

3

PULPING FUNDAMENTALS

3.1 INTRODUCTION TO PULPING

Pulp

Pulp consists of wood or other lignocellulosic materials that have been broken down physically and/or chemically such that (more or less) discrete fibers are liberated and can be dispersed in water and reformed into a web. Fig. 3-1 shows a brown paper (no bleaching) kraft mill process. According to *Pulp & Paper Week*, November 21, 1988, the price of delivered pulps in the 4th quarter of 1988 in the U.S. (per ton) were as follows:

bleached softwood kraft	\$735-760
bleached hardwood kraft	\$685-730
unbleached softwood kraft	\$670-700
dissolving pulp	\$800-810
bleached CTMP	\$625

Pulping

There are four broad categories of pulping processes: *chemical*, *semi-chemical*, *chemi-mechanical*, and *mechanical pulping*. These are in order of increasing mechanical energy required to separate fibers (fiberation) and decreasing reliance on chemical action. Thus, chemical pulping methods rely on the effect of chemicals to separate fibers, whereas mechanical pulping methods rely completely on physical action. The more that chemicals are involved, the lower the yield and lignin content since chemical action degrades and solubilizes components of the wood, especially lignin and hemicelluloses. On the other hand, chemical pulping yields individual fibers that are not cut and give strong papers since the lignin, which interferes with hydrogen bonding of fibers, is largely removed. Fig. 3-2 shows electron micrographs of several pulp types that demonstrate this point. Details of these types of pulps will be considered below.

Table 3-1 summarizes important aspects of the most common classes of pulping processes. Table 3-2 shows the production of pulp by pulping process to show the relative commercial significance of the processes. The relative strength of kraft:sulfite:soda:stone groundwood pulps for a

given species of wood are roughly 100:70:40:30, although this depends on the species of wood, strength property, and pulping conditions. Table 3-3 gives some mechanical and physical properties of representative commercial pulps. While this may not mean much on the first reading through the book, it is useful information for understanding the reason why particular pulps are used in particular grades of paper.

Wood-free, free-sheet

Wood-free pulp or free-sheet paper contains no mechanical pulp or contains pulp subjected to a minimum of refining; consequently, during its manufacture the water drains very quickly from the pulp on the Fourdrinier wire.

Screening

Screening of pulp after pulping is a process whereby the pulp is separated from large shives, knots, dirt, and other debris. *Accepts* consist of the pulp that has passed through the screens. The *accept yield* is the *yield* of accepts. *Rejects* or *screenings* are the larger shives, knots, large dirt particles, and other debris removed by the screens after the pulping process.

Shives

Shives are small fiber bundles of fibers that have not been separated into individual fibers during the pulping process. They appear as "splinters" that are darker than the pulp.

Yield

Yield is a general term used in any phase of pulping, papermaking, chip screening, bleaching, etc. indicating the amount of material recovered after a certain process compared to the starting amount of material before the process. To have meaning, both samples must be compared on an oven-dry basis. In pulping operations the yield is the oven-dry pulp mass expressed as a percentage of the oven-dry wood mass. Mechanical pulp yields are typically 92-96% and bleached chemical pulp yields are typically 40-45%. For example,

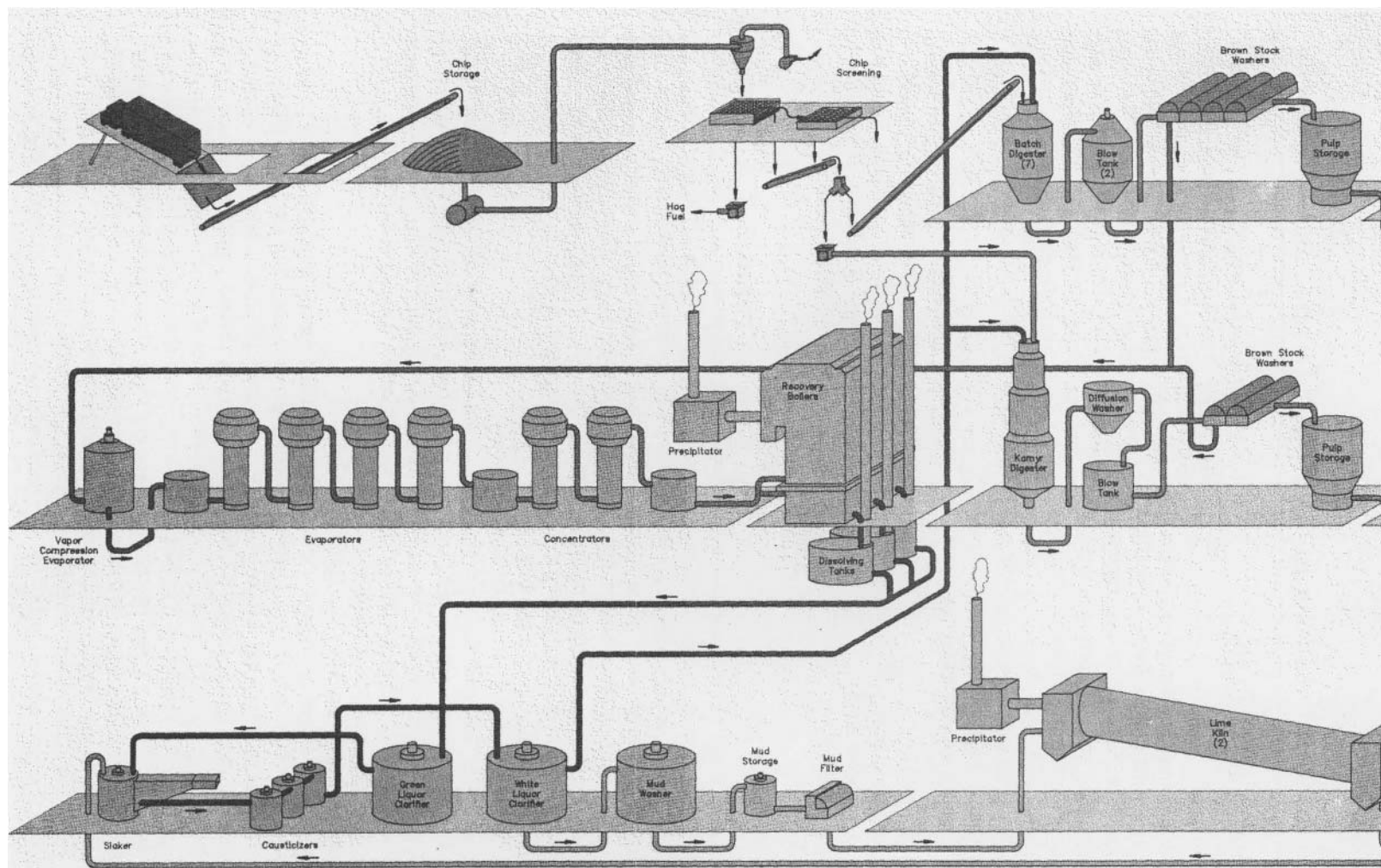


Fig. 3-1. Mill layout of a kraft linerboard mill (no bleaching). Courtesy of Weyerhaeuser Paper Co. (Figure continues linearly from the right-hand side of this page to the left-hand side of the facing page.)

