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 paperlike material. The kind of paper used now 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, art, and information to a larger part of society became possible. With paper, emperors were able to administrate large empires more easily. In former times, paper was a valuable product, and papermaking an art – an art that was often kept secret because of the outstanding advantages of the product.

The worldwide consumption of paper will further increase. Owing to CEPI (Confederation of European Paper Industry), the paper consumption will increase from about 400 million t year^{-1} in 2010 to about 530 million t year^{-1} in 2020 and 605 million t year^{-1} in 230. The growth in individual countries can be mostly related to their increase in gross national product and to their growth in population. So the consumption and production in countries such as China or India have increased over recent years on a large scale. In mature markets such as Central Europe, Japan, and North America production and consumption have stagnated or even decreased.

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 technical, economical, and social evolution and developments in the individual countries and in the world as a whole. Packaging grades have increased, graphic paper grades have stagnated, and newsprint consumption has declined. The pressure from increased sales of industrial products, the growth in internet shopping, and the sharp upward demand for small packaged foods have all increased the demand on packaging materials. The newsprint sector has suffered from the big increase in internet and phone download users as these technologies impact on the need for the printed page. The demand for copy paper and home printing papers for holding as ''hard

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copy'' is still important for easy access of preselected information. The impact of e-book on paper usage has yet to be felt.

The paper and board market is global, and so is the paper industry where an evident consolidation has occurred over the last decades. The concentration of companies has continued under globalization, and the economic ups and downs have affected rising markets and various geographical areas unevenly. The investment costs for new production facilities are high. The capital demand for a new mill lies in the order of magnitude of more than €500 million. The most recent new paper and board mills were mainly installed in the Far East. These high-tech mills show the distinct progress in papermaking, in both technique and technology and new world records in production and machine speed have been set. So it seems that the paper comes back to its roots: China has developed in the last few years to the largest paper and board producer in the world.

The furnish used in paper and board production worldwide are secondary fibers from recovered paper, primary fibers (chemical pulp, mechanical pulp), pigments, and chemical additives. Paper is mainly based on fibers from cultured woods, and is a renewable and recyclable raw material as its strength is given by natural bonding between the individual fibers, which is then loosened by water during recycling.

In former times, with mainly virgin fiber 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 eucalyptus 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 currently in the vicinity of highly populated areas to have easier access to recovered paper resources and to be closer to the market.

Increased paper recycling and sustained foresting (''planting and harvesting'') as well as use of the whole tree help to preserve the wood resources of the earth. Owing to the need of wood fiber resources, the paper industry competes strongly with the building and furniture industries, and also with the energy sector using fibers for biofuel production and solid-fuel heating. There is a strong need to optimize the wood resource and use the best fiber for paper, building, and furniture products first, before using the waste and recycled material as a fuel. This way has proved successful in the oil and plastic products over several decades. The paper industry has started to adopt this to a greater extent. It also makes even more use of cogeneration and mill integration. So paper may play a new, promising role in the discussion about CO_2 footprint.

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 fiber resources.

Papermaking has changed from an ''art'' to an industry with high-tech production facilities and with a scientific approach making use of new technologies by adopting them to their special needs. At present papermaking is a mature technology, and now more focus must be laid on reliable energy supply, waste handling and use, as well as on the optimum integration of all of the subsystems in the mill.

At present high quality demands are placed on the paper and board properties and their uniformity. The functionality of paper as an information carrier is more pronounced and requires high surface quality, for example, for new printing technologies and for more radio-frequency identification (RFID) application. Only high-quality products – at low price – satisfy the expectations of the customer and the end user.

As paper is a commodity, low-cost production is mandatory. One of the challenges is, for example, the huge production quantities per unit with machine downtime costs in the calculation of the paper mill which ranges from about €10000 to 40 000 h^{-1}. So the downtime should be kept as short as possible and unplanned downtime must be avoided. This calls for predictive maintenance and computerized maintenance management systems.

As the fiber raw material is the main cost factor in paper production, the need is for lowest possible basis weight and as much filler as acceptable. Their increased retention during web forming may be supported by nanotechnology and thus further improve paper quality as well. For the same economic reason, 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 – and are – entirely based on recycled fibers. 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 economically or ecologically acceptable. Hence, in some places, recovered paper is presorted automatically, for example, into deinking stock, warehouse furnish, and mixed qualities.

The electronic media are not only a competition to paper as an information carrier but also a challenge in the use of recovered paper as the water-based printing inks degrade the recovered paper. Paper recycling for food packaging grades at present can be threatened by migrating substances. Therefore, all partners in the whole papermaking chain ‘‘from cradle to cradle’’ have to contribute in order to establish and to maintain a sound cycle.

1.2
Paper and Board Manufacturing – an Overview

Herbert Holik

Modern paper mills are large industrial units, one of the latest installations of a paper production line having a maximum production capacity of 4500 t day^{-1}. This involves many demanding actions, for example, in logistics, for raw material supply and shipment of the finished product or to ensure continuous production. A paper production line usually comprises the stock preparation, the paper machine, waste and wastewater handling, and energy generation. Several production lines can be installed in a paper mill.

The furnish components used in paper and board production are secondary and primary fibers, pigments, and chemical additives. Their approximate ratio is

Table 1.1 Furnish components used in paper and board production and their typical ratio in CEPI countries.

