1
Introduction

1.1
Paper and Board Today
Herbert Holik

The history of paper is also the history of human culture and civilization. The Egyptians, Greeks and Romans wrote on "papyrus", a paper-like material. Today's kind of paper was first developed and used in China. Paper was the most important carrier of information in the past. It was only with increasing paper production that the transfer of knowledge, education and information to a larger portion of society became possible. With paper emperors were able to administrate large empires more easily. In former times paper was a valuable product, and paper making an art – an art that was often kept secret because of the outstanding advantages of the product.

Today paper has changed from a rare artisan material to a commodity product, with a high practical value in communication, in educational, artistic, hygienic, sanitary, and technical applications. Nobody can imagine a world without paper. A large variety of paper grades are produced to suit the special requirements of each application: Graphic paper grades, packaging papers and board, hygienic papers, and speciality paper grades. Paper can be impregnated, coated, laminated, creped, molded etc. Paper products embellish our homes, and sanitary products made of paper ease our daily life. An easier life is also more likely with a sufficient number of banknotes in the briefcase. Packaging papers and board grades support supermarket logistics and product presentations. Computer print-outs and other graphic papers such as newspapers, magazines and books accompany us through our life. Even today in our digital world paper is a reliable means of long-time documentation and data preservation.

The worldwide consumption of paper is increasing steadily over the years. The paper consumption in individual countries is related to their gross national product and hence the further increase in paper and board consumption will be different in different countries depending on whether economic saturation, as e.g. in the United States and Central Europe, or fast increasing demand, as in China, is prevailing. The ratio of the worldwide consumption of the different paper and board grades has changed in the past and will change in the future according to

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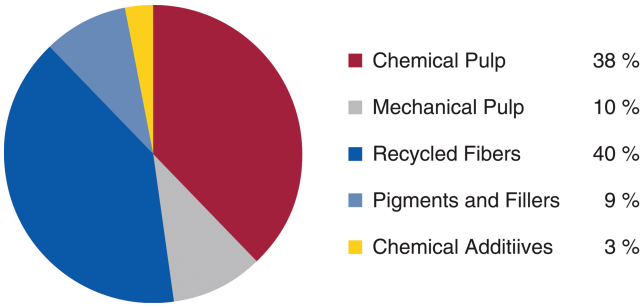

Fig. 1.1 Components used in paper and board production worldwide (by mass ratio).

technical and social evolution and developments in the individual countries and in the world as a whole.

The components used in paper and board production worldwide are given in Fig. 1.1. Today recovered paper has become the main resource for paper and board production, followed by chemical pulp, mechanical pulp, pigments and fillers, and chemical additives. Paper is mainly based on fibers from cultured woods, and is a renewable and recyclable raw material. The special characteristic of this fiber material is that the paper strength results from the hydrogen bonding between the individual fibers. In certain cases it is enhanced by the addition of starch or wet strength additives. The hydrogen bonds are loosened by rewetting the paper which allows easy recycling.

Increased paper recycling and sustained foresting help to preserve the wood resources of the earth. The paper industry has steadily improved its standards in complying with environmental demands as related to water consumption and water effluents, energy consumption, and primary (and secondary) fiber consumption. These standards have to be maintained and even improved in the future because of further increasing paper and board consumption and limited resources. The paper and board market is global, and so is the paper industry where an evident consolidation has occurred over the last decades: In 1980 the 150 biggest companies contributed about 45 % to the overall production, in 2000 this figure was about 70 % in a market which had nearly doubled from about 170 million tons/year to about 320 million tons/year. It seems that this concentration process has not yet come to an end.

Papermaking has changed from an “art”, where all specific processes were kept secret, to an industry with high-tech production facilities and with a scientific approach. Great challenges are e. g. the huge production quantities per unit and the high quality demands placed on the paper and board properties and their uniformity. Only high quality products – at low price – satisfy the expectations of the customer and end user.

Since paper is a commodity, low cost production is mandatory. As the fiber raw material is the main cost factor in paper production recovered paper has become

the main fiber stock material worldwide and its proportion will increase further. Several grades, such as newsprint and many packaging and board grades, can be entirely based on recycled fibers. Today recovered fibers must be used in paper grades similar to the recovered paper grade, downgrading of recovered paper (high quality fibers for lower quality paper products) is no longer economic.

In former times, with mainly virgin fibers consumption, a paper mill was located close to the wood (and the water and energy resources). This is still true for regions of Portugal, Spain and Brazil with Eucalypt plantations used mainly for copy or similar paper grades. One result of the increased use of recovered paper is that certain new "green field" paper mills are established today in the vicinity of highly populated areas to have easier access to recovered paper resources and to be closer to the market.

