Large mobile equipment and trucks used to transport, store, and reclaim logs and chips have limited visibility and even less in bad weather and at dawn and dusk. If two-way radio communication is possible in the mill, it is good to carry one while working in such hazardous areas. Sign-in and sign-out log sheets are also used to keep track of visitors and workers from other parts of the mill. A short, 10 to 15 minute, safety meeting of woodyard and woodroom operators at the beginning of the work period allows everyone on the crew to hear about special situations, like digging of a large ditch across a woodyard road, and identify and remedy hazards that were observed the day before. With everyone participating, prevention is a lot easier than the consequences of a serious accident.

See also: **Harvesting**: Wood Delivery. **Operations**: Logistics in Forest Operations. **Papermaking**: Overview. **Pulping**: Bleaching of Pulp; Environmental Control.

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Mechanical Pulping

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Introduction

When mechanical action is the principal means for separating fibers from wood, the pulping processes are known as mechanical pulping, and the resulting pulps are mechanical pulps. This section contains descriptions of mechanical pulping processes, products, applications, limitations, and future prospects for mechanical pulps.

Mechanical pulping includes a large number of processes involving mechanical action or a combination of mechanical action and chemical pretreatments that separate fibers from the wood matrix. The main difference between mechanical pulping and chemical pulping is that, in mechanical pulping, the fibers are separated without removing the lignin, whereas in chemical pulping, the lignin is dissolved from the wood using chemicals. Mechanical pulps are characterized by high yield, high lignin content, and relatively stiff fibers that can be bleached to high brightness levels but that will photoyellow (darken) on exposure to light. The yield from the mechanical pulping processes ranges from as high as 98% for some groundwood pulps to about 85% for some of the chemimechanical pulps. In refiner mechanical pulping, the woodchips may be pretreated with chemicals either to reduce refiner energy usage or to help separate the fibers. Compared to chemical processes, the chemimechanical pulping processes remove only a small amount of the lignin in the wood. Since mechanical fibers are stiff and contain large amounts of lignin, these fibers form poor fiber-to-fiber bonds, which decreases sheet strength, but increases sheet opacity and bulk. Because of their high yield and low chemical consumption, these pulps are less expensive to produce and have less impact on the environment than do chemical pulps. The production of mechanical pulps worldwide is about 30% of the total virgin pulp production and is increasing because of its higher yield, lower cost, and less complex environmental concerns. On a per-country basis, the percentage of mechanical pulps ranges from 9.2% of virgin pulp in the USA to 45% in Canada and 62% in Germany.

Usage

The major use of mechanical pulps is in nonpermanent (grades that do not require permanent lightfastness) printing grades. Mechanical pulps are historically used in the following grades: newsprint (newspapers, paperbacked books, magazines), supercalendered magazine (catalogs), and coated mechanical and coated fine paper (commercial printing grades). Depending on the strength properties of the mechanical pulp, newsprint usually contains from 80% to 100% mechanical pulp, with the remainder being chemical pulp added to increase sheet strength. In addition to the nonpermanent printing grades, mechanical pulps are also used in a wide variety of other paper products, including board and tissue/towels. A short description of the major applications for mechanical pulp is presented here.

Newsprint

The quality parameters for newsprint are runnability (low frequency of breaks during printing) and printability (smoothness, opacity, brightness, ink pickup, and strikethrough). Traditionally, newsprint furnishes consist of 80–85% stone groundwood with the remaining fiber being lightly bleached kraft. The groundwood provides high bulk, high opacity, and good ink receptivity, while the kraft provides resistance to cross-machine tear.

Supercalendered Magazine

This grade is usually manufactured with mechanical pulp (typically 70% of the fiber), chemical pulp (30% of the fiber), and a high level of filler, typically 20–30%. These papers are printed using gravure and offset printing processes, which require good smoothness, ink receptivity, and high opacity, all provided by the mechanical pulp. The high level of filler reduces sheet strength, requiring a relatively high level of long fibers, usually softwood kraft.