Raw material		Approximate mass ratio (%)
Fiber material	Secondary fibers	40
	Chemical pulp	40
	Mechanical pulp	10
Minerals	Coating pigments	4
	Fillers	3
Chemical additives	All kinds	3

Based on CEPI statistics and Sections 2.1.3 and 26.2.

listed in Table 1.1. The ratio largely varies from country to country and depends on the produced grades. The paper strength results from the hydrogen bonding between the individual fibers (without any artificial gluing). Only in certain cases is the strength enhanced by the addition of starch or wet strength additives. The hydrogen bonds are loosened by rewetting the paper, which allows easy recycling.

Papermaking at present 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 at present – intensive research and development work to meet economic, ecological, and quality 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, for example, printing houses, printing ink and printing machine suppliers, the manufacturers of corrugated board, and other converters.

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

- reduction in consumption of raw material, energy, and water (Figure 1.1) as well as noise reduction;
- high machine runnability and long lifetime of machinery and its components;
- improvement in paper and board quality with respect to improvement in converting quality.

This has led to results of high practical value such as

- better understanding and consequent control of the whole process and quality parameters 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 lightweight coated (LWC) papers;

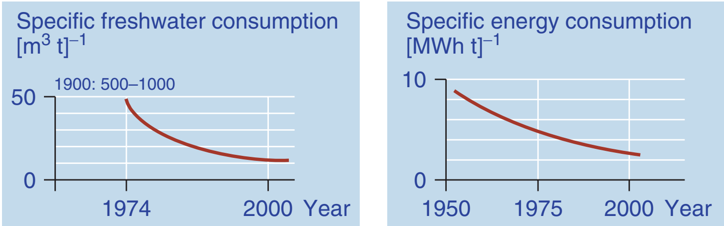


Figure 1.1 Reduction in specific energy and freshwater consumption in the last decades (Germany) [1].

- 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 operations;
- new methods of material design for fighting wear of machine components;
- further closing of water circuits;
- energetical use of waste;
- minimum number of personnel involved in the paper and board production process.

R&D work has been supported by modern tools and sciences in many areas, such as

- process analysis and simulation as well as advanced measuring, visualization, and control techniques;
- chemistry and materials sciences;
- finite element method (FEM) and computational fluid dynamics (CFD).

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

- fibers such as
  - recovered paper in bales or as loose material;
  - 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 mill).
- 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. Virgin pulp preparation mainly needs disintegration and refining.

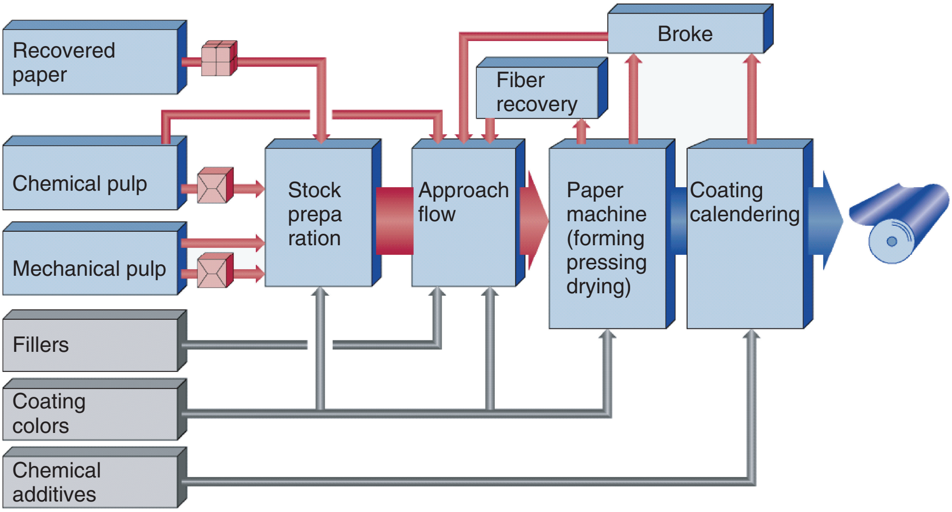


Figure 1.2 Overview of the papermaking process.

Processing of recovered paper afford more expenditure including several steps to separate undesired components from the fiber suspension.

The main objectives and the corresponding equipment in stock preparation are

- **Disintegration (also called slushing or repulping)**: to obtain a suspension of individual fibers from fiber raw material; to do so, vat or drum pulpers, deflakers, and dispergers are used.
- **Separation**: to remove contaminants from the fiber suspension; this is done by screens, hydrocyclones, and flotation cells.
- **Treatment of fibers**: to change fiber properties by use of refiners and by bleaching.
- **Treatment of residual contaminants**: to change their size and shape to reduce or prevent their negative effect.

Fiber stock preparation ends at the paper machine chest. Here stock of high consistency is preferred to minimize carryover of chemicals and contaminants from stock preparation to the paper machine.

Water handling, wastewater purification, and waste processing are of high importance especially in recovered paper usage. An increasing number of mills make use of the thermal value of the waste, which formerly had been landfilled at high costs or supplied to external use. Owing to CEPI, landfilling has been reduced from 76.7 kg t^{-1} of produced paper or board in 1990 down to 17.8 kg t^{-1} in 2008 in Europe.[1)]

Stock preparation is followed by the approach flow system connecting stock preparation with the paper machine and ending at the distributor of the headbox. Its main tasks are

1) CEPI statistics.

