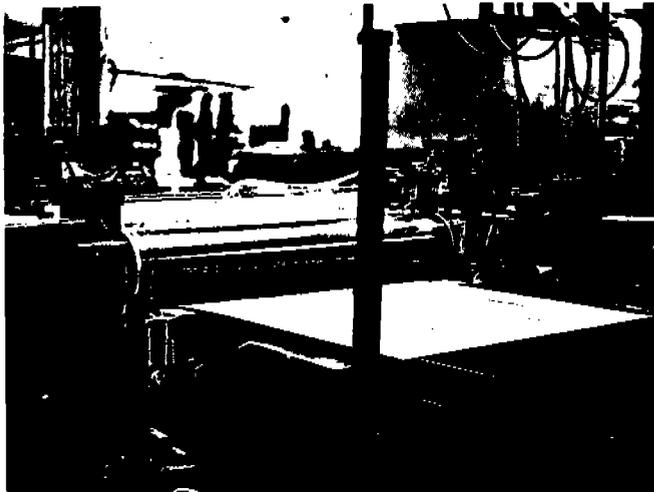


Figure 289—Outfeed end of reverse roll coater applying fill coat to grooved panel.

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.

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

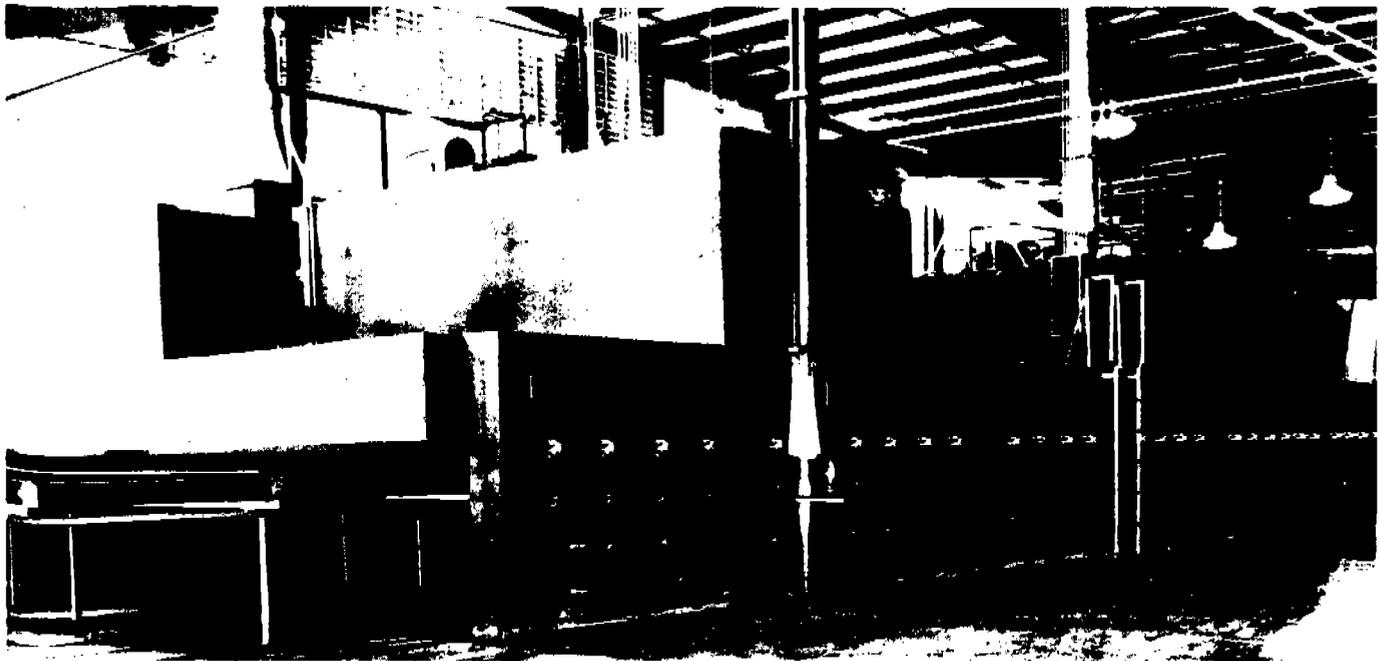


Figure 290—High-velocity hot-air oven, fired with natural gas (Thermal Engineering Corp.). Cross transfer conveyor line visible at left feeds 4- by 8-ft boards laterally. This is a "double pass" oven—two units in series.

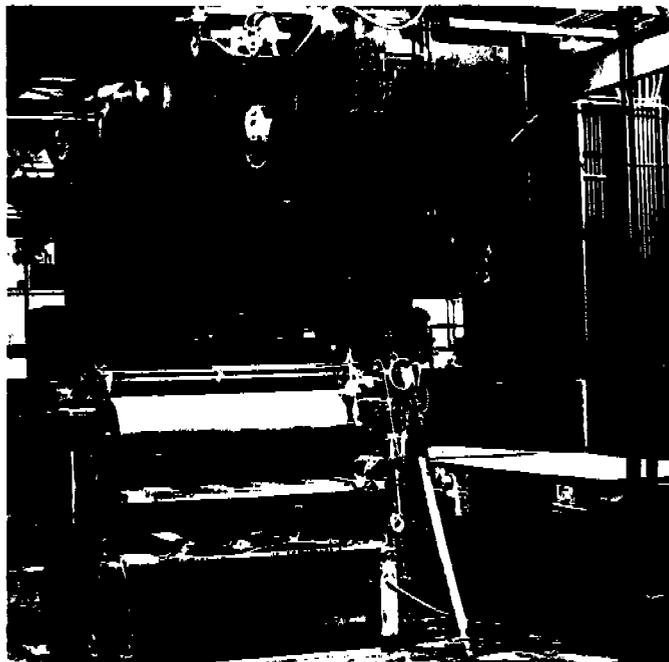


Figure 291—High-velocity hot-air dryer for drying fill coat. This dryer is similar to that shown in figure 290, except that it is equipped with an incinerator for burning evaporated solvent and heat exchanger for recovery of heat of combustion. Both elements are housed in superstructure. Precision roll 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

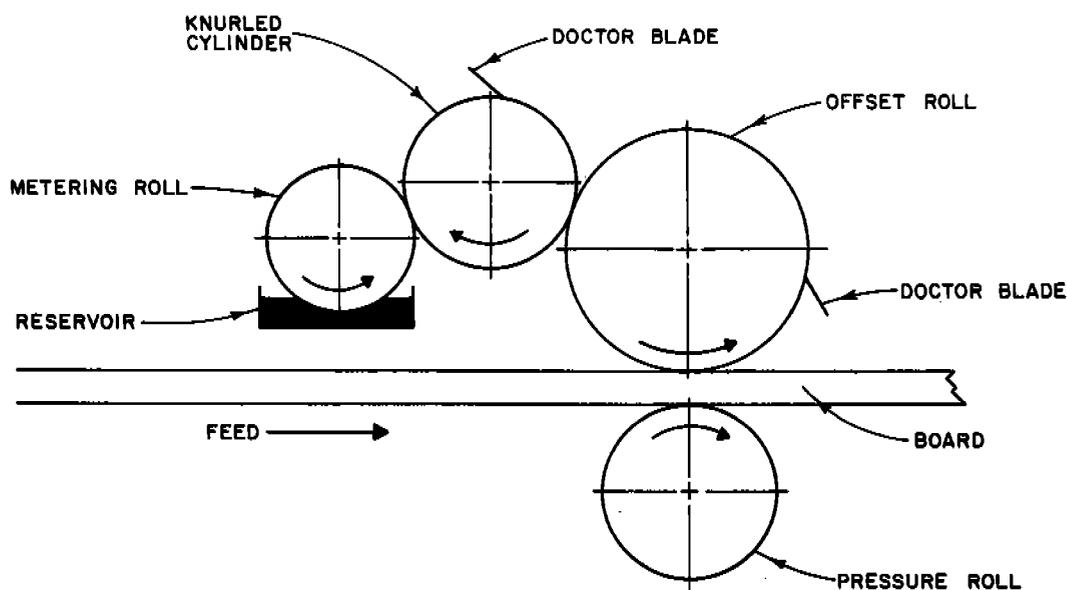
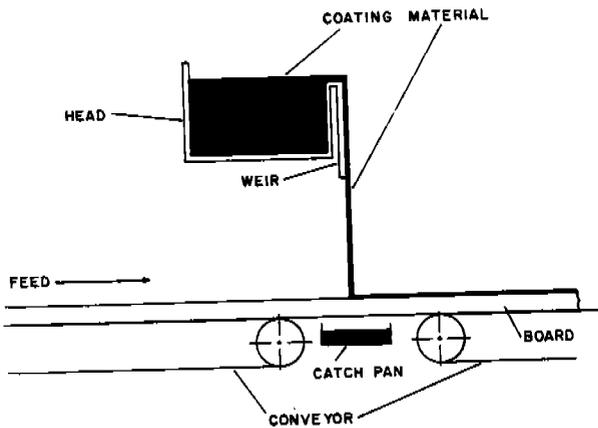


Figure 292—Schematic illustration of precision roll coater.

Suchsland &
Woodson (1986)



293—Schematic illustration of curtain coater.

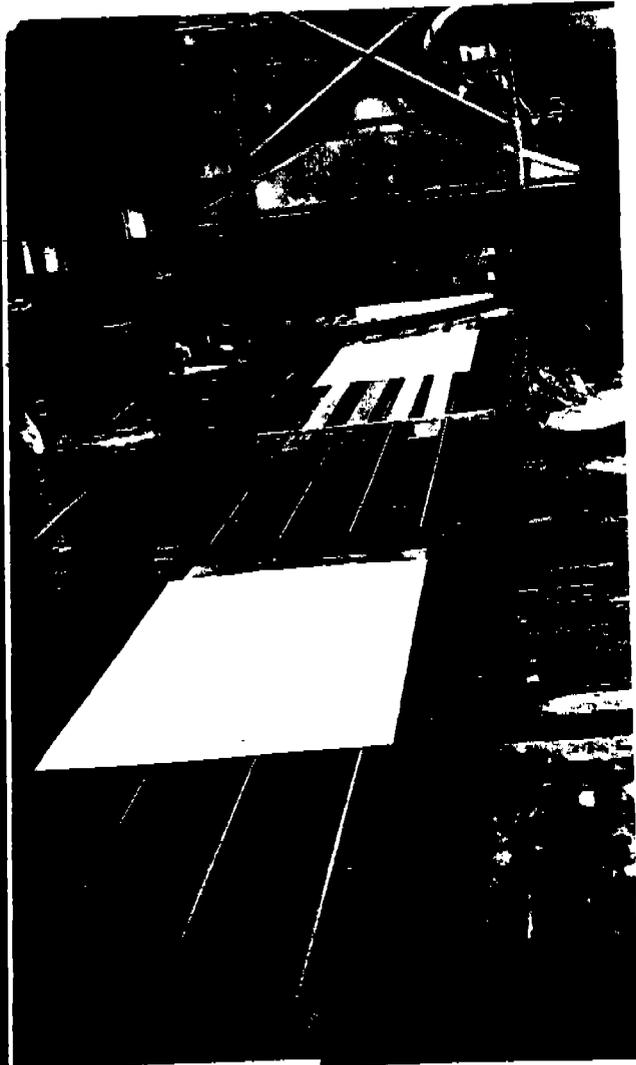


Figure 294—Groundcoat applied to decorative board by curtain coater (under hood).

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,

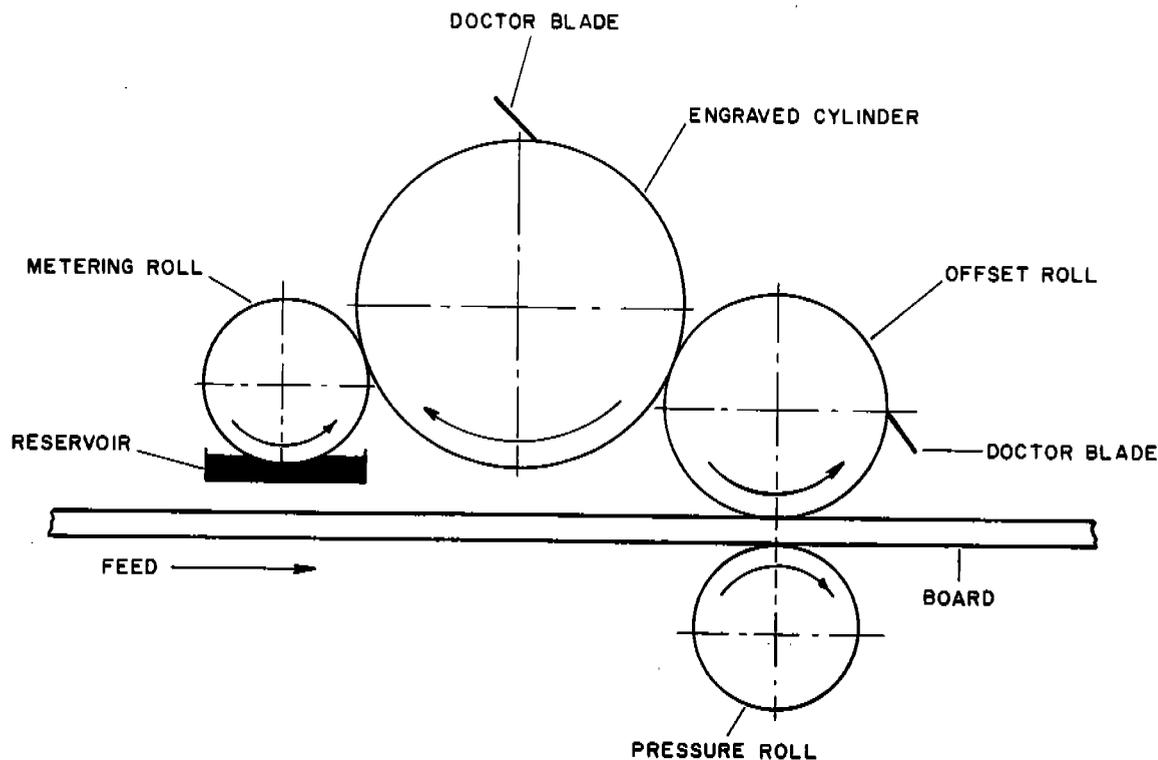


Figure 295—Schematic illustration of offset printer.



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

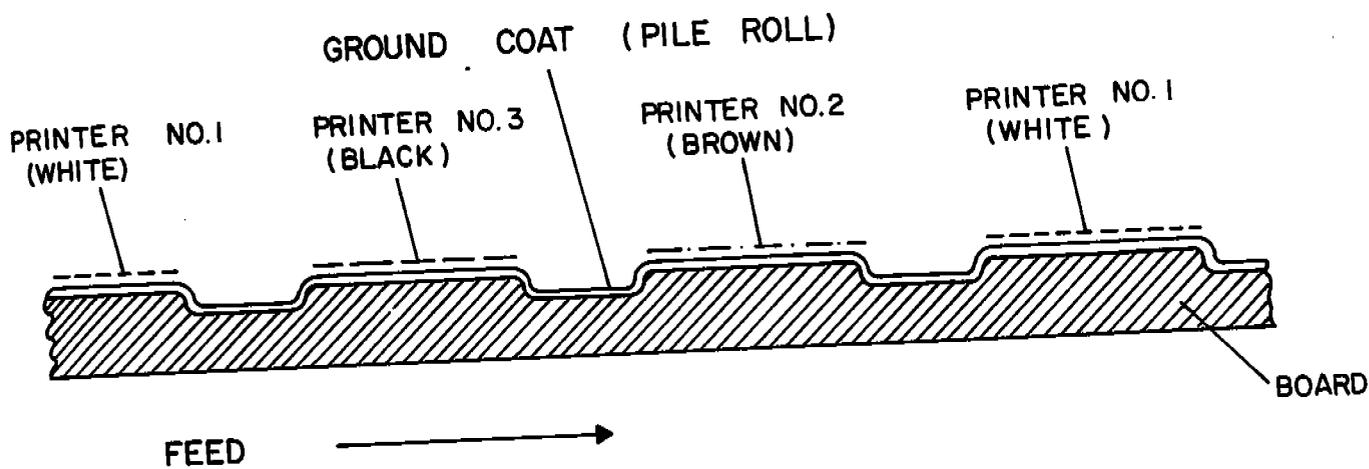


Figure 297—Multicolor printing of panels, to resemble a wall with bricks of three colors, with three off-set printers in series, one for each brick color.



Figure 298—Infrared oven for single pass of 4- by 8-ft board used for the drying of print coat (Thermal Engineering Corp.).

Suchsland &
Woodson (1986)

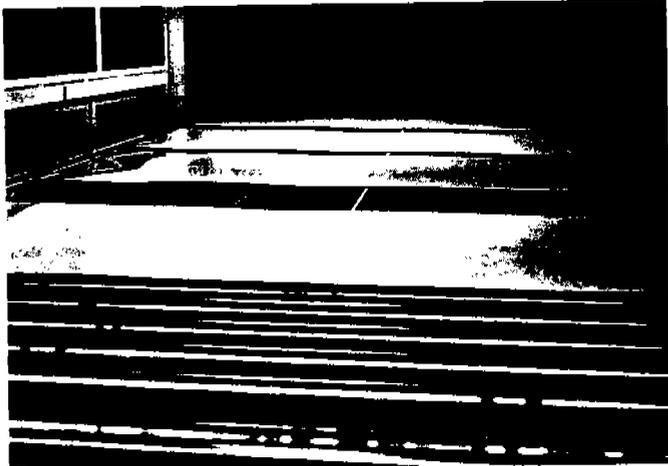


Figure 299—Panels, just after having received top coat, are being exposed to ambient air for evaporation of part of solvent (air flash). This is followed by high-velocity hot-air dryers.



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.)