Coated Papers

One of the most important coated grades is lightweight coated (LWC), used in gravure and offset printing. This grade normally contains 50–70% mechanical pulp with the remaining fiber being chemical pulp and up to 17% filler. These papers have low basis weights (less than $40\,g\,m^{-2}$ for the base sheet), which require a relatively high level of chemical pulp.

Other Products

Fine printing and writing papers are normally classified as wood-free (free of mechanical pulp), but will tolerate as much as 10% mechanical pulp. The mechanical pulp increases opacity, bulk, and printability. Since mechanical pulps are stiff, they are added to the middle layers of multiple-layer board grades. Because of their high bulk, resiliency, and low cost, mechanical pulps are also added to tissue and towel furnishes.

Historical Background

Before 1800, books were printed on handmade paper produced from many different fibers, principally flax before the invention of the cotton gin. With the invention of the cotton gin by Eli Whitney in 1793, cotton gradually replaced flax as the principal papermaking fiber. The first successful use of wood fiber as a paper stock was groundwood in the early 1840s. Fredrich Keller of Hainchen, Saxony and Charles Fenerty of Springfield, Nova Scotia are independently credited with the invention of groundwood pulping. Fredrich Keller, a bookbinder, apparently started experimenting with pressing wood against a grinding wheel with running water after reading about the shortage of rag fibers. By the mid-1840s, he had developed his groundwood process such that newspapers were printed using groundwood. In 1846, Keller sold his invention to JM Voith of Heidenheim, Germany and the first commercial grinders were installed in a mill in 1852. Fenerty, the credited co-inventor, operated a sawmill in Nova Scotia, and pursued groundwood experiments by pressing wood against a grinding wheel. However, after writing to the Halifax newspaper describing his invention, Fenerty did not further pursue the concept.

Mechanical Pulping Processes

From the starting point of pressing wood against a grinding stone with running water, a large number of mechanical pulping processes have been developed. The more important of these are listed here:

- Groundwood (GW): produced by pressing wood against a wet grinding surface.
- Pressurized groundwood (PGW): similar to groundwood but at a temperature of 100°C, which generates steam pressure.
- Refiner mechanical pulp (RMP): plate refining of wood at atmospheric pressure and no chemical treatment.
- Thermorefiner mechanical pulp (TRMP): the wood chips are heated with steam before refining at atmospheric pressure.
- Thermomechanical pulp (TMP): the wood chips are presteamed and fiberized at temperatures above 100°C. After fiberizing at high temperature, the fibers are often further treated by refining at atmospheric pressure.
- Pressure thermomechanical pulp (PTMP): like TMP, but with both refining stages being pressurized.
- Chemical mechanical pulping (CMP): the chips are treated with chemicals before refining at atmospheric pressure.
- Chemithermomechanical pulp (CTMP): chemicals are added prior to fiberizing at temperatures above 100°C.

Mechanical Pulp Properties

Mechanical pulps are produced from many different tree species using several different mechanical pulping processes. These pulps are incorporated into a large number of furnishes for use in a variety of paper products. The characteristics of the pulps depend on the tree species, the mechanical separation process, and the treatment steps following mechanical pulping. The papermaker incorporates specific mechanical pulps into paper furnishes to produce the desired characteristics. In general, mechanical pulps provide good sheet formation, increase sheet bulk, increase sheet absorption, increase sheet opacity, and increase sheet resiliency, but reduce sheet strength. Many of these properties, such as resiliency and bulk, are important for the impact printing processes. The lower strength results from the high lignin content of these pulps, which reduces the surface area available for bonding and reduces the fiber flexibility, thus decreasing the relative bonded area. A major reason why mechanical pulps are not used in permanent grades is that they photoyellow (darken) on exposure to light. One needs to recognize that mechanical pulps differ greatly in their characteristics, and they must be used with knowledge of how the various types will affect the furnish and product properties.