- to dose exactly and mix uniformly all the different components of the final suspension to be delivered to the paper machine;
- to supply a continuous suspension flow of constant consistency, quality, and flow rate at constant pressure to the headbox of the paper machine.

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 by heat;
- 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 in the past. At present both are increasingly integrated into the paper machine. The final activities in paper and board production are finishing, which means slitting of the full width reels into smaller rolls at the winder, followed by packaging the rolls for shipment.

Paper broke from the manufacturing process has to be recycled, and fibers are recovered from the white water of the paper machine in a save-all. White water is fed back from the paper machine to the approach flow system and stock preparation. Freshwater 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 1.2). It is also important to note whether the number gives the overall consistency including fibers and fillers or just fibers.

As paper is now a commodity, high cost pressure is put on paper and board production. The relative production costs listed in Table 1.3 show the high contribution of raw material and energy to the overall costs. The wide range of the figures indicates that the cost situation varies largely depending on the product, the kind of raw material, the machine and mill output, or the energy supply, as well as on the country and area.

Figure 1.3 shows the view of a paper mill for newsprint production in Central Europe. A new paper machine was embedded in the existing infrastructure and it started up late in 2010. The machine replaced one of the existing paper machines.

Table 1.2 Different naming of consistency ranges in the various unit operations in papermaking.

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

Table 1.3 Sources of production costs and typical ratio distribution.

Cost source	Range of cost ratio (%)
Fibers	40–70
Minerals and chemicals	1–18
Labor	4–13
Energy	12–22
Maintenance	4–10

Based on CEPI statistics and Section 26.2.

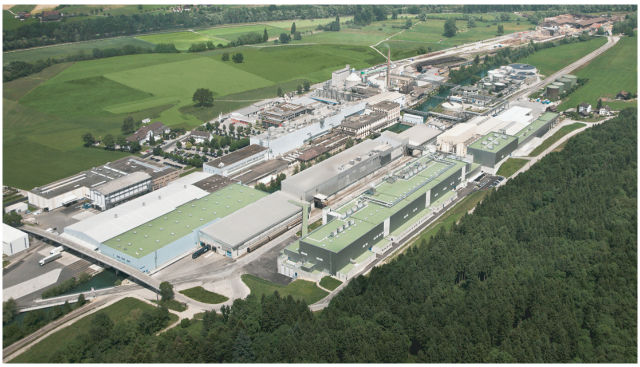


Figure 1.3 View of a paper mill. (Source: Voith.)

It has been planned and built, and is operated based on the main ideas of ecological and economic paper production such as use of recovered paper, high yield in stock preparation, lower freshwater consumption, less electrical and thermal energy demand, reduced amount of additives – and, as a precondition, the produced paper has to meet the required quality level.

1.3
Economic Aspects

*Thomas Moldenhauer and Gert-Heinz Rentrop**

In 2010, the world production of paper and board was about 394×10^6 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. Nearly 5000 paper machines are responsible for production in 104 of the approximately 194 countries in the world, whereby the 15 largest producer countries alone account for 83% of total world production (Table 1.4).

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 Japan.

World paper production has increased ninefold since 1950 when production was about 44×10^6 t (Table 1.5). During this time, the regions that 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 about 3% in 1950 to 13% in 1980

Table 1.4 Production of paper and board by country, 2010.

Country	Production (10^6 t)	Share (%)
China	92.6	24
United States	75.8	19
Japan	27.3	7
Germany	23.1	6
Canada	12.8	3
Finland	11.8	3
Sweden	11.4	3
South Korea	11.1	3
Indonesia	9.9	3
Brazil	9.8	2
India	9.2	2
Italy	9.1	2
France	8.8	2
Russia	7.6	2
Spain	6.2	2
Other countries	67.3	17
World total	393.9	100

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

* Contributed to the First Edition.

Table 1.5 World production of paper and board (10^6 t).

	1950	1960	1970	1980	1990	2000	2010
Europe	13.194	25.826	45.377	59.495	65.873	100.065	109.455
East	2.840	5.765	10.560	14.103	3.538	11.257	22.317
West	10.354	20.061	34.817	45.392	62.335	88.808	87.138
North America	28.286	39.393	56.323	71.179	87.985	106.603	88.636
United States	22.108	31.255	45.186	57.789	71.519	85.832	75.849
Canada	6.178	8.138	11.137	13.390	16.466	20.771	12.787
Japan	0.873	4.513	12.973	18.087	28.086	31.828	27.288
China	0.511	1.914	3.750	5.100	13.719	30.900	92.599
Others	0.876	3.279	11.264	18.257	43.142	54.585	75.921
World	43.740	74.925	129.687	172.118	238.805	323.981	393.899

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

Table 1.6 World production of paper and board by region (%).