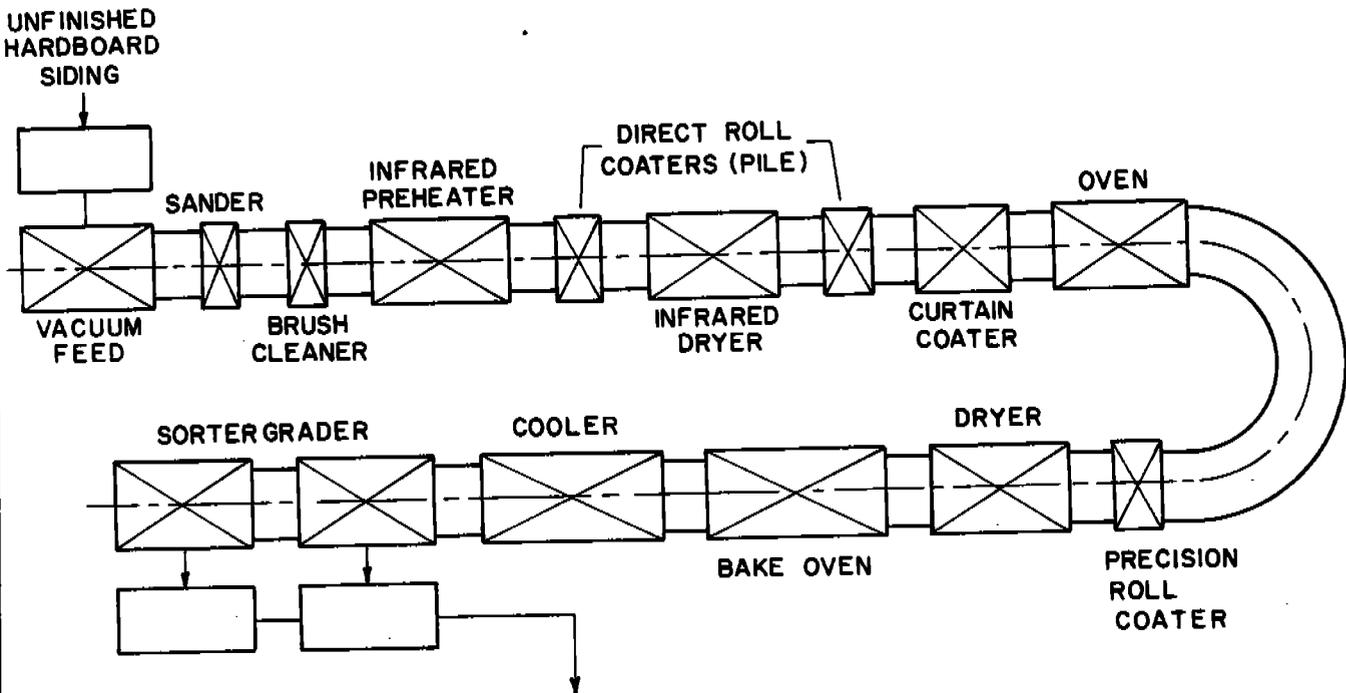


Figure 302—Finishing line for hardboard siding.

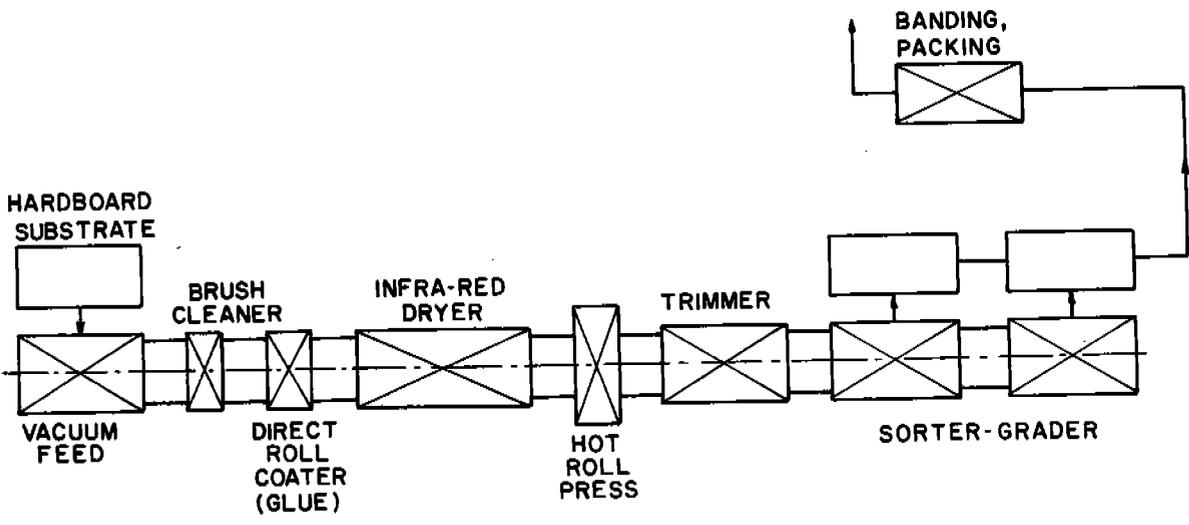


Figure 303—Finishing line for vinyl or paper overlaid hardboard.

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 SIS 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

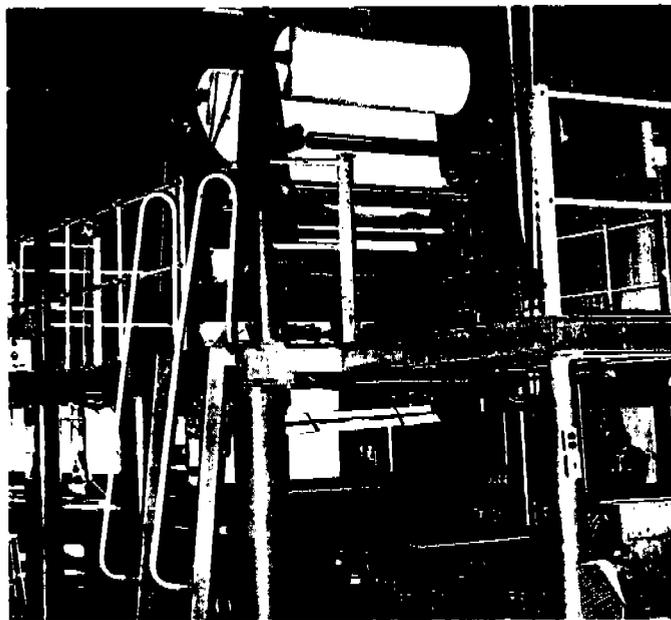


Figure 304—Infeed end of vinyl overlay line. Two rolls of vinyl overlay are visible on top of machine. Material from one roll is being fed down vertically to substrate conveyor where it is applied to adhesive-coated board.

"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).

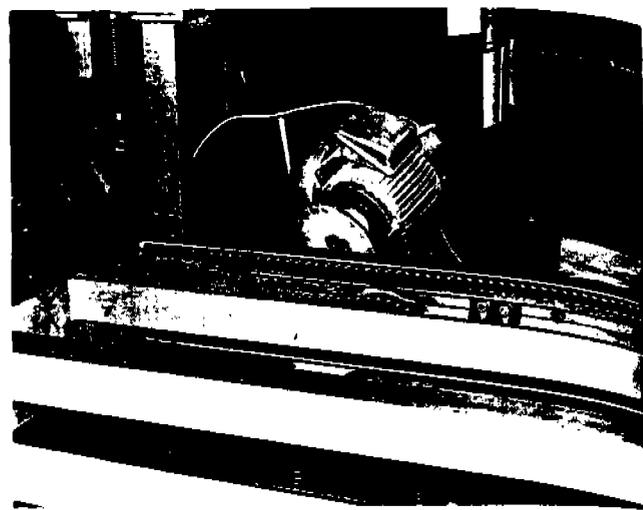


Figure 305—Abrasive wheel for trimming excess overlay along board edges.

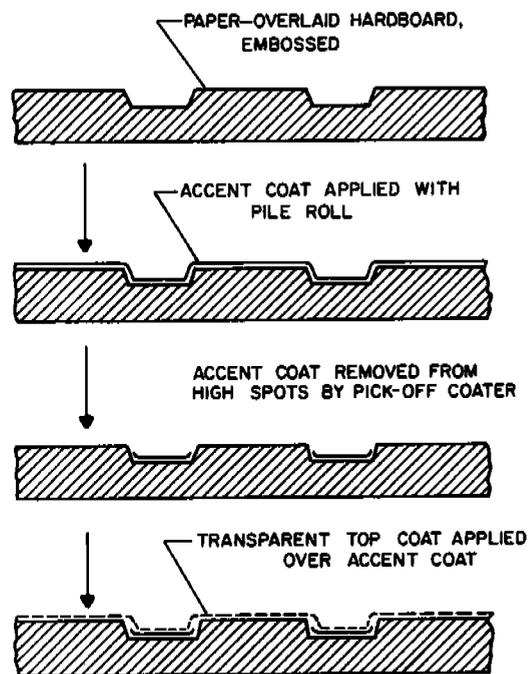


Figure 306—Finishing sequence of paper-overlaid embossed hardboard.

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.

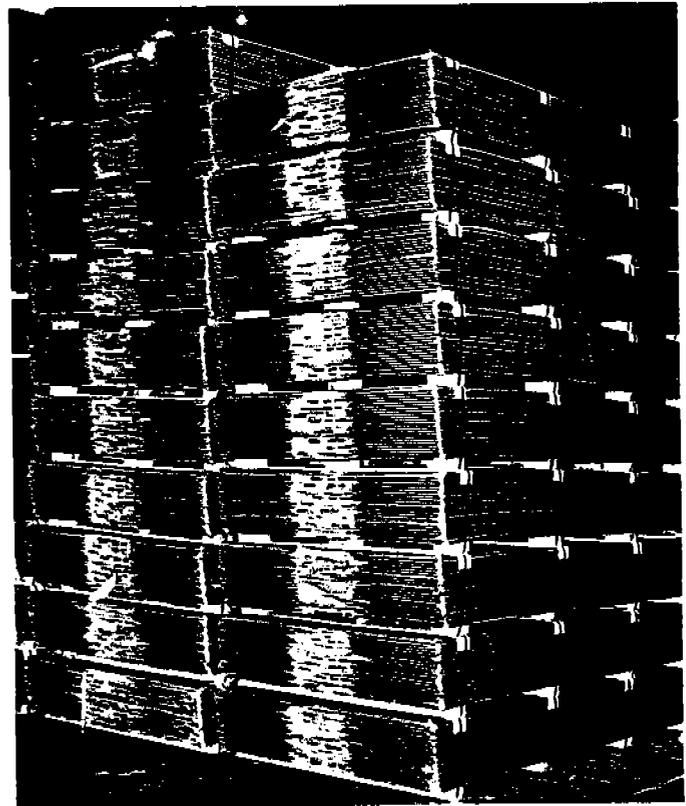


Figure 308—Wrapped and unitized finished hardboard panels. Panels are wrapped individually. Spacer blocks and wood stringers are included in each package to facilitate handling by fork lift truck.

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Suchsland &
Woodson (1986)

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.

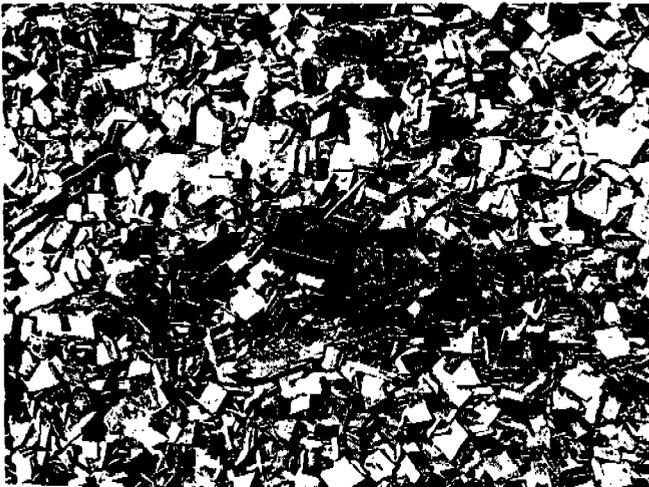


Figure 39—Hardwood pulp chips.

Figure 40 (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 pulp mill (fig. 41).

As an example, a hardboard plant may produce 300 million ft² 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/ft³. 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

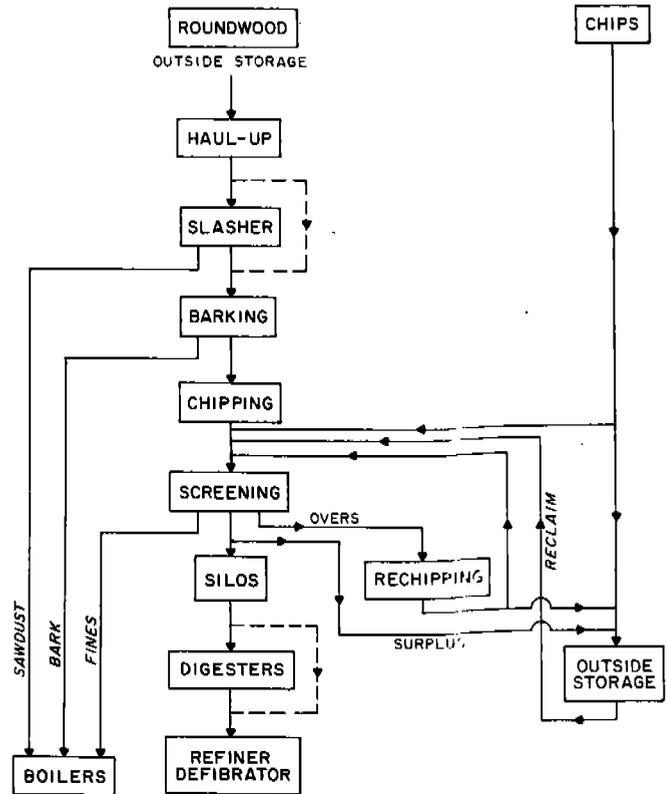


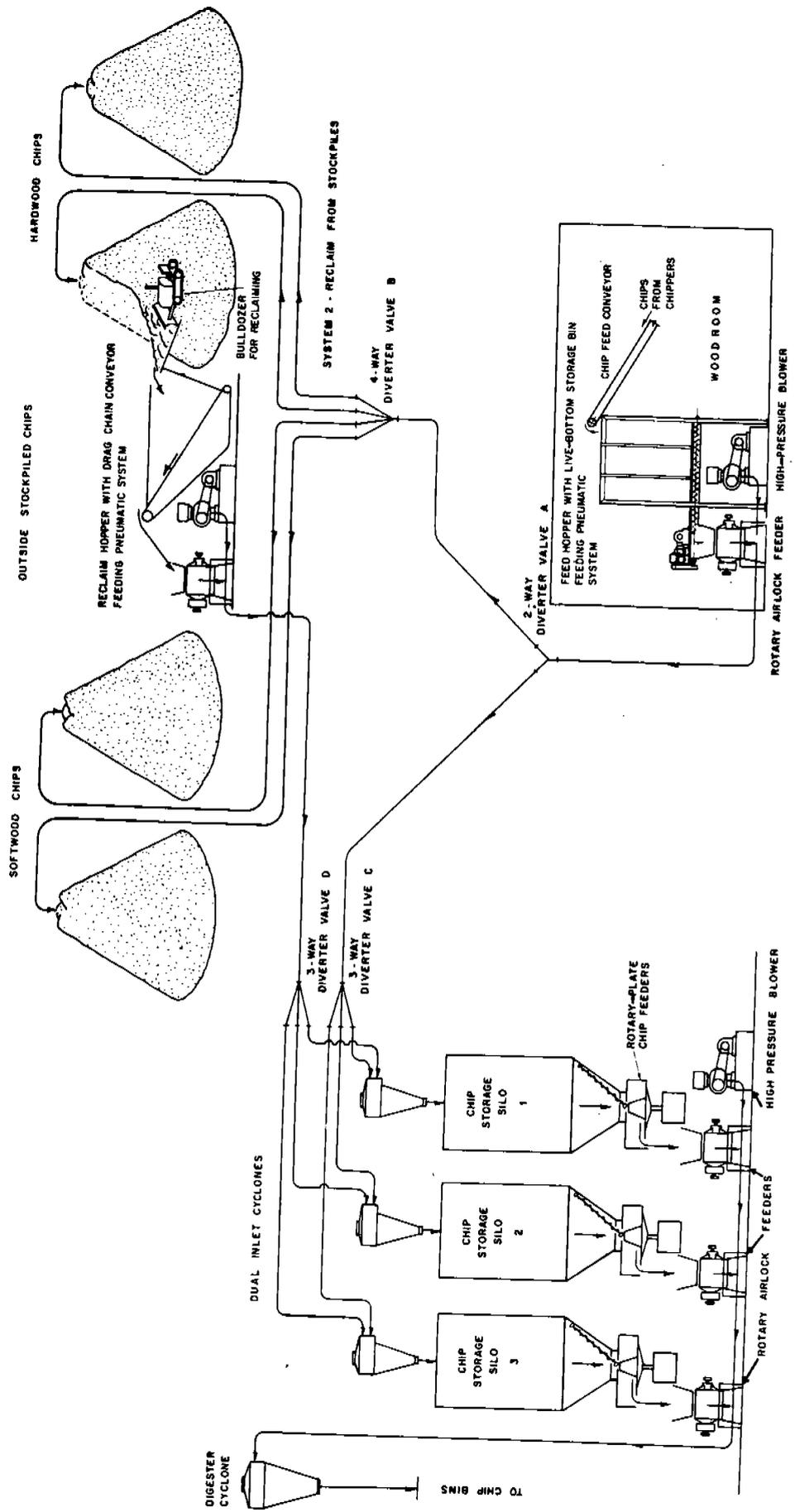
Figure 40—Diagram of wood-preparing operation. (Lamarche 1969).

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 significantly.

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-



SYSTEM 1 - WOODROOM TO STORAGE

SYSTEM 3 - RECLAIM FROM STORAGE

Figure 43—Diagram of typical chip-handling complex showing a typical layout.

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

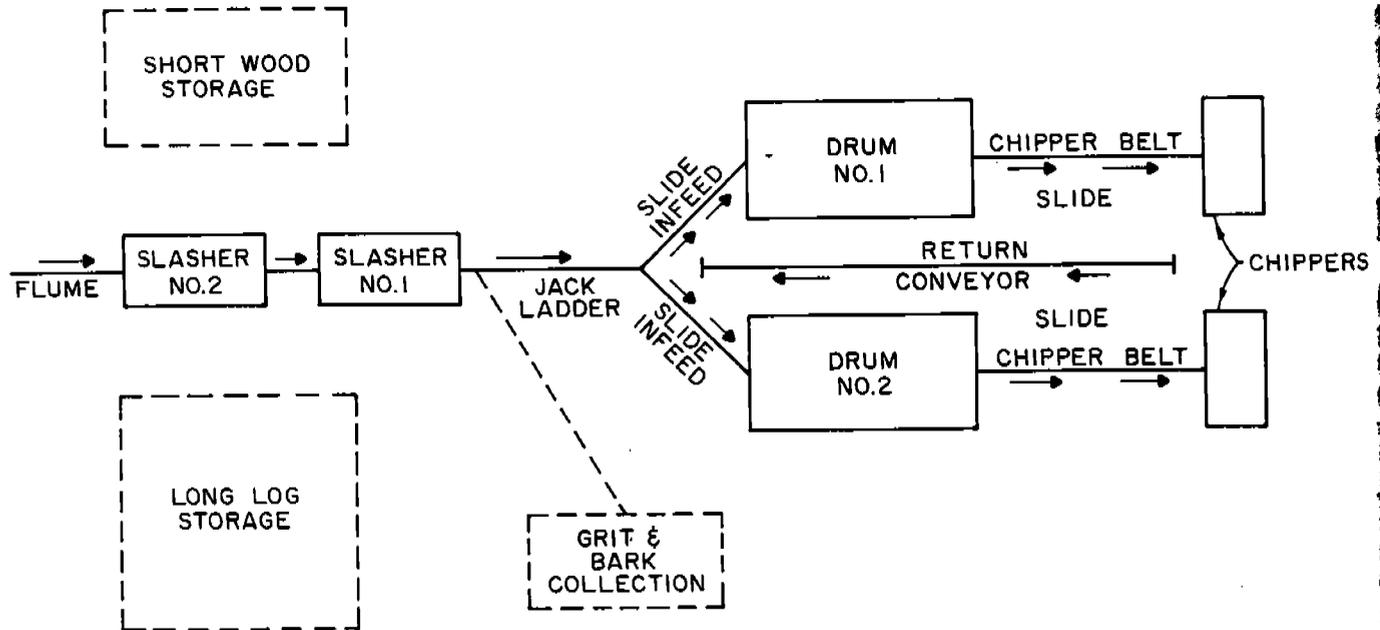


Figure 42—Material flow in woodyard of pulp mill (Gilmer 1977).

