Chapter 2

The Pulp and Paper Making Processes

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The modem manufacture of paper evolved from an ancient art first developed in China, ca. 105 A.D. Although the modem product differs considerably from its ancestral materials, papermaking retains distinct similarities to the processes developed by Ts'ai Lun in the Imperial Chinese Court.[1] In principle, paper is made by: 1) pulping, to separate and clean the fibers; 2) beating and refining the fibers; 3) diluting. to form a thin fiber slurry, suspended in solution; 4) forming a web of fibers on a thin screen; 5) pressing the web to increase the density of the material; 6) drying to remove the remaining moisture; and 7) finishing, to provide a suitable surface for the intended end use.

Pulp and paper are made from cellulosic fibers (i.e., fibers from trees) and other plant materials, although some synthetic materials may be used to impart special qualities to the finished product. Most paper is made from wood fibers, but rags, flax, cotton linters, and bagasse (sugar cane residues) are also used in some papers. Used paper is also recycled, and after purifying and sometimes de-inking, it is often blended with virgin fibers and reformed again into paper. Other products made from wood pulp (cellulose) include diapers, rayon, cellulose acetate, and cellulose esters, which are used for cloth, packaging films, and explosives.

Wood is composed of: 1) cellulose, 2) lignin, 3) hemicellulose, and 4) extractives (e.g., resins, fats, pectins, etc.). Cellulose, the fibers of primary interest in papermaking, comprises about 50 percent of wood by ovendry weight. Lignin, which cements the wood fibers together, is a complex organic chemical the structure and properties of which are not fully understood, It is largely burned for the generation of energy used in pulp and paper mills. As the chemistry of lignin becomes better understood, what is now mostly a waste product used for fuel (some is converted to chemical products) could become a valuable feed stock for new chemical products.

The pulping process is aimed at removing as much lignin as possible without sacrificing fiber strength, thereby freeing the fibers and removing impurities that cause discoloration and possible future disintegration of the paper. Hemicellulose is similar to cellulose in composition and function. It plays an important role in fiber-to-fiber bonding in papermaking. Several extractives (e.g., oleoresins and waxes) are contained in wood but do not contribute to its strength properties; these too are removed during the pulping process.

The fiber from nearly any plant or tree can be used for paper. However, the strength and quality of fiber, and other factors that can complicate the pulping process, varies among tree species. In general, the softwoods (e.g., pines, firs, and spruces) yield long and strong fibers that impart strength to paper and are used for boxes and packaging. Hardwoods, on the other hand, generally have shorter fibers and therefore produce a weaker paper, but one that is smoother, more opaque, and better suited for printing. Both softwoods and hardwoods are used for papermaking and are sometimes mixed to provide both strength and printability to the finished product.

THE PULP AND PAPER MILL

Although there are several chemical and mechanical pulping methods used for delignifying wood (table 2-l), separating fibers, and removing discoloration, all integrated pulp and paper mills involve the same general steps in the manufacture of pulp and paper. These steps include: 1) raw material preparation (e.g., debarking and chipping); 2) mechanical and/or chemical separation of the wood fibers [i.e., grinding, refining, or digestion (cooking)] to dissolve the lignin and extractives; 3) removal of coloring agents (primarily residual lignin) by bleaching; and 4) paper formation and manufacture.

A typical layout of a mill using the kraft chemical pulping process is shown in figure 2-1. Mechanical, semichemical, and sulfite pulp mills differ in detail, particularly in wood preparation, fiber separation, and bleaching, but many of the downstream refining, bleaching, and papermaking processes are similar. In addition to the primary steps in pulp and paper manufacture, each mill has extensive facilities to

IA, H, Nissan, *Paper, Wood: Its Structure and Properties*, F.F. Wangaard (cd.) (University Park, PA: Pennsylvania State University 1981), p.335.

Table 2-1—Major Commercial Wood-Pulping Technologies

Pulp grades use	Wood type	End-product use
Chemical pulps:		
sulfite pulp	Softwoods and hardwoods	Fine and printing papers
Kraft sulfate pulp	Softwoods and hardwoods	Bleached-printing and writing papers, paperboard Unbleached-heavy packaging papers, paperboard.
Dissolving pulp	Softwoods and hardwoods	Viscose rayon, cellophane, acetate fibers, and film
Semichemical pulps:		
Cold-caustic process	Softwoods and hardwoods	Newsprint and groundwood printing papers
Neutral sulfite process	Hardwoods	Newsprint and groundwood printing papers
Mechanical pulps		
Stone groundwood	Softwoods	Corrugating medium
Refiner mechanical (RMP)	Softwoods	Newsprint and groundwood printing papers
Thermomechanical (TMP)	Softwooods	Newsprint and groundwood printing papers

SOURCE: Modified from George H. Soyd III and Chad E. Brown, *Paper Industry: Outlook for Market Pulp* (New York, NY: Kidder, Peabody & Co., 19S1), p. 5.

produce and reclaim chemical agents used in the pulping process; collect, process, and bum lignin and waste wood to produce energy; and remove and treat wastes from process water for release into the environment.