	1950	1960	1970	1980	1990	2000	2010
Europe	30.1	34.5	35.0	34.6	27.6	30.9	27.8
East	6.5	7.7	8.1	8.2	1.5	3.5	5.7
West	23.6	26.8	26.9	26.4	26.1	27.4	22.1
North America	64.7	52.6	43.4	41.3	36.8	32.9	22.5
United States	50.5	41.7	34.8	33.6	29.9	26.5	19.3
Canada	14.2	10.9	8.6	7.7	6.9	6.4	3.2
Japan	2.0	6.0	10.0	10.5	11.8	9.8	6.9
China	1.1	2.6	2.9	3.0	5.7	9.5	23.5
Others	2.1	4.3	8.7	10.6	18.1	16.9	19.3
World	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

and to 43% in 2010. 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 toward self sufficiency is influenced by national economic considerations and the need to save foreign exchange for paper imports (Table 1.4).

In 2010, Europe, North America, Japan, and China accounted for 80% of the total world production (Table 1.5). However, the development in these regions has varied considerably. China's paper production has had a more than 18-fold increase since 1980 and it is now the largest paper producer in the world. In Japan, the paper industry has developed from a low during the postwar years to make the country 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 (Table 1.6).

Table 1.7 World production of paper and board, arranged according to main types (2010).

Paper and board type	Production (10^6 t)	Share (%)
Newsprint	33	8
Other printing and writing papers	110	28
Packaging papers and boards	204	52
Sanitary and household	29	7
Other papers and boards	18	5
Total	394	100

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

In 2010, graphic papers accounted for 36% of total paper production. This included newsprint (33×10^6 t) and other printing and writing papers (110×10^6 t). The production of packaging papers was 204×10^6 t, sanitary and household papers 29×10^6 t, and that of the remaining paper and board grades was 18×10^6 t (Table 1.7).

At present, nearly one-third (112 : 394) of the world production of paper and board is sold across borders. In 2010, exports and imports accounted for about 112×10^6 t.

The net exports to the United States, that is, exports minus imports, amount to 0.6×10^6 t. In contrast, Canada with its comparatively low population, has net exports amounting to 6.5×10^6 t, which is 50% of its paper production. The major part of Canadian exports goes to the United States. Western Europe with 12.7×10^6 t, a quota of 14% (based on the internal production) is a net exporter as well.

In China, the amounts imported and exported balance out at about 0.9×10^6 t. Japan is a net importer with 0.6×10^6 t. 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 2010 was 395×10^6 t. China has by far the highest consumption of all countries, followed by United States and Japan. Germany is the fourth largest consumer, above Italy (Table 1.8).

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 a substantial part of the paper (Table 1.9).

There is also a relatively rapid increase in the consumption of paper in the remaining regions, especially in Asian countries such as India, South Korea, and Indonesia, 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

Table 1.8 World paper and board consumption by country, 2010.

Country	Consumption (10^6 t)	Share (%)
China	91.6	23
United States	75.2	19
Japan	27.9	7
Germany	20.2	5
Italy	10.8	3
India	10.8	3
UK	10.5	3
France	9.9	3
Brazil	9.5	2
South Korea	9.4	2
Russia	6.6	2
Spain	6.5	2
Canada	6.3	2
Indonesia	6.1	1
Turkey	5.0	1
Other countries	88.2	22
World total	394.7	100

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

Table 1.9 World paper and board consumption by region (%).

Region	1950	1960	1970	1980	1990	2000	2010
Europe	27.3	33.6	34.7	33.9	26.4	28.3	25.5
East	6.3	7.7	8.3	8.5	1.4	3.1	6.6
West	21.0	25.9	26.4	25.4	25.0	25.2	18.9
North America	64.2	50.9	43.4	38.4	35.2	31.0	20.7
United States	60.6	47.7	40.7	35.8	32.8	28.6	19.1
Canada	3.6	3.2	2.7	2.6	2.4	2.4	1.6
Japan	2.0	5.8	9.8	10.5	11.9	9.8	7.1
China	1.1	2.4	2.6	2.9	6.1	11.4	23.2
Others	5.4	7.3	9.5	14.3	20.4	19.5	23.5
World	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

printing products. Another important factor is the buildup of exports 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

Table 1.10 Population and paper consumption by region (2010).

Region	Population		Paper consumption	
	$\times 10^6$	%	10^6 t	%
Europe	814	12	100	25
Africa	1028	15	8	2
North America	347	5	82	21
Central and South America	597	8	27	7
Asia	4108	59	173	44
Australia/Oceania	34	1	5	1
World	6928	100	395	100

Source: RISI, VDP (Verband deutscher Papierfabriken) and Federal Statistical Office of Germany.

per capita consumption. For example, while the average consumption in Western Europe is 186 kg and in North America 235 kg, the per capita consumption in Eastern European countries is 63 kg, in Latin America 45 kg, and in Africa only 8 kg. Paper consumption per inhabitant is less than 1 kg in about 16 developing countries.

A comparison between population and paper consumption in different regions shows that Asia, which represents 59% of the world population, accounted for only 44% of world paper consumption. Conversely, North America has 5% of the world's population but a consumption of 21% (Table 1.10). An important indicator for the development of paper consumption is not only the gross national product but also the population growth (Table 1.9).

World population has more than doubled from 2.5×10^9 in 1950 to 6.9×10^9 in 2010. The per capita consumption of paper worldwide was 18 kg in 1950 and 57 kg in 2010, an increase of 316%. 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 developing countries, especially in Asia and Eastern Europe, while industrialized 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.