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/ft ³	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 1 ¼ 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 44—Scaling truck load of pulpwood.

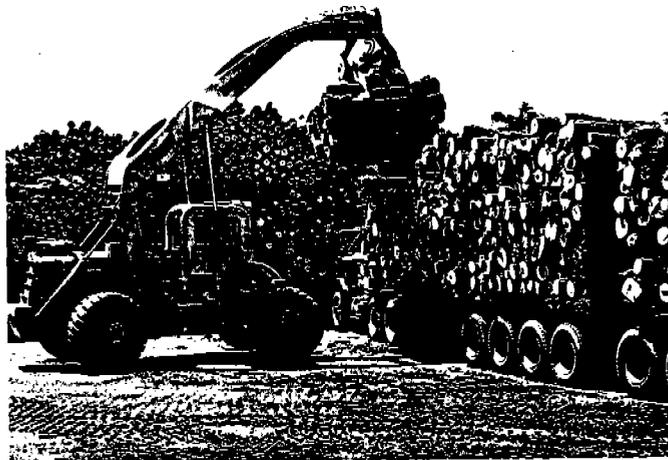


Figure 45—Unloading of truck in woodyard. Total load on truck and trailer approximately 14 cords.

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

Condition of bolts	Solid content (ft ³ /cord)					
	Less than 6 in m.d. bolts		6 to 12 in m.d. bolts		More than 12 in m.d. 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	—	—	—	—

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

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 1/4-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-

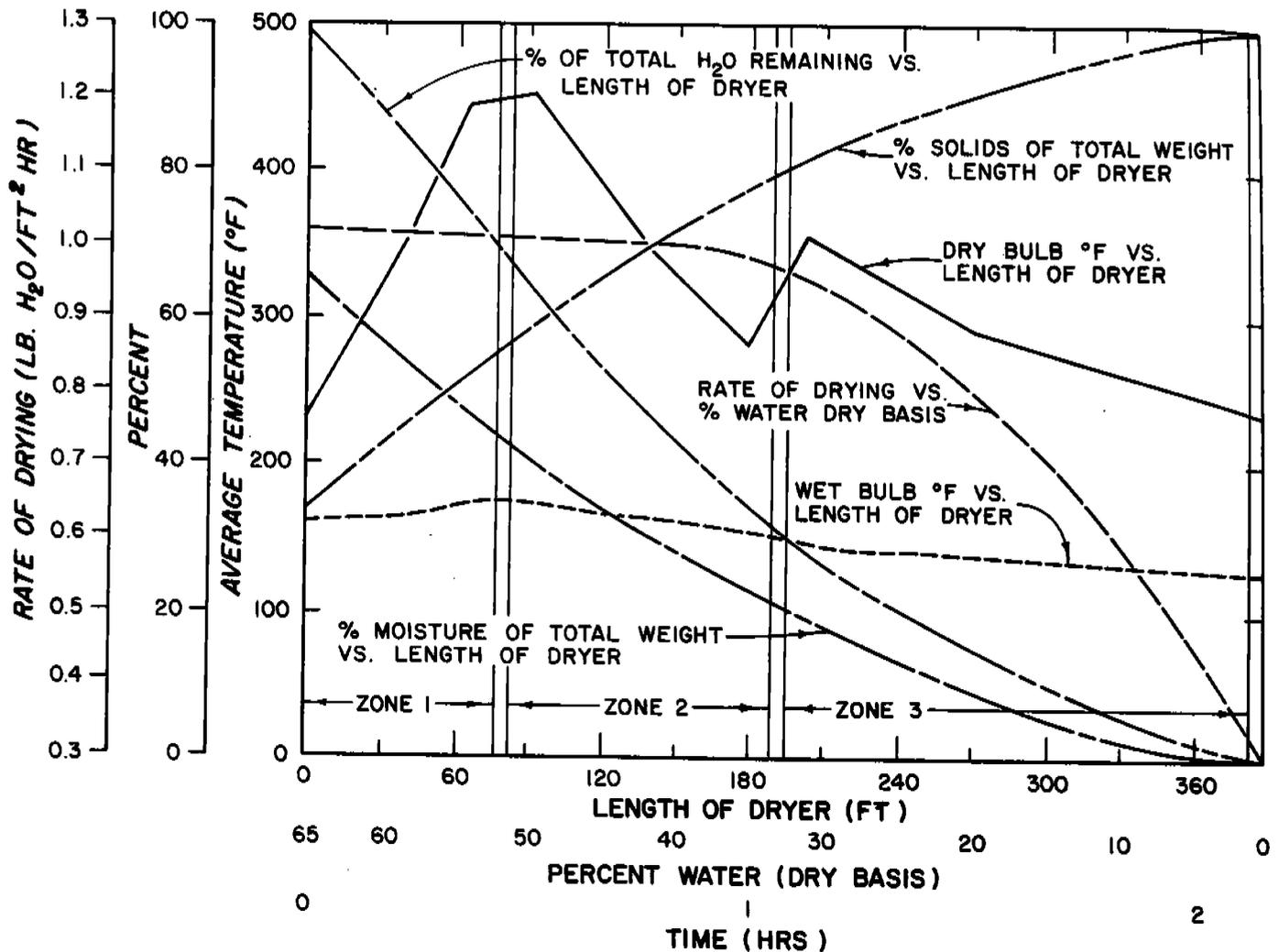


Figure 182—Typical drying curves for a three-zone, gas-fired fiberboard dryer (Lyall 1969).

dryer, where the moisture content is reduced from, say, 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).

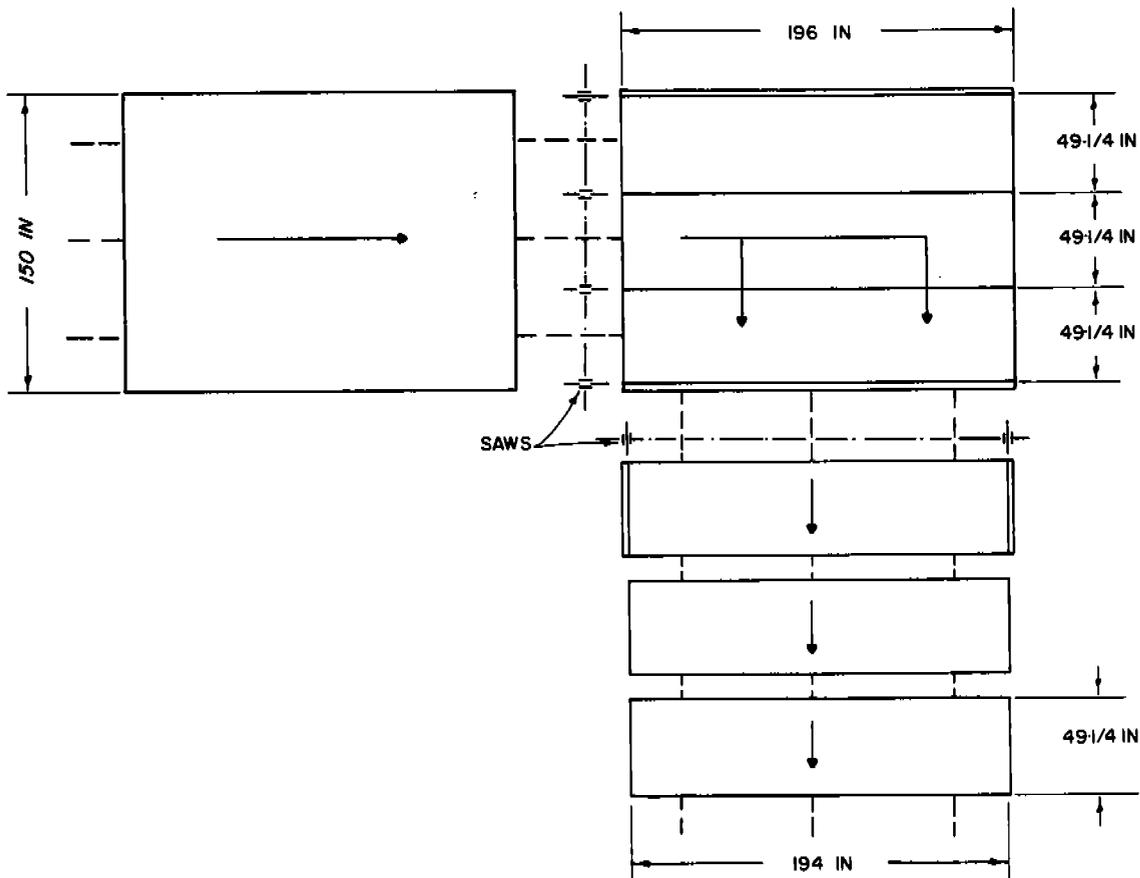


Figure 183—Preparation of 4-ft by 16-ft S2S mats using a double trimmer.



Figure 184—Loading of S2S press. Mats are just entering press. Finished boards show some dislocation.

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 1/4-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 1/4-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, ex-

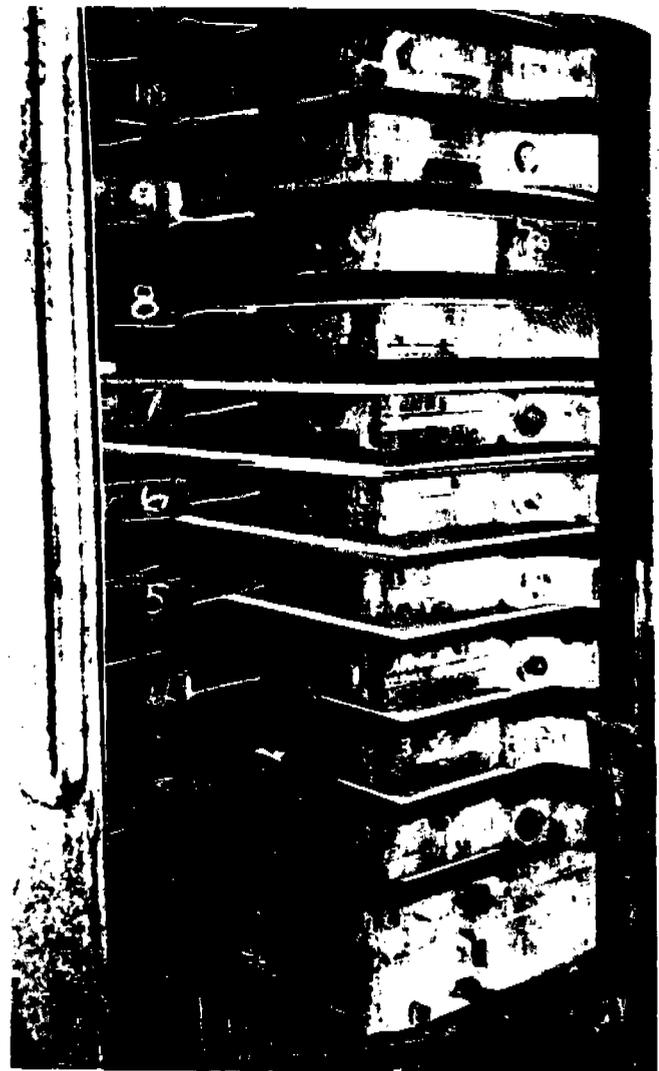


Figure 185—Loading of S2S press. Mats in position are about 1/2 in thick. Press ready to close.

cessive 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.

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

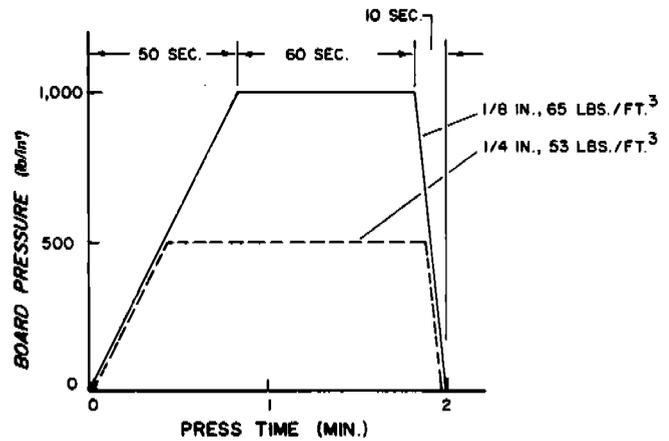


Figure 187—Press cycles for S2S hardboard from hardwood fibers. Press temperature 450 °F.

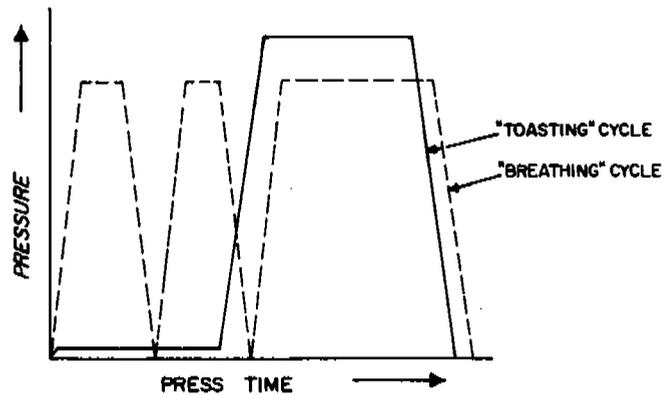


Figure 188—Press cycles for S2S hardboard without predrying.

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/ft³, 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.

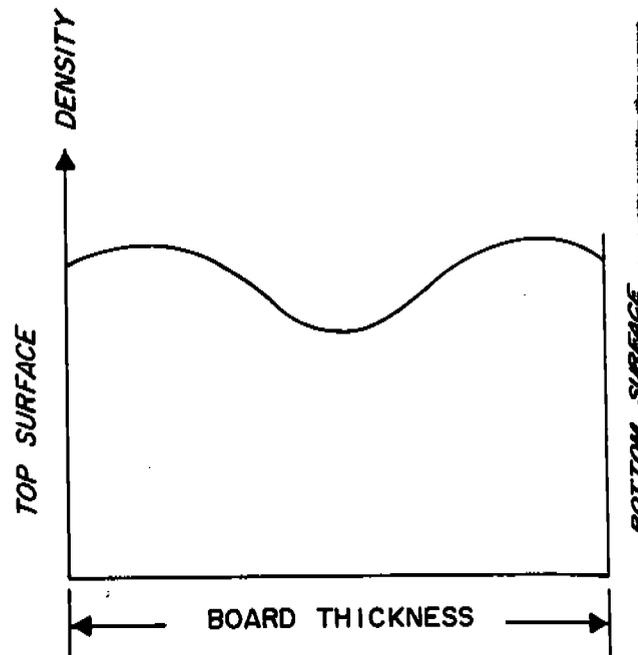


Figure 189—Density profile for S2S hardboard (Spalt 1977).

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S2S Hardboard

Wet Mat



8-stack Dryer



12x16_{ft} mat rigid, low-d.

50% H₂O Mat
1) trimmed
2) intermed. storage to allow for downtime
Predrying or Preheating



~0% H₂O in mat at ~300°F

rigid enough not to need support some

Simultaneously deposited precisely on press platens use caulk plates.*

Mats push out the pressed boards, which float out on emitted gas layer

Hot Press:

- 1) Build up pressure as fast as possible
- 2) Held ~1 min or longer
- 3) Release pressure as fast as escaping gas allows

See also p. 132

* Embossed plate for top caulk to give embossed boards

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 SIS 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.

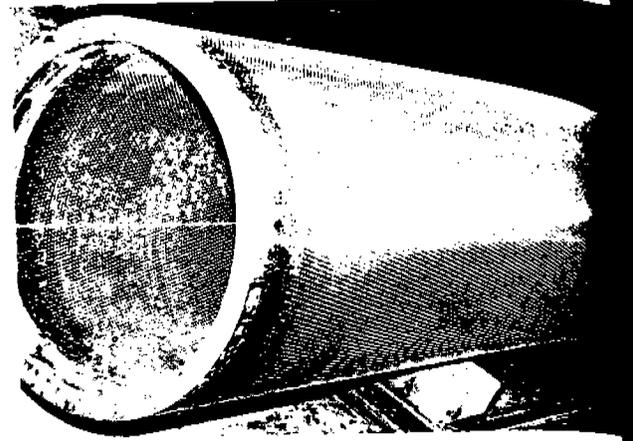


Figure 152—Perforated roll from S2S wet press.



Figure 153—Infeed end of SIS wet press.

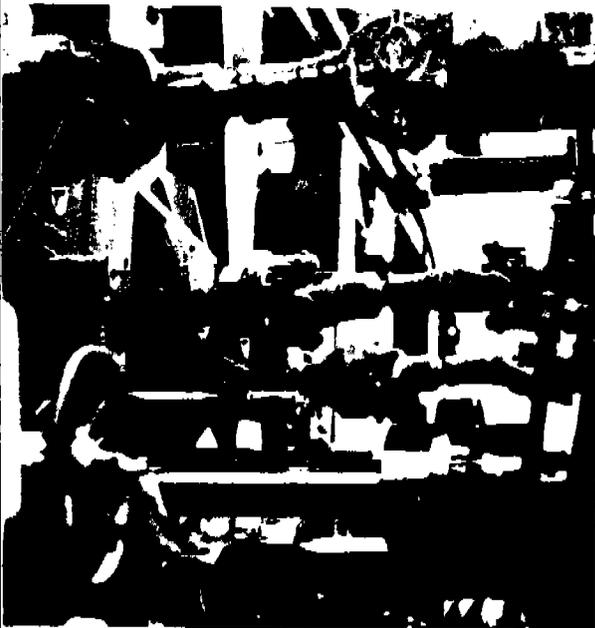


Figure 154—Part of press roll drive of hardboard machine (Edge Wallboard).

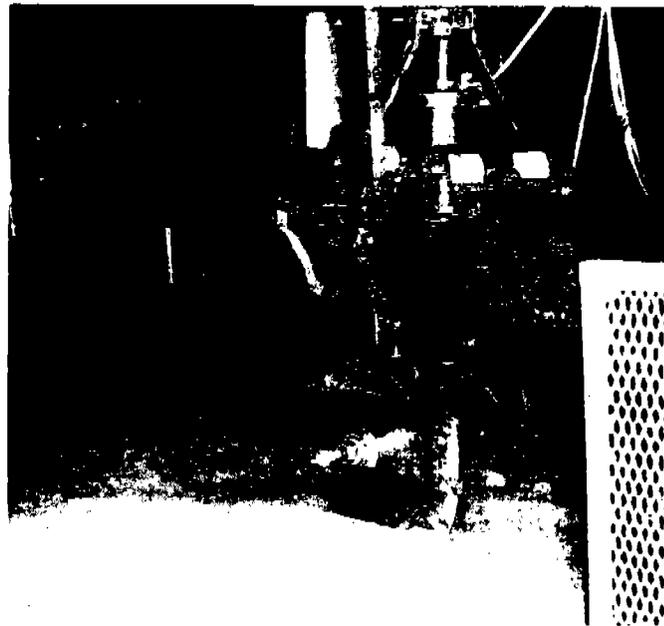


Figure 155—Disk trimmer cutting traveling mat to length. Mat travel is from left to right. Overhead beam travels at same speed and in same direction as mat, while saw travels along beam across mat. When cut is completed the saw lifts up, and beam and saw return to initial position.