General Process Objectives

Groundwood and Pressurized Groundwood

GW is produced by pressing bolts (debarked short-logs) against large rotating grindstones. Today, the grindstones are artificial stones made from silicon carbide or aluminum oxide abrasives with a fused bonding agent. They are typically 1.5 m in diameter and driven by 2000–4000-kW motors. The grit on the stone surface rapidly becomes rounded and the fibers are separated through a series of compression–decompression pressure pulses. **Figure 1** illustrates a representative grinder and shows the key grinder elements. The bolts are fed in a pressurized magazine to the grinding stone. Since the stone gradually wears, an online lathe is periodically used to sharpen the stone. The separated fibers are washed from the stone into the pit with grates controlling the size of the fiber bundles allowed to pass out of the wood magazine.

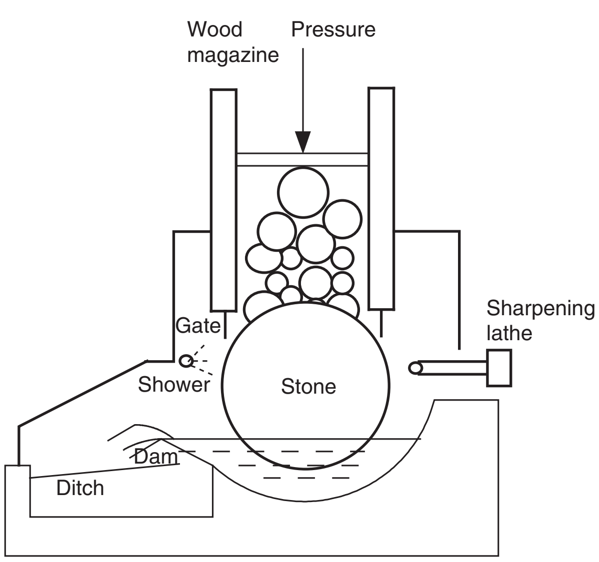

Figure 1 Representative grinder for groundwood production.

Low-density woods, because of their thin fiber wall and relatively large lumens, are good candidates for GW processes. These low-density species tend to be northern species because of the greater predominance of springwood with its thinner fiber walls. The flexing of the fiber walls allows the wood to absorb the compression–decompression, which results in fiber separation. With high-density woods, such as southern pines, the compression–decompression forces are not absorbed by the flexing of the fiber walls, and the fibers are cut rather then separated, resulting in poor pulp quality. Water washes the pulp from the grindstone and keeps the grindstone clean.

Having low density and relatively white color, spruce and fir are commonly used for pulp in newsprint, and in nonpermanent printing grades, while aspen is used in the base sheet of coated mechanical grades. Since these species are found at northern latitudes, Canada produces a high percentage of the GW pulps.

In PGW, the pressure is controlled using compressed air, enabling temperatures as high as 140°C to be reached. This increased temperature softens the lignin between the individual fibers, resulting in better fiber separation and improved strength properties. At high temperatures (typically above 160°C), there is a risk that lignin will become fluid and coat the fibers, which reduces fiber bonding and sheet strength.

Refiner Mechanical Pulp, Thermomechanical Pulp, Pressure Thermomechanical Pulp Processes

Refiner pulping uses two disks marked with bars radiating outward: usually one disk rotates (rotator) and one remains stationary (stator). Before refining, the wood is debarked and chipped. The wood chips enter at the center of the disk and are forced toward the perimeter of the refiner. The disk rotates at high speeds, typically 1500–2000 rpm, exposing the wood chips to a series of compression and decompression stages as the chips are forced from the center to the perimeter of the disks. Normally two refining stages are employed. The first stage operates at a consistency of about 30% and separates the fibers from the wood (fiberizing); the second stage operates at a consistency of about 10% and improves the papermaking properties of the fibers (refining).