Steps in the Pulp and Papermaking Process

Raw Material Preparation

Wood received at a pulp mill may be in several different forms, depending on the pulping process and the origin of the raw material. It maybe received as bolts (short logs) of roundwood with the bark still attached, as chips about the size of a half-dollar that may have been produced from sawmill or veneer mill waste or pre-chipped from debarked roundwood elsewhere, or as waste sawdust in the case of some pulping processes.

If roundwood is used, it is first debarked, usually by tumbling in large steel drums where wash water may be applied. The debarked wood bolts are then chipped in a chipper if the pulping process calls for chemical digestion or are fed into a grinder in the case of some mechanical pulps. Chips are screened for size, cleaned, and temporarily stored for further processing.

Fiber Separation

The fiber separation stage is the point at which the several pulping technologies diverge. In kraft chemical pulping, the chips are fed into a large pressure cooker (digester), into which is added the appropriate chemicals (white liquor). The chips are then cooked (digested) with steam at specific temperatures long enough to separate the fibers and partially dissolve the lignin and other extractives.

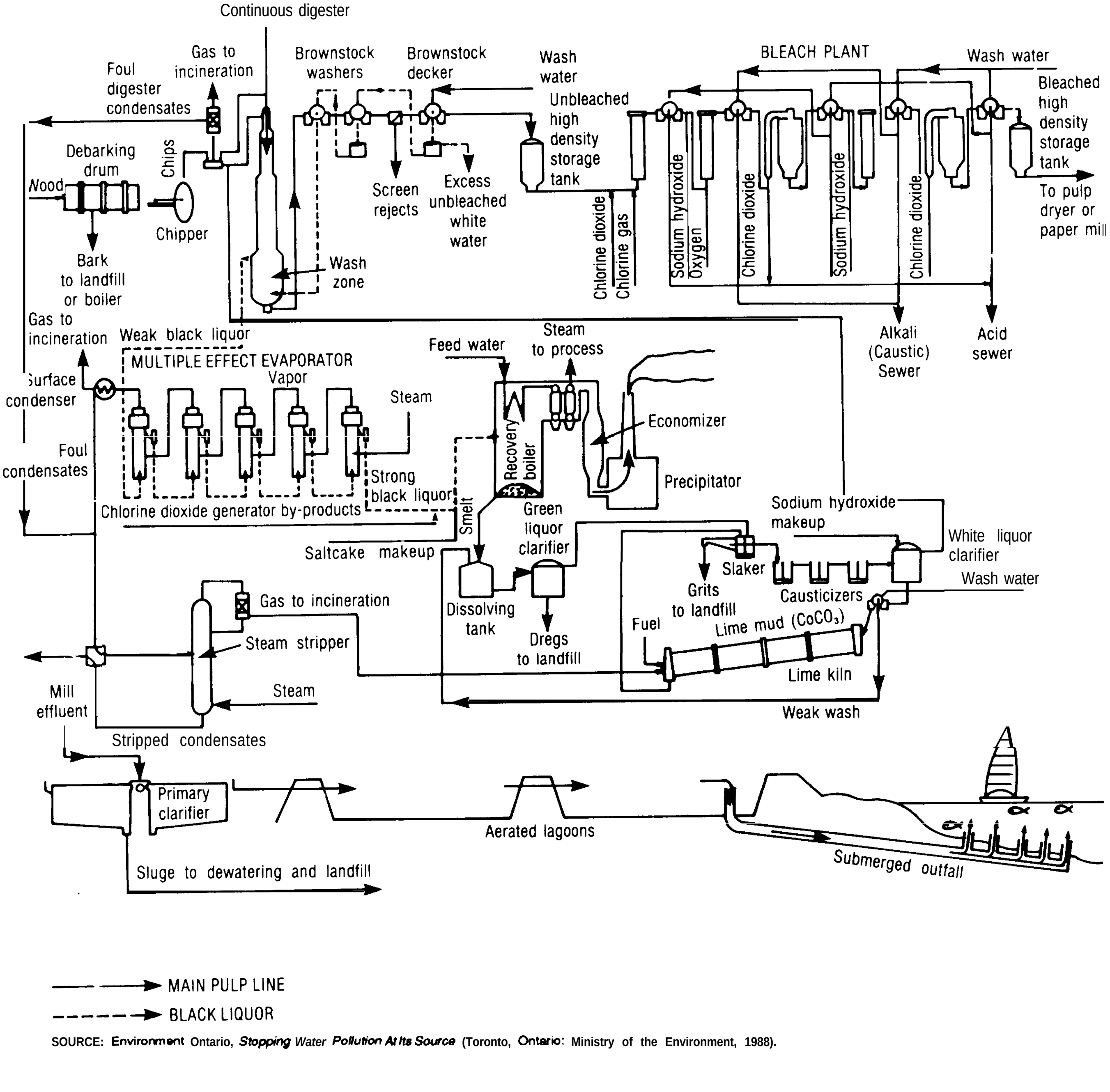
Some digesters operate continuously with a constant feed of chips (furnish) and liquor, others are charged intermittently and treat a batch at a time. After digestion, the cooked pulp (brown stock) is discharged into a pressure vessel (blow tank) where the steam and volatile materials are siphoned off. The cooking liquor, that by this time has turned dark brown from the dissolved lignin (black liquor), is returned to the chemical recovery cycle, In the chemical recovery plant, the lignin in the black liquor is burned for the cogeneration of energy, and the chemicals are recovered, purified, reconstituted, and returned to the digester as white liquor for reuse.