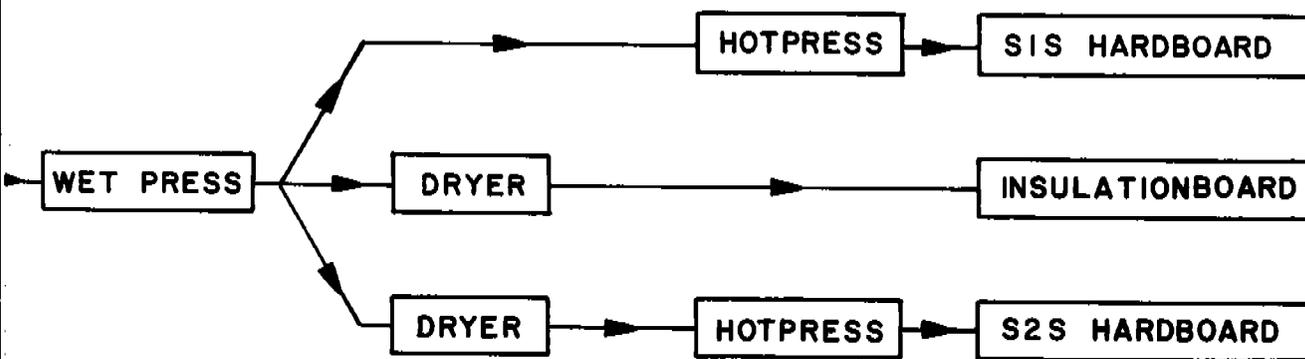


Figure 156—Schematic of processing of wet fiber mats.

Source: Suchsland and Woodson (1986)

- 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 hot-presses 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.

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/in², 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

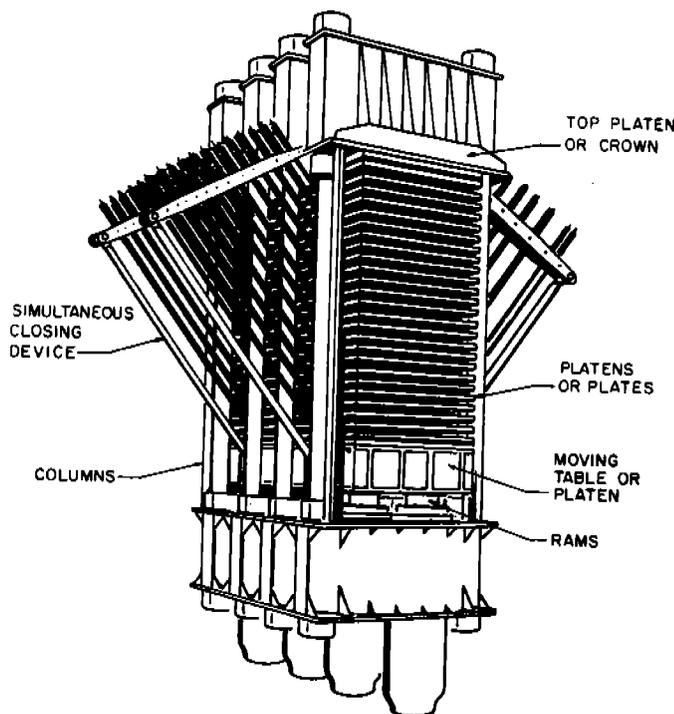


Figure 157—Multi-opening board press (Morse 1967). System of rods on each side of press is designed to lift all platens simultaneously as press table is being pushed up by rams. All openings thus close at the same rate.

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/in². To provide a specific pressure of 1,000 lb/in² 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

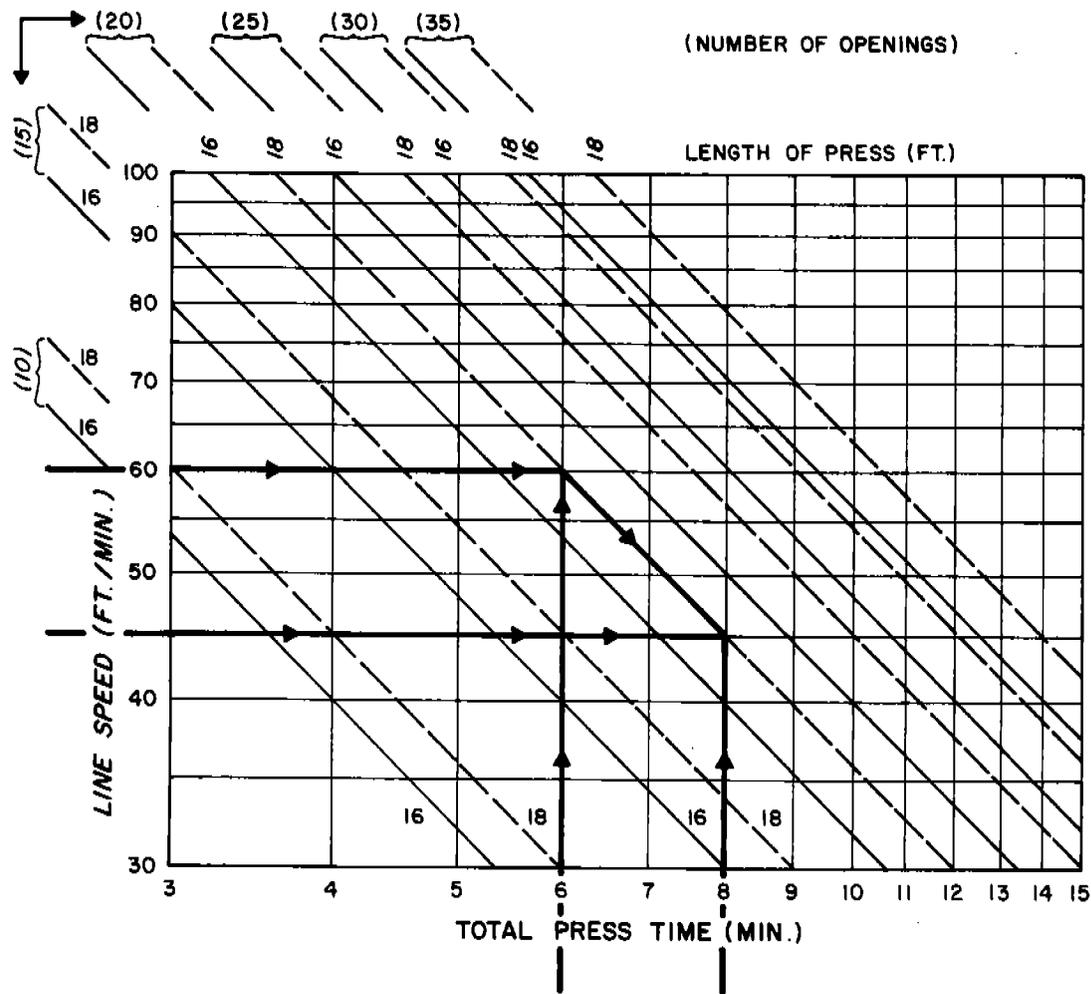


Figure 158—Illustration of relationship between line speed, press time, and press size. Example: The production given by a line speed of 60 ft/min (left scale) and press time of 6 min (bottom scale) requires 20 press openings, 18 ft long (top scale). If the press cycle were increased to 8 min, the line speed would have to be reduced to 45 ft/min.

Hot Pressing SIS Fiberboard

65-75% ^{to} Mat _{water} H₂O: dry fiber ratio ~ 2:1

Phase I High-Pressure Squeeze
800-1000 lb/in.²
(min. 400 for low-d. boards)

1.5 min. ~~End:~~ All squeezable water out
Final temp. 212°F
remaining water

Mat 1:1 ratio

Phase II Drying
80-100 lb/in.²

3-4 min. End: When visible steam emissions end

Mat < 80% H₂O

Elim'd if
Final board
d. < 55 lb/ft³

Phase III Densification & Fiber Bonding
400-500 lb/in.²

2-3 min. End: Final moisture content

Mat 0.5-1.0% moisture

Total press time 6-8 min. for 1/8" hardboard
+ ~~loading~~ + unloading @ 1.5 min/cycle
↑ ~ 8 press loads/hr
[6.3-8.00]

SIS Pressing
+ Drying the mat
wet

Suchsland & Woodson
(1986)

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_o . 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.

SIS 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

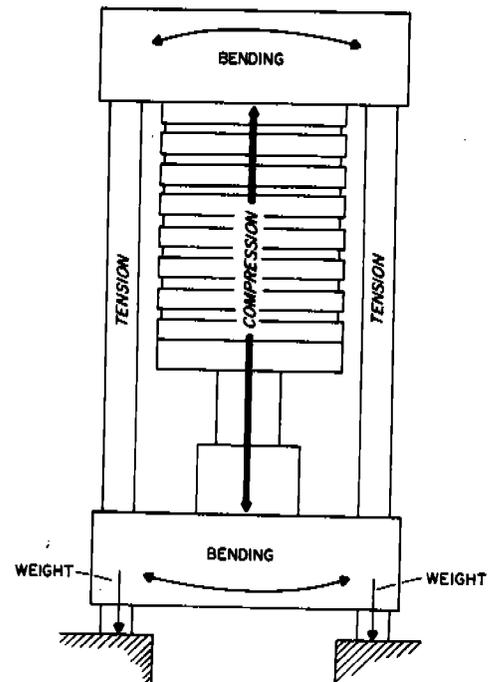


Figure 159—Forces and bending moments in hydraulic press.

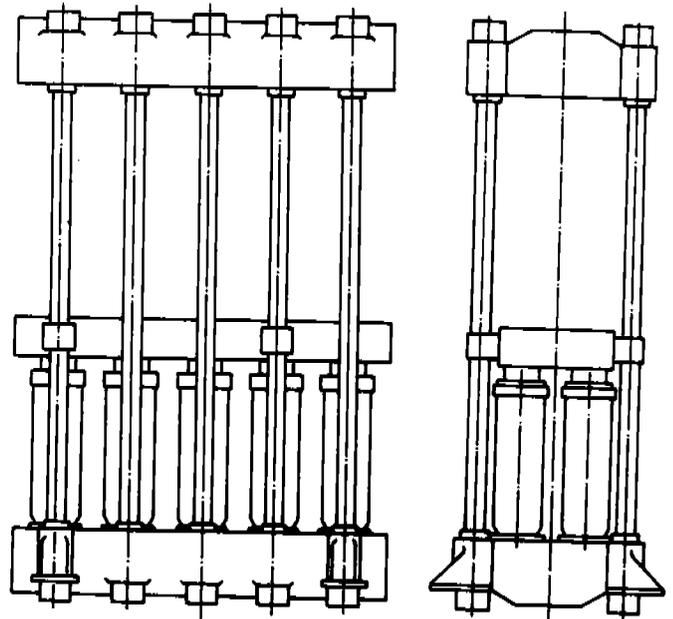


Figure 160—Column-type hydraulic press (Hedin 1970).

Have used
112-115 Hot pressing + Drying

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

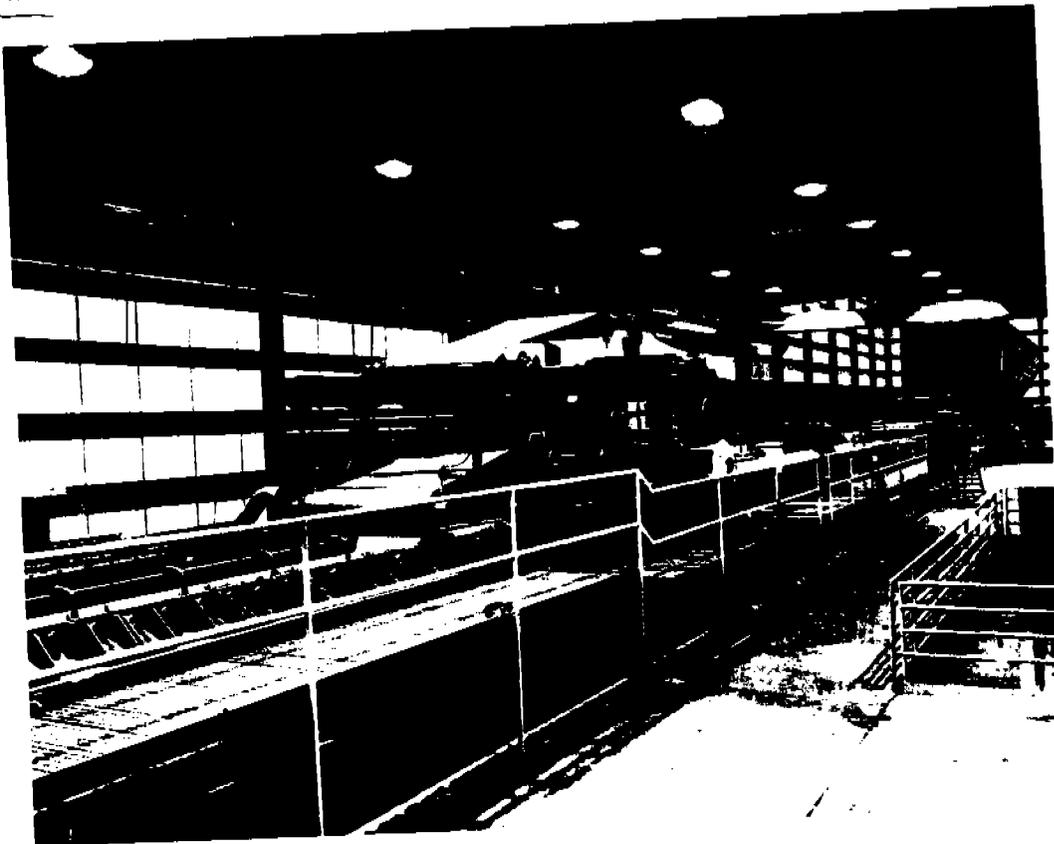


Figure 165—Siempelkamp wet-process hardboard press line in western SIS fiberboard plant (Siempelkamp 1980).

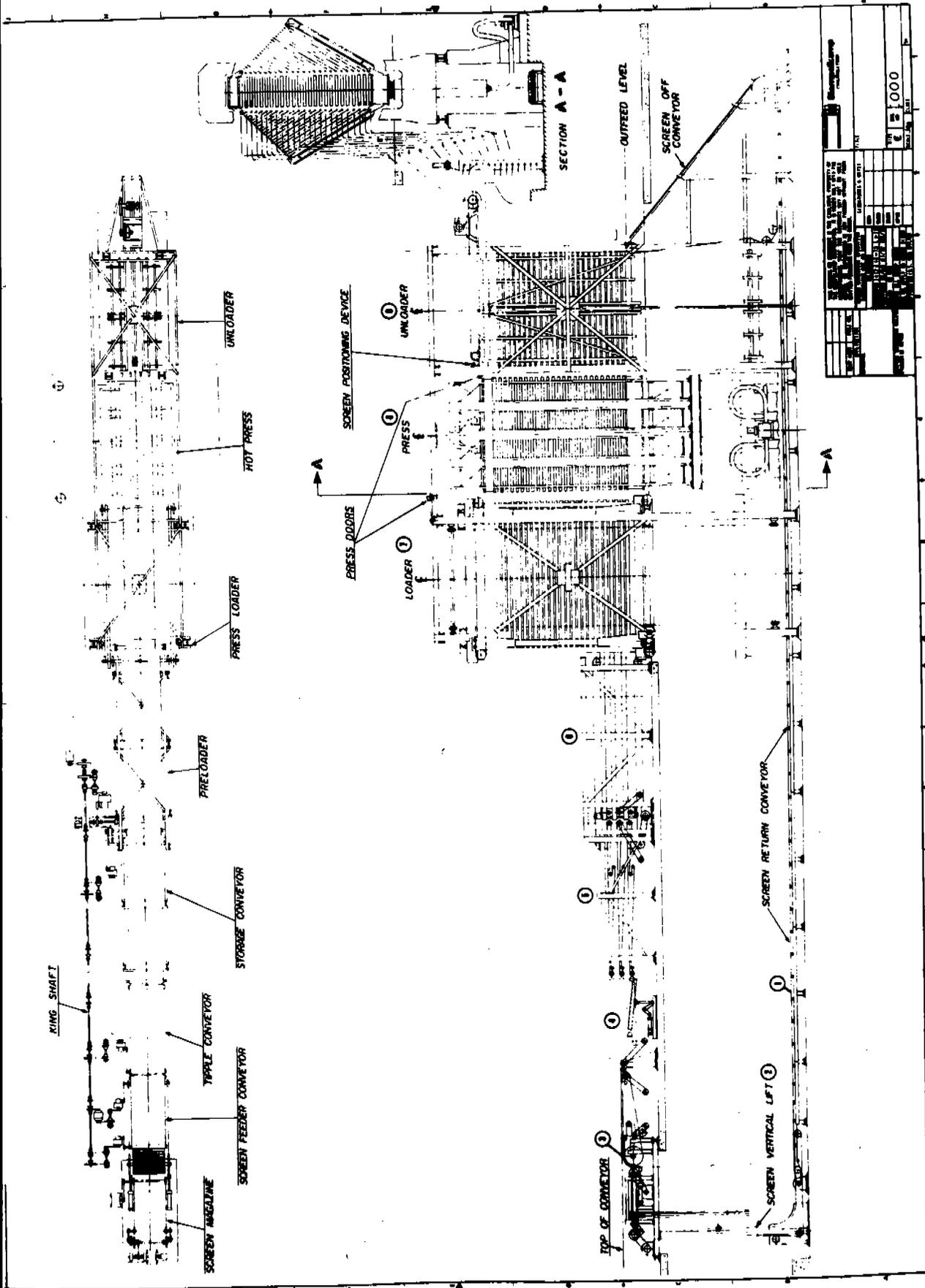


Figure 166—Layout of Siempelkamp SIS hardboard press line (Siempelkamp 1980).