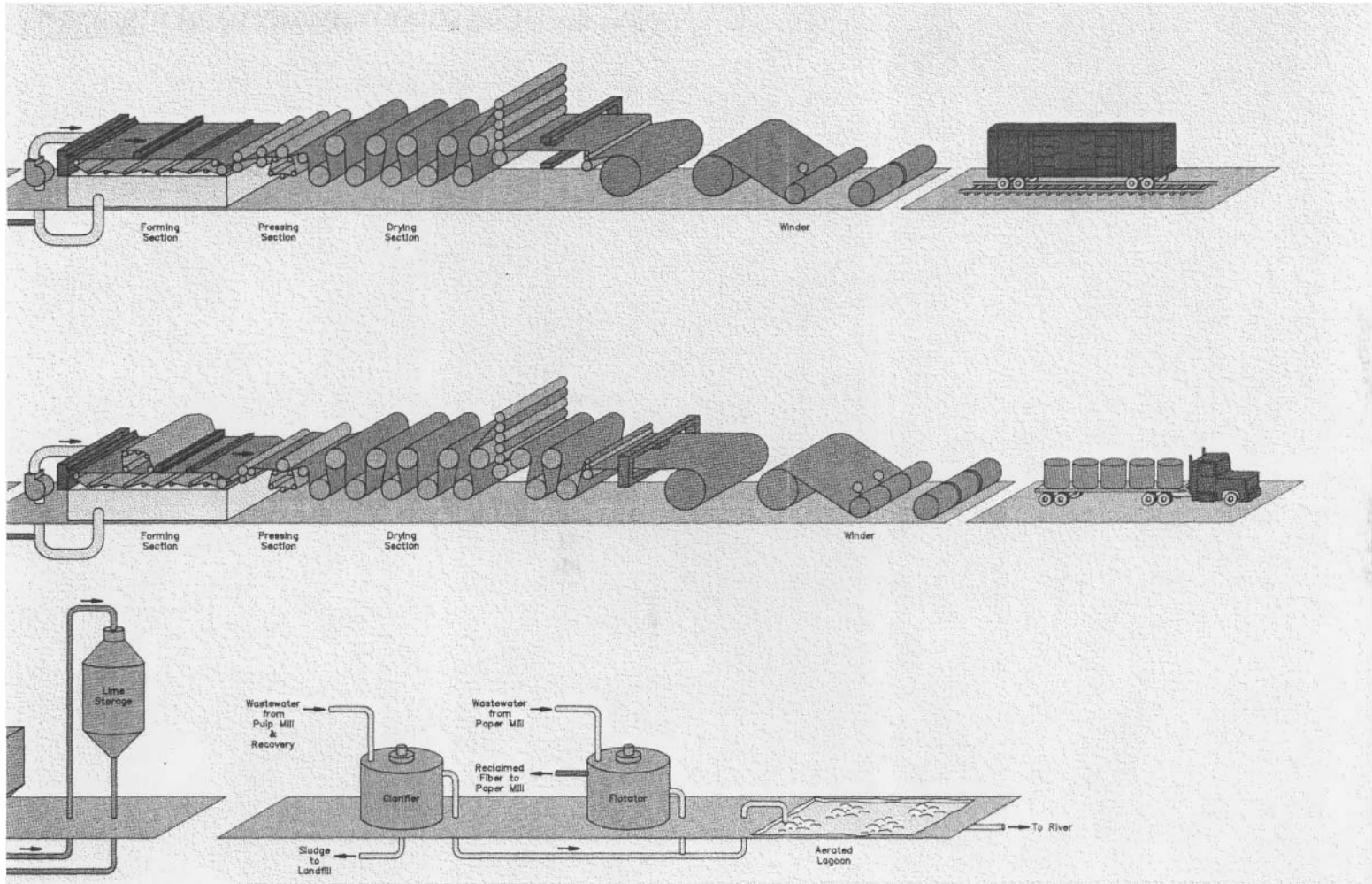


Fig. 3-1. Continued.

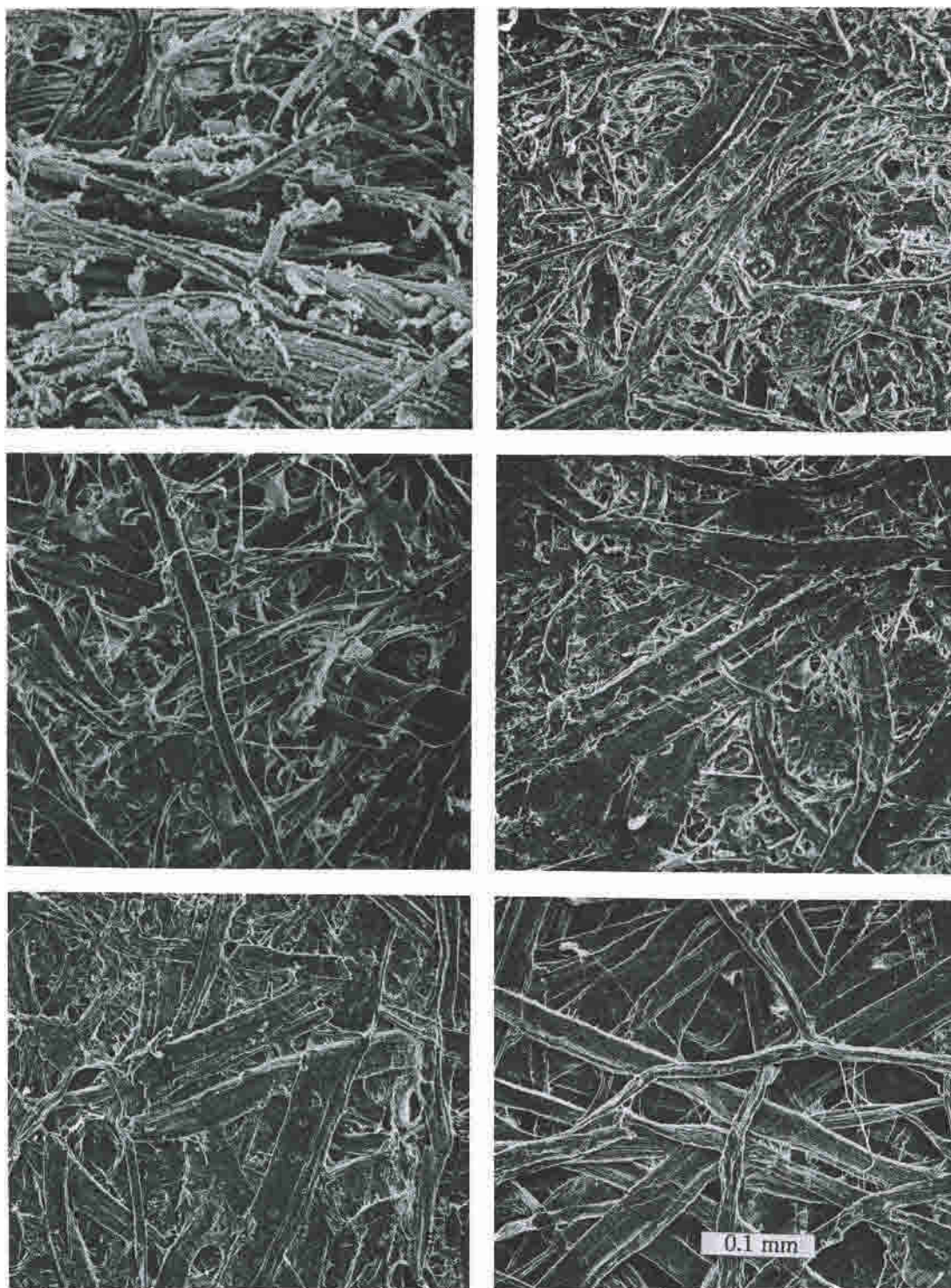


Fig. 3-2. (A) steam exploded hardwood. Papers of (B) SGW hardwood, (C) TMP softwoods, (D) newsprint, (E) NSSC hardwood/OCC corrugating medium, and (F) bleached kraft softwood fibers.