The capital demand for a new mill is of the order of magnitude of 500 million €. In the last thirty years the investment costs (inflation-adjusted) related to the specific annual production (t/a) have been approximately halved. This drop is mainly due to increased machine speeds and machine widths as well as to improved runnability. On the other hand the investment costs related to annual turnover have remained constant or even increased.

1.2 Overview of the Manufacturing Process for Paper and Board

Papermaking today includes, in principle, the same process steps as applied for centuries: preparation of the fiber material, sheet or web forming, pressing, drying, sizing and smoothing. However, in the last two centuries much of the detail has changed. Each process step has undergone – and still undergoes today – intensive research and development work to meet economic and ecological requirements. All links in the chain between fiber and end user contribute to this progress. The chain does not only include the paper producing industry itself and its suppliers such as the machine and chemical industry, but also the paper industry's customers and related industries, e. g. printing-houses, printing ink and printing machine suppliers and the manufacturers of corrugated board.

R&D focus has been on economic and environmental aspects such as

- reduction in consumption of raw material, energy and water as well as noise reduction
- high machine runnability and long lifetime of machinery and its components
- improvement of paper and board quality with respect to improvement of converting quality

which has led to results of high practical value such as

- better understanding and consequent control of the whole process in a narrow band
- reduction in fiber consumption by reducing basis weight at the same quality level and practical value

- increased ratio of recycled fibers in graphic paper production, with up to 100% for newsprint and a growing ratio in high grades such as supercalendered (SC) and light weight coated (LWC) papers
- fillers and coatings replacing part of the expensive fiber material and improving quality
- new coating and calendering technologies
- higher safety in Yankee dryer and suction press roll operation
- new methods of material design for fighting wear of machine components
- minimum number of personnel involved in the paper and board production process.

R&D work is supported by modern tools and sciences e. g.

- process analysis using advanced measuring and analysis techniques
- process simulation and advanced control techniques
- morphological characterization of fibers for papermaking
- chemistry developing functional and process chemicals
- finite element method (FEM) and computational fluid dynamics (CFD)
- visualization techniques in the micro- or nano-ranges, video documentation and analysis
- material sciences including plasma ions implantation into the base material at low temperatures.

The papermaking process (Fig. 1.2) starts with the delivery of the raw material of the stock components. These are

- fibers such as
  - virgin pulps (chemical or mechanical) which are usually supplied in bales or, in special cases, as a suspension when both pulp and paper are manufactured at the same location (integrated processing)
  - recovered paper in bales or as loose material
- fillers and pigments
- chemical additives
- coating colors when coated paper is produced.

All these components have to be adequately prepared for optimum use in the papermaking process steps. The additives may be delivered ready for use or may have to be finally prepared according to the requirements in the mill. Fiber stock preparation includes several unit operations depending on the furnish and the purpose. Stock preparation of virgin fiber pulp needs less machinery and energy than the preparation of recovered paper which, however, is the cheaper raw material. Fiber stock preparation ends at the paper machine chest. Here stock of high consistency is preferred to minimize carry-over of chemicals and contaminants.

Stock preparation is followed by the approach flow system connecting stock preparation with the paper machine. Its main tasks are

- to dose exactly and mix uniformly all the different components of the final suspension to be delivered to the paper machine

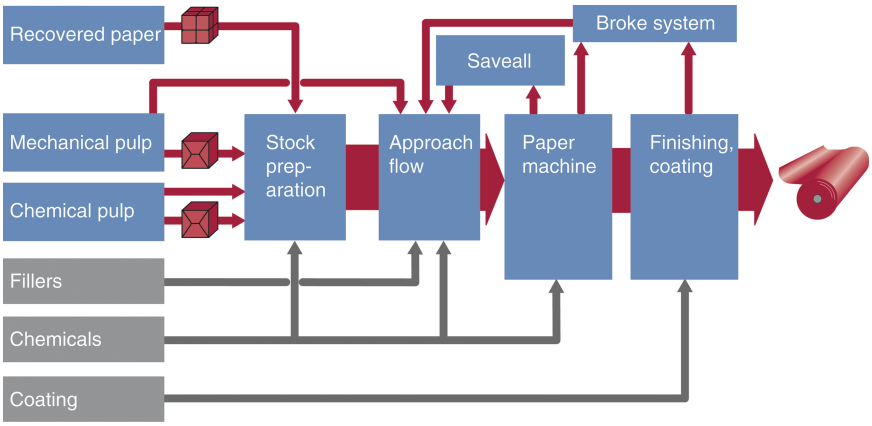

Fig. 1.2 Overview of the paper making process.

- to supply a continuous suspension flow of constant consistency, quality and flow rate at constant pressure to the headbox of the paper machine.

The approach flow system ends at the distributor of the headbox.