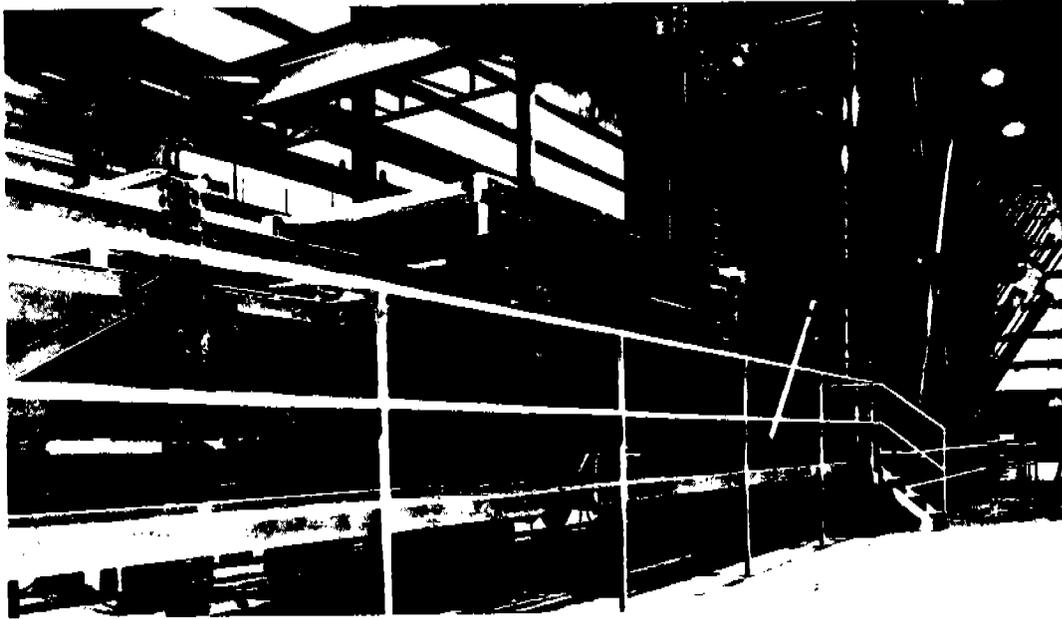


Figure 167—Siempelkamp SIS hardboard press line, showing storage conveyor, preloader, loader, and press (Siempelkamp 1980).

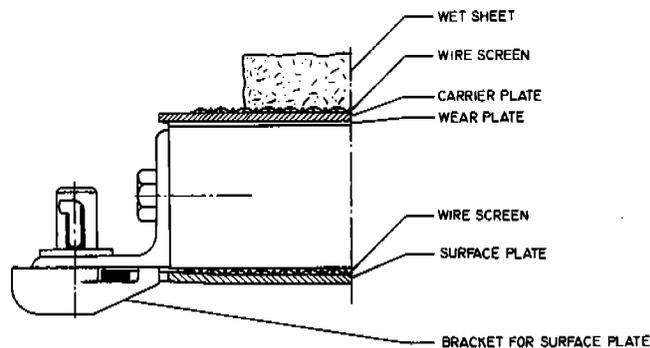


Figure 168—Arrangement of mat, screen, and caul plates in SIS hotpress (Hedin 1957).

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.

① 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 platens. This deposits the screens on the press

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 a roller or belt conveyors.

② 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/in², 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/in². Pressure levels in excess of 1,000 lb/in² 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 viscosity.

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

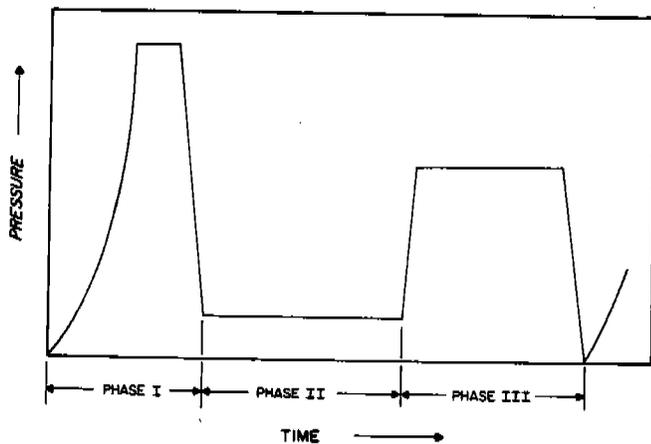


Figure 170—Typical SIS hardboard press cycle.

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/in², 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/in². 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/ft³, 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/ft³ 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-

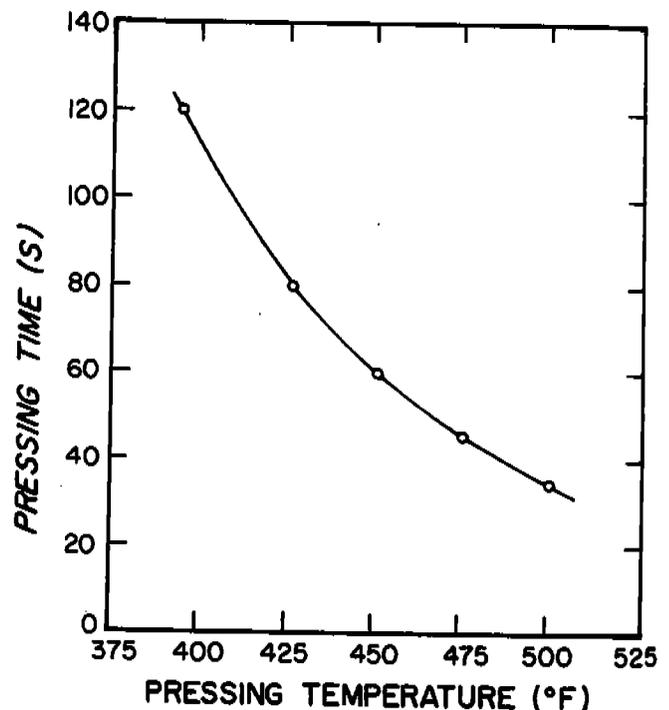


Figure 171—Effect of press temperature on press time for dry-formed hardboard (Steinmetz 1970).

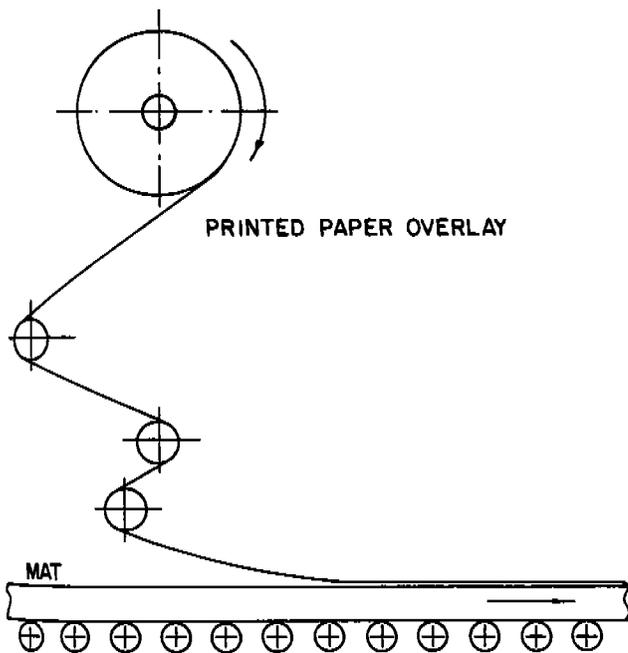


Figure 172—Application of printed overlay to wet mat prior to hotpressing.

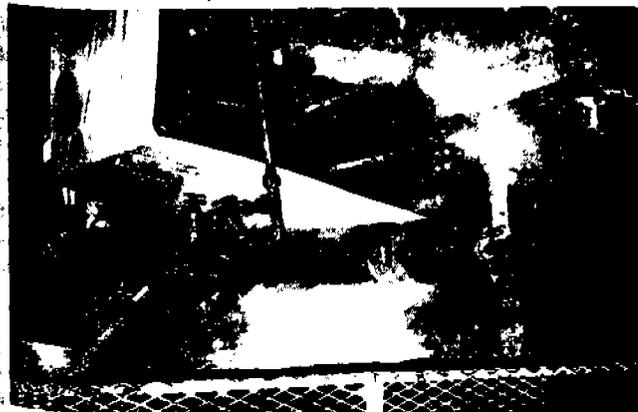


Figure 173—Paper overlay being applied to wet mat.

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.

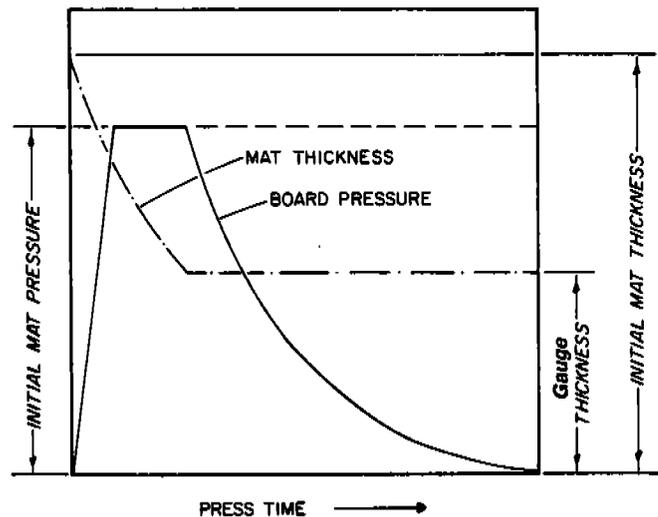


Figure 174—Pressing to stops: board pressure and mat thickness as functions of press time.

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.

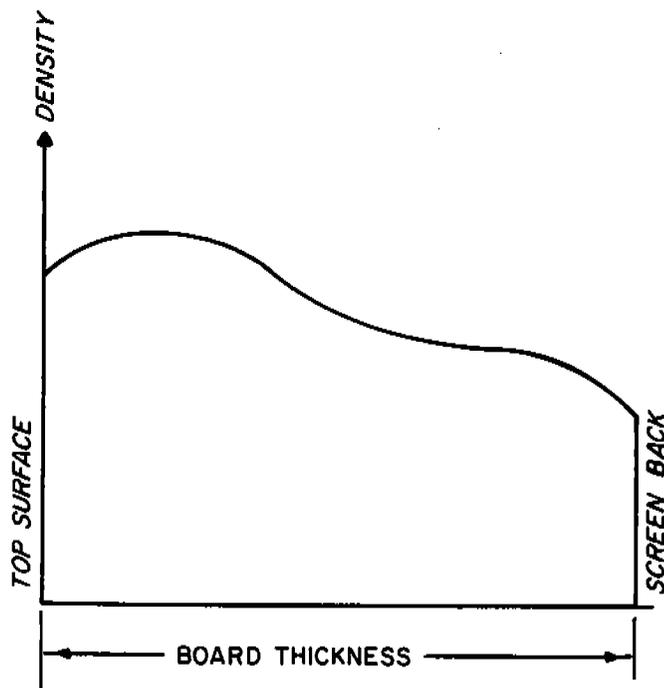


Figure 175—Density profile of SIS hardboard (Spalt 1977).

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 SIS 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.

New topic: S2S; No dryer for S2S board

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).

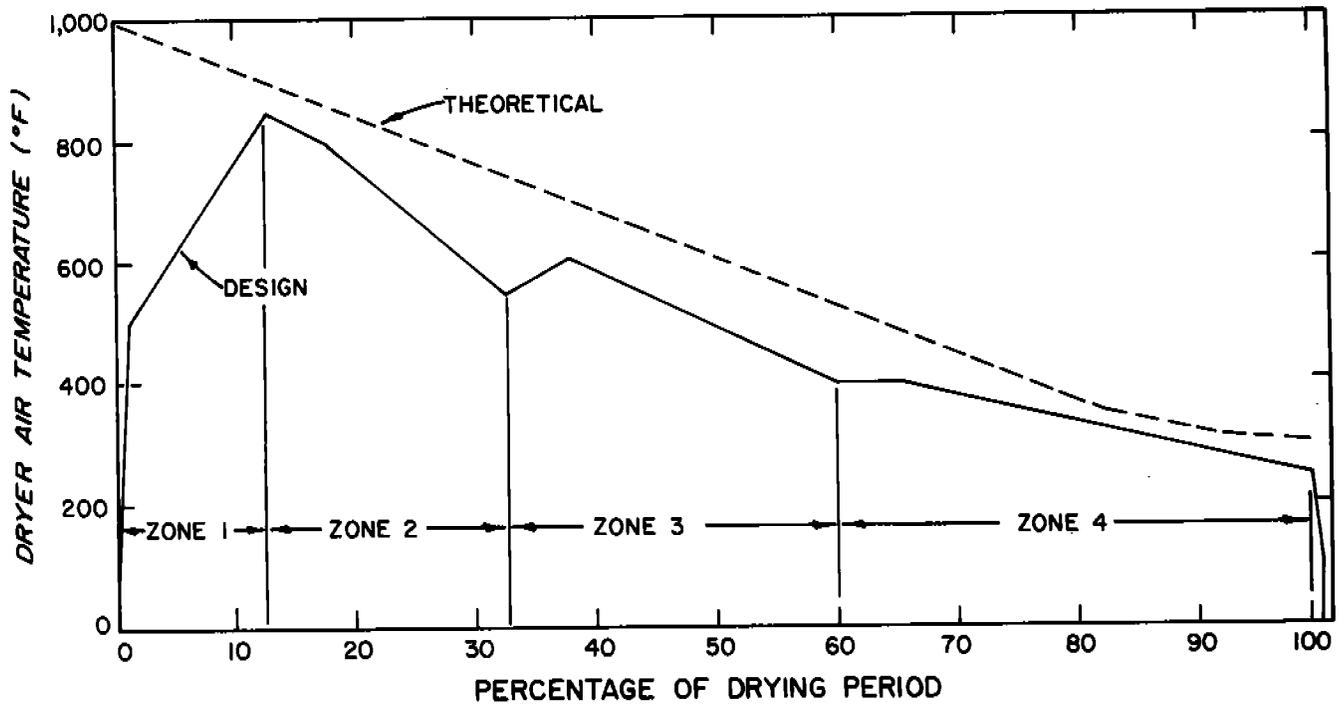


Figure 176—Ideal (theoretical) and actual (design) temperature distribution in four-zone board dryer (McMahon).

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 ft³/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 ft³/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 ad-

justable 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 tippie is ready to charge deck 5. The previous mat in deck 5 is just leaving the speed-up section of the speed-up section, this particular conveyor will shift to the speed of the tippie (40 ft/min) and will run at this speed until the mat has left the tippie and has caught up close to the previous mat. In the meantime the next mat has entered the tippie and will reach the end of the tippie 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 tippie 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

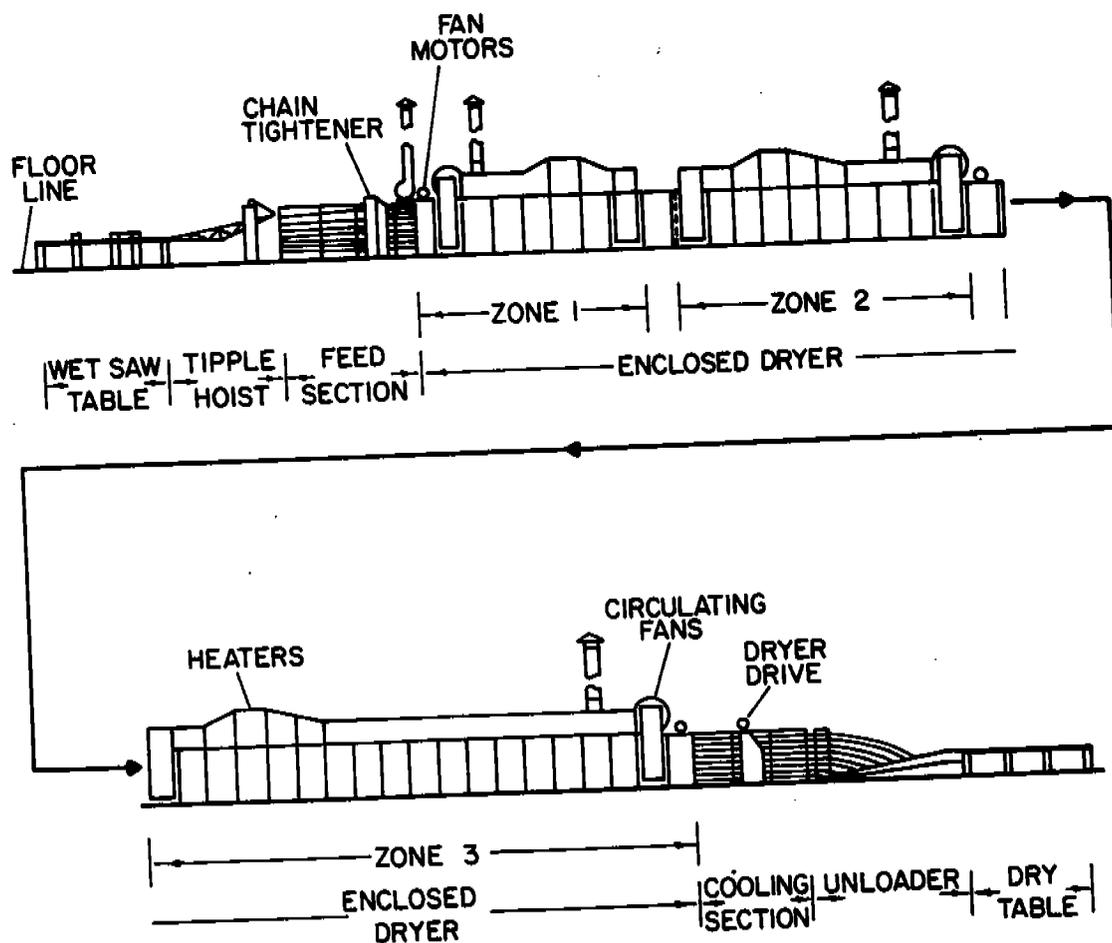
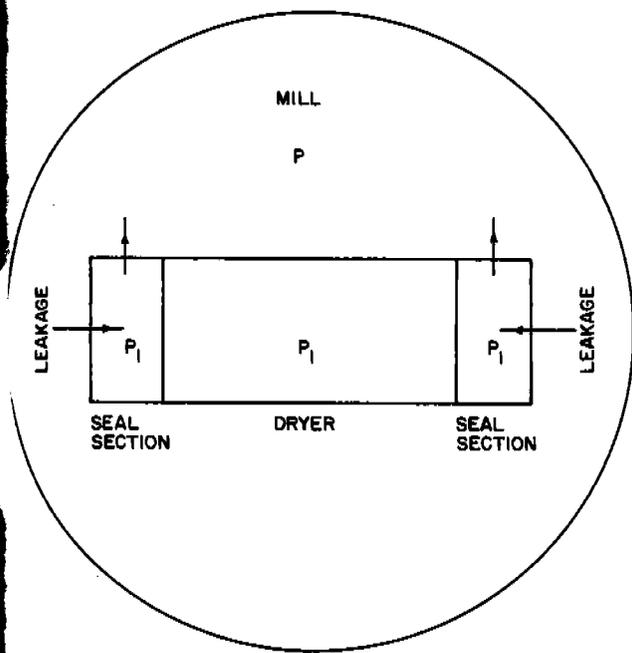


Figure 177—Gas-fired board dryer (Lyll 1969). Mats enter dryer at top left. Heaters and circulating fans are mounted on top of drying chambers. First zone is a high-temperature zone with countercurrent flow. In zones 2 and 3, air flows in direction of mat travel.



P = Air pressure in mill
 P_1 = Air pressure in dryer $P_1 < P$

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.

