Paper Raw Materials and Technology

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Introduction

Paper and paper products in today's world play a very important role in everyday life. One cannot think of any activity without the use of paper; in fact paper is almost synonymous with development in the contemporary world. Per capita annual paper consumption is one of the indicators of economic development and the literacy rate of a country. Consequently the pulp and paper industry is one of the most important industries of the world, which provides employment to a very large number of people in most of the countries of world. Furthermore, the rising population and the recent change in lifestyles necessitate that paper should be available in plenty and at a very cheap price. Consequently, significant research and development has taken place for finding different raw materials for the manufacture of pulp (the basic constituent of paper) and for developing efficient, environmentally friendly, and economical technologies for papermaking. These two aspects will be the focus of this article, with special emphasis on non-wood fibers.

Definition and History

'Paper' is defined as the sheet or web formed by the deposition of (vegetable, animal, or synthetic) fiber from a suspension (in water, vapor, or gas) with or without the addition of sizing chemicals and filtered over a fine screen in such a way that the fibers are bonded and intermeshed together after pressing and drying. The raw material for these fibers is pulp, which is commercial cellulose, fibrous in nature and derived from wood, bamboo, grasses, or any other raw material by mechanical or chemical means. The paper thus formed may be coated or impregnated with the use of different materials to make it suitable for various specific end uses such as writing paper, packing paper, currency paper, and so on.

The use of non-wood fiber (NWF) for making pulp and paper dates back more than 2000 years. The oldest surviving piece of paper, discovered in 1957 in a tomb in Sian, China has been dated to between 140 and 87 BC. This paper and similar pieces of ancient papers are all made up of pounded and disintegrated hemp fibers. Furthermore, paper historians argue that the earlier Egyptian papyrus sheets, being woven and not 'wet laid' should not be referred to as true paper. Until the late nineteenth century the only source of fiber for papermaking was rags, i.e., worn-out clothes. Since at the time clothing was made of hemp and flax (occasionally cotton), it would not be wrong to say that almost all paper in history was thus made from NWFs. However, an increased demand for paper coupled with a shortage of rags and a scarcity of hemp and flax compelled the paper industry to look for alternative sources and modifications in papermaking technology. This led to the use of the world's most abundant and cheap source of fibers: our forests. Consequently, the usage of NWF as paper pulp has been reduced to 5% of total pulp production and is restricted to developing countries and some parts of Europe.

Characteristics of Non-Wood Cellulosic Raw Material and Paper Properties

All lignocellulosic fibrous raw materials used for pulp and paper essentially consist of cellulose and lignin along with some extraneous material called extractives such as gums and resins (**Figure 1**). Cellulose, a polymer of carbohydrates $(C_6H_{10}O_5)_n$, is the main constituent of the cell wall of plants and its natural source in pure form is cotton. The length of cellulose fibers affects various physical strength properties of paper, such as tensile, burst, and tear indices, and surface and optical properties, such as smoothness and brightness. Furthermore, the degree of polymerization (DP) denoted by n in the formula varies with the source of raw material and is also affected by chemical treatment during pulping and bleaching. DP in papermaking fibers varies from 600 to 1800. Decrease in DP during pulping results in a decrease in the strength properties of paper. Hemicellulose is another constituent composed of short-chain polysaccharides, which is a polymer of five different sugars, namely glucose, mannose, galactose, xylose, and arabinose. The hemicelluloses are chemically bonded with cellulose and lignin in a plant cell wall (**Figure 1**). Thus the total carbohydrate part of the fiber is referred to as holocellulose.

Lignin

Lignocellulosic material contains a polymerized hydrophobic substance lignin, which is amorphous, highly branched, and three-dimensional. It acts as a cementing material in woody plant fibers and is mainly concentrated in the intercellular portion called the middle lamellae and to a lesser degree

