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Chemical Engineering in the Paper Industry to Meet the Needs of Society

Paper is a material that impacts our lives on a daily basis. Some of its uses include mass communication through newspapers and books, personal communication through documents and reports, keeping physical business records, art and decoration, and packaging. Papermaking began nearly two thousand years ago in China. Individual sheets of paper had to be produced by hand, one at a time. Later the initial batch process improved allowing more than a single sheet to be produced per batch. Although the batch process had much improved by 1760, due to the growth of the industrial revolution global demands for paper required a faster means of production. In addition, the need for stronger paper required by industry influenced the development of new production methods. Changes in culture defined the role of early chemical engineers to develop a process for mass production of paper suitable for both personal and industrial uses. In recent times, chemical engineers have had to take into account the pressing wish of society that paper production refrain from damaging the environment.

Wood pulp is a dry fibrous material prepared by separating fibers from wood. Two types of pulping, mechanical and chemical, have been used to improve papermaking during the last 1400 years. Mechanical pulping uses physical work to reduce a wood log into fiber suspended in water. Chemical pulping pre-treats wood with chemicals that remove lignin from the wood. Lignin is an inter-fiber bonding agent that binds cellulose fibers together.

Paper gets its strength in two ways: the purity of the cellulose fibers and the length of the fiber chains used to make the paper. Because chemical pulping removes lignin from the wood pulp, physical damage to the cellulose fibers is minimal. Therefore, chemical pulping produces paper much stronger than that produced via mechanical pulping. The chemical pulping process responsible for approximately 85% of global production is known as the Kraft process.

The Kraft process was conceived in 1879 by a German scientist named Dahl. However, his process was aptly named “kraft,” German for strength, because the wood pulp produced could create paper much stronger than that produced mechanically. During the Kraft process, wood chips are cooked in pulping liquor, an aqueous solution of sodium hydroxide and sodium sulfide. Because sodium sulfide stabilizes the cellulose fibers in the wood chips, little damage is done to the fibers during pulping unlike the sulfite process, the dominant process until the

1940's. Additional process chemicals such as surfactants and anthraquinone are introduced to ease the pulping process. Surfactants allow for shorter cooking times by improving absorption of the pulping liquor by the wood chips, and anthraquinone oxidizes cellulose and reduces lignin which decreases damage to the cellulose and increases the solubility of lignin, allowing the Kraft process to produce pulp quickly. A cyclic recovery system is used to reduce chemical waste, pollution and consumption of chemicals. Because the pulping liquor dissolves the resins present in the wood chips, the versatility of the Kraft process allows pulping not only of hardwoods and softwoods, but also resinous and pitchy woods.

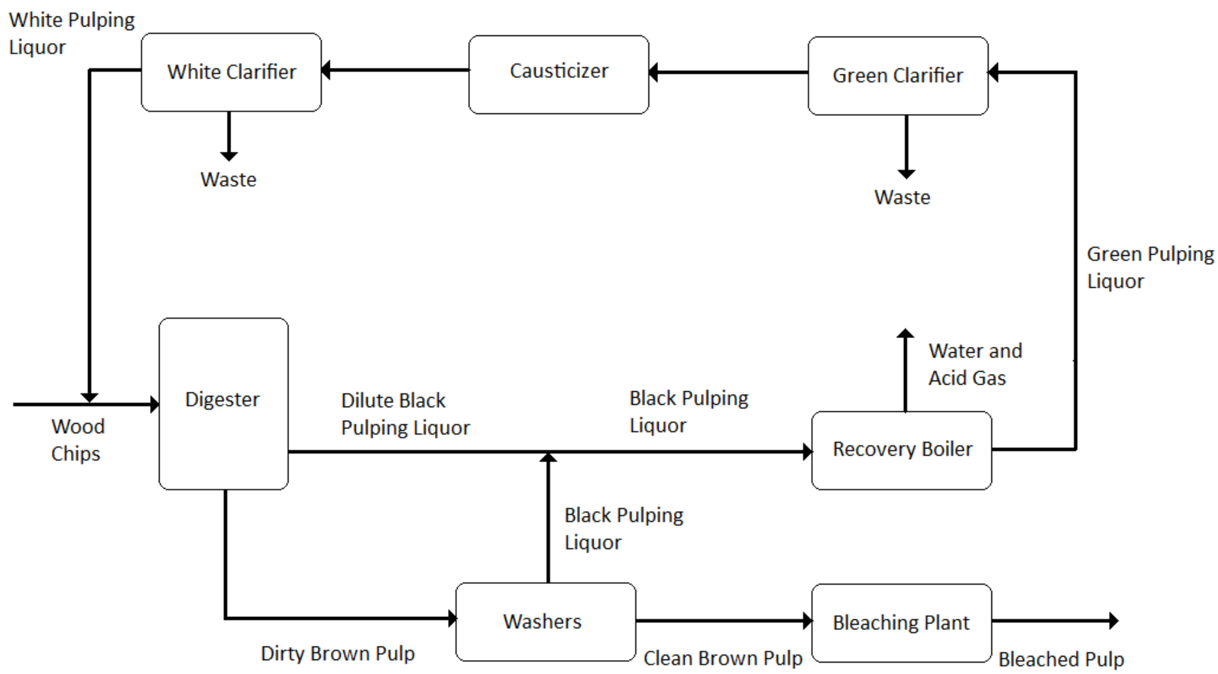

Figure 1: Simplified Kraft process flow diagram.