The task of the paper machine is to produce paper or board of the quality required by the end user – or by the intermediate process steps such as converting or printing. The paper and board properties have to be uniform in machine direction (MD) as well as in cross machine direction (CD). Further, the paper machine has to make the best use of the quality potential of the entering stock. The paper machine includes

- the headbox distributing the suspension across the machine width onto the wire
- the wire section where the suspension is formed into an endless web by dewatering
- the press section pressing water out of the web by mechanical means
- the dryer section where the residual water is evaporated
- often a sizing unit where starch, or pigments are transferred onto the web
- sometimes a coating section where coating color is applied to the web
- the calender to finally smooth the paper or board surface.

The paper manufacturing process ends with the paper web being reeled at the reeler at full width.

By tradition and technical feasibility, coating and supercalendering for surface quality improvement have been off-line processes. Today both are increasingly integrated into the paper machine. The final activities in paper and board production are slitting of the full width reels into smaller rolls at the winder followed by packaging the rolls for shipment.

Table 1.1 Different naming of consistency ranges in the various unit operations in paper making.

Unit operation	Actual consistency		
	LC (%) (low consistency)	**MC (%) (medium consistency)**	**HC (%) (high consistency)**
Repulping	< 6	< 12	12–28
Screening	< 1.5	< 4.5	–
Centrifugal cleaning	< 1.5	< 2.5	2.5–6
Bleaching	–	10–15	25–35
Refining	3–6	10–13	28–35
Web forming (headbox)	< 2.0	–	> 2.5

Paper broken during the manufacturing process has to be recycled and fibers are recovered from the white water of the paper machine in a saveall. White water is fed back from the paper machine to the approach flow system and stock preparation. Fresh water is supplied to the paper machine.

Along the paper production line stock consistency varies according to the requirements of the unit operations. Unfortunately the terms low, medium and high consistency relate to different consistency numbers depending on the actual unit operation (Table 1.1). It is also important to note whether the number gives the overall consistency including fibers and fillers or just fibers.

1.3 Historical Background and General Aspects [1]

Peter F. Tschudin

1.3.1 Introduction

Paper is defined internationally as a thin layer of mostly cellulosic plant fibers, produced on a screen by dewatering a slurry of fibers in water [2]. The slurry is called *pulp*. Despite recent developments (proteinic or synthetic fibers, chemical additives, coating, etc.) the "cellulosic plant fiber" will be the main, not exclusive, component of paper, and water will be used in preparing the pulp and in forming the paper web also in the future.

1.3.2 Precursors of Paper

1.3.2.1 Tapa (Bark-cloth)

Bark-cloth, made since prehistoric times, is found widely along the Equator belt in nearly all cultures, used mainly for decorating and clothing [3]. It is produced by beating or pressing the inner bark (*liber*, bast) of trees and shrubs like paper mulberry, lime-tree, fig or daphne, and is known by the generic term "tapa", derived from the Polynesian language. Tapa is a felt-like material, similar to thick woven paper, showing in most cases traces of the beating mallets. Technically speaking, it is a kind of non-woven paper.

There are three different techniques to be observed in tapa-making. The most sophisticated method consists of three steps. In the first, small strips of bast are cut and cooked for several hours in suds of wood ash. This cooking is very similar to the basic operation of our alkaline pulping. Then the strips are rinsed, placed together on a wooden board and beaten with a mallet, thus forming a small sheet on the board. The third step consists of drying and smoothing.

1.3.2.2 Felt

Felting techniques go back into prehistory [4]. Plant fibers or animal hair are separated from their original linking as much as possible and spread in thick layers onto a cloth or mat. Then they are covered by another cloth and beaten by foot stamping or with heavy wooden sticks to entangle them and stick them together. In another way, the ground mat bearing the fibers is rolled and the roll is beaten. The mat is unrolled and rolled again several times. In wet felting, water is used to soak the fibers and help felting.

1.3.2.3 Papyrus

Papyrus, the most commonly used writing material of Ancient Egypt and Classical Antiquity, was made in Egypt from the beginning of the 3rd millennium BC. The triangulated stem of the papyrus plant is peeled and the pith cut into thin, small strips. A first layer of wet strips placed vertically side by side with a slight overlap is laid onto a board. Then, a similar layer of horizontally oriented stripes is laid above it. Beating with wooden sticks and pressing the still wet layers leads to a sheet of entangled fibers, most remaining in the original linking of the pith. After drying and smoothing several sheets are glued together to form a roll, ready to be written on. Gluing of several papyrus sheet fragments, usually recycled material, results in board or papier-mâché.

New papyrus rolls are very strong and flexible, an ideal writing material. They were exported in large quantities into the Mediterranean area until the 8th century AD. Parchment replaced the dwindling supply from Egypt. When paper was imported from the East, it was given the name of the Egyptian writing material because of its resemblance to papyrus.