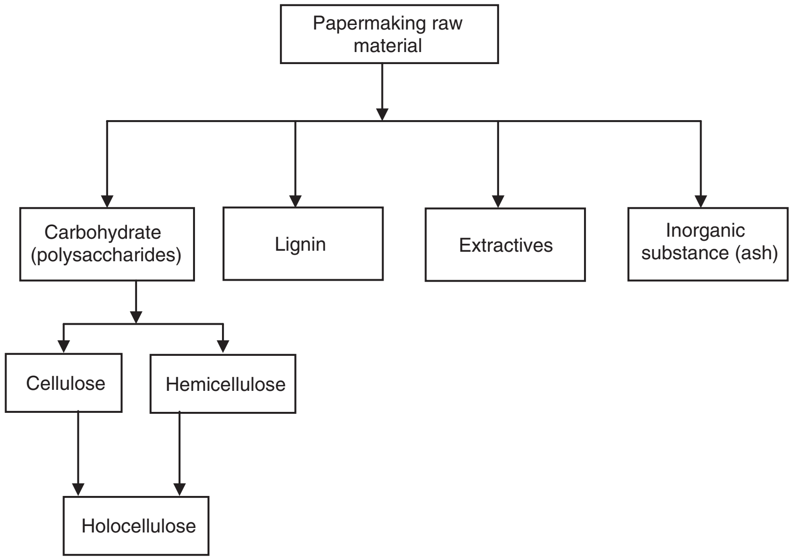

Figure 1 Components of cell wall of raw materials used for papermaking. The process of papermaking essentially comprises isolation of holocellulose and removal of lignin, extractives, and inorganic substances.

distributed in the cross-section of the cellulosic fiber. It imparts structural strength to wood but it is undesirable for papermaking as it inhibits interfiber bonding during the process of papermaking. Therefore, lignin is removed by treatment with acid or alkali, which results in its dissolution and facilitates fiber separation. The degree of lignin removal is dependent upon the desired quality and type of paper to be prepared.

In addition to cellulose, hemicelluloses, and lignin, the other group of chemical substances such as gum, resin, fatty acids, turpenes, and alcohols are also found in native fibers, depending upon the type of plant source. These substances, commonly referred to as extractives, are also undesirable for papermaking and are removed during pulping.

Most of the cellulosic raw materials due to their hydrophilic nature contain an appreciable amount of water either in green or air-dried conditions. It is, therefore, very essential to express the weight of raw material on a dry basis or wet basis. The common practice in paper mills is to express raw material weight on an oven-dried basis. This also helps in calculating the amount of various chemicals needed for wood or pulp processing. Further, wood specific gravity plays a very important role in the papermaking process and the properties of the end product. The specific gravity for softwood and hardwoods falls in the range of 0.29–0.57 and 0.30–0.70 respectively. High-density woods are harder to chip, require more energy for chipping, and are difficult for chemical penetration during pulping. Wood specific gravity strongly influences the fiber flexibility or collapse, which in turn influence the interfiber bonding and paper surface roughness. Low specific gravity wood will produce thin-walled, less coarse fibers, which collapse easily to give high physical strength properties with high paper sheet density. This makes softwoods suitable raw material for the manufacture of paper sheet of high density, low bulk, and higher physical strength. Therefore, it is clear that an ideal raw material for papermaking should have maximum holocellulose content, minimum lignin, and higher LD ratio, which is ratio of fiber length to fiber diameter. Accordingly softwoods are the best raw material for pulp making followed by hardwoods, bamboo, kenaf, and agricultural residues (**Table 1**).

Non-Wood Raw Materials for Pulp and Paper

Although any cellulose raw material can be used for the preparation of pulp and paper in the laboratory using the kraft pulping process, a proper selection of raw material is very important (from the vast source of vegetable kingdom) for commercial production. Wood, however, is the main source (60–70%) of raw material while non-woods such as bagasse, rice straw, wheat straw, reeds, bamboos and secondary fiber commonly known as recycled fiber (wastepaper) account for the rest of commercial production.

Bamboo

Apart from softwood and hardwood another most commonly used raw material for pulp is bamboo, which is used mainly in countries of the Asian

Table 1 Chemical composition, fiber dimensions, and global availability of wood and non-wood fibers for manufacture of various types of papers

