Chapter 2
Brief Description of the Pulp and Paper Making Process

2.1 Introduction

Pulp and paper are manufactured from raw materials containing cellulose fibers, generally wood, recycled paper, and agricultural residues. In developing countries, about 60% of cellulose fibers originate from nonwood raw materials such as bagasse, cereal straw, bamboo, reeds, esparto grass, jute, flax, and sisal (Gullichsen 2000). The main steps in pulp and paper manufacturing are: Raw material preparation and handling, Pulp manufacturing, Pulp Washing and Screening, Chemical recovery, Bleaching, Stock Preparation, and Papermaking.

Pulp mills and paper mills may exist separately or as integrated operations. An integrated mill is one that conducts pulp manufacturing on-site. Nonintegrated mills have no capacity for pulping but must bring pulp to the mill from an outside source. Integrated mills have the advantage of using common auxiliary systems for both pulping and papermaking such as steam, electric generation, and wastewater treatment. Transportation cost is also reduced. Nonintegrated mills require less land, energy, and water than integrated mills. Their location can, therefore, be in a more open setting where they are closer to large work force populations and perhaps to their customers. A paper mill can house a single paper machine or several machines. Each machine can make a single grade of paper or a variety of papers. A dedicated machine usually manufactures a commodity grade paper such as liner board or tissue. Machines designed to make specialty grades typically have more operating flexibility and will manufacture many types of paper. The basic process of papermaking remains the same despite the type of paper manufactured or the size of the machine.

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2.2 Pulp and Paper Making Process

2.2.1 Pulp Making Process

Manufacturing of pulp starts with raw material preparation (Smook 1992a; Biermann 1996a). This includes debarking (when wood is used as raw material), chipping, and other processes such as depithing (for example, when bagasse is used as the raw material). Cellulosic pulp is manufactured from the raw materials, using chemical and mechanical means. The manufacture of pulp for paper and cardboard employs mechanical (including thermomechanical), chemimechanical, and chemical methods.

Mechanical pulping separates fibers from each other by mechanical energy applied to the wood matrix causing the gradual break of the bonds between the fibers and the release of fiber bundles, single fibers, and fiber fragments (Smook 1992b; Biermann 1996b). It is the mixture of fibers and fiber fragments that gives mechanical pulp its favorable printing properties. In the mechanical pulping, the objective is to maintain the main part of the lignin in order to achieve high yield with acceptable strength properties and brightness. Mechanical pulps have a low resistance to aging which results in a tendency to discolor. The main processes are Stone Groundwood Pulping (SGW), Pressure Groundwood Pulping (PGW), Thermo-Mechanical Pulping (TMP), or Chemi-Thermo-Mechanical Pulping (CTMP). The groundwood pulping process grinds wood into pulp. Usually this involves taking a log and pressing it against a rotating surface to grind off small pieces. The groundwood pulp is then often cooked to soften it. This pulp is used in newsprint and other low cost book grades where it contributes bulk, opacity, and compressibility. Groundwood pulp is economical since all the wood is used; however, it contains impurities that can cause discoloration and weakening of the paper. Chemimechanical processes involve mechanical abrasion and the use of chemicals. Thermomechanical pulps, which are used for making products such as newsprint, are manufactured from raw materials by the application of heat, in addition to mechanical operations. The process involves high-temperature steaming before refining; this softens the interfiber lignin and causes partial removal of the outer layers of the fibers, thereby baring cellulosic surfaces for interfiber bonding. TMP pulps are generally stronger than groundwood pulps, thus enabling a lower furnish of reinforcing chemical pulp for newsprint and magazine papers. TMP is also used as a furnish in printing papers, paperboard and tissue paper. Softwoods are the main raw materials used for TMP, because hardwoods give rather poor pulp strength properties. This can be explained by the fact that hardwood fibers do not form fibrils during refining but separate into short rigid debris. Thus, hardwood TMP pulps, characterized by a high-cleanness, high-scattering coefficient, are mainly used as filler-grade pulps. Chemimechanical pulping and chemithermomechanical pulping (CTMP) are similar but use less mechanical energy and soften the pulp with sodium sulfite, carbonate, or hydroxide. The CTMP pulps show good strength properties, even when using hardwood as a fiber source, and provided that the reaction conditions are appropriate to result in high degrees of sulfonation. Mechanical pulps are weaker than chemical pulps, but cheaper to produce (about 50% of the costs of chemical pulp) and are generally obtained in the yield range of 85–95%. Currently, mechanical pulps account for 20% of all virgin fiber material.