Table 3-1. Summary of pulping processes.¹

Process	Chemicals	Species	Pulp Properties	Uses	Yield, %
Mechanical pulping	none; grind-stones for logs; disk refiners for chips	Hardwoods like poplar or light-colored softwoods like spruce, balsam fir, hemlock, true firs	High opacity, softness, bulk. Low strength and brightness.	Newsprint, books, magazines.	92-96%
Chemi-mechanical pulping	CTMP; mild action; NaOH or NaHSO ₃		Moderate strength		88-95%
Kraft process, pH 13-14	NaOH + Na ₂ S (15-25% on wood); unlined digester, high recovery of pulping chemicals, sulfur odor	All woods	High strength, brown pulps unless bleached	Bag, wrapping, linerboard, bleached pulps for white papers	65-70% for brown papers, 47-50% for bleachable pulp; 43-45% after bleaching
Sulfite, acid or bisulfite pH 1.5-5	H ₂ SO ₃ + HSO ₃ ⁻ with Ca ²⁺ , Mg ²⁺ , Na ⁺ , or NH ₄ ⁺ base; Ca ²⁺ is traditional but outdated since no recovery process; lined digesters	hardwoods-poplar and birch and non-resinous softwoods; Douglas-fir is unsuitable	light brown pulp if unbleached, easily bleached to high brightness, weaker than kraft pulp, but higher yield	Fine paper, tissue, glassine, strength reinforcement in newsprint	48-51% for bleachable pulp; 46-48% after bleaching
	Mg ²⁺ base	almost all species-spruce and true firs preferred	Same as above but lighter color and slightly stronger	Newsprint, fine papers, etc.	50-51% for bleachable pulp 48-50% after bleaching
Neutral sulfite semi-chemical (NSSC) pH 7-10	Na ₂ SO ₃ + Na ₂ CO ₃ about 50% of the chemical recovered as Na ₂ SO ₄	Hardwoods (preferred) aspen, oak, alder elm, birch; softwoods Douglas-fir sawdust and chips	Good stiffness and moldability	Corrugating medium	70-80%

¹Reprinted from Krahmer, R.L. and A.C. VanVliet, Ed., *Wood Technology and Utilization*, O.S.U. Bookstore, Corvallis, Ore., 1983 with permission.

Table 3-2. Approximate pulp production (thousands of MT) by pulping method.¹

Category	Process		U.S. 1990	U.S. 1960	Canada 1989	Global 1986
Mechanical pulp	TMP		3400		7000	31,000 total
	CTMP		30		2800	
	SGW		3200	3292		
	PGW		600			
	RMP		342			
Chemical	Kraft	Total	50,000	14,590	10,850	88,000
		Bleached softwood	14,000		6868	29,000
		hardwood	13,000		1577	26,000
	Sulfite		1600	2578	1627	9000
	Dis-solv-ing	Kraft	800	1138 total	273 total	
		Sulfite	650			
	Soda (hardwoods)		300	420		
Semi-chemical	NSSC, etc.		5000	1991 total	432	8000
Chemi-mechanical	steam explosion/Asplund		600			
	cold soda		200			
Total virgin wood pulp			62,700	25,316	23,700	136,000
Wastepaper, recycling			18,400	8000		56,000

¹Data from 1990 *Pulp and Paper Fact Book* as pulp productions or capacities, FAO, and Libby Volume I for U.S. 1960 data. There is significant rounding of values here as this table is meant only as an approximation. Different sources differ appreciably in amounts. In 1986 the world paper production was 202,000 thousand tons. The nonwood and non-secondary fiber portion of 10,000 tons consists of minerals for coating and fillers and other plant fibers such as bagasse, straw, and bamboo.

Table 3-3. Properties of commercial pulp samples ca. 1975 from manufacturer's specifications.¹

Beating time (minutes)	CSF (ml)	Break length (km)	Tear factor (metric)	Double folds	Bulk (cc/g)	Air resist. (sec)	Opacity
<i>IA. Softwood kraft pulp (Kamyr dig.) of long-fibered western hemlock, redcedar, and Doug.-fir. The alpha cellulose content is 82%, the pentosans content is 5.6%, and the lignin content is 2.7%</i>							
0	662	4.7	222	70	1.88	4	
20	508	9.1	121	780	1.60	50	
45	205	11.3	104	1720	1.44	802	
<i>IB. The same fiber mix as IA after fully bleaching by CEDED to 88+ brightness is 86.5% alpha cellulose and 4.5% pentosans. The cellulose viscosity is C_p 22, and the stretch is 3.2-3.5%</i>							
0	661	5.0	242	120	1.83	3	73
15	494	9.9	122	900	1.56	34	67
30	249	11.0	114	1600	1.48	513	63
<i>II. Sulfite softwood pulp of 94% brightness, 88% alpha cellulose, and 350 cps viscosity</i>							
0	705	1.9	136	3	1.78	1	75
31	550	5.9	102	130	1.45	15	70
75	250	7.5	83	650	1.33	250	65
<i>III. Hardwood kraft pulp of 91% brightness, 87.5% alpha cellulose, and 65 cps viscosity</i>							
0	585	2.6	106	5	1.85	2	82
13	550	4.5	101	30	1.75	5	79
81	250	8.3	87	350	1.45	80	74
<i>IV. Hardwood sulfite of 93% brightness, 88.5% alpha cellulose, and 160 cps viscosity</i>							
0	625	1.5	54	0	1.85	1	82
15	550	2.8	67	5	1.67	5	80
74	250	5.5	68	40	1.35	65	86
<i>V. Softwood thermomechanical pulp of 50% brightness (Determined in OSU lab. in 1991)</i>							
0	396	1.3	5.4	1	3.49		97
120 (PFI)	123	3.4	7.8	8	2.65		97
240 (PFI)	102	3.8	6.7	9	2.53		96

¹Note that testing conditions of 60 g/m² handsheets at 73°F at 50% relative humidity with refining by the valley beater (except TMP as noted). The relative mullen burst values are similar to those of the tensile breaking length. All tests are TAPPI Standard methods.

100 lb of dry wood yields about 40 to 45 lb of pulp for bleached printing paper.

$$\text{yield, \%} = \frac{\text{dry product mass out}}{\text{dry material mass in}} \times 100\%$$

Total yield, %

The total yield is equal to the amount of pulp removed during screening and the yield of pulp after the screens when all three are expressed as a percentage of the original wood put in the digester. When one speaks of pulp yield it is necessary to state whether it is the total yield or screened yield.

$$\text{Total yield (\%)} = \text{Screenings (\%)} + \text{Screened yield (\%)}$$

Consistency

Consistency is a measure of the *solids content* as a percentage in a pulp slurry.

$$\text{consistency} = \frac{\text{dry solids mass}}{\text{slurry mass}} \times 100\%$$

3.2 MECHANICAL PULPING

Mechanical Pulp

Mechanical pulp is pulp produced by using only mechanical attrition to pulp lignocellulosic materials; no chemicals (other than water or steam) are used. Light colored, non-resinous softwoods and some hardwoods are often the fiber source. The total yield is about 90-98%. Lignin is retained in the pulp; therefore, high yields of pulp are obtained from wood. Mechanical pulps are characterized by high yield, high bulk, high stiffness, and low cost. They have low strength since the lignin interferes with hydrogen bonding between fibers when paper is made. The lignin also causes the pulp to turn yellow with exposure to air and light.