The brown stock containing the recovered fibers (having the consistency of cooked oatmeal) is washed with water, screened to remove undigested wood, and cleaned to remove other foreign matter. It is then ready for bleaching and further processing.

Fiber separation in mechanical pulping is less dramatic. In the stone groundwood process, debarked logs are forced against rotating stone grinding wheels that are constantly washed by a stream of water. The ground pulp is then screened to remove course debris, thickened, and stored for the papermaking process.

Chips are used to produce refiner pulp and thermomechanical pulp. In both processes the chips are ground by passing them through rapidly rotating

Figure 2-1-Overall View of Papermaking From Chemical Pulp by the Kraft Process



SOURCE: Environment Ontario, *Stopping Water Pollution At Its Source* (Toronto, Ontario: Ministry of the Environment, 1988).

disk grinders. Thermomechanical pulp is refined (ground) under pressure after the chips are pretreated with steam (chemical thermomechanical pulp uses chemicals and steam for pretreatment). After further refining in a second stage, the pulp is screened, cleaned, and most of the process water is removed in preparation for papermaking.

Bleaching or Brightening

Since the raw pulp (brown stock) still contains an appreciable amount of lignin and other discoloration, it must be bleached to produce light colored or white papers preferred for many products. Bleaching is normally done in several stages (multistage bleaching). Through chlorination and oxidation the fibers are further "delignified" by solubilizing additional lignin from the cellulose.

A number of bleaching agents may be used and are applied in a stepwise fashion within a bleaching sequence. These include chlorine gas, chlorine dioxide, sodium hypochlorite, hydrogen peroxide, and oxygen. Between bleaching treatments, a strong alkali (usually sodium hydroxide) is used to extract the dissolved lignin from the surface of the fibers. The bleaching agents and the sequence in which they are used depend on a number of factors, such as the relative cost of the bleaching chemicals, type and condition of the pulp, desired brightness of the paper to be produced, and sometimes in response to environmental guidelines and regulations.

Bleaching of mechanical pulp is much different than that for chemical pulp. Mechanical pulping leaves the lignin and the cellulose intact, whereas the purpose of chemical pulping is to chemically separate the lignin from the cellulose fibers and remove it from the pulp. A major advantage of mechanical pulping is the high yields of pulp that can be achieved from a given volume of wood. Therefore, bleaching or brightening of mechanical pulps is designed to minimize the removal of the lignin that would reduce fiber yields.

Chemicals used for bleaching mechanical pulps selectively destroy coloring impurities but leave the lignin and cellulosic materials intact, These include sodium bisulfite, sodium or zinc hydrosulfite (no longer used in the United States), calcium or sodium hypochlorite, hydrogen or sodium peroxide, and the Sulfur Dioxide-Borol Process (a variation of the sodium hydrosulfite method). Originally, much of the mechanical pulp was not bleached, but the bleaching of groundwood has increased and improved technology now enables bleached groundwood pulp to be used for printing papers, tissues, and towelling.

Papermaking

The bleached or unbleached pulp may be further beaten and refined to cut the fibers and roughen the surface of the fibers (fibrillate) to improve formation and bonding of the fibers as they enter the paper machine. Before entering the paper machine, water is added to the pulp slurry to make a thin mixture normally containing less than 1 percent fiber. The dilute slurry is then cleaned in cyclone cleaners and screened in centrifugal screens before being fed into the ''wet end* of the paper-forming machine.

In the paper making process, the dilute stock passes through a headbox that distributes the fiber slurry uniformly over the width of the paper sheet to be formed. The "web" of fiber that will make the new paper sheet is formed on a continuously moving bronze or polymer screen (Fourdrinier) or between two such wire screens. Water drains from the slurry through the mesh of the screen, the wet paper web is consolidated and the paper sheet gains some strength through fiber bonding.

The wet sheet of paper is continuously lifted from the screen (couched) and transferred to a woven felt belt where additional water is squeezed from the paper sheet by pressure rollers, The remaining water is removed on steam-heated cylinders. When the paper is dry it may be treated with stabilizing materials and surface finishes to improve durability or printability.