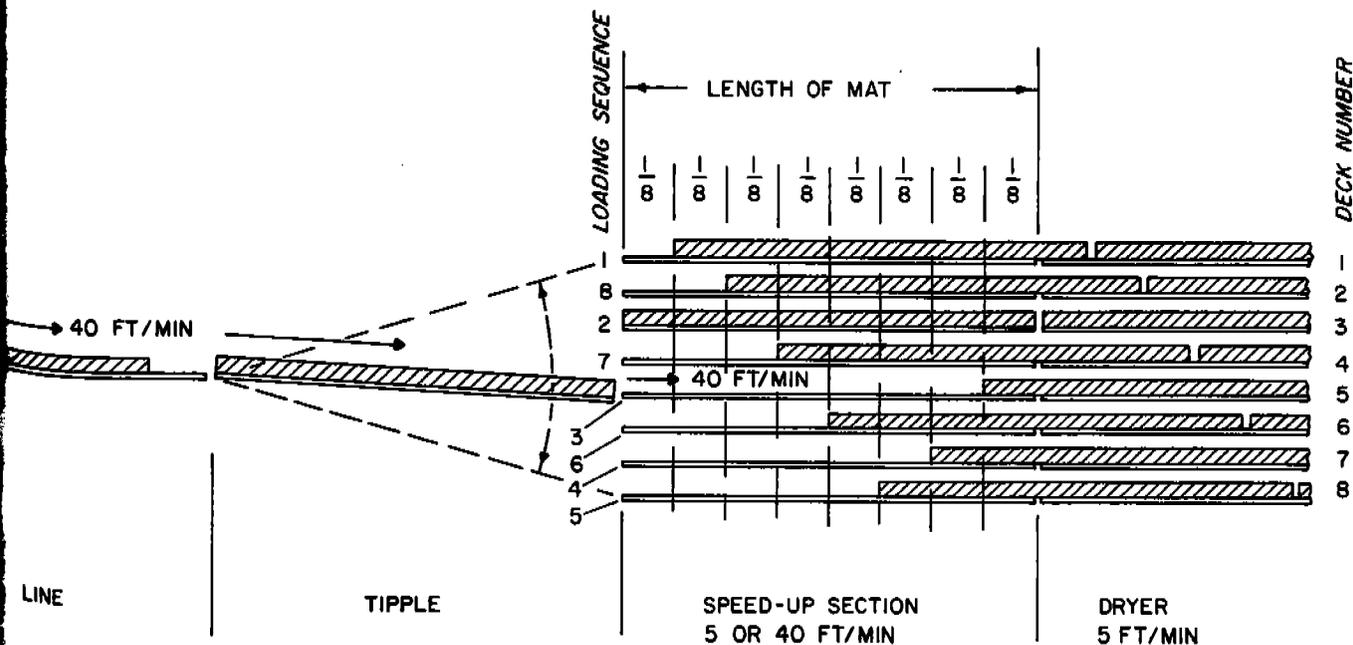


Figure 179—System of loading 8-deck dryer reduces mat speed from 40 to 5 ft/min without causing gaps between individual mats.

The heat energy required per hour can be calculated following equation (Jessen 1952):

$$K = A \cdot \left[(t_e - t_l) \cdot \left(c + \frac{b}{100 + b} \right) + \left(\frac{a}{100 - a} - \frac{b}{100 - b} \right) \cdot (1182 - t_l) \right]$$

- 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 ($^{\circ}\text{F}$),
 t_l = temperature of material leaving dryer ($^{\circ}\text{F}$), and
 c = specific heat of material (British thermal units per $^{\circ}\text{F}$ 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-

mat?? insulation board

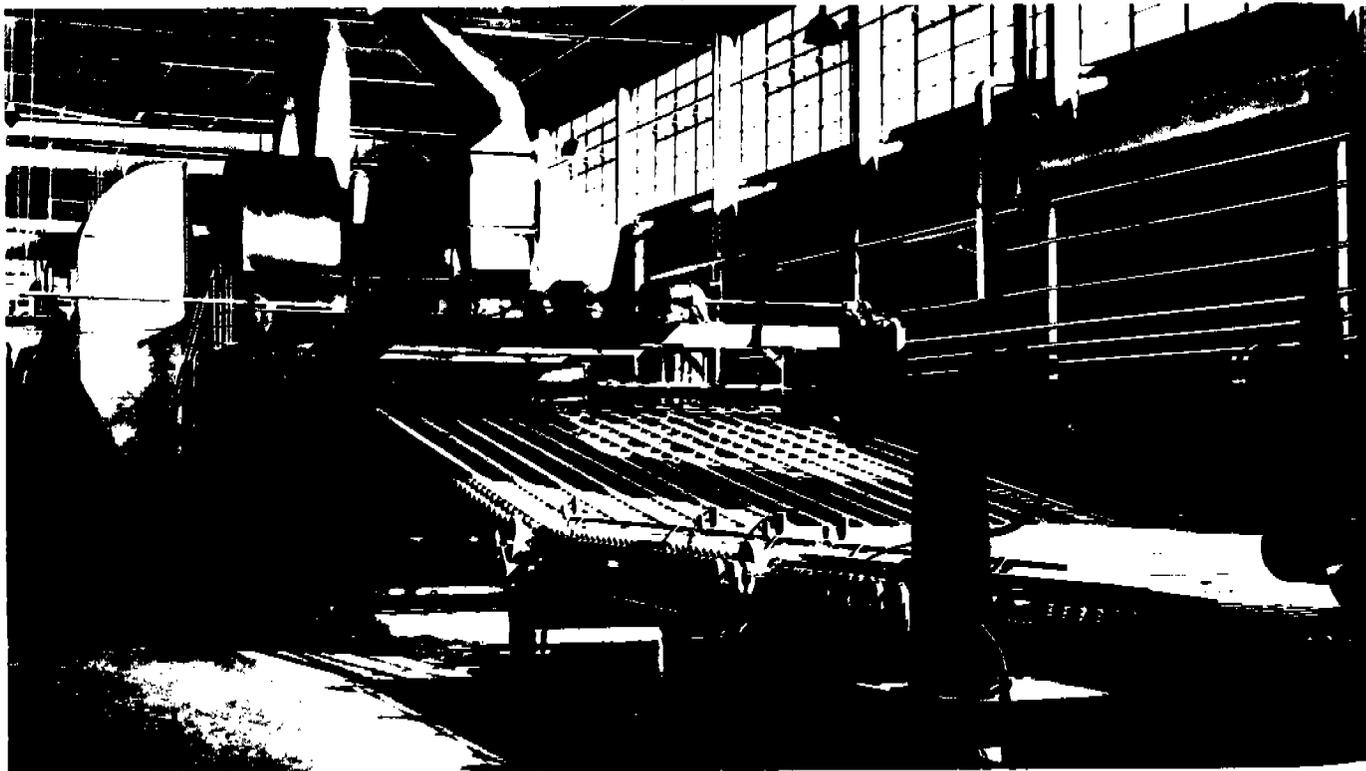


Figure 180—Fiberboard dryer, tipple loader (Coe).

Suchsland &
Woodson (1986)

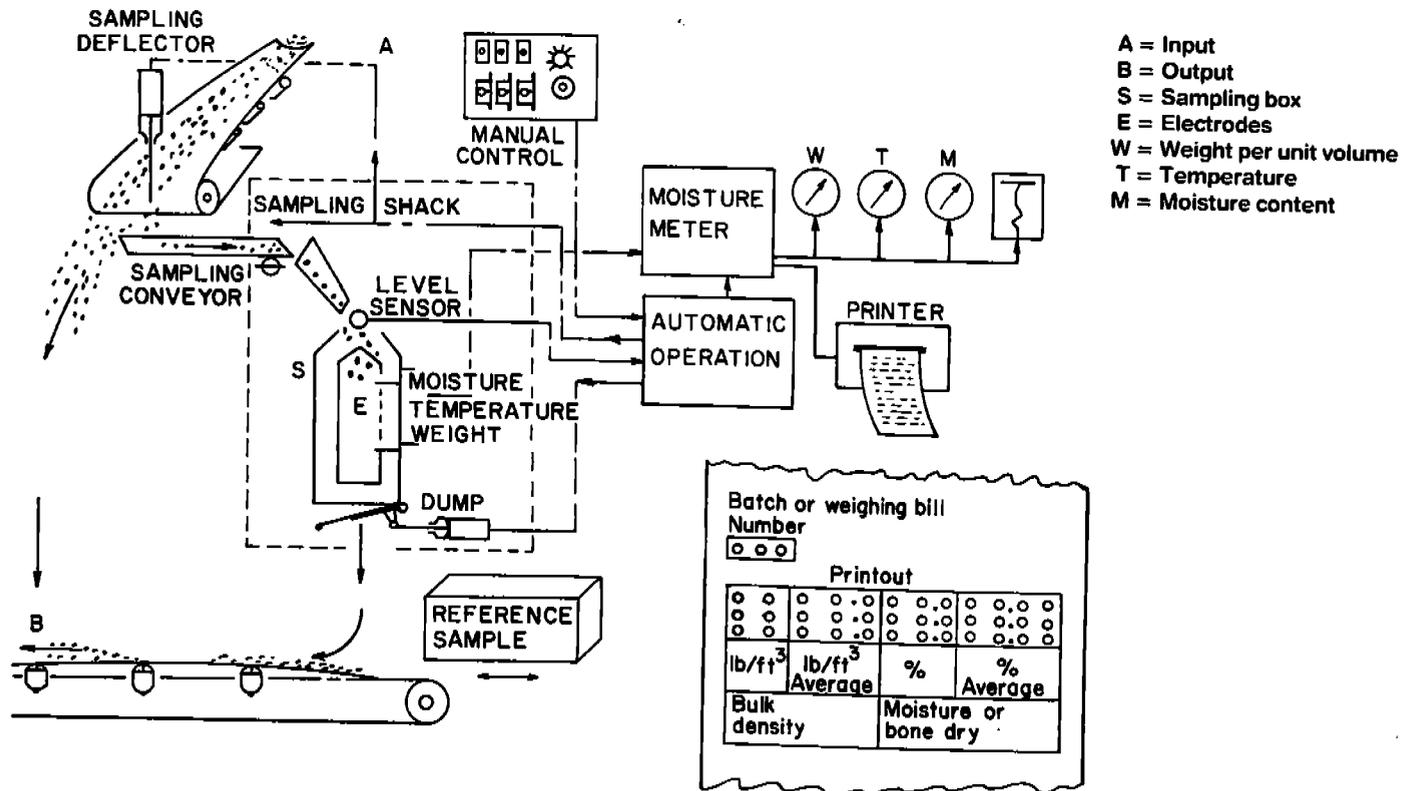


Figure 61 — Chip moisture meter with automatic sampling configuration and digital averaging and print out circuitry (Wilhelmsen and others 1976). (© 1976 TAPPI. Reprinted from Tappi Journal, August 1976, pp. 56-59, with permission.)

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.

Suchsland &
Woodson (1986)

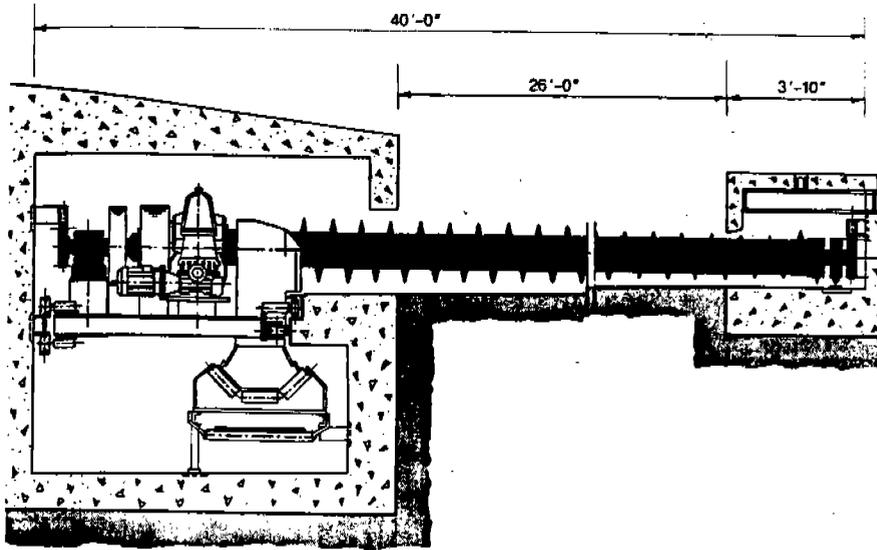


Figure 66—Traveling reclaimer screw (K.M.W. Systems).

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.

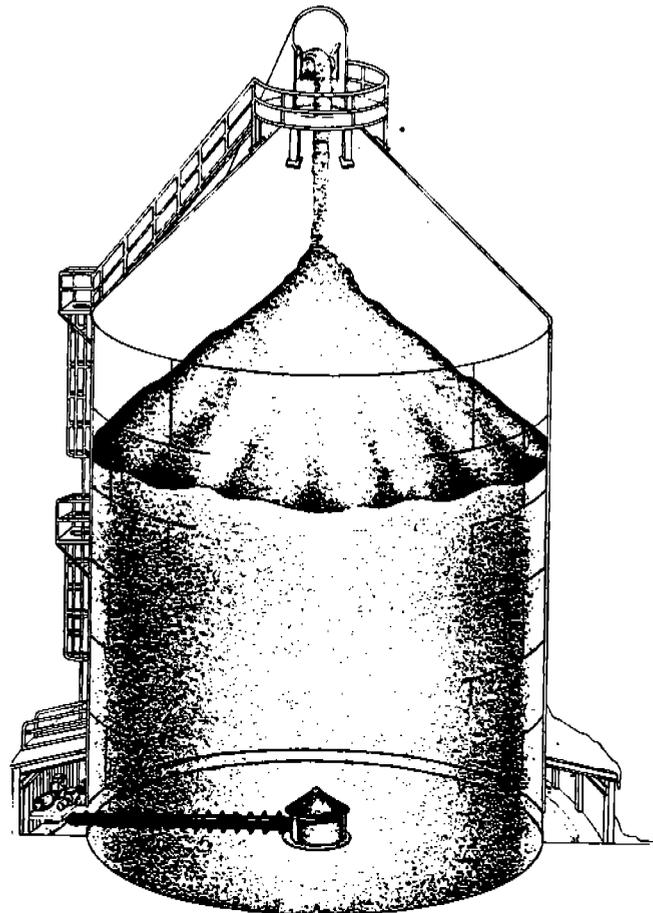


Figure 67—Mechanical reclaimer system for circular chip piles and silos (K.M.W. Systems).

Suchsland
& Woodson (1986)

Debarking,
chipping
& screening

See also "cleaning whole tree chips"



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

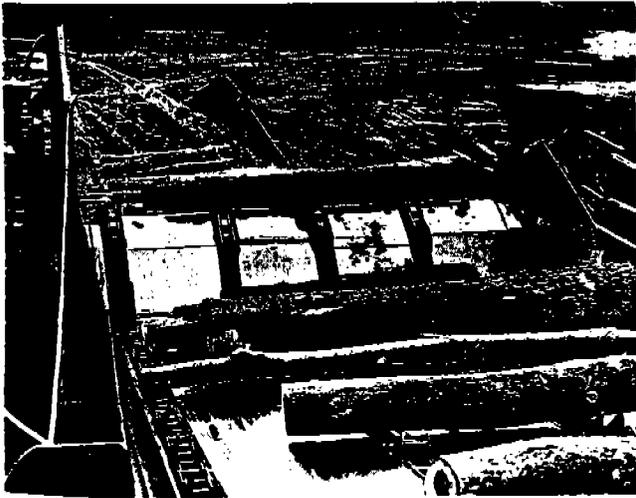


Figure 48—Jack ladder. Water spray reduces friction, eases handling of logs.

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.

Removal of bark is especially harmful for several reasons (Dunn 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 ~~softwood chips are a better~~ 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 dif-

ficult 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 good penetration of steam or cooking liquid, and is easily handled and transported. Only the two ends (A) of a log are cut by the chipper knives. The length can thus

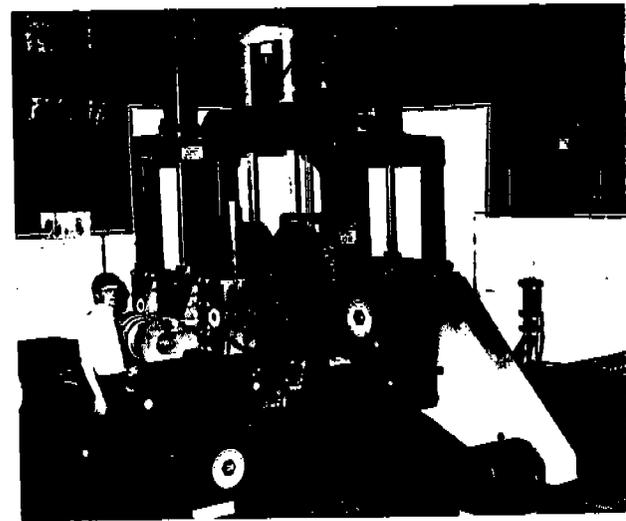


Figure 49—Carthage-Brunette ring debarker (Carthage).

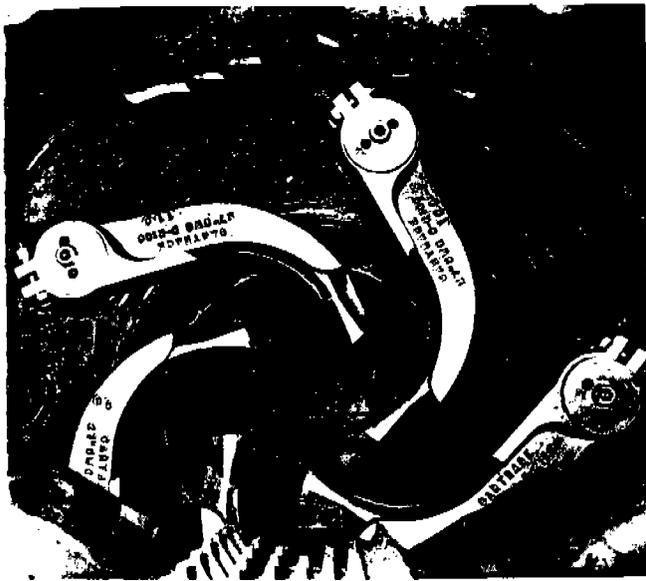


Figure 50—Carthage-Brunette ring debarker. Close-up of air-operated abrading tools (Carthage).

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,

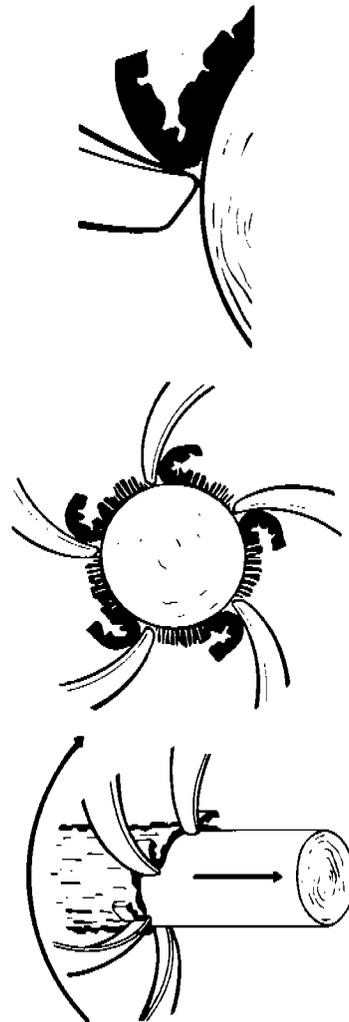


Figure 51—Illustration of tool action in ring debarker (Koch 1972).