Chemical pulping is used on most papers produced commercially in the world today (Smook 1992b; Biermann 1996b). Traditionally, this has involved a full chemical treatment in which the objective is to remove noncellulose wood components leaving intact the cellulose fibers. In practice, separation of the components is never completely realized. Yet satisfactory compromises are reached in the processes which yields somewhere between 45 and 55% of the wood mass. Chemical pulps are made by cooking (digesting) the raw materials, using the kraft (sulfate) and sulfite processes. The kraft (sulfate) process is the most dominating chemical pulping process worldwide. The term "sulfate" is derived from the makeup chemical sodium sulfate, which is added in the recovery cycle to compensate for chemical losses. In the kraft pulp process the active cooking chemicals (white liquor) are sodium hydroxide (NaOH) and sodium sulfide (Na_2S). Kraft process is applicable to all types of wood species but its chemistry carries with it an inherent potential problem of malodorous compounds. Kraft pulp possesses superior pulp strength properties in comparison to sulphite pulp. Kraft processes produce a variety of pulps used mainly for packaging and high-strength papers and board.

Chemical recovery is an essential part of the pulp production process (Tran 2007; Vakkilainen 2000; Bajpai 2008; Biermann 1996c). Half of the wood raw material is utilized as chemical pulp fiber. The other half is utilized as fuel for electricity and heat generation. In fact, a pulp mill has two main lines. Wood is turned into pulp on the fiber line. Energy is produced on the chemical recovery line from the wood material cooked in the liquor; the cooking chemicals are recovered for reuse. In the chemical recovery line, the black liquor is evaporated and combusted in a recovery boiler, and the energy content of the dissolved wood material is recovered as steam and electricity. The chemical pulping process generates more energy than it uses. A pulp mill generates energy for its own use and energy to sell.

Sulfite process uses different chemicals to attack and remove lignin. The sulphite process is characterized by its high flexibility compared to the kraft process, which is a very uniform method, which can be carried out only with highly alkaline cooking liquor. In principle, the entire pH range can be used for sulphite pulping by changing the dosage and composition of the chemicals (Smook 1992b; Biermann 1996b). Thus, the use of sulphite pulping permits the production of many different types and qualities of pulps for a broad range of applications. The sulphite process can be distinguished according to the pH adjusted into different types of pulping. The main sulphite pulping processes are Acid (bi)sulphite, Bisulphite (Magnefite), Neutral sulphite (NSSC), and Alkaline sulphite.

Each pulping process has its advantages and disadvantages (Smook 1992b; Biermann 1996b). The major advantage of mechanical pulping is its high yield of fibers up to 90%. Chemical pulping yields approximately 50% but offers higher strength properties and the fibers are more easily breached because the mechanical pulping process does not remove lignin. Even with subsequent bleaching, these fibers are susceptible to yellowing. This is the reason that paper grades containing high quantities of mechanical pulp fiber such as newsprint discolor quickly, especially when exposed to sunlight.

After pulp production, pulp is processed in wide variety of ways to remove impurities, and recycles any residual cooking liquor via the pulp washing process. Some pulp processing steps that remove pulp impurities are screening, defibering, and deknotting. Residual spent cooking liquor from chemical pulping is washed from the pulp using pulp washers, called brown stock washers for Kraft and red stock washers for sulfite. Efficient washing is critical to maximize return of cooking liquor to chemical recovery and to minimize carryover of cooking liquor (known as washing loss) into the bleach plant, because excess cooking liquor increases consumption of bleaching chemicals. Specifically, the dissolved organic compounds contained in the liquor will bind to bleaching chemicals and thus increase bleach chemical consumption.

Mechanical pulp can be used without bleaching to make printing papers for applications in which low brightness is acceptable – primarily, newsprint. However, for most printing, for copying, and for some packaging grades, the pulp has to be bleached (Smook 1992c). For mechanical pulps, most of the original lignin in the raw pulp is retained but is bleached with peroxides and hydrosulfites. In the case of chemical pulps (kraft and sulfite), the objective of bleaching is to remove the small fraction of the lignin remaining after cooking (Smook 1992c; Reeve 1996a, b). Oxygen, hydrogen peroxide, ozone, peracetic acid, sodium hypochlorite, chlorine dioxide, chlorine, and other chemicals are used to transform lignin into an alkali-soluble form (Reeve 1989). An alkali, such as sodium hydroxide, is necessary in the bleaching process to extract the alkali-soluble form of lignin.