Pulping Technologies

Mechanical Pulping Processes

There are six basic mechanical pulping processes: 1) stone groundwood, 2) refiner, 3) thermomechanical pulping, 4) chemical mechanical, 5) defibrated or exploded pulping, and 6) recycled paper.[2] Mechanical pulping is generally used with softwoods be-

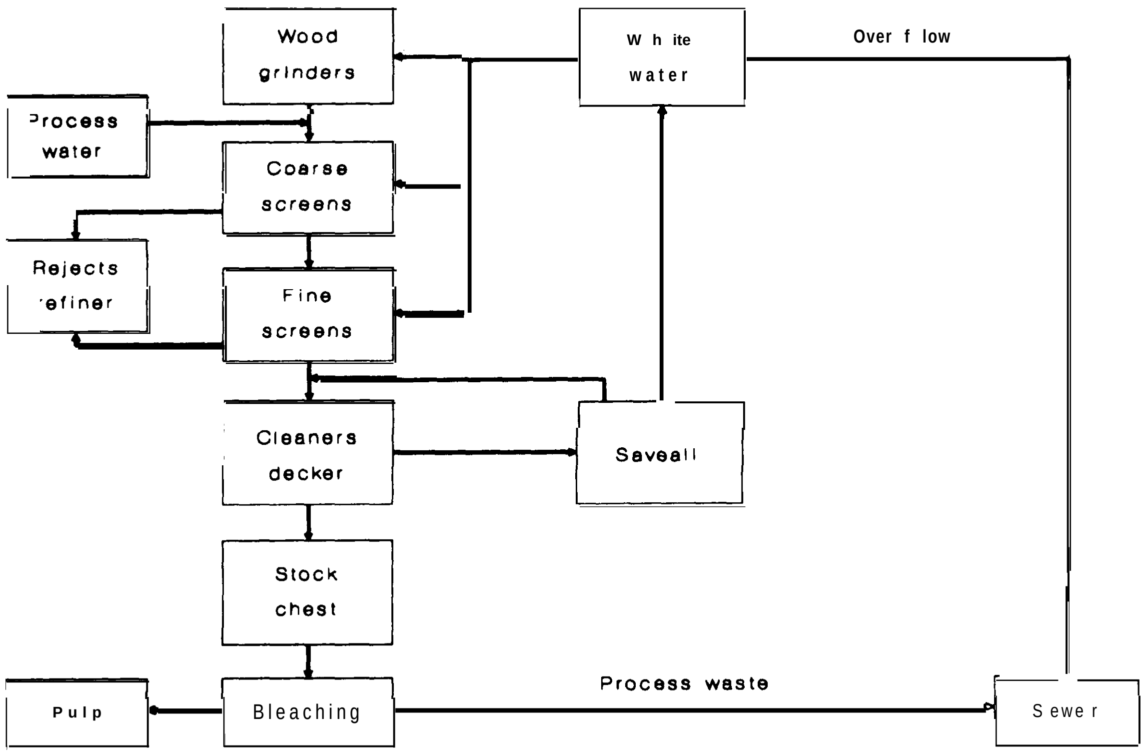
[2]This section on pulping technologies borrows heavily from a previous OTA assessment: *Wood Use U.S. Competitiveness and Technology, Vol. II: Technical Report*, OTA-M-224 (Springfield, VA: National Technical Information Service, 1984), pp. 79-94.

cause of the added strength imparted by the long fiber length of softwood species. Some hardwoods require chemical pretreatment (chemical mechancial pulping) to produce a suitable groundwood pulp. Fibers separated mechanically are substantially damaged in the process and therefore make weaker paper or paperboard. However, since both lignin and cellulose fibers remain intact, the yield of paper per unit volume of wood is still greater than that produced by chemical pulping. Pulp yields from all of the mechanical pulping processes typically are near 90 to 95 percent recovery, which is a much higher yield per unit of wood than with the chemical pulping methods because of the retention of lignin. However, paper made from mechanical pulp discolors and becomes brittle with age because of its lignin content, which results in a shorter useful life than paper made from chemical pulp.

Mechanical pulps are used principally to manufacture newsprint, printing papers, towelling, tissue, and coated specialty papers that do not require high-strength. Secondary uses include wallpaper and paperboard. Small amounts of chemical pulp are often mixed with groundwood pulp for additional strength. Recycled pulp is used mainly for the manufacture of folding boxboard (gray board), tissue, corrugated board, and newsprint. Paper products made from defibrated pulp include hardboards, construction boards, and roofing papers.

In the stone groundwood process, debarked short logs (roundwood) are fed whole against wet stone grinders by hydraulic rams. Counter-revolving steel disks are sometimes used in place of abrasive stone in the grinding process. The abrasion of the grinding wheel against the wood physically separates the wood fibers. The grinding process usually is automatic and continuous. The groundwood pulp is then screened, bleached or brightened, treated, and prepared for the paper machine (figure 2-2).

Figure 2-2-Stone Groundwood Pulp Mill Flow



SOURCE: Allan M. Springer, *Industrial Environmental Control: Pulp and Paper Industry* (New York, NY: John Wiley & Sons, 19SS), p. 147.