Fiber source	*Cellulose (%)*	*Lignin (%)*	*Mean fiber dimension (mm)*		*Global availability in million tonnes (bone dry)*	*Types of papers*
			Length	*Width*		
Long fibers						
Cotton staple	85–90	0.7–1.6	25	0.02	18.3	Specialty papers, permanent document, banknotes, etc.
Seed flax	43–47	21–23	30	0.02	2.0	As reinforcement pulp to improve physical strength of paper, specialty papers
Hemp	57–77	9–13	20	0.022	0.12	Cigarette paper, tissue, lightweight paper, filter paper, greaseproof paper, security papers, tea bags, etc.
Abaca (manila)	56–63	7–9	6.0	0.024	0.08	Tissue and specialty papers
Medium long fibers						
Softwood	53–62	26–34	4.1	0.025	99.2	Almost all types of paper and board, and tissues of all grades
Sisal	47–62	7–9	3.3	0.02	0.50	Specialty papers
Bamboo	26–43	21–31	2.7	0.014	30.0	Printing and industrial grade papers
Kenaf	44–57	15–19	2.6	0.02	3.0[a]	Printing and industrial grade papers, tissues, etc.
Jute	45–63	21–26	2.5	0.02	13.7[b]	Most paper grades
Bagasse	32–37	18–26	1.7	0.02	120.20	Printing and industrial grade papers, greaseproof papers, and dissolving grade pulp
Short fibers						
Hardwood	54–61	23–30	1.2	0.03	41.6	Printing and industrial grades, tissues, etc.
Wheat straw	49–54	16–21	1.4	0.015	600.00	Printing and industrial grades of papers
Rice straw	43–49	12–16	1.4	0.008	360.00	Printing and industrial grades of paper
Esparto	33–38	17–19	1.2	0.013	-	Specialty papers
Rye straw	50–54	16–19	1.3	0.014	40.00	Printing and industrial grades of paper

[a] Bast fiber.
[b] Whole stalk.

subcontinents such as India, China, Malaysia, Indonesia, Thailand, Myanmar, etc. Bamboo fiber is longer than that of hardwoods but shorter than softwood and has a high silica content, which poses some problems in chemical recovery and papermaking. This is overcome by using desilication of pulping spent liquor and improved paper technology. The bamboo species most widely used for pulp and paper manufacture are *Dendrocalamus strictus*, *D. hamiltonii*, *Bambusa tulda*, and *Melocanna baccifera*.

Agricultural Residues

Growing demand for pulp, shrinkage of forests, and the consequent shortage of pulpwood experienced by pulp and paper mills around the globe have led to the search for alternative sources of raw material from agricultural residues such as sugarcane bagasse, rice straw, wheat straw, and cotton stalks. These raw materials are used for the manufacture of pulp and paper in the countries where forest-based raw material, i.e., wood is not available due to environmental considerations and to dwindling forest cover. The use of these raw materials has increased considerably and is expected to raise further the pulp and paper manufacture capacity particularly in countries like India, Pakistan, China, Egypt, Turkey, Indonesia, Bangladesh, Mexico, and Taiwan. The major sources of NWF in agricultural residue category are as follows.

Bagasse Sugarcane is an important annual crop grown primarily for the manufacture of sugar on a very large area all over the globe particularly in Asian countries, South America, South Africa, the USA, and the UK. The fibrous residues left after the extraction of sugar juice is known as bagasse and is a very promising pulping material for paper.

The greatest advantage in using bagasse as NWF lies in the fact there is no additional cost involved in growing and harvesting, and only the collection cost is borne by the paper industry. However, bagasse is usually used as fuel in the sugar mill's boiler furnace. Therefore only the surplus bagasse is available for use as a pulp material in the vicinity of sugar mills. Bagasse contains 25–30% pith, a nonfibrous material unsuitable for pulping. It is, therefore, removed by a wet or dry depithing operation and subsequently pulped either by soda or kraft process. Recent advances in pulping and papermaking technology have made it possible to use bagasse for the manufacture of cultural, industrial, and greaseproof grades of paper. It is also used for the manufacture of dissolving grade pulp for the manufacture of viscose rayon.

Rice and wheat straw Rice and wheat, like sugarcane, are annual crops grown in major areas of the globe. Their straw is used for the manufacture of pulp which is then made into various grades of paper using the soda process in minimills in various parts of the world. These agricultural residues yield short fiber and due to its higher silica and ash content, wheat straw is favored over rice straw as pulp material. Papers made solely from straws can be recycled only a few times due to weak fibers, which loses its strength properties after one or two pulping cycles. Therefore, these short-fibered straw pulps are occasionally blended with long-fiber reinforcement pulp to produce various varieties of cultural and industrial grades of papers of higher strength. These straws represent a promising source of fiber and are being used primarily in countries where wood is in short supply.