1.3.3 Paper

1.3.3.1 Invention of Paper

The oldest papermaking technique, pouring pulp into a primitive mould, is still in use at a few locations in the Himalayas, in some remote spots of China and in Southeast Asia. It shows clearly the descent from tapa and felting techniques. From recent findings of the oldest papers in Chinese tombs or in refuse heaps of military posts it must be concluded that some kind of paper was produced in China since the final centuries BC. Nevertheless, the Chinese chronicles state that in 105 AD in Loyang, the court official Cai Lun invented papermaking from textile waste, i. e. from rags, and propagated paper as a writing material [5]. This was the birth of paper as we know it today.

1.3.3.2 Chinese Paper

Chinese papermakers improved the effectiveness of the production, replacing the pouring technique by dipping the bamboo screen into a vat filled with diluted pulp. After lifting the mold out of the vat and dewatering, the newly formed sheet of paper was immediately couched on a wooden board or a plastered wall to let it dry. The flexible bamboo screen was rolled off and could be reused with the vat. Thus, the handicap of waiting until a sheet dried on the mold, was surmounted. Because of rag and paper mulberry shortages, they chose bamboo as a further source of fiber [6] the pulping of which took several months.

China developed many kinds of specialty papers (sized, coated and dyed paper; anti-moth paper; waterproof paper); over-size sheets were made by couching the wet borders of smaller sheets together, and decoration watermarks were added by putting leather or board figures on the screen before pouring the pulp. Paper served for almost everything: writing, drawing, wrapping, clothing, protection from wind and rain, decoration, windows, even for making balloons and kites, and, last but not least, for making paper money or special currency to be burned in honor of the ancestors.

1.3.3.3 The Eastern Spread of Papermaking

Chinese papermaking techniques were introduced into Korea at an early date, and reached Japan in 610 AD. In both countries, fibers of the paper mulberry were mainly used. In Japan, splash dipping was developed, using a big mold suspended on a teetering twig [7]. Japanese papermakers were fond of art papers for decoration purposes. The ultimate in Japanese papermaking was the production of Shifu, paper yarn woven into heavy, beautiful fabric.

1.3.3.4 The Spread of Papermaking into Central and Southern Asia

At an early date (4th to 6th centuries AD), it is attested that there were Chinese papermakers in Central Asia along the Silk Road, using the very old technique and local fiber plants like black mulberry. There, Tibetans learned the papermaking craft and transferred the knowledge into the high valleys of the Himalayas where they used local plants like the roots of Stellera Chamaejasme. From Southern China, the old-fashioned pouring technique spread into the emerging kingdoms of South Eastern Asia. India kept its traditional use of bark, textile cloth and palm leaves as writing materials for a long time. Only at a later period (11th century AD?), was papermaking introduced from the north through contacts with Central Asia and Persia [8].

1.3.3.5 Arab Paper

The Arabs, in the course of their eastern expansion, became acquainted with the production of the new writing material reaching Samarkand. Subsequently, papermills were set up in Baghdad, Damascus, Cairo, and later in the Maghreb. Having no paper mulberry trees and using screens made of reed, the Arabs made thin sheets of poorly beaten rag pulp and coated them on both sides with starch paste (from wheat or rice) which could be colored. This gave Arab paper its good writing properties and its fine appearance but also made it prone to damage due to humidity, crumbling or insects. In the 11th century AD, Arab papermaking knowledge spread into the Byzantine world and into medieval Europe, especially Spain (Xativa, Cordoba) and Italy (Amalfi, Genoa).

1.3.3.6 Medieval European Paper

Papermakers from Genoa and Fabriano tried to improve the Arab technique. They still exploited linen or hemp rags to get pulp, but improved the beating. Water power was used to drive heavy stamping mills, huge oak trunks comprising four to six large troughs with three or four heavy wooden stampers each beating the rags in fresh circulating water. The rags were transferred from trough to trough every six hours to ensure a better degree of refining. Further improvements were molds consisting of a wooden frame with inlaid copper or brass wire, heavy screw presses, and the replacement of starch sizing by dip sizing in animal glue.

This is the origin of the division of labor leading to a considerable increase in production: Work at the vat normally involved four people: the vatman, who made the sheet using the mold; the couchman working alongside the vatman, placing the sheet on felt; the layman, who removed the moist sheets from the felts, and the apprentice, who had to feed pulp to the vat and provide vat heating. The press was operated jointly by this team. Depending on the format, up to nine reams (4500 sheets) of paper were made during a working day averaging 13 to 15 hours. The paper was dried by women hanging it on ropes in the drying loft. Apart from different sizes, three main sorts of paper were produced: writing paper (for letter and chancery use), printing paper (mostly unsized) and cheap wrapping paper (also broke, screenings), used also for drafts.