1.4 Historical Background and General Aspects

Peter F. Tschudin

1.4.1 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, 3]. The slurry is called *pulp*. Despite recent developments (proteinic or synthetic fibers,

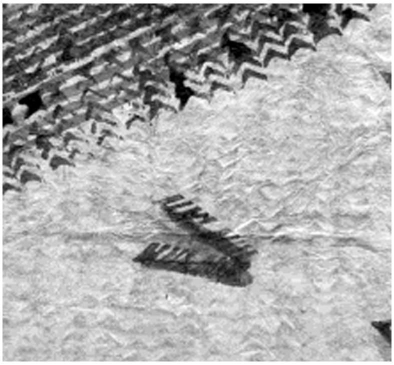


Figure 1.4 Decorated bark cloth (tapa), of finest quality. Hawaii, eighteenth century. The impressed grooves of the beating mallet are markedly perceptible.

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. The difference between paper and other modern, sheetlike materials (plastic films; technical textiles; nonwovens), consisting also in the formation technology, is dwindling. More and more compounds and sandwiched materials include paper, either natural or treated, or paperlike materials.

1.4.2 Precursors of Paper

1.4.2.1 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 [4]. It is produced by beating or pressing the inner bark (*liber*, bast) of trees and shrubs such as paper mulberry, lime tree, fig, or daphne, and is known by the generic term *tapa* derived from the Polynesian language. Tapa (Figure 1.4) is a feltlike material, similar to thick woven paper, showing in most cases traces of the beating mallets. Technically speaking, it is a kind of nonwoven paper. There are three different techniques to be observed in tapa making. The first consists of peeling off big pieces of the inner bark and beating them with a mallet. In the second, peeled pieces of bast are beaten together to form a larger and/or thicker piece. 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.

1.4.2.2 Felt

Felting techniques go back into prehistory [5]. Plant fibers or animal hair are separated from their original linking as much as possible and spread in thick layers

Figure 1.5 Felting: rolling up the mat covered with wetted layers of multicolored wool. Hotan (China), 1993.

onto a cloth or mat (Figure 1.5). Then they are covered by another cloth, rolled up, 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 up 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, generating hydrogen bonds.

1.4.2.3 **Papyrus**

Papyrus, the most commonly used writing material of Ancient Egypt and Classical Antiquity, was made in Egypt from the beginning of the third 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 (Figure 1.6). 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

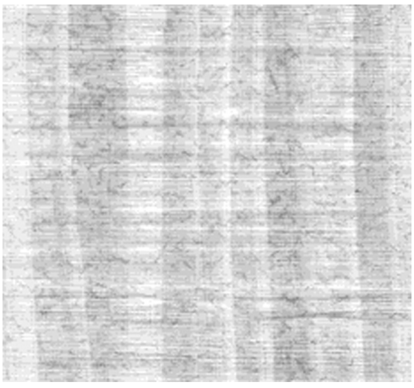


Figure 1.6 Transparency photograph of a papyrus sheet.

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 to the Mediterranean area until the eighth century AD. Parchment, made from hides, 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.

1.4.3 Paper

1.4.3.1 Invention of Paper

The oldest papermaking technique, pouring pulp into a primitive mold, 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 (Figure 1.7). 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, that is, from linen or hemp rags, and propagated paper as a writing material [6]. This was the birth of paper as we know it now.

1.4.3.2 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

Figure 1.7 Beating mulberry bark to make pulp. Hotan (China), 1993.

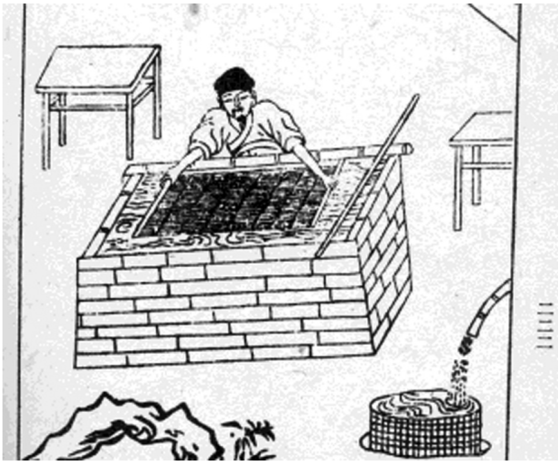


Figure 1.8 Chinese papermaker, dipping the mold. (From: Tiangong Kaiwu, 1637.)

pulp (Figure 1.8). 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 [7], the pulping of which took several weeks. China developed many kinds of specialty papers (sized, coated and dyed paper; anti-moth paper; waterproof paper); oversize 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.

1.4.3.3 **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 [8]. 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.