TRMP and TMP are modifications of RMP, with TMP being the dominant RMP process. With thermorefiner pulping, the wood chips are heated with steam but are refined at atmospheric pressure. With TMP, the chips are presteamed at atmospheric pressure and then screw-fed to pressurized refiners. Both refining stages are usually pressurized and operate at pressures from 3 to 5 bars and temperatures from 140 to 160°C. The higher temperatures provide easier fiber separation and result in an increase of about 50% in paper strength at the same freeness and same total refiner energy relative to RMP.

RMP processes offer several advantages over GW and PGW processes. These include the ability to refine wood residues, including sawdust, less staffing requirements, and the ability to use lower-quality woods.

Chemical Mechanical Pulping and Chemithermomechanical Pulping

In these processes, the wood chips are treated with chemicals before the fibers are mechanically separated in the refiner. Compared to chemical pulping, the chemical treatment in these processes is very light, and the yield typically ranges from 80% to 95% compared to the yield of 45–50% in the chemical pulping processes. The objective of the chemical pretreatment is not to remove the lignin, as would be the case in chemical pulping, but to aid in the mechanical separation of the fibers in the refiner. Among the benefits of the chemical pretreatment are improved fiber properties, whose properties are between those of RMP and chemical pulping, and reduced refiner energy. Although the major reason for the chemical pretreatment is improved fiber properties, it is common to treat the wood chips simply to reduce the required refiner energy.

CMP consists of treating the wood chips with sodium sulfite (2–4% on oven-dried wood basis) in the case of softwoods and sodium sulfite (0–4%) plus sodium hydroxide (1–7%) in the case of hardwoods. Few hardwoods, the exceptions being aspen and popular, can be mechanically refined without the addition of chemicals. Sodium peroxide, which bleaches the pulp and allows higher hydroxide levels to be used, can be added in combination with the sodium hydroxide and sodium sulfite. The cold process, used for some of the denser hardwoods, employs sodium hydroxide without sodium sulfite. The wood chips are refined at atmospheric pressure, and the temperature is held relatively low (70–80°C), with higher temperatures resulting in darker wood.

In chemithermomechanical refining, the wood chips are presteamed with chemicals at temperatures above 100°C, followed by first-stage refining above 100°C and atmospheric second-stage refining. CTMP and TMP are the most widely used mechanical refining processes.

Postprocessing of Mechanical Pulps

Refining of Fiber Rejects

Since only part of the wood is separated into fibers during the first mechanical pulping stage, the fiber bundles must be separated from the fibers and further refined. The separation process consists of a series of screens and centrifugal cleaners. In addition to separating the fiber bundles (sieves), course fiber, sand, and other inorganic materials are removed at this stage. The screens and cleaners are arranged in cascade sequence, such that the amount of material to be disposed is minimized. The fiber rejects from the screens and cleaners consists of fiber bundles and course undeveloped fibers; these are further refined at either low consistency (3–5%) or at high consistency (30–50%) in a single-disk refiner. High consistency increases the refining intensity and normally produces superior fiber properties.

Bleaching of Mechanical Pulps

While increasing brightness is the bleaching objective for both mechanical and chemical pulps, the means through which this is accomplished are significantly different. With chemical pulps, bleaching is accomplished by removing the lignin remaining in the pulp after chemical pulping and brightening the other pulp constituents. This is often referred to as true bleaching. With mechanical pulps, bleaching is accomplished by brightening the color-containing compounds (chromophores), which are primarily lignin structures.

Pulp brightness is dependent on wood species, wood storage, the pulping process, and the bleaching process. There are considerable color differences between wood species and between sapwood and heartwood. For example, loblolly pine (*Pinus taeda)* has a typical brightness of 50%, while black spruce *(Picea mariana)* has a typical brightness of 67%. The cellulose and hemicelluloses are almost colorless and contribute little to mechanical pulp's color. While the extractives are yellow and reduce brightness, they are present at relatively low levels. Since lignin is present at high levels and is dark in color, it is the primary compound responsible for the darker color of mechanical pulps.