As a further consequence of the change in mold construction, watermarking was invented in medieval Italy. The real watermark, a bright figure in the paper sheet, is seen by the naked eye. In hand papermaking, it is formed by a curved wire which is sewn onto the screen of the mold; the wire reduces the thickness of the sheet, thus making the figure transparent. The watermark serves as a trademark and provides the historian with an unsurpassed dating and authenticating tool. By comparing a watermark with others of a certain date or origin, the paper historian will be able to determine the age and origin of a document or print. Shadow watermarks are produced on a mold bearing a fine, embossed woven wire, showing an image like a black and white photograph.

1.3.3.7 **Mechanization and Industrialization**

In Europe, technical progress continued. In the 16th century, glazing the sheets by hand using a glass or stone burnisher was supplemented by the use of the glazing hammer, similar to a forging hammer. Towards the end of the 17th century, a most efficient tool, the so-called "hollander" beater, supplemented or even replaced the stamping mill. As the rotating knives of the Hollander beater cut and shorten the fibers more than a stamper, the ageing of paper was accelerated. This phenomenon is true also for the change in sizing. To improve the solubility and the penetration of the animal glue solution, alum was added, leading to acidic deterioration of paper.

Further development of printing during the 18th and 19th century led to a steeply rising demand for paper, especially for new printing grades. This and the tremendous upsurge in papermaking soon led to a serious shortage of raw material and to regulations governing the trade in rags, to ensure the local production of paper for administrative purposes. Rags of minor quality, even cotton and wool were used, together with fillers like starch or kaolin. So systematic search for rag fiber substitutes was needed [9].

Since the 17th century, there had been some concentration of handicraft activities in big factories, consisting of several mills, which still depended on skilled papermakers organized in open guilds. The efforts made to improve paper quality (woven wire molds since 1738) and to step up production as much as possible employing local people and developing auxiliary mechanical means (rag cutter, rag digester, hollander beater, vat paddles, strainers, couching press, hydraulic press, glazing table, glazing hammer, calender) culminated in the design and construction of paper machines.

1.3.3.8 **Paper Machines**

A Frenchman, J. N. L. Robert, built the first paper machine, patented in 1799. It was driven by one worker using a crank. The diluted pulp contained in a large vat was hurled into a wooden chest by a rotating paddle wheel and directed onto an endless wire screen of laid type. The screen bearing the forming paper web was moved forward, horizontally shaken and passed a pair of couch rolls equipped with

felts. The web, still moist, was then taken by a worker and cut into large pieces which were hung on ropes to dry.

This machine was further developed in England by Bryan Donkin and by the Fourdrinier brothers. Soon, other types were developed, e. g. the cylinder machine (Bramah, 1805; Dickinson, 1809) in which a cylinder with mounted wire-screen rotates in a vat filled with pulp. Other types were the mold-chain machine (Fourdrinier, 1806) and the twin-wire machine. Flat-type and cylinder machines gained ground in the 19th century and were extended to include a dryer section (Crompton, 1820) and a reeler, somewhat later (1850) also a calender section. Steady improvements led to a considerable increase in production. The paper machine heralded industrialization. In this new situation, the small operators who were unable or unwilling to afford machines tried to survive with piece work or by producing special grades and cardboard, but they were sooner or later compelled to discontinue their activities. Others had to adapt their existing buildings or set up new mills elsewhere.

The decisive step in developing the US paper industry was initiated by Joshua Gilpin (1815). Special paper machines were successfully built (e. g. the so-called "Yankee" cylinder machine), and soon the US paper production became the largest in the world.

1.3.3.9 **Pulping and Sizing**

In European medieval papermaking, the rags were moistened and exposed to air in order to rot for weeks before beating (fermentation). This helped to dissolve dirt, yarn knots or knit links and was equivalent to a modern enzymatic fiber treatment. During beating, slaked lime was added to the slurry, which resulted in fiber swelling, fiber bleaching and improved fiber separation and quality [10]. Even after washing and beating, particles of calcium carbonate and magnesium carbonate remained sticking to the fibers and got into the vat and into the paper sheet. There, they acted as a buffer, neutralizing acids and thus inhibiting the ageing of old hand-made papers.

In the 18th and 19th centuries, efforts were made to improve the efficiency of rag pulping. Rag cutting machines and rag digesters replaced old-fashioned breaking and boiling. The stampers were replaced by the hollander beater and later by refiners. To obtain rag substitutes on an industrial scale, in 1774, Claproth in Leipzig promoted de-inking, using a kind of bentonite. Straw was propagated as a raw material but failed because of poor paper quality (Koops, 1800). Only the invention of the stone groundwood process (Keller, 1843) and of chemical pulping (soda process: first patents, 1851: Watt, 1854: Mellier; sulfate process: Dahl 1884; sulfite process: Tilghman 1866) solved the problem of getting large fiber quantities.