Other Non-Wood Plant Fibers

Other non-wood plant fibers are esparto, elephant grass, reeds, sabai grass, bast fibers of jute, hemp, kenaf, flax, and leaf fibers of abaca and sisal. In this class also comes seed hairs, e.g., cotton linter. Cotton is an extensively used raw material in the textile industry, so its use in pulp and paper is very limited and used only in the manufacture of specialty paper like currency paper and permanent papers. Some of the most abundant and widely used NWF in this category are described in brief in the following section.

Kenaf Kenaf (*Hibiscus cannabinus* and *H. sabdariffa*) belongs to the same plant family as cotton, okra, the ornamental hibiscus, and hollyhocks. It is an annual crop, which is normally cultivated in the tropics and subtropics where temperatures are greater than 20°C. It is harvested for fiber soon after its flowering. Under good conditions kenaf will grow to a height of 5–6 m in 6–8 months and can yield up to 30-35 tonnes ha^{-1} of dry woody material. It is grown in Thailand, China, India, Australia, and the USA. Kenaf fiber is classified as medium long fiber similar to bagasse; however, it has a higher cellulose content and lower lignin content as compared to bagasse, and is preferred as a pulp material over bagasse. Kenaf crops are more susceptible than trees to abnormalities in seasonal weather changes, e.g., droughts and floods. Further, the harvested raw material needs storage for a number of months to sustain the supply of pulp material and it is prone to decay. Moreover, kenaf has a mixture of long bast fiber (57%) and short core fiber (41%), which need separation and subsequent pulping in separate lots. Kenaf is used for the manufacture of almost all varieties of paper including specialty papers.

Hemp Hemp (*Crotoleria juncea*) is an annual crop, which can be grown on normal to poor soils and yields three to four times more useful fiber per hectare per year than forests. It attains 2.5–3 m in height after 4 months of growth and is widely grown in Asia, Central America, and Africa. Hemp fiber is classified as a long fiber material and is considered as one of the best pulping materials for the manufacture of expensive specialty papers such as cigarette paper and others lightweight papers, and also in blending with weak pulps as a reinforcement pulp in certain grades of cultural, industrial papers.

Jute Jute (*Corchorus olitorius, C. capsularis*) is also an annual herbaceous plant mainly cultivated in South and Southeast Asia. The average dry yield of jute fiber varies from 1.6 to 2.0 tonnes ha^{-1} year^{-1}. After extraction of fibers, the remaining jute sticks (core) are usually used to make fences and as fuel. However, the core fibers, which are shorter than bark fibers, are utilized for many other value-added industrial purposes and cheap-grade pulp and paper manufacture. The five major jute producing countries (namely India, Bangladesh, China, Nepal, and Thailand) account for about 95% of world production. Jute fiber is used for the production of high-quality writing and printing papers and a variety of specialty papers. Like the other NWF, using jute for pulp and paper has many advantages; it requires less chemicals for pulping and consumes less energy due to its lower lignin content than woody fibers.

Waste Paper (Secondary Fiber)

Waste paper has become a very important secondary source of raw material for papermaking in recent years. However, collection and sorting of various grades of waste paper, such as mixed waste paper, corrugated waste paper, white paper cuttings (waste from printing presses), waste news print and its conversion into paper, is important in those regions where it is difficult to get a large amount of cheap raw material on a sustainable basis for papermaking. Further the cost of collection, sorting, and transportation are practical problems, which limit its wide-scale use in papermaking. But due to easy recycling and emerging new technologies for de-inking by biological and chemical treatments, the use of waste paper is likely to increase in future. The recycling of waste paper is further preferred due to environmental reasons as it facilitates conservation of trees and other cellulose raw material for future use.

Papermaking Process for Non-Wood Fibers

Essentially the process of papermaking involves the breaking up of the raw material into small pieces, pulping, bleaching, washing, stock preparation, and preparation of paper sheets (**Figure 2**). A brief account of various aspects of these processes is explained below.