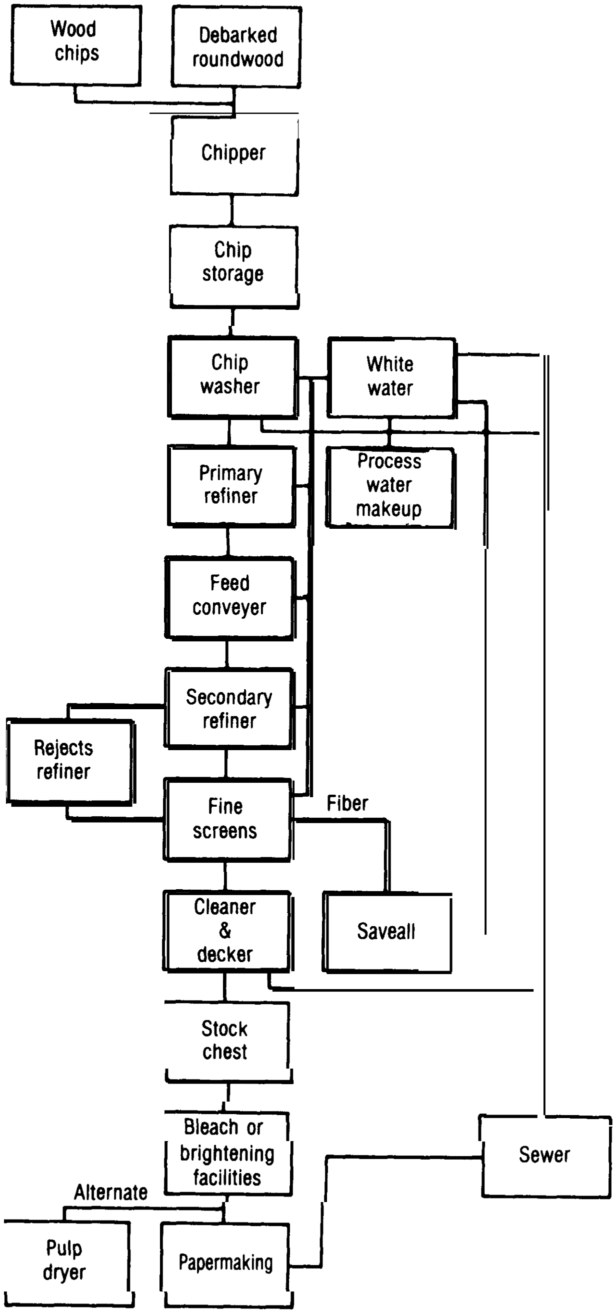
Refiner mechanical pulping (RMP) uses chips in lieu of roundwood and produces paper with higher strength than conventional groundwood because of less damage to the fibers in the pulping process. The chips are passed through a refiner that has fixed and rotating disks operating under a stream of water. A wider range of species, including hardwoods, can be processed by the refiner pulping process, Sawdust and other saw mill wastes can also be used (figure 2-3).

Thermomechanical process (TMP) was developed as a modification of the refiner mechanical pulping process. In TMP, the wood chips are steamed for several minutes under pressure and subsequently refined in one or two stages. The lignin is softened by heating the wood chips with pressurized steam before they are refined (i.e., blended by passing the fiber through rapidly rotating disks). The refined wood pulp, although stiIl weaker than chemical pulp, makes a stronger paper than groundwood or refiner pulp with only a small sacrifice in yield but with large energy requirements. Some newsprint is now produced wholly from thermomechanical pulp, thus eliminating the need for the addition of chemical pulp often needed for strengthening paper made from mechanical pulp.

The neutral sulfite semichemical (NSSC) pulping process is used at a number of U.S. mills to produce courser-grade products such as corrugated board, which has a yield of about 75 percent of the wood raw material. In NSSC pulping, wood chips are softened by briefly cooking them in a neutral sodium or ammonium sulfite solution and then separating the fibers (defibrating) in a refiner (see also Sulfite *Pulping below).*

Recycling can effectively reduce the consumption of both wood raw material and energy when used in conjunction with other mechanical pulping processes. It does so, however, with some sacrifice in paper strength. Recycled pulp is manufactured from wastepaper that is processed into paper stock. **A** small proportion of the paper stock (5 to 10 percent) is de-inked, usually with caustic soda-based chemicals. Most recycled paper, however, is pulped without de-inking. Pulping is accomplished through violent agitation and shearing action performed at high temperatures. The paper produced from recycled pulp is generally weaker than papers from virgin materials, because of the breakdown of the used fibers and loss of fiber bonding.

Figure 2-3-Refiner Groundwood Pulp Mill Process



SOURCE: Allan M. Springer, *Industrial Environmental Control: Pulp and Paper Industry* (New York, NY: John Wiley& Sons, 1986), p. 140.

Three major developments in mechanical pulping technologies show promise for improving pulp quality: 1) pressurized groundwood pulping, 2) chemical thermomechanical pulping, and 3) hardwood chemical mechanical pulping. All of these technologies have reached some stage of commercialization. Chemical thermomechanical pulping is currently used at several U.S. mills. Improvements in mechanical pulping show promise for improving the quality (strength characteristics) of paper now produced by mechanical processes. The resulting higher quality mechanical pulps may displace the kraft pulps that are currently mixed with mechanical pulps to improve paper strength.