Dip sizing of paper bundles in a solution of animal glue was replaced by pulp sizing, using rosin and alum (Illig, 1807). The resulting acid conditions in papermaking are in a large part responsible for the poor ageing behavior of machine-made paper until the 1980s, especially of wood-containing grades in which lignin reactions are triggered.

1.3.3.10 From Industrialization to Automation and Globalization: Technical and Economic Trends of the 19th and 20th Centuries

Several partly overlapping periods may be distinguished, each marked by definite trends. Rising capital investment was needed to mechanize papermaking, and the lack of rag supply was a problem for the papermakers. In consequence the introduction of a pulping section in a papermill or the construction of independent pulp mills became a priority task.

The evolution of the paper machine depended on progress in engineering and metallurgy. Until turbines replaced the venerable waterwheels, water energy was too slow and too poor to drive an improved paper machine. Even the introduction of steam engines did not help much; only when the steel quality available allowed the use of high pressure or superheated steam, did progress in papermaking begin. But the problem of power transmission to the different parts of the paper machine remained. Here the introduction of electricity, permitting the installation of individual drives to every part of the machine, triggered a leap into the future: The web width was enlarged, working speed increased considerably and machines designed specifically for the production of particular paper and board grades (e.g. multicylinder machines) were developed.

Alongside the development of printing in the 19th century, new paper grades were created, together with some kind of paper specialties like punchcards, standup collars, tube papers, flong, pergamyn, ammunition papers, envelopes, tobacco paper, toilet paper etc. The size of a pulping plant and of a paper machine grew to such an extent, that new factory complexes had to be erected, and there were also changes in research and development, marketing, controlling and transportation. In most cases, this evolution led to commercial group building and mergers.

Since the 1980s, the use of new materials (thermomechanical pulp, deinked recycled fibers, new fillers, process chemicals and dyes) and new web forming principles (e.g. twin-wire or gap formers), neutral sizing and – the most effective change – automation have brought further progress. This led to further specialization in specific paper types, development of new paper grades (e.g. LWC papers, technical papers). In consequence, corporate mergers and international company groups came up with raw material supply and trading organizations of their own and unprofitable operations were shut down.

Environmental problems, documented in the 19th century already, also triggered changes. New forestry principles have been introduced, fiber recycling covers more than half the fiber demand; heat recovery, closed water loops and the replacement of aggressive chemical treatments in pulping have helped to improve the poor ecological image of the paper and pulp industry.

Paper production and consumption increased from medieval times to the end of the 18th century by a factor of 50 (Fig. 1.3). Since then, paper and board have become a world-wide, large-scale commodity with exponential growth. The FAO statistics substantiate a forecast of about half a billion metric tons in 2010, of which about 2/5 will be produced in the fastest growing industrial market, Asia.

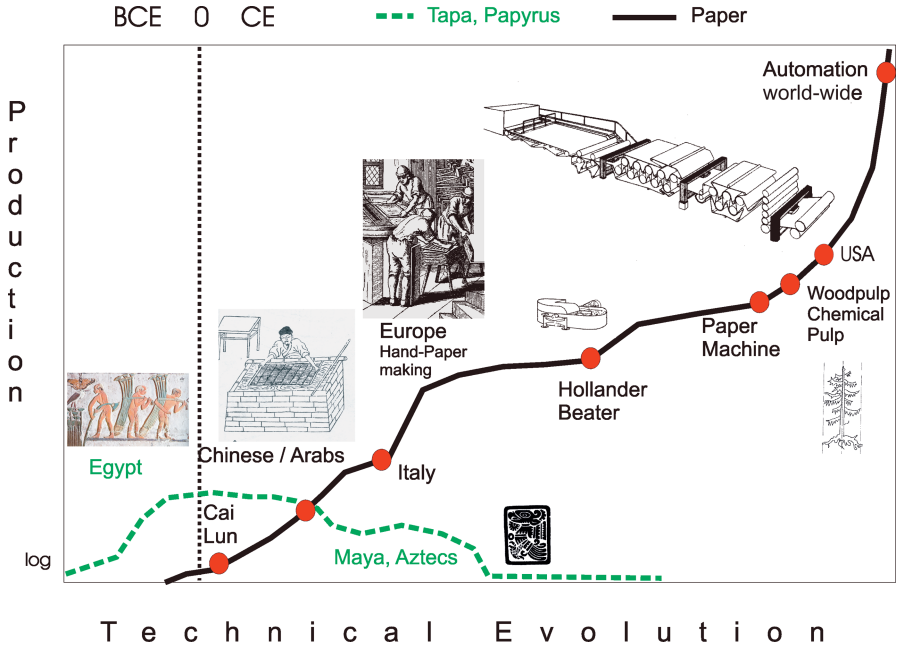

Fig. 1.3 Development of paper technology (source: Basler Papiermühle).