Pulping (from Raw Material to Pulp)

- Cleaning: This involves elimination of all undesirable components such as dirt, sand, and other contaminants.
- Cutting/chipping: Most of the NWF are too long or big in size. Therefore, to facilitate homogeneous chemical treatment or mechanical treatment raw material is cut or chipped to uniform size.
- Screening/classification: Fibers are screened or classified by centrifugal and gravitational processes to get a uniform sized fibrous material for further processing.
- Fiber separation: Cellulose fibers are separated either by chemicals that dissolve the lignin, or by mechanically separating the fiber structure. The material thus prepared is referred to as pulp and this process of fiber separation is called the pulping operation.
- Bleaching: This is an optional operation to achieve a higher brightness or whiteness for a better appearing sheet of paper. For some grades of paper manufacture such as packaging paper and board, bleaching is not required. Traditional bleaching has been done by chlorine compounds, which are being replaced gradually due to environmental considerations, by the use of oxygen, hydrogen peroxide, and ozone. Non-woods can be bleached relatively easily by hydrogen peroxide.
- Refining/beating: In this process fibers are subjected to mechanical action for the modification of the fiber structure and to facilitate fiber-to-fiber bonding. This process adds to the strength of the paper in the finished paper sheet.

Papermaking (from Pulp to Paper)

- Dilution: The pulp is diluted with a large amount of water to convert pulp into a dilute fiber suspension to facilitate formation of a uniform sheet.
- Formation: The dilute fiber suspension is injected on to a fine-mesh wire screen. This results in drainage of excessive water and settling of the fiber networks into a flat sheet.
- Pressing: Sheet consolidation and dewatering results by mechanical pressing.
- Drying: The wet sheet is dried over a steam-heated dryer cylinder by the evaporation of water.
- Calendering (optional): The dried sheet is calendered for surface smoothness.
- Sheeting/reeling: Finally the formed dried paper sheet is cut to the required size.

Conclusions

Rising concern about the 'greenhouse effect' demands that wasteful disposal of fibrous material