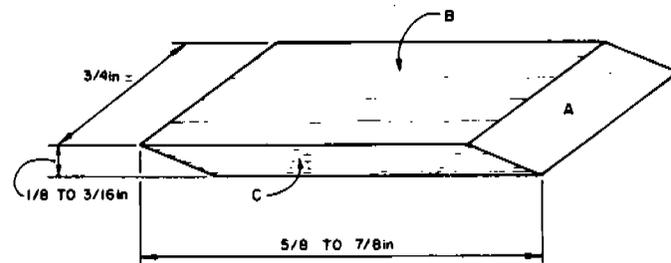
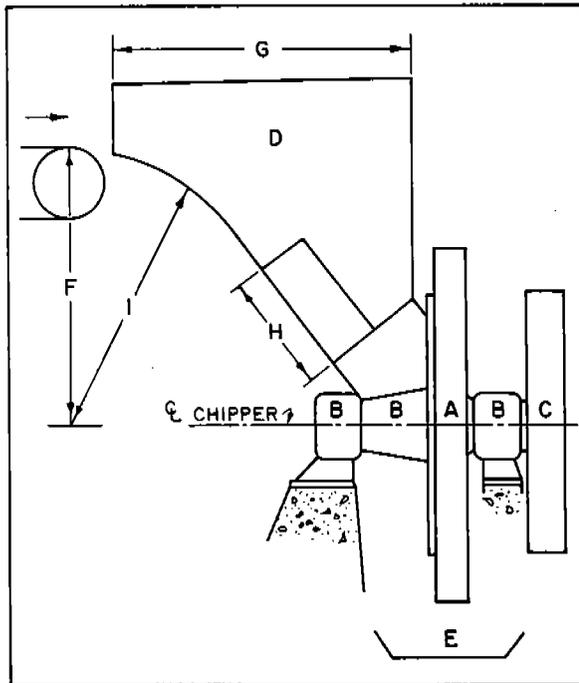


Figure 52—Basic shape and dimensions of pulp chip. Surface A cut by chipper knife, surfaces B and C split parallel to grain (Koch 1972).

Suchsland &
Woodson (1986)



- 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.)

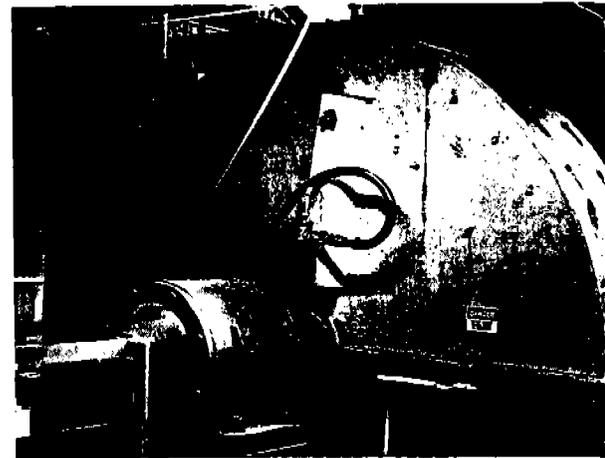


Figure 54—A 116-inch gravity feed chipper carrying 16 knives, with a 1,000-hp motor.

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

¹Other knife configurations are available to meet specific requirements.

²Will vary with conditions.

nage of the chips produced in that region.

These considerations result in a helically twisted bevel and a helically ground face plate, which are the features of the so called **Norman chipper**. This design ensures full contact between log and disk (Hartler and de 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 Stadel 1977). The average chip thickness is not of as much 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 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 production requirements. If production requirements are low, a wound rotor motor is preferable. In use, 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 **finer**. Overs are oversized chips containing large slivers and **cards** (chips of correct length but of excessive width). These overs can be rechippered (fig. 58) and returned to the screens. Finer are small particles, generally of less than 1/8 in diameter, consisting of sawdust, small bark particles, and very small chips. The finer 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 upsetting 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	19 1/4 x 20	27 1/2	15	6-8	400/600	600
78	23 x 26	34	18	6-8-10	800/1,000	514
84	21 x 27	35 1/2	21	6-8-10	800/1,250	514
96	25 x 30 1/2	39	24	6-8	1,000/1,250	450
	25 x 30 1/2	39	22	10-12	1,500/1,750	450
106	29 x 35	45	27	6-8	1,000/1,250	400
	29 x 35	45	27	10-12	1,500/1,750	400
116	33 x 40	52	30	6	1,000	360
	33 x 40	52	30	8	1,250	360
	29 x 35	52	28	12	1,750	360
	29 x 35	52	28	15	2,000	360
135	37 x 45	58	34	6	1,250	300
	37 x 45	58	34	8	1,500	300
153	40 x 50	64	38	6-8	1,500	277
	40 x 50	64	38	10	2,500	277
164	45 x 55	71	42	6-8	1,500/2,000	257
175	50 x 60	78	46	6	1,500	225
	50 x 60	78	46	8	2,000	225

¹ Knife configurations are available to meet specific requirements.
² Vary with conditions.

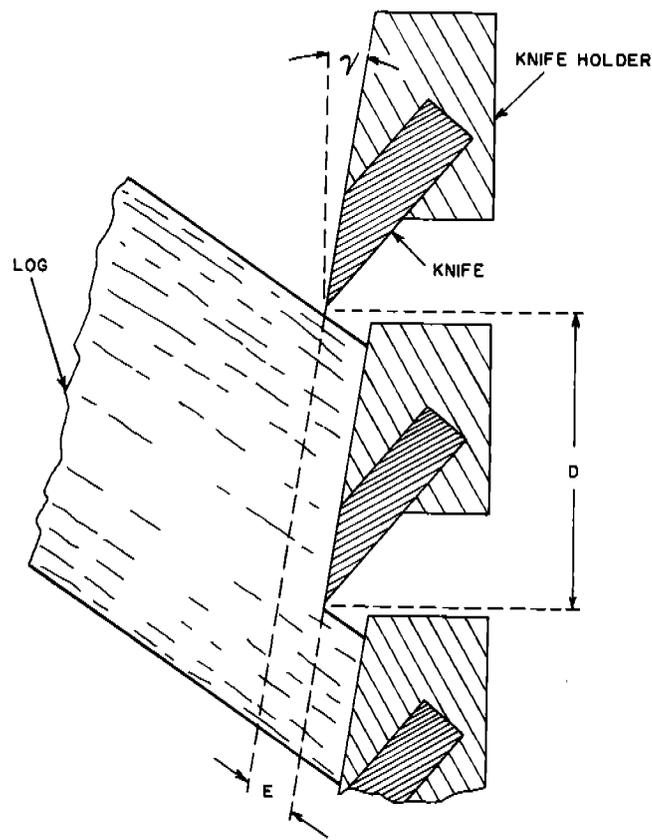


Figure 55—Section through chipper illustrating relationship between suction angle γ , knife spacing D , and advance of log = chip length E .

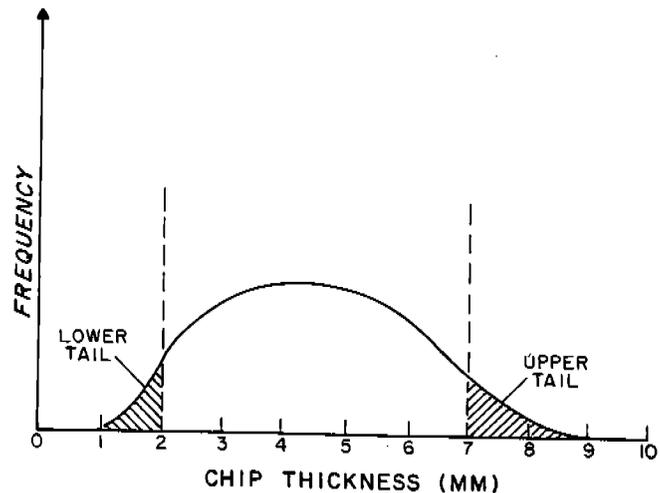


Figure 57 — Example of chip thickness distribution (after Hartler and Stade 1977).

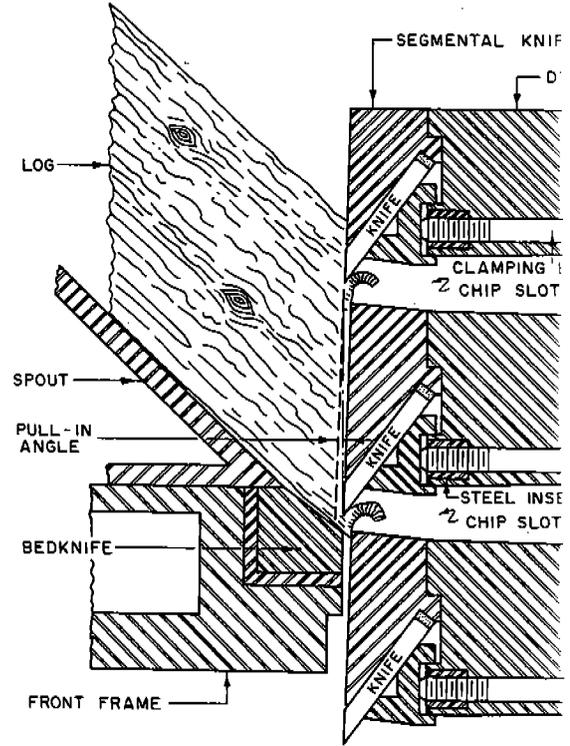


Figure 56—Section through Carthage Norman type chipper, illustrating cutting action (Lamarche 1969).

rubber balls that continuously tap its undersize sizes of the upper screen vary from 1/4 to 2 in a of the lower screen from 1/8 to 1/4 in.

Other types of screens have high-frequency movements (vibrating screens) that cause a mor chip action, tending to free the undersized mater ped between larger components by throwing larg up into the air. Some of these larger chips may t through the upper screen endwise (Barnes and 1979). Size distribution of chips before or after s can be monitored by a standard **screen analysis** (Standard T 16). The size of openings in the vario used in the chip analysis varies according to nom: size:

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

This quality control tool will detect dulling c (increase in fines content), wear of chipper bed p crease of coarse content), or effect of spec moisture content. Dry and frozen wood increase t content (Eustis 1980).



Suchsland & Woodson (1986)

includes debarking

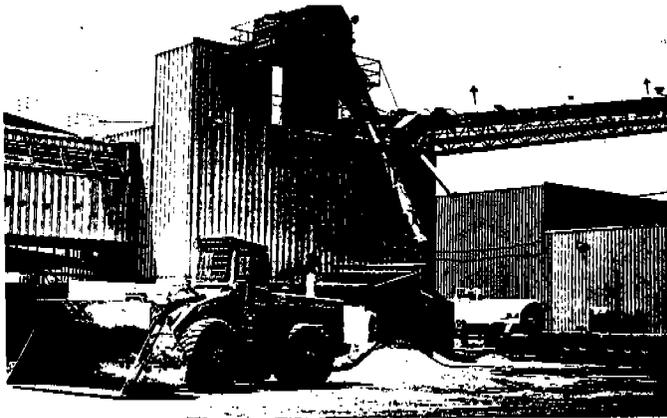


Figure 68—Facility for feeding stored chips into conveyor system, bypassing the woodroom.

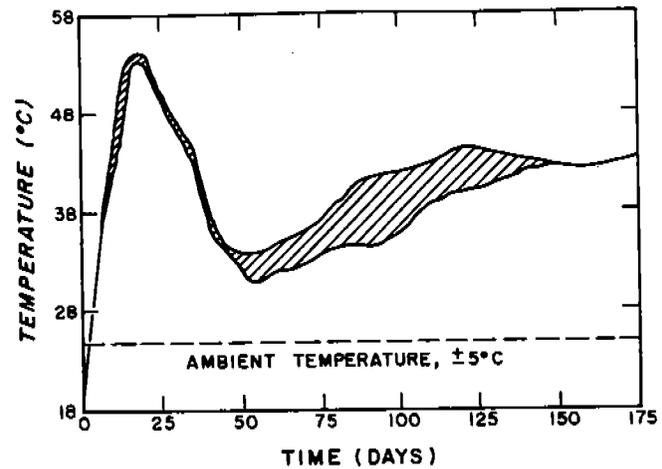


Figure 69—Temperature development in simulated aspen chip pile (Feist and others 1973).

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.

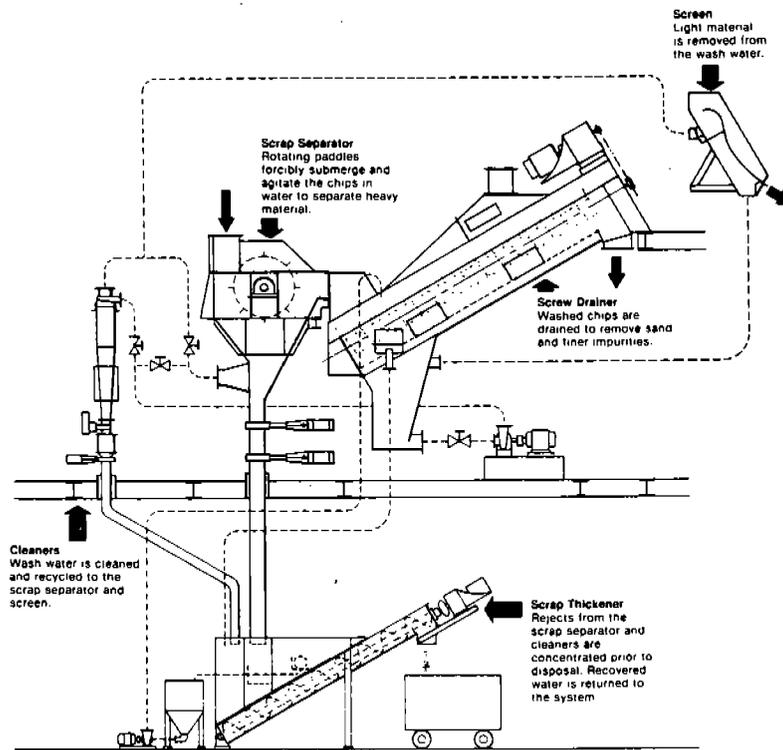


Figure 70—Defibrator chip washing system (Sunds Defibrator).

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 non-magnetic 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).

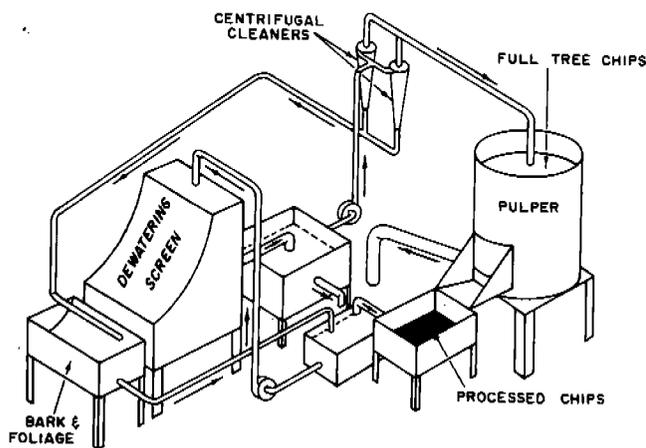


Figure 71 — Schematic of pilot plant for washing and debarking of conditioned chips (after Berlyn and Gooding 1979).

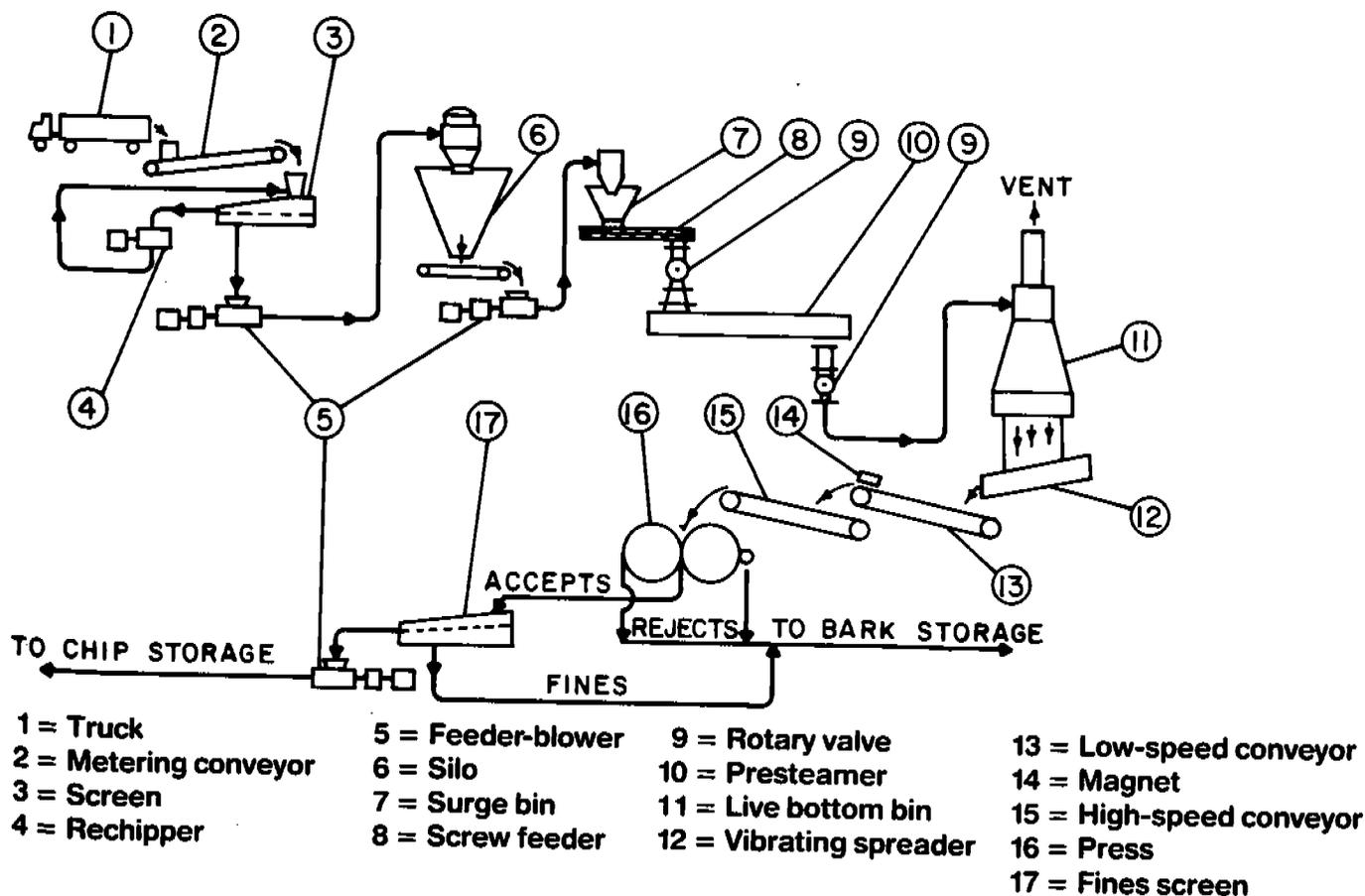


Figure 72 — Schematic of chip compression debarking plant (after Wawer and Misra 1977).

Suchsland &
Woodson (1986)

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.