Wood will darken during storage, with unbarked logs darkening more than debarked logs. Although some of this darkening can be removed by bleaching, the final pulp will almost always be darker in color. To preserve brightness, unbarked logs have been stored underwater. Another reason for darkening of mechanical pulp is the condensation of colorless phenolic groups that form color compounds when they condense, a development that is accelerated at the high temperatures used in some of the mechanical pulping processes.

Some of the mechanical pulps, such as those produced from black spruce, have a high enough initial brightness for use in some applications, such as newsprint, without brightening. Other mechanical pulps need to be bleached because the processes and species used for their production result in low brightness levels, or because the product requires a higher brightness level.

Both reductive and oxidative bleaching are used with mechanical pulps. The objective of bleaching mechanical pulps is to convert the chromophores nonlight-absorbing compounds – to brighten the pulp. In addition to brightening the pulp, bleaching also reduces the extractive content of the pulps. The reductive agents include sodium dithionite–sodium hydrosulfite ($Na_2S_2O_4$), sodium bisulfite ($NaHSO_3$), formamidine sulfininc acid (FAS $HO_2S\text{-}CNH\text{-}NH_2$), and borohydride; and the oxidative agents include hydrogen peroxide (H_2O_2), sodium hypochlorite (NaOCl), and ozone (O_3). Of these bleaching agents, the most common are sodium dithionite and hydrogen peroxide.

Peroxide Bleaching

Both high pulp consistency and high pH increase the brightness levels that can be achieved with peroxide bleaching. Therefore the consistency is normally adjusted to 15–20% and the pH to about 11.5. There is an increase in brightness with increasing peroxide dosage up to a peroxide dosage level of about 4% based on (OD, % oven dried, ISO 287) pulp. Brightness increases of about 15 points, (% ISO), can be achieved with 4% addition of hydrogen peroxide.

Dithionite Bleaching

Sodium dithionite bleaching is usually performed at a pH of 6.0–6.5 and at 8–12% consistency. The normal dosage levels are from 0.5–1.0% and result in a four- to eight-point increase in brightness. An addition level of 2.0% sodium dithionite on OD pulp increases the brightness by about 10 points, % ISO.

Two-Stage Bleaching

The bleaching effects of peroxide and dithionite tend to be additive and two-stage processes are in operation. These consist of a medium peroxide stage followed by sulfur dioxide or sodium bisulfite acidification of the pulp to destroy the residual peroxide, thickening to high consistency and dithionite bleaching. Brightness gains from 15 to 20 points are achieved with two-stage processes.

Transitional Metal Ion Removal

A key variable in mechanical pulp bleaching is the presence of transitional metal ions, such as iron or magnesium. These ions catalyze the decomposition of both hydrogen peroxide and sodium dithionite. In addition to decomposing the bleaching agents, they also accelerate color reversion of the bleached pulp. Transitional elements need be avoided by using evaporator condensate in the bleaching plant or by the use of chelating agent, the most common being either ethylenediaminetetraacetic acid (EDTA) or diethylenetetraminepentaacetic acid (DTPA).

Color Reversion of Mechanical Pulps

Color reversion, either photoyellowing or thermal darkening, is the most significant hindrance for further acceptance of mechanical pulps. The optical and strength properties of CTMPs are sufficient for use in most printing paper grades. Unfortunately, CTMP darkens during storage or on exposure to light (photoyellowing). Photoyellowing of lignin-containing paper can lead to a brightness decrease of more than 30 points in a short time (6–8 months) compared to only a 3-point decrease with kraft pulp. Although wood pulps may be bleached to various brightness levels, all pulps diminish in brightness with age. Brightness reversion has been studied with various high-yield pulps, such as GW, TMPs, and CTMP. Progress on extending the brightness of high-yield, lignin-containing pulps has come slowly. Although many techniques for reducing color, including free radical scavengers (such as ascorbic acid), ultraviolet absorbers or chemical modification of the chromophores have been proposed, there is no accepted commercial process for eliminating or reducing color reversion of mechanical pulp.