The use of mechanical pulps is confined mainly to non-permanent papers like newsprint and catalog paper. Mechanical pulps constitute 20-25% of the world production and this is increasing due to the high yield of the process and increasing competition for fiber resources. Furthermore, technological advances have made mechanical pulps increasingly desirable.

Table 3-4. Mechanical pulp capacity by region in thousands of metric tons¹.

Region	Year	TMP	CTMP	PGW
USA	1980	1619	0	0
	1988	3028	38	224
Canada	1980	996	110	0
	1988	4144	2421	0
Scandinavia	1980	1411	110	40
	1988	4596	685	743
Europe	1980	663	30	0
	1988	1559	155	307
Japan	1980	862	0	0
	1988	1161	310	150
Other	1980	320	0	0
	1988	1238	897	44

¹Data from Kayserberg (1989). Europe values exclude Scandinavia.

Table 3-4 shows the production of various types of mechanical pulp in 1980 and 1988 for several areas of the world. During this time global mechanical pulp production increased from 6 to 15 million metric tons. Several important aspects of mechanical pulping are condensed from this article. In the last decade, TMP processes have largely replaced SGW. CTMP and bleached CTMP (BCTMP) are displacing small amounts of chemical pulps in certain grades of paper. Most CTMP is produced in Canada. PGW is important in Scandinavia, but has limited production outside this region.

Chip quality and cleanliness

Some aspects of chip quality are very important in mechanical pulping. Since mechanical pulps cannot be brightened very much by chemicals, chip quality (except for SGW, which uses wood logs) is of extreme importance. Generally chips less than two weeks old are used with stringent bark and dirt tolerances. Chips older than two weeks tend to be discolored too much by decay and air oxidation. Washing the chips (Fig. 3-3 shows one type of chip washing system) before pulping is a necessity, just as in any me-

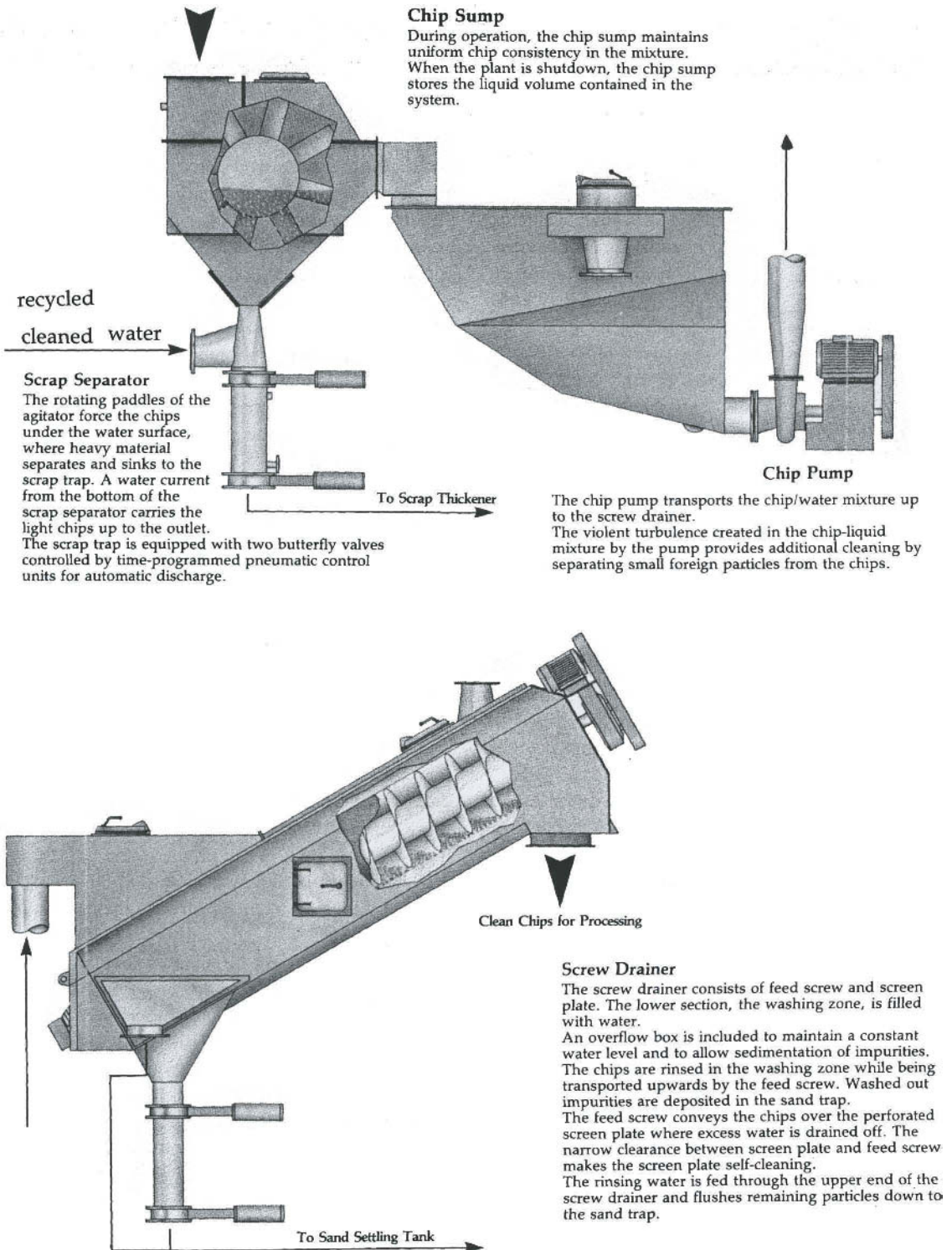


Fig. 3-3. Chip washing system that incorporates water reuse. Courtesy of Sunds Defibrator.

chanical or semi-chemical pulping operation where disk refining is ultimately required to break apart the wood chips. Sand, pebbles, tramp metal, and other gritty materials would otherwise cause undue damage to the refiners.

Stone groundwood (SGW)

Groundwood mechanical pulp is produced by grinding short logs, called *bolts*, with grindstones on the tangential and radial surfaces. Original grindstones were sandstone, but segmented stones with embedded silicon carbide or aluminum oxide are used now. The sandstone grindstones had to be treated carefully to prevent them from bursting due to thermal shocks; they were phased out in the early 1940s. SGW was first produced in the 1840s as a wood meal using technology from grain mills; the French naturalist DeReamur realized that paper could be made from wood when his study of wasp nests in 1719 showed that they were made from wood particles held together with proteins from wasp saliva. Early mechanical pulps were merely fillers to extend the supply of cotton and other fibers. However, advances in the process gave stronger pulps. The large amount of fines makes this pulp useful for increasing the opacity of some printing papers, although hardwood CTMP (discussed below) is a suitable substitute for this purpose. The energy use is about 1300 kWh/ton (50-80 hp-day/ton) with the higher amounts for high grade papers; yields are 93-98%.

The mechanism of grinding is not a cutting action, and stones with sharp edges are not desired. Instead, reasonably selective fiber-fiber separation is achieved by peeling caused by repeated shear stresses. The shear stresses begin when the fibers are about 3 to 5 fiber diameters away from the stone's surface. These are obtained by repeated compression and decompression of the wood generated by the groove pattern on the stone's surface. Woods of low density are particularly suited to groundwood production because they allow the most deformation due to large lumens that accommodate expansion and contraction of the fibers caused by impact with the grits on the surface of the stone. If the wood is not able to distribute the load by flexing, fibers tend to be cut rather than separated from each other, leading to pulp of high fines content and low strength.