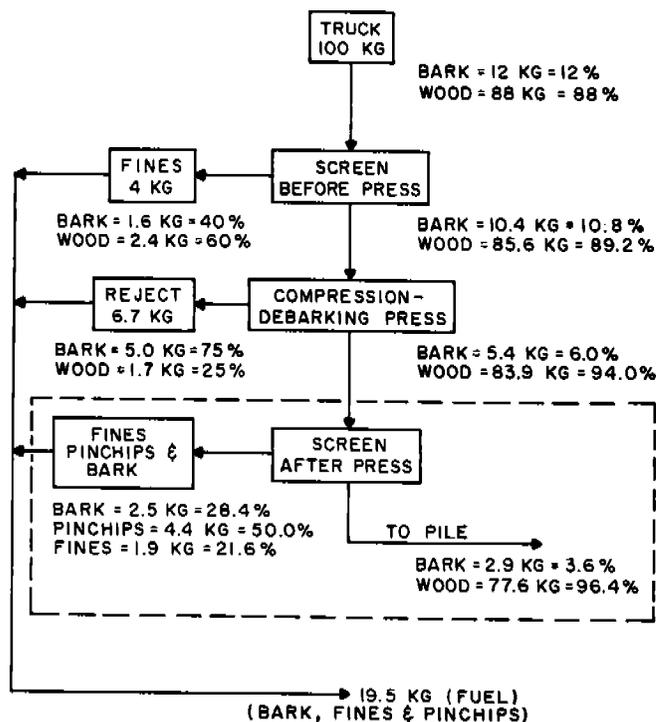


Figure 73 — Compression debarking pilot plant overall material balance (after Wawer and Misra 1977). Weights in kilograms are based on oven-dry material.

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Chapter 8.
Wet process
Fiber board
manuf.

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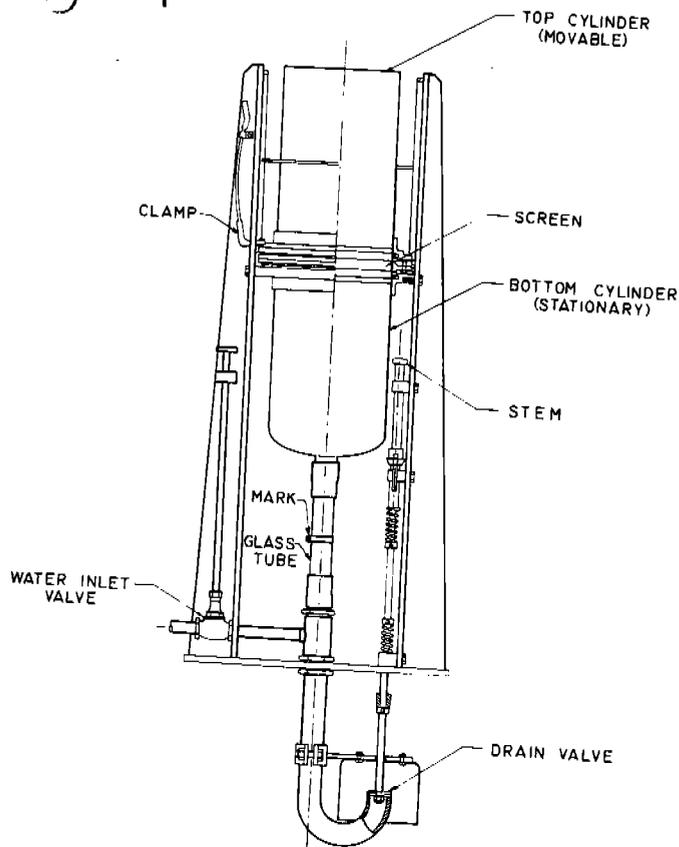


Figure 78—Defibrator pulp freeness tester (Sunds Defibrator).

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 ft³, (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/in²—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/in², 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

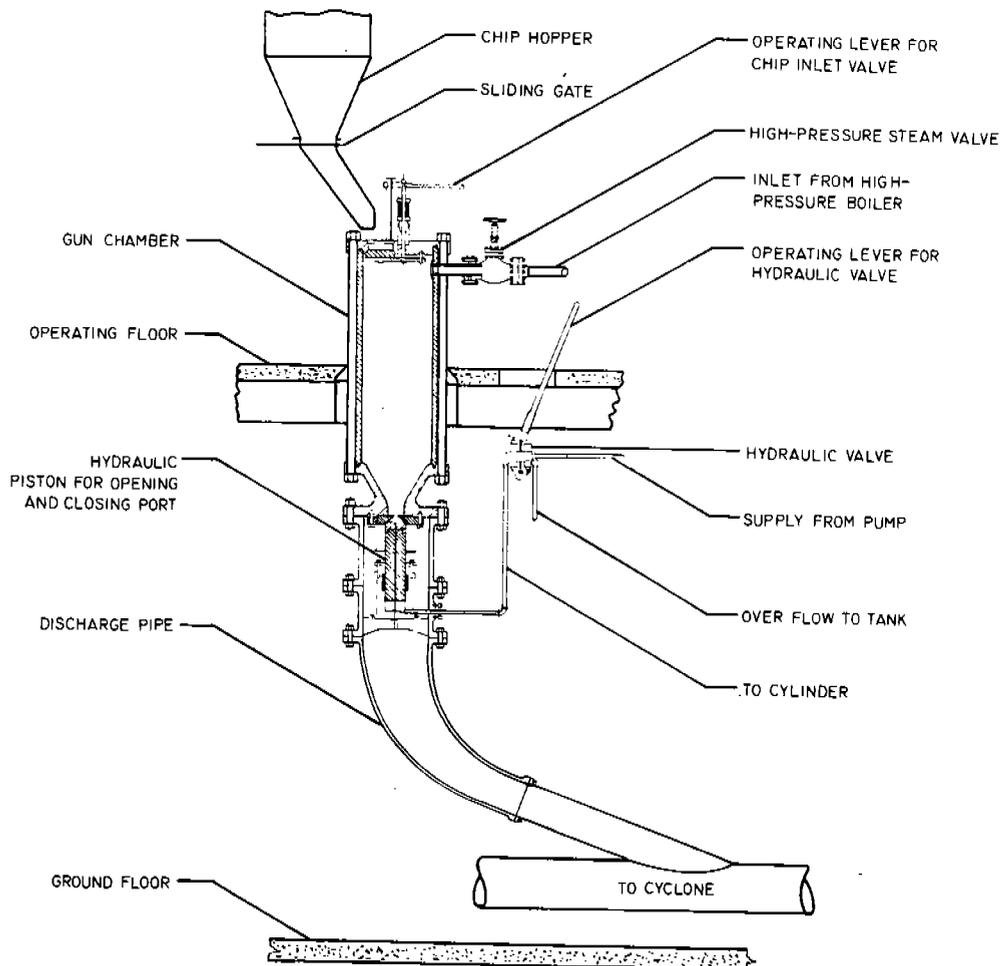


Figure 79—Cross section of Masonite gun (Mason 1927).



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



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

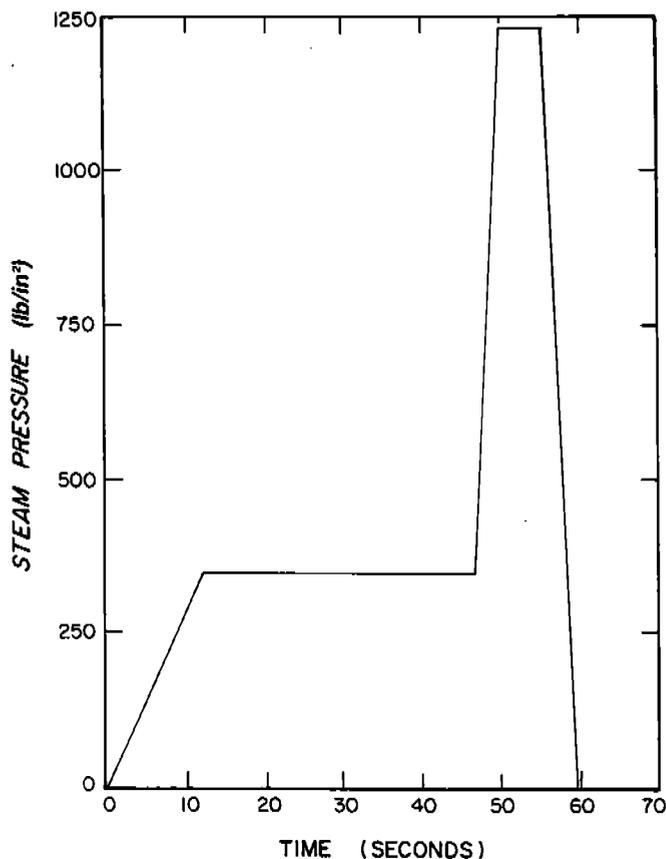


Figure 82—Typical Masonite gun cycle.

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, is illustrated by steam pressures between 300 and 400 lb/in² is illustrated as a sudden rise in the hot water extractability (fig. 84). The effect of preheating time on pulp yield is shown at various temperatures in figure 84.

Pulp yields of the Masonite process have been reported as low as 65 to 70 percent, and more recent yields are 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 variables such as species, specific gravity, growth factor, 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. The fiber 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 fibers 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 well, an important characteristic in the manufacture of wet-formed hardboard.

Because of the presence in the pulp of acetic and other organic acids, the pH of Masonite stock is low, between 2.0 and 4.0.

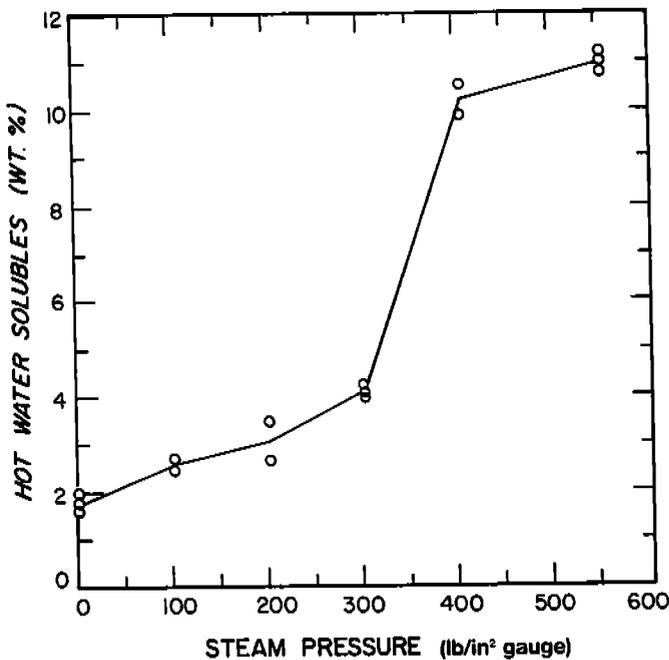


Figure 83—Hot-water extractability of wood chips as a function of saturated steam pressure used in the preheat segment of the digesting operation (Spalt 1977).

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.

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,

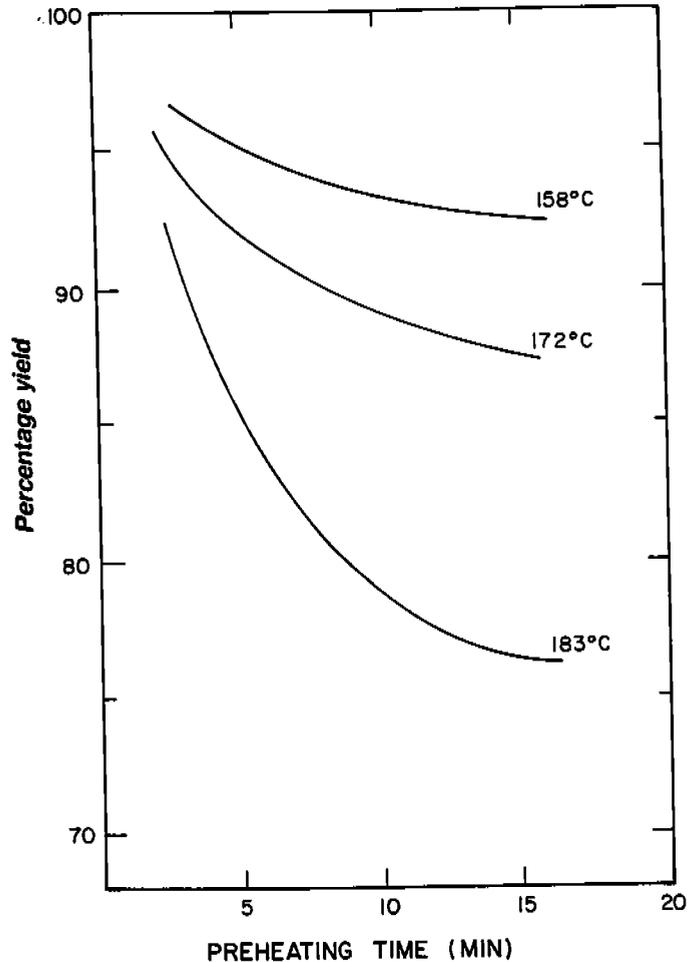


Figure 84—Effect of preheating time and temperature on pulp yield (EPA 1973).

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).

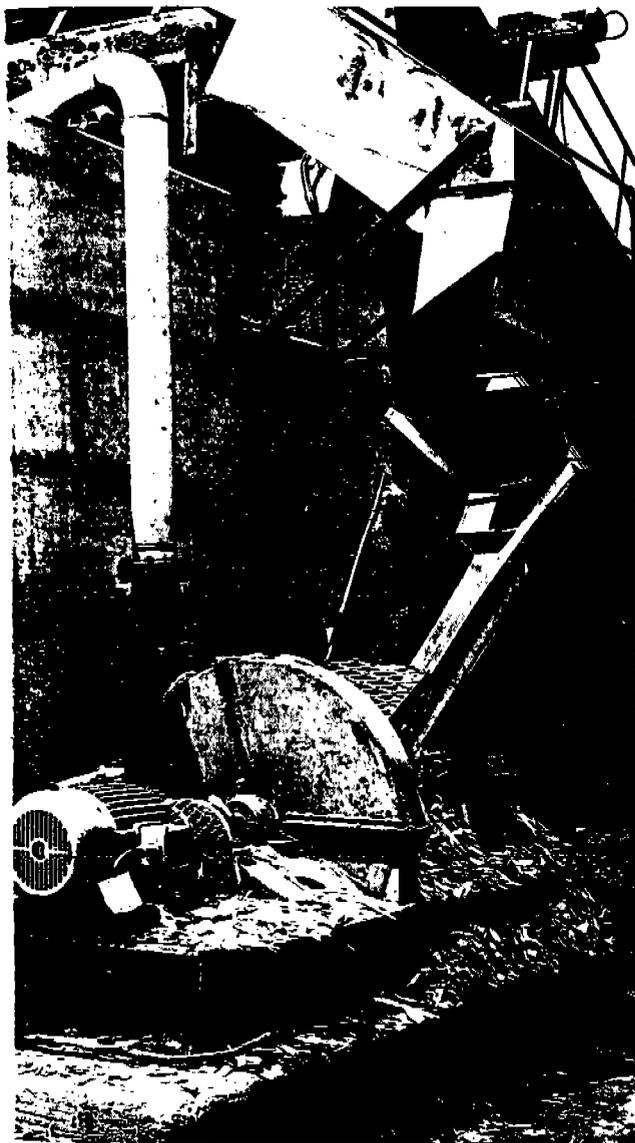


Figure 58—Rechipper located outside woodroom.

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, fines, 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.

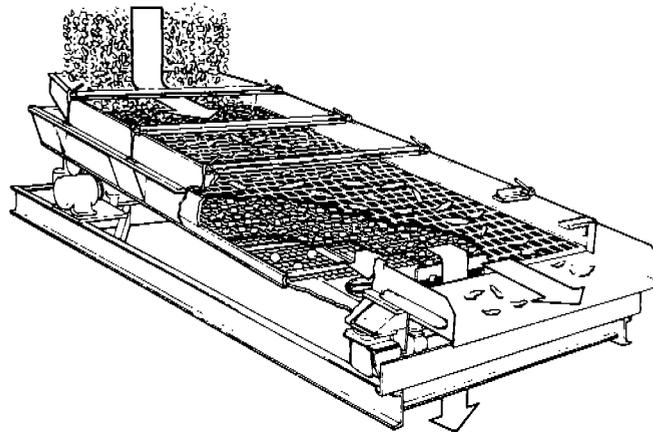


Figure 59—Rotex chip screener (Rotex).

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).

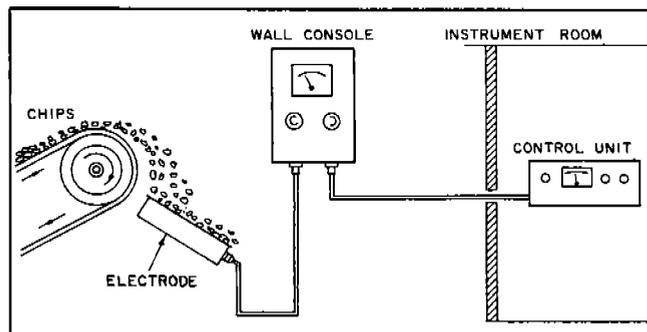


Figure 60—Schematic of continuous chip moisture content measurement (Lundstrom 1970). (© 1980 TAPPI. Reprinted from *Tappi Journal*, May 1980, pp. 857-861, with permission.)

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Woodson (1986)

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		Species	Percent moisture content ¹	
	Heartwood	Sapwood		Heartwood	Sapwood
Hardwoods			Softwoods		
Alder, red	—	97	Tupelo		
Apple	81	74	Black	87	115
Ash			Swamp	101	108
Black	95	—	Water	150	116
Green	—	58	Walnut, black	90	73
White	46	44	Yellow-poplar	83	106
Aspen	95	113			
Basswood, American	81	133	Baldcypress	121	171
Beech, American	55	72	Cedar		
Birch			Alaska-cedar	32	166
Paper	89	72	Eastern redcedar	33	—
Sweet	75	70	Incense-cedar	40	213
Yellow	74	72	Port-Orford-cedar	50	98
Cherry, black	58	—	Western redcedar	58	249
Chestnut, American	120	—	Douglas-fir		
Cottonwood, black	162	146	Coast type	37	115
Elm			Fir		
American	95	92	Grand	91	136
Cedar	66	61	Noble	34	115
Rock	44	57	Pacific silver	55	161
Hackberry	61	65	White	98	160
Hickory, pecan			Hemlock		
Bitternut	80	54	Eastern	97	119
Water	97	62	Western	85	170
Hickory, true			Larch, western	54	110
Mockernut	70	52	Pine		
Pignut	71	49	Loblolly	33	110
Red	69	52	Lodgepole	41	120
Sand	68	50	Longleaf	31	106
Magnolia	80	104	Ponderosa	40	148
Maple			Red	32	134
Silver	58	97	Shortleaf	32	122
Sugar	65	72	Sugar	98	219
Oak			Western white	62	148
California black	76	75	Redwood (old-growth)	86	210
Northern red	80	69	Spruce		
Southern red	83	75	Eastern	34	128
Water	81	81	Engelmann	51	173
White	64	78	Sitka	41	142
Willow	82	74	Tamarack	49	—
Sweetgum	79	137			
Sycamore, American	114	130			

¹Based on oven-dry weight.