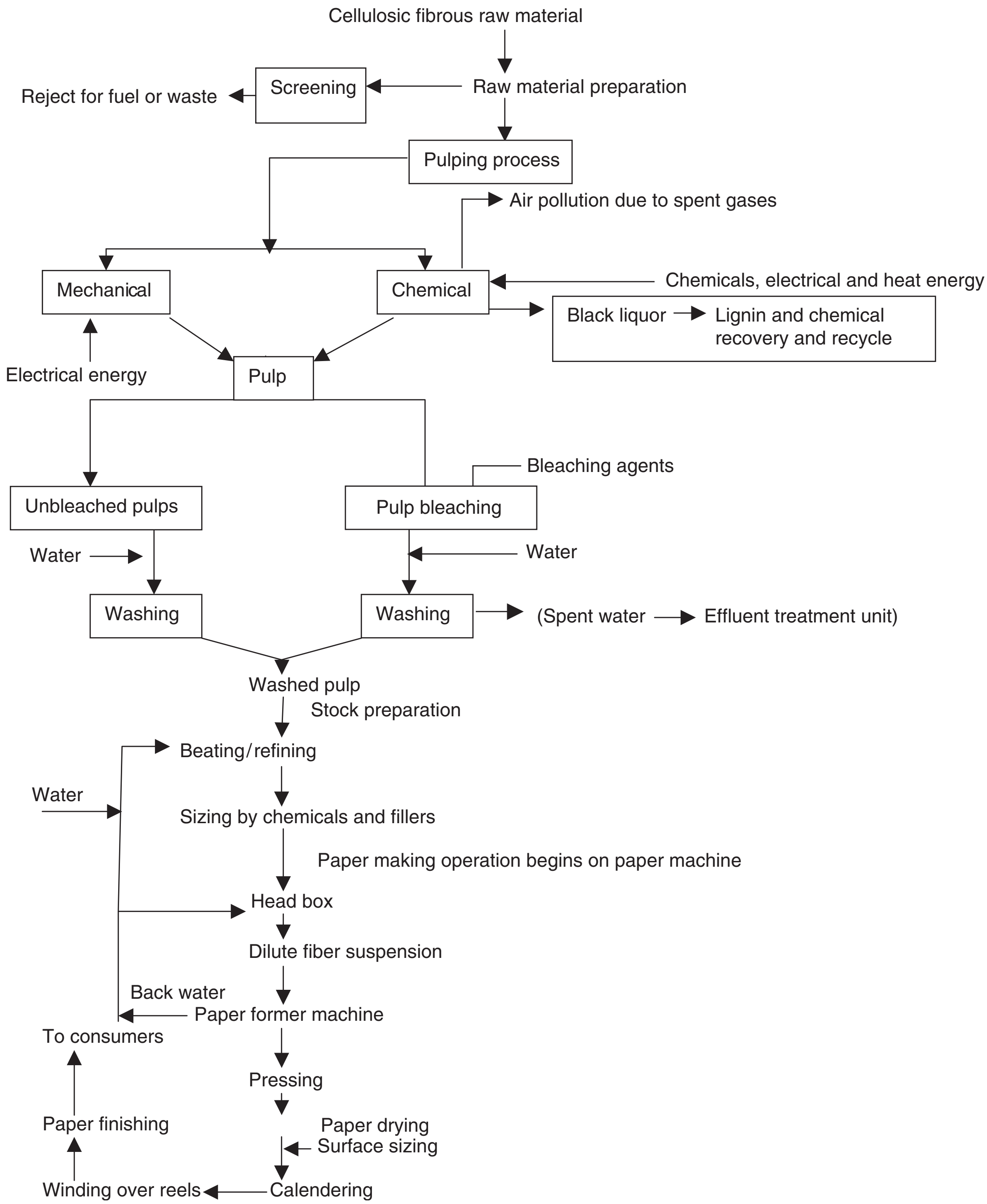

Figure 2 Flow diagram of pulping and papermaking process.

through carbon emission should be stopped. Consequently, efforts are being made to increase the use of non-wood fibers such as flax, hemp, rice, and wheat straw as valuable fiber supplements to the pulp and paper and allied industries. It has been suggested that such efforts will not only reduce demands on forest fiber supplies, but can also reduce greenhouse gas emissions. Further, carbon can be managed in a valuable material form as opposed to burning the agriculture residues as waste. Further, there is consensus all over the world that the non-wood fibers can be easily and quickly grown and are suitable for making paper of excellent quality. However, their usage is restricted to tropical developing countries due to the fact that contemporary papermaking in developed countries relies primarily on wood as the only significant source of paper fiber. The recent interest in using non-wood fibers, particularly hemp, in the Western world perhaps stems from strong environmental considerations.

Most of the forest resources in Europe, North America, Asia, and Australia have been utilized for paper production and other uses. So there seem to be valid reasons to look to NWF as a paper pulp source so that forests have sufficient time to rejuvenate and increase the forest cover. However, the research and development side of the papermaking industry has been focused on wood pulping technologies and equipment. Therefore, a lack of success and conservative attitudes with most non-wood initiatives stem from the application of wood pulping technology to non-wood fibers resulting in poor pulp quality and incorrect handling. This is generally true for digestion and refining operations, which tend to produce overcooked and over refined pulps due to the higher energy requirements of wood-based processes when they are used for non-wood fibers. Further, lack of will and financial support for the research and development wings of the paper industry, despite strong technical evidence of the potential of non-wood fibers, has resulted in the nonproliferation of this new concept. Nevertheless, there are many NWF-based paper mills already producing a wide range of paper grades. Finally, there is also a resurgence of initiatives for advancing the cause of the NWF paper industry to promote non-wood fiber as a cost-effective, high-quality competitive, and an environmentally friendly source for papermaking.

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Overview

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Introduction

There is no denying that paper is very important in today's world. We use it for money, record-keeping, communication, personal hygiene, and many other uses personally, commercially, and industrially. We often take paper for granted: it is ubiquitous but essential in our lives. However, very few of us think about how it is made beyond that it is made from trees. Paper can be an extremely complicated product, both in its components and in its manufacture. For example, printing and writing paper has distinctly different properties from tissue. It is often difficult to use one type of paper for another purpose. (How many of us has tried to draw on a dinner napkin?) **Table 1** is a selected list of the variety of paper grades that are produced today.

Papermaking is ever-evolving and developing. As the needs of society change, the types of paper being produced have also changed. The personal computer revolution was supposed to bring about the 'paperless office' and make printed newspapers obsolete. Paper consumption has not decreased, however, due to the increased use and popularity of computers. The types of paper demanded by consumers have changed significantly. In keeping up with computer technology, grades of paper for use in ink-jet printers and for the home-printing of digital photographs have been developed. Per capita consumption of paper has been increasing steadily over the past decade. Worldwide, paper consumption is increasing at an even greater rate as developing countries make