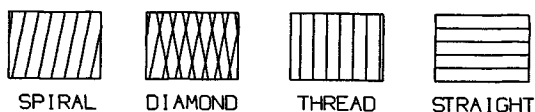


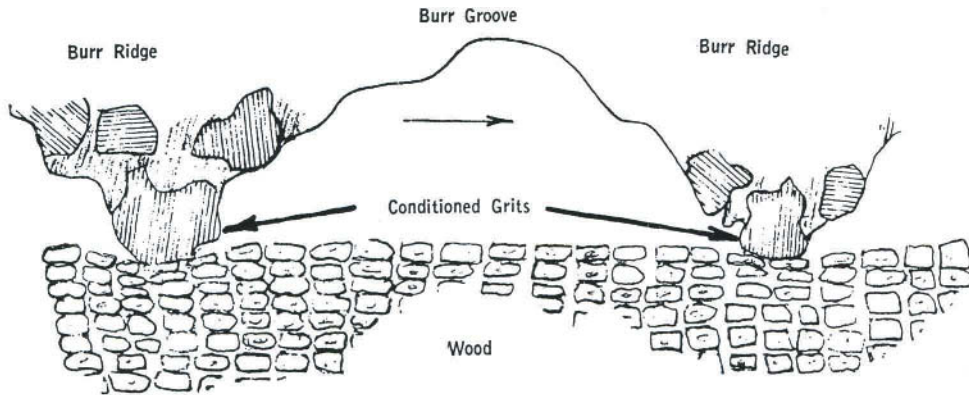
Fig. 3-4. Burr patterns used for sharpening pulp stones for stone groundwood production.

The burr pattern is very important. The commonly used patterns are shown in Fig. 3-4. They include *spiral*, which is the most commonly used pattern type since it produces a high quality pulp; *diamond*, which is usually used to erase old patterns and resurface the stone; *thread*, which is not often used since it tends to generate both chunky fibers and fines (actually flour); and *straight*, which makes long, coarse pulp fibers suitable for building and insulation boards. A No. 9, 1 in. lead, spiral burr has 9 threads per inch with the thread rising 1 in. from the left to the right hand side. Burr patterns are cut by the metal burr which makes several passes over the stone until the burr pattern depth on the stone is about 1.6 mm. This is called stone sharpening and must be done every 50-150 hours.

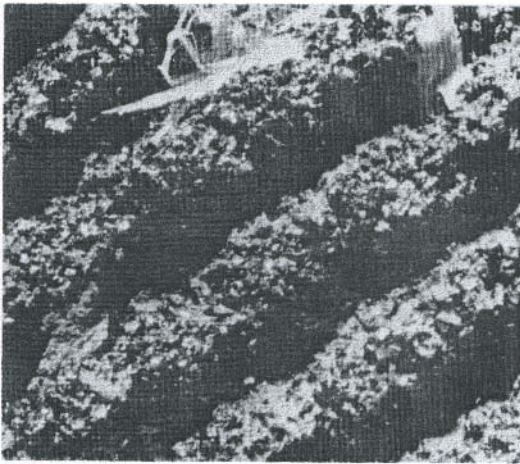
Pulp strength properties are considerably lower right after sharpening of the stone, so stone sharpening must be staggered from grinder to grinder in a mill. Pulp burst and strength properties increase between stone sharpenings by 25-50% (advantageous). However, pulping specific energy increases 25-50%, production rate decreases 25-100%, and freeness decreases by a factor of 1 to 3, all three of which are disadvantages.

Water is used in the grinding process before and after the grinding area to control the temperature of the grindstone and to wash the pulp from the grindstone. The pulp leaves at 2-5% consistency. A 3,000-5,000 hp motor spinning a 1.5 m (typically 54-70 in.) diameter grindstone at 240-300 rpm (18-24 m/s or 3400-4500 ft/min at the grinding surface) will grind about 50 ton/day, corresponding to 30-40 hp/ft² grinding area. The grinding pressure is 40-80 psi. The water temperature in the pit is 140-180°F. Newsprint requires 55-70 hp-day/ton while book paper uses 60-85 hp-day/ton. The important grinding variables are:

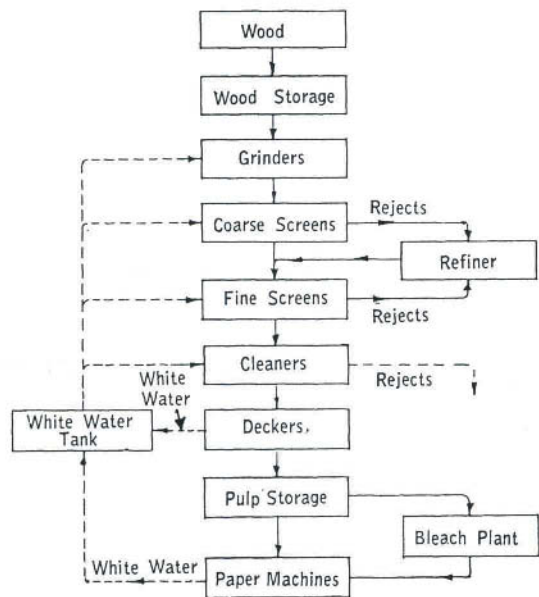
1. Wood species and other wood variables.
2. Type of pulpstone.



Fiberizing by Compression of the Wood by Conditioned Grits



Burr Pattern Imprinted by Sharpening Tool
(Stone Surface 9x)



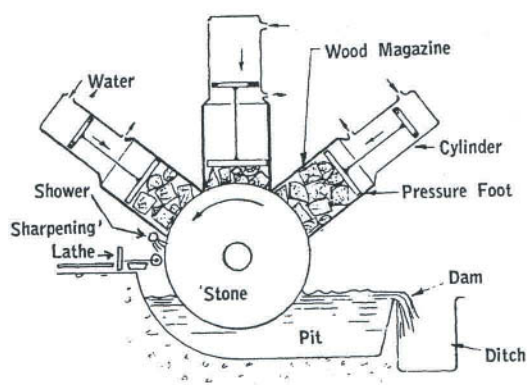
Stone Groundwood Process—Flow Diagram

Fig. 3-5. Grinding action and overall stone groundwood (SGW) process. Reprinted from *Making Pulp and Paper*, ©1967 Crown Zellerbach Corp., with permission.

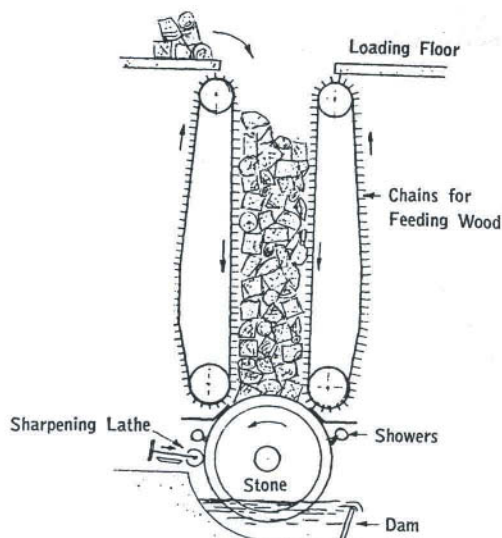
3. The use (or not) of a water-filled grinding pit.
4. Type of burr pattern on the stone.
5. Stone surface speed.
6. Hours on the stone since last burring.
7. Pressure of wood against the stone.
8. Temperature of grinding surface, 130-180°C (265-355°F).
9. Amount of water used (and, therefore, the final pulp consistency).