Pressurized Groundwood Pulping—h pressurized groundwood pulping, debarked logs are fed to the grinding wheel through a heated, pressurized chamber. The heat and pressure help separate the fiber, thus breaking fewer fibers in the grinding process and improving pulp quality. Paper produced from pressurized groundwood pulp is more tear-resistant than paper made from stone-ground pulp, but is slightly inferior to that of thermomechanical pulp. Pressurized groundwood pulping may have the potential for displacing some high-quality chemical pulps in the manufacture of newsprint and other printing papers.

Chemical Thermomechanical Pulping— Chemical thermomechanical pulping involves treating softwood chips with mild sulfite solutions to modify the lignin and partially delignify the wood prior to grinding in a refiner. This "sulfonation" treatment results in paper with higher tear resistance than thermomechanical, refiner, or stone-ground pulps. Pulp yields decrease slightly to between 85 and 90 percent with chemical thermomechanical pulping, but these yields are still higher than chemical pulping (40 to 56 percent).

Hardwood Chemical Mechanical Pulping— Mechanical methods for producing pulp from hardwood species involve pretreating hardwood chips with hydrogen peroxide or sodium hydroxide and processing them like refiner mechanical pulps. Both hardwoods and softwoods have been successfully pulped by this method, with fiber recoveries in the 80 to 90 percent range. Pulp produced by hardwood chemical mechanical pulping can be used to produce newsprint and printing papers.

Chemical Pulping

Chemical pulping involves treating wood chips with chemicals to remove the lignin and hemicellulose, thus separating and cleaning the fibers. Delignification gives the fibers greater flexibility, resulting in a substantially stronger paper (because of greater contact between the fibers in the finished sheet) than can be manufactured from high-lignin fibers produced by mechanical pulping. Paper strength and durability is gained at the expense of fiber yield. Chemical processes may yield only half the fiber that can be recovered by the use of mechanical pulping techniques.

Two major chemical pulping processes are currently in commercial use: 1) kraft (sulfate) pulping, and 2) sulfite pulping. The kraft process dominates the pulp and paper industry, accounting for 76 percent of the pulp produced for paper and paperboard in 1984.[3] Paper produced from kraft pulp accounts for most of the bleached boxboard and linerboard used by the packaging industry (which consumes about 58 percent of the paper in the United States). Bleached softwood kraft pulps are often mixed with mechanical pulps to add strength to newsprint and printing papers. Bleached hardwood kraft pulps are added to bleached softwood pulp to improve printability for specialty paper products like magazine stock and coated papers. Both kraft pulp and sulfite pulp can be used for the production of dissolving pulp, which is used for the production of rayon and acetates.

Kraft Pulping—Kraft pulping involves treating wood chips and sawdust with a sodium sulfide and sodium hydroxide solution (see figure 2-1). The highly alkaline chemical and wood mixture is cooked with steam under pressure (digested) for between 1 and 3 hours. Digestion may be either a continuous process or treated in discontinuous ''batches.' Most of the lignin and some of the hemicellulose is dissolved, leaving the remaining cellulose fibers separated.

The cooking liquor containing the dissolved lignin and other extractives (black liquor) is routed to a chemical recovery plant where the lignin and

[3] *Lockwood's Directory of the Paper and Allied Trades 1986* (New York, NY: Vance Publishing Corp., 1986), p. 1.

organic wastes are burned to produce energy needed in the pulping process. Valuable extractives (e.g., turpentine, tall oil, and resin) are separated for sale as commodity chemicals. Process chemicals are recovered with only a relatively small loss in volume, and after replenishment with sodium salts, they are returned to the digester for reuse.

The brown pulp (brown stock) from the digester is washed, screened, and passed through a battery of cleaners. If the pulp is to be bleached, it is "thickened" by removing excess water and sent through a series of bleach operations. These can vary widely in the type of chemicals used and their sequence. Bleached pulp is then ready for the paper making process.

Both softwood and hardwoods can be pulped by the kraft process. Fiber recovery is largely a function of the wood species used, the time and temperature of cooking, the degree of bleaching, and the paper strength required. Generally, kraft pulp recoveries from softwoods are approximately 47 percent for unbleached pulp and 44 percent for bleached.[4] Hardwood recoveries range from 50 to 52 percent for unbleached kraft pulp to 50 percent for bleached.

Sulfitee Pulping—Lignin can be dissolved by sulfonation with an aqueous solution of sulfur dioxide and calcium, sodium, magnesium, or ammonium bisulfite cooked at high temperature and pressure in a digester (see figure 2-4). There are four basic sulfite pulping processes currently in commercial use: 1) acid sulfite, 2) bisulfite, 3) neutral sulfite, and 4) alkaline sulfite. The major differences between the sulfite processes are the levels of acidity and alkalinity of the sulfite chemical solutions used to break down the wood and remove the lignin.