1.4.3.4 **The Spread of Papermaking into Central and Southern Asia**

At an early date (fourth to sixth 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 such as black mulberry. There, Tibetans learned the papermaking craft and transferred the knowledge into the high valleys of the Himalayas where they used local plants such as the roots of *Stellera chamaejasme*. From Southern

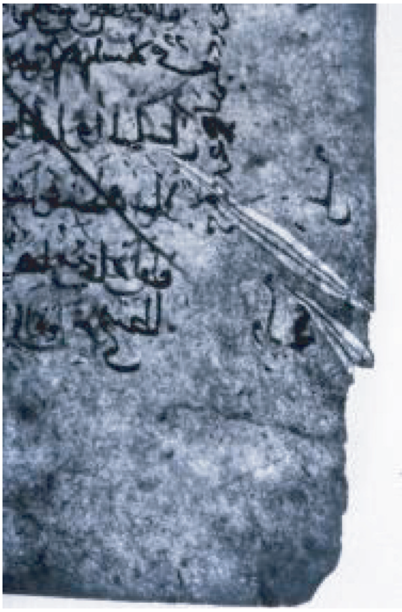


Figure 1.9 Transparency photograph of an Arab paper sheet. Creases in coating are markedly perceptible. Fourteenth century AD. (*Photo: Library of the University, Basel*.)

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 (eleventh century AD, perhaps), was papermaking introduced from the north through contacts with Central Asia and Persia [9].

1.4.3.5 **Arab Paper**

The Arabs, in the course of their eastern expansion, became acquainted with the production of the new writing material reaching Samarkand. Subsequently, paper mills 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 (Figure 1.9). This gave Arab paper its good writing properties and its fine appearance but also made it prone to damage because of humidity, crumbling, or insects. They also pressed two newly formed sheets together (wet couching), in order to obtain more strength. In the eleventh century AD, Arab papermaking knowledge spread into the Byzantine world and into medieval Europe, especially Spain (Xativa, Cordoba) and Italy (Amalfi, Genoa).

1.4.3.6 **Medieval European Paper**

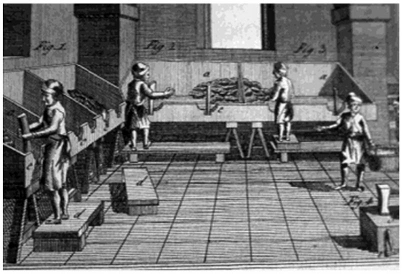
Papermakers from Genoa and Fabriano tried to improve the Arab technique. They still exploited linen or hemp rags to get pulp, but improved the beating. Water power was used to drive heavy stamping mills, huge oak trunks comprising four to six large troughs with three or four heavy wooden stampers, each beating the rags in fresh circulating water. The rags were transferred from trough to trough every 6 h to ensure a better degree of refining. Further improvements were stiff molds consisting of a wooden frame with inlaid copper or brass wire, which had to be couched on felts, 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 13–15 h. 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. Figure 1.10a–h show the separate steps in hand papermaking, from the work in the rag cellar to sorting and packaging.

1.4.3.7 **Mechanization and Industrialization**

In Europe, technical progress continued. In the sixteenth 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. Toward the end of the seventeenth century, a most efficient tool, the so-called ''Hollander'' beater, supplemented or even replaced the stamping mill (Figure 1.11). As the rotating knives of the Hollander beater cut and shortened the fibers more than a stamper, the aging 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 eighteenth and nineteenth centuries 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 such as starch or kaolin. So systematic search for rag fiber substitutes was needed [12]. From the seventeenth century, there was 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


(a)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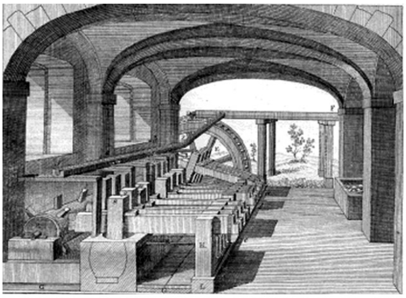
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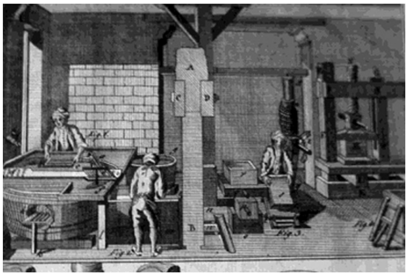
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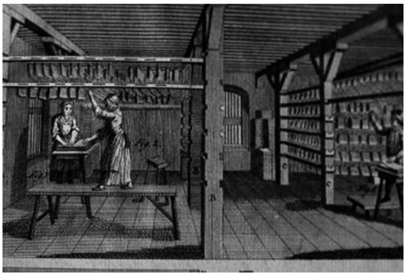
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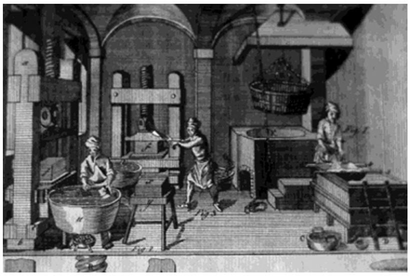
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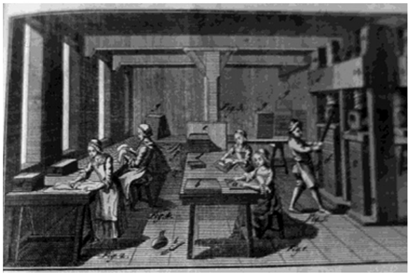
(g)


(h)

table, glazing hammer, and calender) culminated in the design and construction of paper machines.