1.4
Economic Aspects

Gert-Heinz Rentrop

In 2002 the world production of paper and board was ca. 331×10^6 t. Although paper and board are used in some form or other in all parts of the inhabited world, the production is left to a limited number of countries. More than 9000 paper machines are responsible for production in 111 of the approximately 200 countries in the world, whereby the 15 largest producer countries alone account for 82 % of total world production (Table 1.2).

The various requirements for the production of paper are not met everywhere. For instance, suitable raw materials must be available, including water, energy, and trained personnel. Furthermore, the construction of paper mills requires a very high investment, and a sufficiently large market and a favorable location are both essential prerequisites for economic papermaking. For these reasons, the modern paper industry is based mainly in the coniferous forest zone of the Northern Hemisphere, with centers in Europe, North America, and in Japan.

World paper production has increased more than sevenfold since 1950 when production was ca. 44×10^6 t (Table 1.3). During this time, the regions which did not belong to the classical paper producing countries – above all China – have come to the fore, and their share of world production grew from ca. 3 % in 1950 to

Table 1.2 Production of paper and board by country, 2002.

Country	Production, 10^6 t	Share, %
United States	80.8	25
China	37.8	11
Japan	30.0	9
Canada	20.0	6
Germany	18.5	6
Finland	12.7	4
Sweden	10.7	3
South Korea	9.8	3
France	9.7	3
Italy	9.2	3
Brazil	7.7	2
UK	6.2	2
Russia	5.8	2
Spain	5.3	2
Taiwan	4.3	1
96 other countries	62.2	18
World total	330.7	100

Table 1.3 World production of paper and board (10^6 t).

	1950	1960	1970	1980	1990	2000	2002
Europe	13.194	25.826	45.377	59.495	65.873	100.065	101.290
East	2.840	5.765	10.560	14.103	3.538	11.257	12.780
West	10.354	20.061	34.817	45.392	62.335	88.808	88.510
North America	28.286	39.393	56.323	71.179	87.985	106.603	100.949
United States	22.108	31.255	45.186	57.789	71.519	85.832	80.871
Canada	6.178	8.138	11.137	13.390	16.466	20.771	20.078
Japan	0.873	4.513	12.973	18.087	28.086	31.828	30.033
China	0.511	1.914	3.750	5.100	13.719	30.900	37.800
Others	0.876	3.279	11.264	18.257	43.142	54.585	60.632
World	43.740	74.925	129.687	172.118	238.805	323.981	330.704

Table 1.4 World production of paper and board by region (%).

	1950	1960	1970	1980	1990	2000	2002
Europe	30.1	34.5	35.0	34.6	27.6	30.9	30.6
East	6.5	7.7	8.1	8.2	1.5	3.5	3.9
West	23.6	26.8	26.9	26.4	26.1	27.4	26.8
North America	64.7	52.6	43.4	41.3	36.8	32.9	30.5
United States	50.5	41.7	34.8	33.6	29.9	26.5	24.5
Canada	14.2	10.9	8.6	7.7	6.9	6.4	6.1
Japan	2.0	6.0	10.0	10.5	11.8	9.8	9.0
China	1.1	2.6	2.9	3.0	5.7	9.5	11.4
Others	2.1	4.3	8.7	10.6	18.1	16.9	18.3
World	100.0	100.0	100.0	100.0	100.0	100.0	100.0

13% in 1980, and to 30% in 2002. At the same time, the circle of paper producing countries has widened considerably from 61 to 111 and now includes a large number of developing countries. In these countries, the tendency towards self sufficiency is influenced by national economic considerations and the need to save foreign exchange for paper imports (Table 1.2).

In 2002, Europe, North America, Japan and China produced 82% of the total world production (Table 1.3). However, the development in these regions has varied considerably. China's paper production has increased more than threefold since 1980 and it is now the second largest paper producer in the world. In Japan, the paper industry has developed from a low during the postwar years to become the third largest paper producer. In the last four or five decades, Western Europe has more or less been able to maintain its share of world production. North America has had to accept large losses of its share of production, which has, however, been increasing relatively constantly (Table 1.4).

In 2002 graphic papers accounted for 43% of total paper production. This included newsprint (37×10^6 t) and other printing and writing papers (104×10^6 t). The production of packaging papers was 153×10^6 t, and that of the remaining papers and boards was 37×10^6 t (Table 1.5).

At present, a nearly one-third (100:330) of the world production of paper and board is sold across borders. In 2002 exports and imports accounted for about 100×10^6 t.

The net imports to the United States, i.e. imports minus exports, amount to 7.3×10^6 t which corresponds to a quota of 8% (based on the consumption). In contrast, Canada with its comparatively low population, has net exports amounting to 12×10^6 t which is 60% of its paper production. The major part of Canadian exports goes to the United States. Western Europe with 9.5×10^6 t, a quota of 11%

Table 1.5 World production of paper and board, arranged according to main types (2002).