Despite the cyclic chemical recovery system, the Kraft process nevertheless presents some environmental pollution. Volatile hydrogen sulfide and methyl mercaptan are released from pulping plants. Hydrogen sulfide gas has the odor of rotten eggs, is known to cause eye, nose, and throat irritation at low concentrations, and can cause loss of consciousness and death at high concentrations. Because the density of hydrogen sulfide is lower than that of air, it rises into the atmosphere where it reacts with moisture to from sulfur dioxide and sulfuric acid after 18 hours. Methyl mercaptan gas has the odor of rotten cabbage. In addition to causing eye, nose, and throat irritation, low concentrations also may cause headaches, dizziness, seizures, nausea, and vomiting. At high concentrations, the nervous system becomes suppressed leading to death. Unlike hydrogen sulfide, the density of methyl mercaptan is larger than that of air causing it to hug the ground. Consistent with current pollution rules for safety, between 0.03 and 2.8 kg of sulfide emissions are released per ton of pulp produced, down substantially from 8.3 to 14.1 kg released prior to recent controls.

Effluents that have high concentrations of suspended solids, are acidic or basic, or have a high BOD (biochemical oxygen demand) are detrimental to aquatic life and the surrounding ecosystems. In practice, a clarifier is used to remove 90-95% of the suspended solids in an effluent, acidic and basic effluents are blended and neutralized until they reach the pH of the receiving body of water, and reduction of BOD is accomplished by running alkaline waste effluent through an activated-sludge plant.

Because paper is used in a wide variety of applications, production of paper is a multi-billion dollar annual business. Table 1 shows the growth of paper production in metric tons (1 metric ton is equal to 1000 kilograms) over the past 5 decades. Paper recycling is necessary to minimize landfill space and to reduce the number of trees that need to be farmed for paper production. Today paper comprises nearly 40% of landfill waste, the largest fraction of any waste category. Recently recycling in the US has increased from 33.5% in 1990 to 53.4% in 2006, with a target of 55% by 2012. For every metric ton of paper recycled approximately 21 mature trees, 8,500 gallons of water, 2.78 m^3 of landfill space, 2.4 barrels of oil and 5,000 kWhr of electricity are conserved.

	Production of Wood Pulp by Year, in Thousands of Metric Tons				
	1960	**1970**	**1980**	**1990**	**2000**
Brazil	453	811	3,361	4,844	6,473
Canada	10,397	16,609	13,390	16,466	20,921
China		1,220	6,825	17,057	35,439
Finland	3,700	6,471	5,919	8,777	13,509
France	1,139	1,787	5,152	7,049	10,006

Japan	3,524	8,801	18,088	28,088	31,828
Norway	1,645	2,182	1,373	1,819	2,300
Sweden	5,611	8,142	6,182	8,419	10,786
USA	22,966	39,304	56,839	71,965	81,529
USSR	3,213	6,679	8,733	10,718	5,310
West Germany	1,452	1,732	7,580	11,873	18,182
Other	5,480	11,034	37,506	51,975	87,763
World	59,580	104,772	170,948	239,050	324,046

Table 1: Global paper production by country over the past 5 decades.

Without the development of processes to mass produce paper, life as we know it would be drastically different. If paper was produced by hand, one sheet at a time, the cost would be enormous because there would be tremendous demand on an extremely limited supply, precluding daily newspapers. Without mass production of paper, only important books would only be published. The extent of education would be low because books would not be available to everyone who is willing to learn. While information can still be provided electronically, books are nevertheless necessary, especially in the underdeveloped world where electronic devices are rare.

Without inexpensive paper, there would be a lack of public records, such as property titles, birth and death certificates, and other legal records. This would hinder the organization of trade, and create property disputes. Without birth and death records it would be difficult to gauge the size and growth of the population. Without legal records a new justice system would be required.

In an industrialized world, what containers would be available? A large portion of shipping packaging is produced solely from paper products. Even with paper made by hand, the durability required to ship heavy objects cannot be achieved. Without a chemical process, such as the Kraft process, paper couldn’t be used for packaging. Without a suitable alternative, mass production of many items used daily, such as shampoo, toothpaste, soaps, and detergents, may be economically infeasible due to outrageous packaging costs.

The significant increase in cultural demand for paper between 1700 and 1800$_{A.D.}$, stimulated chemical engineers to develop methods for mass production. The cultural demand for paper had a strong influence on chemical engineers to study the paper making process toward production of stronger paper. On the other hand, in development of a process to mass produce paper, chemical engineers developed processes that were also capable of producing stronger paper required for necessary packaging for numerous household products used by millions of consumers on a daily basis.

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