1.4.3.8 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 between a pair of couch rolls equipped with felts (Figure 1.12). 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, for example, the cylinder machine (Bramah, 1805; Dickinson, 1809) in which a cylinder with a 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 nineteenth century and were extended to include a dryer section (Crompton, 1820) and a reeler, and somewhat later (1850), also a calender section (Figure 1.13a,b). 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.

1.4.3.9 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 [13].

Figure 1.10 Processing steps in European papermaking. (From: Chr. Ludwig Seebass: Die Papiermacher-Kunst in ihrem ganzen Umfang; aus dem französischen Original des Herrn Desmarest . . . bearbeitet. Lipsia, 1803 [10].) (a) The rag cellar: weighing, sorting, rotting, and washing the rags. (b) Rag cutting (work done by women or boys). (c) Stamping mill. (d) Main room: (to the left) dipping and couching; (to the right) pressing and laying off. (e) Drying loft: suspending the sheets. (f) Sizing hangar: (to the right) size boiling; (to the left) dip sizing, pressing. (g) Glazing hammer. (Extracted from: J.S. Halle, Werkstätte der heutigen Künste, vol. 2, Brandenburg/Lipsia 1762 [11].) (h) The Salle: (to the right) dry pressing; (middle and left) cleaning, sorting, glazing by hand, format cutting, counting, and packaging.

Figure 1.11 Hollander beater, cast iron tub, Papeteries de Vaux, Payzac (France), about 1860.

Figure 1.12 The Robert paper machine (reconstruction, University of Grenoble).

(a) (b)

Figure 1.13 Cylinder machine, Papeteries de Vaux, Payzac (France), about 1860. (a) Breast box with pulp cleaning and sorting cascade. (b) Cylinder with couch roll and board felt.

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 aging of old handmade papers. In the eighteenth and nineteenth 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 deinking, 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 aging behavior of machine-made paper until the 1980s, especially of wood-containing grades in which lignin reactions are triggered.

1.4.3.10 **From Industrialization to Automation and Globalization: Technical and Economic Trends of the Nineteenth and Twentieth 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 paper mill 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 nineteenth century, new paper grades were created, together with some kind of paper specialties such as punch cards, stand-up collars, tube papers, flong, pergamyn, ammunition papers, envelopes, tobacco paper, and toilet paper. The size of the pulping plant and of the 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

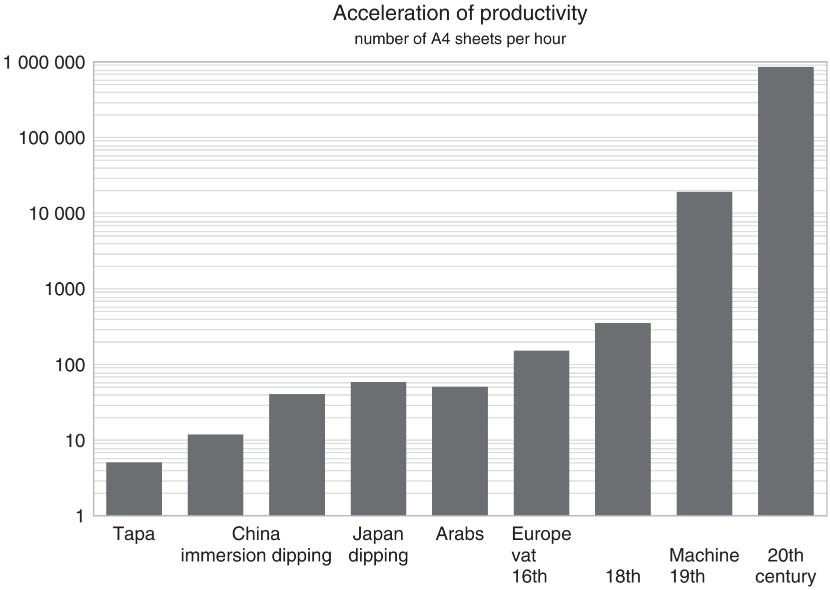


Figure 1.14 Productivity development until 2000.

gap formers), neutral sizing and – the most effective change – automation have brought further progress. This led to further specialization in specific paper types, and development of new paper grades (e.g., LWC papers and 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, already documented in the nineteenth century, 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 eighteenth century by a factor of 50 (Figure 1.14). Since then, paper and board have become a worldwide, large-scale commodity with exponential growth. In 2010, about 400 million metric tons were produced, of which about two-fifths in the fastest growing industrial market, Asia.

1.4.4
Historical Watermarking and Security

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 (Figure 1.15). The watermark serves as a trademark and provides the historian with an unsurpassed dating and authenticating tool. By comparing a

Figure 1.15 Watermark of the Basel Paper Mill.

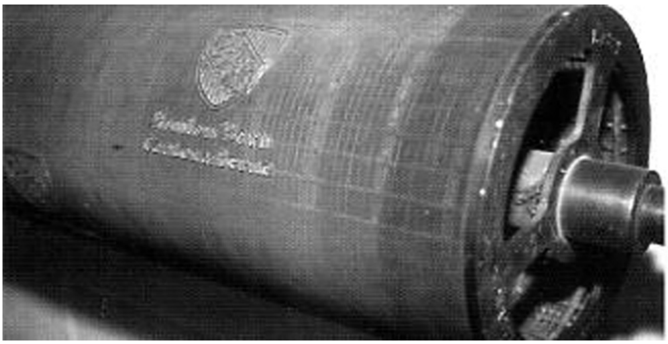


Figure 1.16 Dandy roll with soldered watermarks.