An example of SGW paper from hardwoods is shown in Fig 3-2. This paper was from an experimental press run of the March 26, 1959 *Savannah Evening News* where a mixture of seven southern U.S. hardwoods were used. While relatively intact fibers and vessel elements are observed in this figure, there are numerous fiber fragments as well.

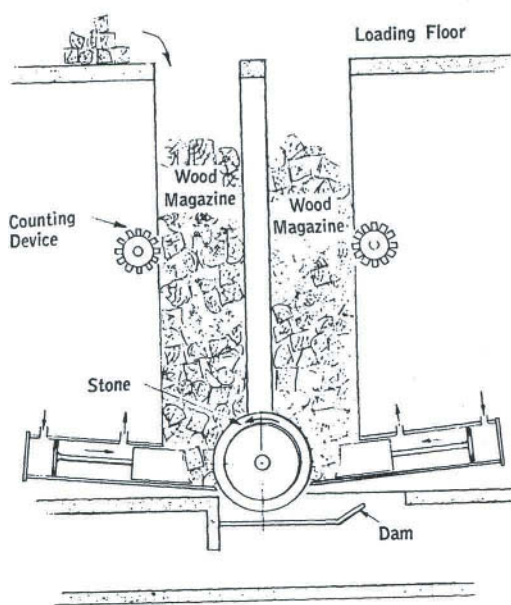
The overall process and grinding action are shown in Fig. 3-5. Fig. 3-6 shows some of the



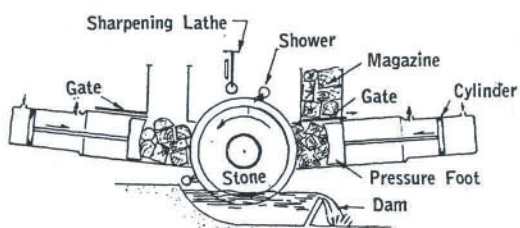
Three Pocket Hydraulic Grinder



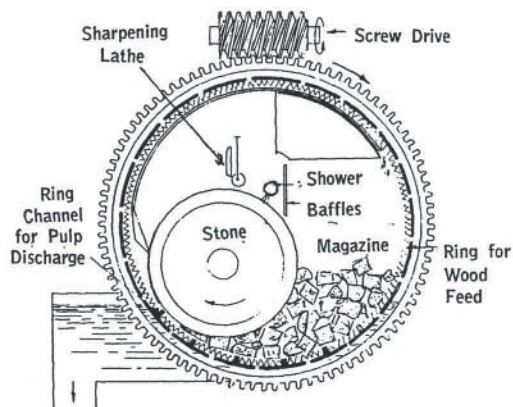
Chain Grinder



Hydraulic Magazine Grinder



Great Northern Grinder



Roberts Ring Grinder

Fig. 3-6. Grinder configurations used in the stone groundwood process. Reprinted from *Making Pulp and Paper*, ©1967 Crown Zellerbach Corp., with permission.

many types of grinder configurations that have been used. Pocket grinders were once popular, but have been largely replaced by the various magazine grinders that have continuous feeding of wood, which greatly reduced the manpower required to load wood. The three pocket hydraulic grinder was introduced around 1900. When the wood in one of the pockets is consumed the door is opened after the pressure foot is retracted, wood is added manually, the door is closed, and the pressure foot is engaged with water pressure. The magazine grinder was introduced by Voith of Germany in 1908.

The Great Northern Grinder (and modifications such as that of Koehring-Waterous Ltd.) was installed at many mills making newsprint in the 1950s. Large units grind wood 1.6 m (5 ft) long at the rate of 80 tons/day using 5500 horsepower. The chain grinder is the most common of the continuous grinders introduced in the 1920s. Large units pulp wood 2 m (6.5 ft) long at the rate of 100 tons/day using 7000 horsepower. The continuous Roberts ring grinder was introduced in the 1940s.

Pressure groundwood (PGW)

By pressurizing the grinder with steam at temperatures of 105-125°C (220-255°F), the wood is heated and softened prior to the grinding process. This gives better separation of fibers with less cutting action and lower fines generation. This process yields a pulp that has higher tear strength and freeness and is brighter than SGW, yet has lower power requirements. About one-half of the world's PGW is produced in the Scandinavian countries. As one reads through this section it will become apparent that PGW is to SGW as TMP is to RMP.

Refiner mechanical pulp (RMP)

Refiner mechanical pulp is produced by disintegrating chips between revolving metal disks or plates with raised bars (Plate 23 and pages 144-146) at atmospheric pressure. This process was developed during 1948-1956 by Bauer Bros. and is patented by Eberhardt. Some of the steam generated in the process softens the incoming chips resulting in fibers that maintain more of their original integrity compared to SGW, because there

is less cutting action and increased separation of fibers at the middle lamella. Because of this action, there are less fines formed, and RMP is bulkier and stronger than SGW. Power requirements are 1600-1800 kWh/ton (90-100 hp·day/ton). Disk refiners are up to 1.5 m (60 in.) in diameter and rotate at 1800 rpm with 60 Hz power; this gives a velocity at the periphery of up to 140 m/s. The plates containing the metal bars must be replaced every 300-700 hours or low quality pulp is produced and energy use increases. Refining is usually carried out in two stages. The first is at 20-30% consistency to separate the fibers, while the second is at 10-20% consistency to alter the surface of the fibers for improved fiber bonding in the final paper. The pulping variables are:

1. Wood species and other wood variables.
2. Pulp consistency.
3. Sharpness and pattern of refiner plates.
4. Temperature of refining.
5. The gap between the refiner plates. (0.005 to 0.1 in.; 0.035 in. typically)
6. Rate of feed through the refiner.
7. Speed of the refiner plates.

The RMP process was an important development in the history of mechanical pulping. Now, however, TMP, a modification of the RMP process, and other mechanical pulping processes have made the RMP process almost obsolete.

Thermomechanical pulp (TMP)

TMP was developed about 10 years after RMP and has become the most important mechanical pulping method. For example, in 1975, less than 200,000 metric tons of TMP were produced in North America. In 1989 the U.S. capacity was just under 3 million metric tons, while Canada was just under 6 million metric tons.

The TMP process is very similar to the RMP process except that pulp is made in special refiners that are pressurized with steam in the first stage of refining. Fig. 3-7 shows a typical flow diagram for a TMP plant. TMP is usually carried out in two stages of refining. In the first stage, the refiners are at elevated temperature and pressure

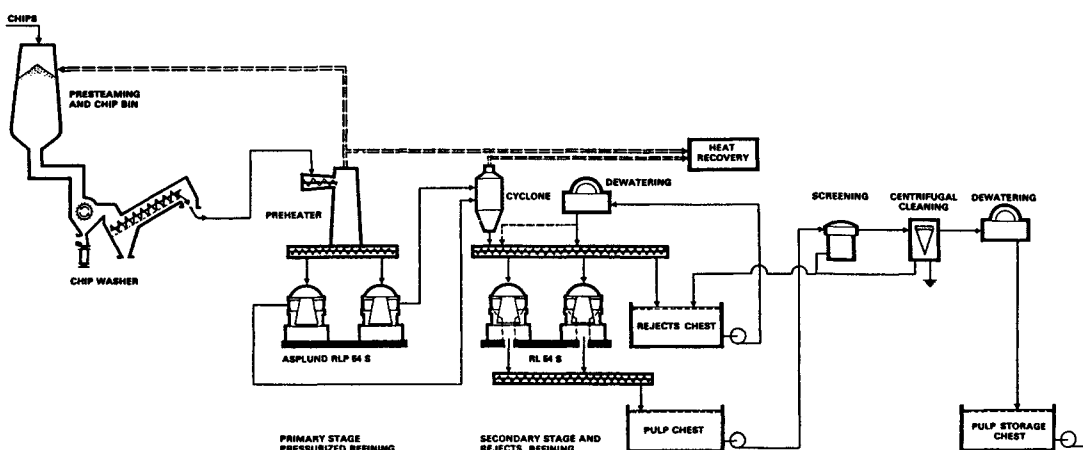


Fig. 3-7. Representative layout of a newsprint TMP plant. Courtesy of Sunds Defibrator.