Mechanical Pulp Properties

Fiber properties depend on the pulping process and type of wood, and are influenced by the species, percentage of juvenile wood, and the earlywood (springwood) to latewood (summerwood) ratio. The fiber properties that are considered the most important in determining paper properties are fiber length, cell wall thickness, and juvenile wood percentage. In comparing mechanical pulps to chemical pulps, mechanical pulp fibers are stiffer, shorter, and contain a higher level of lignin than do chemical pulps. In comparing the different mechanical pulping processes, CTMP and TMP bond better than do GW or RMP. Therefore, less chemical reinforcing pulp is required with TMP and/or CTMP than is required with GW. Conversely, the incorporation of GW would increase light scattering more than TMP or CTMP.

The Future

Mechanical pulp usage is expected to increase by about 4% per year. The current trend of decreasing fine paper basis weight is expected to continue, leading to increased use of mechanical pulps for their high opacity and bulking attributes. These changes will likely increase the need for strength and brightness of mechanical pulps. This, together with the need to decrease the electrical refining energy, will result in more complex mechanical pulping processes with new pretreatments to decrease energy usage and improve the fiber properties. The strength properties of mechanical pulps will continue to improve, decreasing the need for chemical pulps in nonpermanent printing grades. Recycled fiber, which can be produced with less energy than mechanical pulps and can replace mechanical pulps in many of the current grades, is the principal competition to mechanical pulping. The continual growth of recycled fiber may constrain the growth of mechanical pulps.

See also: **Packaging, Recycling and Printing**: Packaging Grades. **Papermaking**: Overview; Paper Grades; Paperboard Grades; The History of Paper and Papermaking; World Paper Industry Overview. **Pulping**: Fiber Resources.

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Chemical Pulping

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Introduction

Pulping processes reduce wood or any other fibrous raw material to a fibrous mass. Chemical pulping essentially dissolves the noncellulosic components in wood, mainly lignin, and thereby liberates the fibers. This process, also known as 'delignification,' centers around the removal of ligneous binding material, but, in the process, certain hemicellulosic as well as cellulosic components are dissolved. Once the pulping process becomes less selective (in the removal of lignin as compared to cellulose and hemicellulose), the process is stopped; further processing of pulp proceeds via extended delignification and bleaching processes. Although the bleaching process is intended to bleach the 'brown' unbleached pulp into bright white pulp, the initial stages in a multistage bleaching process are more aptly called delignification since they essentially contribute to additional and preferential lignin dissolution.

In a chemical pulping process, upwards of 80% of wood lignin is removed with some concomitant carbohydrate (mainly hemicellulose and some cellulose) dissolution. The overall yield of pulp in this stage can be expected to be around 50% of the original wood. Further delignification cannot be effectively carried out by conventional pulping chemicals and is hence left to bleaching chemicals.

Two major chemical pulping processes are sulfite pulping and kraft pulping. Sulfite pulping can be carried out at different pH levels with different bases – calcium at low pH (1–2), magnesium (3–5), and ammonium and sodium over the entire range of pH. The pH levels used in sulfite pulping cover the entire range of 1–13 (1–2, acid sulfite; 3–5, bisulfite; 5–7 neutral sulfite (semichemical) – NSSC; 9–13, alkaline sulfite). On the other hand, kraft pulping is a distinctly alkaline process and works in the range of pH 11–14, using the cooking chemicals of sodium hydroxide and sodium sulfide (the reactive species being the hydroxide and hydrosulfide ions).

History

The first commercial sulfite pulp was used in 1874, while the kraft process was commercially used almost a decade later (1885). However, the superior strength properties obtained by kraft pulp came to be