Sulfite pulping processes are suitable only for species with low extractive contents (i.e., those low in tannins, polyphenols, pigments, resins, fats, and the like) because of the interference of these substances with the sulfite pulping process. Although calcium is the cheapest sulfite base available, it forms insoluble compounds that cannot be reclaimed economically. Thus, calcium-based pulping is seldom used. Because magnesium- and sodium-based chemicals are recoverable, and ammonium-based chemicals are less expensive and can be burned without harmful environmental effects, they are the most frequently used.

Sodium-based sulfite pulping can consist of multistage cooking, successive stages of which differ in acidity. Because one stage optimizes chemical liquor penetration and the other the removal of lignin, more lignin may be removed with less fiber degradation, so that fiber yields are higher, fibers are stronger, and a wider range of wood species may be used. Sulfite pulping dissolves some of the hemicellulose as well as the lignin. Neutral sulfite pulping, using sodium and ammonium bases, recovers the largest proportion of fiber (75 to 90 percent) of all the sulfite pulping methods.

Sulfite pulp is a light color and can sometimes be used without bleaching if high brightness is not required. Unbleached sulfite pulp is often blended with groundwood and other high-yield mechanical pulps for strengthening newspaper stock. Sulfite pulp is easily bleached to very bright pulps for writing and printing paper. It is also used for the manufacture of dissolving pulps (through the further removal of hemicellulose) for the production of viscose rayon, acetate fibers and films, plastic fillers, and cellophane.

Potential for New Pulping Technologies

The search for new pulping technologies and process improvements for established commercial technologies continues in the United States, Canada, Sweden, Finland, Japan, Germany, and elsewhere. In the United States, about $815 million is estimated to have been spent on pulp and paper research and development in 1987.[5] OTA could not determine what proportion of the R&D was directed at improving pulping technologies. Nearly all R&D is sponsored by the industry, with only $3 million (<0.4 percent) expended by the Federal Government.

Industry pulping R&D is largely focused on improving established pulping and bleaching processes rather than seeking new pulping technologies. Some of the research and development is driven by

[4]P.J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, WI: Institute of Paper Chemistry, 1978),

[5]Battelle Memorial Institute, *Probable Levels of R&D Expenditures in 1987: Forecast and Analysis* (Columbus, OH: Battelle, 1986), p.11.

the need for broadening the raw material base in response to concerns over forest resources. Restrictions on water use and pollution control have contributed to the impetus for seeking process improvements.

Energy costs as reflected in both energy use by the industry and their impact on the cost of chemicals has led to process improvements in the past, although moderating energy prices have recently reduced these concerns. The emphasis on recycling to reduce the massive problems of solid waste disposal in metropolitan areas has also been an incentive to using more reclaimed material in paper manufacturing. Finally, the increasing cost of capital to rebuild aging sectors of the pulp and paper industry have fed the need for more R&D by the industry.

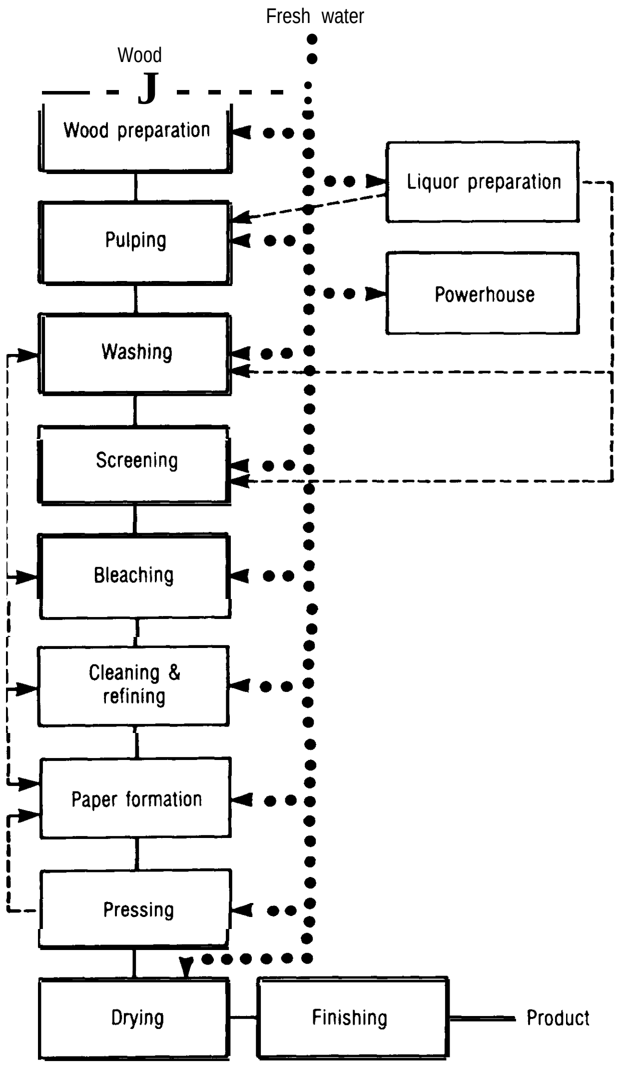
There are several reasons why major advancements in pulp and paper technology appear to be glacial in comparison to some other more rapidly advancing technologies. First, the pulp and paper industry is mature; the commercial technology, much of which was developed in the late 1700s and 1800s, has undergone evolutionary change, and satisfaction with the basic technology has led to little reason to fix something that does not appear to be broken. Concerns over future environmental problems and competition from other materials could change this, and to some degree already has.