to promote fiber liberation; in the second stage, the refiners are at ambient temperature to treat the fibers for papermaking. The higher temperature during refining in the first step, 110-130°C (230-265°F), softens the fibers and allows their recovery with minimal cutting and fines compared to SGW or even RMP. The refining is just under the glass transition temperature of lignin, which is approximately 140°C (285°F), so that separation

of fibers occurs at the S-1 cell wall layer. This improves fibrillation (surface area) and access to hydroxyl groups for hydrogen bonding. A laboratory pressurized refiner for making TMP pulp is shown in Fig. 3-8.

The high strength of this pulp relative to the other mechanical pulps has made it the most important mechanical pulp. Energy requirements are 1900-2900 kWh/ton (100-150 hp-day/ton),

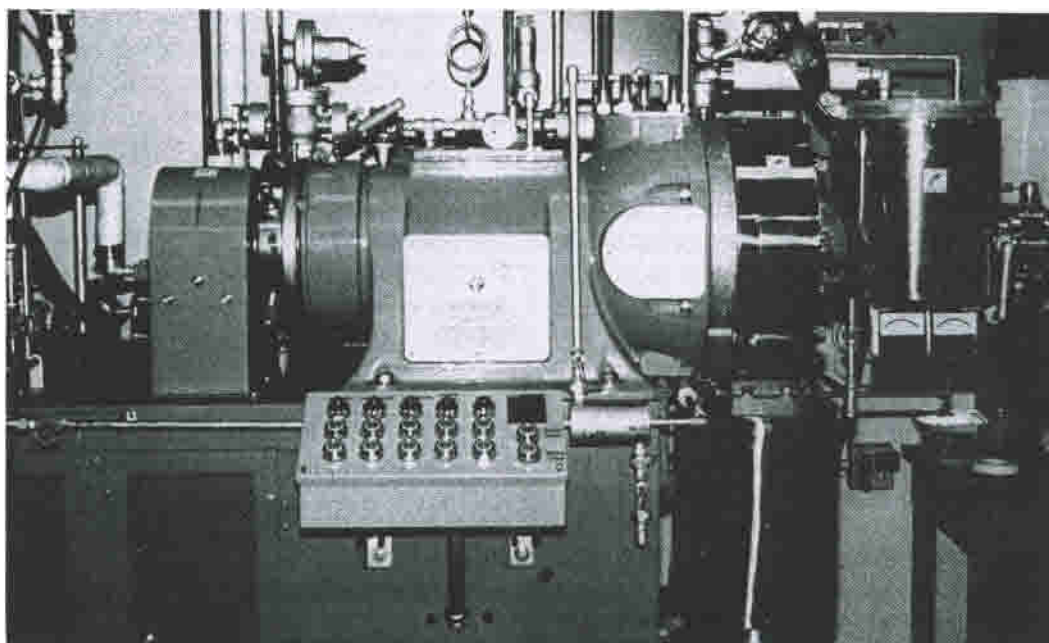


Fig. 3-8. Pressurized laboratory refiner for making TMP pulp.

slightly more than RMP, and significantly more than SGW. Over two-thirds of this is used in the primary pressurized refining step, and less than one-third is used in the secondary atmospheric pressure refining step. An even consistency of 20-30% is ideal for primary refining and is the most important operating variable; lower consistencies cause fiber damage from the refiner plate bars while higher consistencies cause the refiner to plug. TMP tends to be darker than SGW due to chemical reactions at the elevated temperatures and wood chip supplies often contain more bark, dirt, and other impurities than bolts used in SGW. The pulp yield is 91-95%.

Solubilization of wood components make BOD levels relatively high in mill effluents. If the steaming temperature is too high then the process has the problems of the Asplund process (Section 3.4), that is, the surface of the fibers becomes coated with lignin that interferes with hydrogen bonding. This results in weak, dark paper.

Fig. 3-2 shows two samples of TMP. The first is softwood TMP from the refiner chest of a newsprint mill. The second is a sample of a 1990 newsprint. These samples show much less fiber fragmentation than the SGW sample, but there are still more fiber fragments and fiber delamination than in the bleached kraft softwood fibers.

3.3 CHEMI-MECHANICAL PULPING

General aspects

What are now called chemi-mechanical processes were originally called chemi-groundwood processes since these chemical pretreatments were developed and used commercially at a time (early 1950s) when stone groundwood was the predominant mechanical process. (The original laboratory work on chemi-mechanical pulping and cold soda pulping of straw had been done much earlier.) However, these chemical pretreatments have application to all of the mechanical pulping processes.

ESPRA (Empire State Paper Research Associates), whose laboratories are in Syracuse, New York, applied the NSSC process (Section 3.5) in a mild form prior to groundwood pulping. In one operation, four-foot long hardwood logs were treated in large digesters (60 feet high by 10 feet

in diameter). A vacuum was first applied to remove much of the air from the logs and allow better liquor penetration. The liquor, containing aqueous Na_2SO_3 and Na_2CO_3 , was then introduced and kept at 130-155°C (265-310°F) depending on the species of wood. The pressure was maintained at 150 psi. The pretreated logs were then pulped by the stone groundwood method. All of the advantages of the CTMP process (over TMP) were observed long before CTMP was thought of with the original chemi-groundwood method. The grinding requirements were about half that required without pretreatment and the CSF was 300-350 ml. At around the same time, the cold soda method was developed, although it has only had limited use.

The chemi-mechanical pulping process consists of two stages with yields of 85-95%. A particularly mild chemical treatment is followed by a drastic mechanical action, but not as drastic as without chemical pretreatment. The original lignin structure and content is preserved, but extractives and small amounts of hemicellulose are lost. When higher temperatures are used in the various steps, a darker pulp is usually obtained. One of several chemical pretreatments can be applied prior to SGW, PGW, RMP, or TMP. The most common chemi-mechanical process is now CTMP. The pretreatments are hot sulfite or cold soda and are particularly applicable to hardwoods that otherwise do not give mechanical pulps of high quality. Several mills have also begun to use an alkaline peroxide chip pretreatment.

Chemical pretreatments

In the *hot sulfite* process pressurized hot sulfite liquor is used to treat chips prior to fibrillation. This results in a pulp brighter than the cold soda process that is usable in book papers, catalogs, and newspapers. The pulp is usable in papers by itself in the case of softwood pulp, but 10-15% chemical pulp must be added to the hardwood pulp to achieve adequate strength. With hydrogen peroxide bleaching, brightness levels up to 82% may be obtained.