Pulp is washed with water in the bleaching process. In modern mills, oxygen is normally used in the first stage of bleaching (Bajpai 2005a). The trend is to avoid the use of any kind of chlorine chemicals and employ “total chlorine-free” (TCF) bleaching. TCF processes allow the bleaching effluents to be fed to the recovery boiler for steam generation; the steam is then used to generate electricity thereby reducing the amount of pollutants discharged. Elemental chlorine-free (ECF) processes, which use chlorine dioxide, are required for bleaching certain grades of pulp. The use of elemental chlorine for bleaching is not recommended. Only ECF processes are acceptable, and, from an environmental perspective, TCF processes are preferred. The soluble organic substances removed from the pulp in bleaching stages that use chlorine or chlorine compounds, as well as the substances removed in the subsequent alkaline stages, are chlorinated. Some of these chlorinated organic substances are toxic; they include dioxins, chlorinated phenols, and many other chemicals. It is generally not practical to recover chlorinated organics in effluents, since the chloride content causes excessive corrosion.

2.2.2 *Stock Preparation and Paper Making Process*

Before pulp can be made into paper, it must undergo several steps called stock preparation (Smook 1992d; Biermann 1996e) Stock preparation is conducted to convert raw stock into finished stock (furnish) for the paper machine. The pulp is prepared for the paper machine including the blending of different pulps, dilution, and the addition of chemicals. The raw stocks used are the various types of chemical pulp, mechanical pulp, and recovered paper and their mixtures. The quality of the finished stock essentially determines the properties of the paper produced. Raw stock is available in the form of bales, loose material, or, in the case of integrated mills, as suspensions. Stock preparation consists of several process steps that are adapted to one another as fiber disintegration, cleaning, fiber modification, and storage and mixing. These systems differ considerably depending on the raw stock used and on the quality of furnish required. For instance, in the case of pulp being pumped directly from the pulp mill, the slushing and deflaking stages are omitted. The operations practiced in the paper mills are: Dispersion, Beating/Refining, Metering, and blending of fiber and additives.

Pulpers are used to disperse dry pulp into water to form a slurry. Refining is one of the most important operations when preparing papermaking fibers (Baker 2000, 2005; Bajpai 2005b; Biermann 1996d; Stevens 1992). The term beating is applied to the batch treatment of stock in a Hollander beater or one of its modifications. The term refining is used when the pulps are passed continuously through one or more refiners, whether in series or in parallel. Refining develops different fiber properties in different ways for specific grades of paper. Usually, it aims to develop the bonding ability of the fibers without reducing their individual strength by damaging them too much, while minimizing the development of drainage resistance. So the refining process is based on the properties required in the final paper. Different types of fiber react differently because of differences in their morphological properties. The refining process must take into account the type of fibers. During beating and refining, fibers randomly and repeatedly undergo tensile, compressive, shear and bending forces (Baker 2000; Bajpai 2005b; Biermann 1996d; Stevens 1992). They respond in three ways:

- Fibers develop new surfaces externally through fibrillation and internally through fiber wall delamination.
- Fibers deform, resulting in changes in their geometric shape and the fibrillar alignment along their length. Overall, the fibers flatten or collapse. Fiber curl changes and kinks are induced or straightened. On the small scale, dislocations, crimps, and microcompressions are induced or diminished.
- Fibers break, resulting in changes in length distribution and a decrease in mean-fiber length. A small amount of fiber wall material also dissolves. All these changes occur simultaneously and are primarily irreversible. The extent of the changes depends on the morphology of the fibers, the temperature, the chemical environment, and the treatment conditions. The conditions depend on the design of the equipment and its operating variables such as the consistency, intensity, and amount of treatment. Each pulp responds differently to a given set of conditions and not all fibers within it receive the same treatment.

The furnish (as it is now referred to) can also be treated with chemical additives. These include resins to improve the wet strength of the paper, dyes and pigments to affect the color of the sheet, fillers such as talc and clay to improve optical qualities, and sizing agents to control penetration of liquids and to improve printing properties (Bajpai 2004; Hodgson 1997). After stock preparation, the next step is to form the slurry into the desired type of paper at the wet end of the paper machine.