Second, R&D is fragmented by the emphasis on process improvement, therefore few scientists **and** engineers focus on new pulping processes. In addition, many researchers specialize in one pulping process or another depending on the needs of a specific firm; few are able to consider all technological options or innovations for improving pulp yield or overall quality.

Third, R&D investment in incremental improvement in established processes is easier to sell to corporate directors than risky, long-term, radical changes. Large existing investments in plant equipment stretch the amortization period of old equipment and slow the acceptance of new processes that require substantial changes and alterations.

Finally, the absence of major government investment in long-range, high-risk R&D to seek new, innovative pulping and bleaching technologies may

Figure 2-4—Sulflte Pulp Mill Process



SOURCE: Allan M. Springer, *Industrial Environmental Control: Pulp and Paper Industry* (New York, NY: John Wiley & Sons, 1986), p. 153.

limit the advancements that could be made through collective R&D efforts. Individual firms have little incentive to undertake a major, long-term, high-investment R&D program to develop radically new technologies with uncertain payoff in the end, particularly in the current investment climate.

Organosolv Pulping (Ester Pulping)—Organo- solv pulping—sometimes called ester pulping—is a two-stage process involving hydrolysis (decomposition of the wood by dilute acids or enzymes) and the removal of lignin with an organic solvent, usually a mixture of alcohol and water. The still experimental process is suitable for both hardwoods and softwoods. Sawdust as a byproduct from lumber manufacture can also be pulped,[6] Pulp recovery from organosolv pulping ranges between 50 and 60 percent for hardwoods, and 40 and 45 percent for softwoods. Typical hardwood fiber recoveries compare favorably with those from kraft pulping.

Fibers produced by the organosolv process are weaker than those recovered by the kraft process. Thus, the papers produced from organosolv pulp are suitable for uses where strength is not the most important property (e.g., printing papers, fluff pulps, and dissolving pulp). Little waste is produced by the process, and low alcohols are recovered easily by distillation, thus requiring relatively low capital investment.[7] Commercial viability of this technology will require that markets be developed for byproducts of the process.

A commercial demonstration plant using the Alcell process developed by Repap Enterprises Corp. of Canada is currently under construction at Newcastle, New Brunswick. The 33-ton-per-day pilot plant will cost $65 million. The Canadian government is underwriting half the cost of the plant. Alcell is an alcohol cellulose organosolv process.

Hydrotropic Pulping-Hydrotropic solutions are aqueous salt solutions that impart greater volubility to slightly soluble substances (e.g., lignin) than does water at the same temperature. Sodium xylenesulfonate, a hydrotropic salt, has been used experimentally to delignify wood.[8] A hydrotropic pulping process was patented by Ralph H. McKee in 1943.[9] Laboratory pulping texts suggested that dissolution of lignin with aqueous sodium xylenesulfonate solutions of 30 to 40 percent had little or no effect on the strength of the pulp and yielded a high alpha cellulose content (important for dissolving pulp).

Pulping of poplar was conducted at temperatures of about 150 °C for 11 to 12 hours. Tests yielded 52 percent cellulose, compared to 47 percent from comparable sulfite pulp. Unlike sulfite or kraft pulping which uses contaminating inorganic chemicals, the lignin recovered through precipitation by hydrotropic pulping is relatively pure and is suitable for conversion to other chemical products. The process is not suited for resinous coniferous species, however, and comparatively little serious attention has been given to this process by the industry.

[6]Theodor N, Keinert, "Oranosolv Pulping With Aqueous Alcohol," *TAPPI J.*, August 1974, vol. 57, p, 99 et seq.

[7]N. Sawyer, Stare *of New Pulping* Processes: *Problems and Perspectives* (Madison, WI: U.S. Forest Products Laboratory, 1982), p. 10; see also Raymond W. Young and Kenneth W. Baierl, "Ester Pulping of Wood: A Revolutionary Process," *Southern Pulp & Paper*, November 1985, pp. 15-17.

[8]Ralph H, McKee, "Use of Hydrotropic Solutions in Industry," *Industrial and Engineering Chemistry*, vol. 38, No. 4.1946 p. 382; see also Ralph H. McKee, "Comparison of Wood Pulping Process," *Pulp and Paper Magazine of Canada, vol. 55, No, 2, 1954,* pp. 64-66,

[9]U.S. patent No. 2308564, Jan. 19, 1943.