The *cold soda* process was first investigated by the U.S. Forest Products Laboratory in Madison in the early 1950s as a pretreatment prior to making RMP or stone groundwood. By 1960,

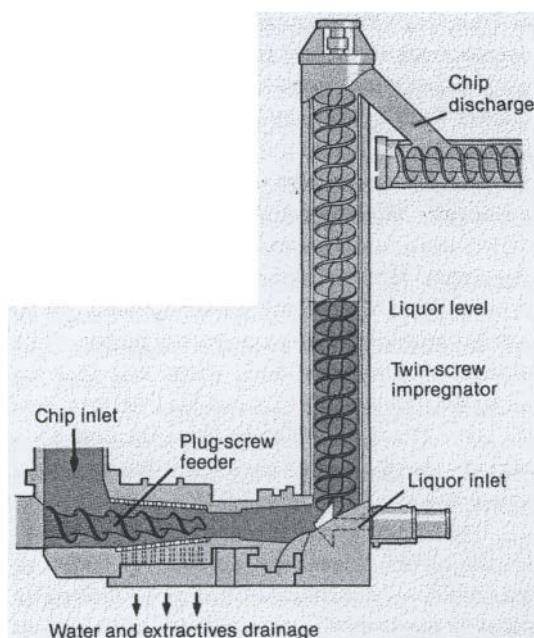


Fig. 3-9. Liquor impregnation using the pressure-expansion technique. Courtesy of Sunds Defibrator.

about 10 mills used the process, however by 1970, only a few mills used the process as other processes for pulping hardwoods had been developed.

The yield of the cold process is 80-95%. Chips are first soaked in 5-15% cold caustic soda (sodium hydroxide solution) as a swelling agent. Lignin is retained, but some hemicelluloses and all resins are lost, resulting in a pulp with good drainage. Softwoods resist this treatment, producing coarse fibers with unusually high power demands. When used prior to SGW (CSGW), this method results in a pulp which drains faster than groundwood pulp, meaning that faster paper machines can be used. Refining energy is 500-700 kWh/ton (28-40 hp-day/ton).

The *alkaline peroxide* pretreatment for mechanical pulping (APMP) was introduced by Sprout-Bauer in 1989. This process (McCready, 1992) is used to make 600 t/d of aspen pulp at the Millar Western mill in Saskatchewan, Canada, using a modification of Scott Paper's patented process. Four stages of chip compression (using a Hymac screw press with a 4:1 ratio) and chemical impregnation are used prior to refining. Much, if not all, of the bleaching is claimed to

occur here, often saving the cost of a separate bleach plant. The refiners are reported to require about 30-40% less energy than with sulfite pretreatment for BCTMP pulp. This pulp mill used a closed water loop by concentrating certain effluents to 70% solids for combustion. APMP does not require pressurized refiners. Increasing the amount of caustic in the pretreatment increases the strength of the pulp. Increasing the amount of peroxide increases the pulp brightness. This method is particularly profound because effluents with high BOD and inorganic chemical levels have prevented the use of CTMP in many locations.

Chemi-thermomechanical pulp (CTMP)

CTMP is a chemi-mechanical process that is similar to the TMP process except the chips are first pretreated with relatively small amounts (about 2% on dry wood) of sodium sulfite or sodium hydroxide (with hydrogen peroxide in the new alkaline peroxide method) under elevated temperature and pressure prior to refining. Liquor penetration is often achieved by a system that compresses the wood chips into a liquid tight plug that is then fed into the impregnator vessel where the chips expand and absorb the liquor (Fig. 3-9.) Unlike TMP, CTMP is effective with most hardwoods particularly with the cold soda process. CTMP processes produce effluents of high color and BOD which may be difficult to treat; environmental considerations have kept this process from being used in many locations.

3.4 RELATED PULPING METHODS

Asplund process

Interestingly, the Asplund process was developed about 30 years prior to TMP. It involves presteaming wood chips at temperatures above the glass transition temperature of lignin, 550-950 kPa (80-140 psi) steam pressure at 150-170°C (300-340°F), prior to refining between revolving metal disks or plates. The lignin is sufficiently soft that separation occurs at the middle lamella, and fibers are left with a hard lignin surface that is not amenable to fibrillation by refining or bonding by hydrogen bonding. Such fibers are very useful for hardboard materials where adhesives are used that react with the lignin and pressing at high tempera-

tures will allow the lignin-coated fibers to adhere to each other.

Masonite process (steam explosion)

This process was invented by Mason and patented in 1926 as an attempt to make pulp for paper. Chips are steamed at 180-250°C (355-480°F), well above the glass transition temperature of lignin, for one to two minutes until the final pressure is on the order of 4-7 MPa (600-1000 psi). The contents of the reactor are suddenly blown to atmospheric pressure through a slotted plate and to a cyclone where the fibers are collected. The glassy lignin surface and dark color of the fibers preclude their use in paper, although they make a very useful, high density fiberboard product. In fiberboard the fibers are held together by resins such as phenol-formaldehyde, not by hydrogen bonding as in paper. The yield is 80-90%. However, a mild explosion pulping process is being used at one mill to process recycled paper.

Fig. 3-2 shows TMP fibers from mixed hardwoods of the southern U.S. Notice the fibers exist in fiber bundles. The color (not observable in the SEM photograph) is dark brown. The fibers have glassy surfaces high in lignin that prevent hydrogen bonding. This pulp is unsuitable for use in paper.

3.5 SEMI-CHEMICAL PULPING

Vapor-phase pulping

Vapor-phase pulping is a process where chips are impregnated with cooking liquor (Fig. 3-9), the free liquor is drained or otherwise removed, and cooking occurs in an atmosphere of steam.

Semi-chemical process

Also called high yield chemical pulping, semi-chemical pulping processes involve two steps with pulp yields of 60-80%. In the first step a mild chemical treatment is used which is followed by moderate mechanical refining. There is partial removal of both lignin and hemicellulose. The first step of the semi-chemical process may be similar to any of the commercial chemical pulping methods (to be described), except that the temperature, cooking time, or chemical charge is

reduced. The NSSC and the kraft semi-chemical methods are the most common of this category.

For yields below 65%, the pulp is washed and chemical recovery continues as outlined in the sulfite or kraft section, except the pulp can be cleaned by dewatering presses to limit dilution of the liquor. Up to 75% of the liquor can be removed without dilution. Because the liquor is not easy to recover in small operations, the majority of semi-chemical mills are integrated with chemical mills so that the dilute spent liquors may be used as a source of makeup chemicals in the associated chemical process. This *cross recovery*, however, limits the size of the semi-chemical plant, because a large plant would produce excess chemical beyond that required for make-up in the kraft mill.

NSSC, Neutral Sulfite Semi-Chemical

The NSSC process is most frequently used (and is the most common method) for production of corrugating medium. This process was developed in the early 1940s by the U.S. Forest Products Laboratory in Madison as a means of using hardwood in the paper industry, especially the chestnut of the appalachian region, which was being devastated by the chestnut blight. In this process, high pulp yields are obtained (75-85%).

NSSC cooking liquors contain Na_2SO_3 plus Na_2CO_3 (10-15% of the chemical charge to act as a buffer); the liquor pH is 7-10. Cooking time is 0.5-2 h at 160-185°C (320-365°F). The residual lignin (15-20%) makes paper from this pulp very stiff, an important property for corrugating medium. Hardwood is usually the fiber source, and NSSC hardwood pulp is approximately as strong as NSSC softwood pulp and even stronger than kraft hardwood pulp. The low lignin removal makes chemical recovery difficult. Anthraquinone additives may be used to improve the pulp properties or yield, particularly from softwoods. The degree of cooking is controlled by the temperature, the chemical concentration, and the residence time in the digester. Subsequent refining energy of the pulp is 200-400 kWh/ton (10-20 hp-day/ton). Fig. 3-2 includes an electron micrograph of paper made with 50% hardwood NSSC pulp and 50% fiber recycled from old corrugated containers.