The pulp is pumped into the head box of the paper machine at this point (Smook 1992e; Biermann 1996f). The slurry consists of approximately 99.5% water and approximately 0.5% pulp fiber. The exit point for the slurry is the "slice" or head box opening. The fibrous mixture pours onto a traveling wire mesh in the Fourdrinier process, or onto a rotating cylinder in the cylinder machine (Biermann 1996f). The Fourdrinier machine is named after its French inventors, the Fourdrinier brothers, and is essentially a table over which the wire moves. Greater quantities of slurry released from the head box result in thicker paper. As the wire moves along the machine path, water drains through the mesh. Fibers align in the direction of the wire travel and interlace to improve the sheet formation. After the web forms on the wire, the task of the remaining portion of the paper machine is to remove additional water. Vacuum boxes located under the wire aid in this drainage.

One of the characteristics inherent in the performing of the sheet on a Fourdrinier paper machine is that all the water is removed through one side of the sheet. This can lead to differences in the sheet properties on one side as opposed to the other. This two-sided property increases as machine speed increases. In response to this, manufacturers developed twin wire and multiple Fourdrinier machines. Manufacturers of such equipment use different engineering designs that can be vertical or horizontal. After the paper web has completed its short forming distance, it continues along the second wire losing water as it travels.

The next stop for the paper is the pressing and drying section where additional dewatering occurs (Smook 1992e; Biermann 1996f). The newly created web enters the press section and then the dryers. As the paper enters the press section, it undergoes compression between two rotating rolls to squeeze out more water. The extent of water removal from the forming and press sections depends greatly on the design of the machine and the running speed. When the paper leaves the press section, the sheet usually has about 65% moisture content. The paper web continues to thread its way through the steam heated dryers losing moisture each step of the way. The process evaporates many tons of water.

Paper will sometimes undergo a sizing or coating process. The web in these cases continues into a second drying operation before entering the calendaring stacks that are part of the finishing operation. Moisture content should be about 4–6% as predetermined by the mill. If the paper is too dry, it may become too brittle. About 90% of the cost of removing water from the sheet occurs during the pressing and drying operations. Most of the cost is for the energy required for drying.

At the end of the paper machine, paper continues onto a reel for winding to the desired roll diameter. The machine tender cuts the paper at this diameter and immediately starts a new reel with the additional paper falling as an endless web.

For grades of paper used in the manufacture of corrugated paperboard, the process is now complete. For those papers used for other purposes, finishing and converting operations will now occur, typically off line from the paper machine. These operations can include coating, calendaring, or super calendaring and winding.

Coating is the treatment of the paper surface with clay or other pigments and/or adhesives to enhance printing quality, color, smoothness, opacity, or other surface characteristics. There is a great demand for paper with a very smooth printing surface.

Various grades of paper, including paperboard, printing, writing and industrial or packaging grades sometimes have coatings. Most coated paper is ground with paper made from mechanical pulp. The term “coated free sheet” describes paper made from ground wood-free fibers being produced from chemical pulp. Three major coated paper categories exist – glossy, dull, and mat. Many people equate coated paper with the gloss stock of a magazine. Books and other products may use dull coated paper to retain the advantages of coated paper while reducing light glare.

Two popular coating methods are air knife and blade coating. In the air knife process, a jet of air acts like a blade to remove excess coating applied to the paperboard. The blade coating process using a flexible blade set in an adjustable angle to remove excess coating across the web. Following the coating operation, the sheet must again be dried and rewound.

Calendering is an on-machine process where the paper passes through a series of polished steel rolls to smooth the paper surface before rewinding on a reel. Besides imparting smoothness, calendering can reduce variations in the sheet and create a higher density sheet. It can also affect the water absorption properties of the paper.

Winding may appear to be a simple process, but anyone who has ever tried to rewind a roll of bathroom tissue after a small child has played with it will think differently. Maintaining proper tension on the reel so that the sheet lies flat and attains proper alignment for both edges is a difficult task. Further complications occur with the higher speeds (up to 6,000 ft/min) of the paper machine. At this rate, the paper web is moving faster than a car at highway speed and paper the length of 20 football fields would wrap on a roll every minute.

Other operations can also take place including cutting, sorting, counting, and packaging. For some products such as tissue and copy paper, the typical paper mill will conduct all of these operations. In most cases, however, the rolls are wrapped and readied for shipment to their final destination.

The nature of paper and papermaking has changed very little over the past 150 years since the introduction of the Kraft Fourdrinier process. However, the techniques and equipment necessary to make paper have changed dramatically. Because of this, we can rely on a consistent supply of high quality graded papers for almost any need we can imagine.

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