Paper and board type	Production, 10^6 t	Share, %
Newsprint	37	11
Other printing and writing papers	104	32
Packaging papers and boards	153	46
Other papers and boards	37	11
Total	331	100

(based on the internal production) is a net exporter. Western Europe as a whole has more than 380×10^6 consumers and is the largest market in the world.

In Japan the amounts imported and exported balance out at ca. 1.5×10^6 t. China is a net importer with 4.8×10^6 t, a quota of 11 %. Of the remaining regions, the countries in Africa and Asia are the largest net importers. The imports and exports of South and Central America are roughly balanced.

World consumption of paper and board in 2002 was 331×10^6 t. The United States has by far the highest consumption of all countries, followed by China and Japan. Germany is the fourth largest consumer, above the United Kingdom (Table 1.6).

Looking at the world paper consumption from a geographical point of view, it is apparent that the industrial countries of Western Europe, North America, and Japan not only produce but also consume the bulk of the paper (Table 1.7).

There is also a relatively rapid increase in the consumption of paper in the remaining regions, especially in Asian countries such as China, South Korea and Taiwan, which are becoming increasingly important for the international paper market. In the past 40 years, countries in South and Central America as well as in Eastern Europe and Africa have increased their share of world paper consumption annually. Improvements in the living conditions in these regions have been accompanied by a corresponding increase in the consumption of paper. The rise in both the standard of living and the individual income is as important a prerequisite as the spread of literacy for the consumption of writing paper and printing products. Another important factor is the build up of export and consumer industries with their demand for packaging materials.

The amount of paper consumed, however, is not an adequate measure of the standard of living of a country. The relative per capita consumption can only give a very rough indication of the living standard because other factors such as the average income, way of life, and consumer patterns must also be taken into consideration. In terms of paper consumption, the countries can be grouped according to their per capita consumption. For example, while the average consumption in Western Europe is 204 kg and in North America 280 kg, the per capita consumption in Eastern European countries is 36 kg, in Latin America 33 kg, and in

Table 1.6 World paper and board consumption by country, 2002.

Country	Consumption, 10^6 t	Share, %
United States	88.1	27
China	42.6	13
Japan	30.0	9
Germany	18.2	6
UK	12.4	4
Italy	10.9	3
France	10.8	3
South Korea	8.1	3
Canada	7.7	2
Spain	6.9	2
Brazil	6.8	2
Taiwan	4.6	1
Russia	3.8	1
Australia	3.6	1
The Netherlands	3.5	1
186 other countries	72.7	22
World total	330.7	100

Africa only 7 kg. Paper consumption per inhabitant is less than 1 kg in about 25 developing countries.

A comparison between population and paper consumption in different regions shows that Asia, which represents 60% of the world population, accounted for only 34% of world paper consumption. Conversely, North America has 5% of the world's population but a consumption of 29% (Table 1.8). An important indicator for the development of paper consumption is not only the gross national product but also the population growth (Table 1.7).

World population has more than doubled from 2.5×10^9 in 1950 to 6.2×10^9 in 2002. The per capita consumption of paper worldwide was 18 kg in 1950 and 53 kg in 2002, an increase of 294%. Thus the relative consumption of paper per capita has increased considerably faster than the world population. It is obvious that these average global values do not reflect the substantial regional differences.

In summary, the largest growth percentage potential for paper consumption is in the Third World countries, especially in Asia and Eastern Europe, while in-

Table 1.7 World paper and board consumption by region (%).

Region	1950	1960	1970	1980	1990	2000	2002
Europe	27.3	33.6	34.7	33.9	26.4	28.3	27.5
East	6.3	7.7	8.3	8.5	1.4	3.1	3.6
West	21.0	25.9	26.4	25.4	25.0	25.2	23.9
North America	64.2	50.9	43.4	38.4	35.2	31.0	29.0
United States	60.6	47.7	40.7	35.8	32.8	28.6	26.6
Canada	3.6	3.2	2.7	2.6	2.4	2.4	2.4
Japan	2.0	5.8	9.8	10.5	11.9	9.8	9.1
China	1.1	2.4	2.6	2.9	6.1	11.4	12.9
Others	5.4	7.3	9.5	14.3	20.4	19.5	21.5
World	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 1.8 Population and paper consumption by region (2002).

Region	Population		Paper consumption	
	$\times 10^6$	%	10^6 t	%
Europe	729	12	91	28
Africa	878	14	6	2
North America	312	5	96	29
Central and South America	529	8	19	6
Asia	3706	60	114	34
Australia/Oceania	30	1	4	1
World	6184	100	330	100

dustrialized countries such as the United States, Japan, and the Western European countries have relatively low growth rates, but still represent, in absolute terms, a considerable market potential.

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