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 have been produced since the eighteenth century on a mold bearing a fine, embossed, woven wire, showing an image such as a black-and-white photograph [14]. On the flat-wire machine, real (line) watermarks are made by passing the newly formed web under the dandy roll on which watermark figures are mounted (Figure 1.16). On the cylinder machine, watermark figures are mounted onto the forming cylinder. To

Figure 1.17 Assignat (Bank note of the French Revolutionary Government), transparency photograph. Paper security devices: combined line and shadow watermark, signature print, and embossed stamp.

ensure uniformity, wire figures are replaced by casts. Besides the art form, real watermarking remains one of the most effective security measures.

Security and application aspects of watermarking, also publicity, influenced the development of other methods. Combined line/shadow watermarks (Figure 1.17) were supplemented by embossing, impressing (e.g., using molettes), and printing techniques (e.g., with engraved patterns or with a white or colorless ink) [15].

1.5
A Philosophy of Papermaking: Life Lessons on the Formation of Paper and People

Wilhelm Kufferath von Kendenich

In papermaking, both the manufacturing process and one of the primary properties of the finished sheet are referred to as *formation*, a concept that embodies all the design features of the interior and exterior of the sheet. Those attributes and processes that apply to the making of a sheet of paper may also apply – analogously – to the formation of a person. In life, a person's formation depends on upbringing, training, education, design – all those things that contribute to one's personality and overall makeup. These aspects also translate to the bigger picture of society's fundamental interactions and interdependencies. Therefore, it might not seem so far-fetched to attempt to apply the fundamental rules for sheet forming from its basic scientific foundations toward man and society.

1.5.1
Fibers as Individuals

Fibers have various fundamental characteristics: diameter, length, stiffness, and so on. They are the basic building material of a sheet of paper, and each fiber has its own individual character; as with snowflakes, no two fibers are identical, not even when they are all taken from the same wood and woven into the same sheet. Fibers are made – born, really – from wood by mechanical or chemical processes that give ''birth'' to the fibers. After liberation from the wood, the fibers are put into a water suspension and fines and fillers are added; these contribute to a smoother and better final sheet. One could imagine equivalent fines and fillers for people to be those things that make societal life more bearable and enjoyable: education, ambition, compassion, and civility.

1.5.2 Paper as a Social Construct

A sheet of paper is really nothing more than a collection of many fibers, fines, and fillers. In comparison to a community or society as a collection of many people, a sheet of paper is a microcosmic manifestation, a miniature society in its own right, each individual a sentient being, each one prepared for and taking its proper place, each fiber an equal member of that society. Sometimes, people find themselves grouped together and proclaim, ''We are the people!'' Given the opportunity, fibers could be reasonably expected also to exclaim, ''We are the paper!''

1.5.3 Fiber Preformation and Human Training

The fundamental quality of the final sheet of paper is locked in place during the preformation, called stock preparation. In the stock preparation process, all fibers experience superficially the same treatment (for example, all are subjected to refining), but the effect is not the same for all the fibers as some may differ in their physical properties; each is, after all, an individual. But all are of equal value, equally useful for the paper being produced, equally valued, and equally important. All become part of the paper sheet by their interconnection. This is the basic tenet of the papermaker's wisdom: the quality of paper is set in the stock preparation process. Thus, the foundation established in the preformation of fibers applies to analogous processes for people as well: recognize the nature of your individuality and your natural gifts as soon as you are able; protect and nurture them no matter what anyone says; follow them to the future they can provide. Making the leap from paper to human society and assessing the quality of the raw material at the end of the preparation period, we say to each individual, ''You are unique and unlike any other but you have the same value as everyone else; now go out and make your unique and valuable contribution to society!''

1.5.4 Into the World of Turbulence

As the stock preparation was the nursery for those essential properties that determine the quality of a sheet of paper, so basic maturation and professional training begin in the headbox. The suspension is transported from the nursery to the headbox, as young people are fledged from home at 18 or so. Bursting from the feed pipes into the vastly larger open volume of the headbox, we now see how the qualities imbued in the preformation process express themselves in this larger and far more turbulent world. How will young people behave and react when they find themselves on this long journey into and through the unknown? What kind of joy, fears, and anxieties will they develop? What new things will they experience? Will they be freed from old constraints, making and exploring new contacts? Properly formed in their earlier lives, it is to be expected that they will absorb and digest their new stimuli and grow accordingly.

1.5.5
Flocs and Vicissitudes

Fibers exhibit an annoying behavior as they travel from the stock preparation stage into the headbox, namely, the formation of unwanted clumps of fibers. The papermaker calls these groups *flocs*; incredibly, within the extremely short time span of only tenths of a second, they bind together very tightly and proceed through the pipes to the headbox. The papermaker cannot change this phenomenon; it is a behavior that interferes with the fibers' normal free state and is to be prevented if at all possible. Correspondingly, young people are quite often anxious about the unknowns they will face on their outward journey and may wish to remain closer to relatives, friends, and acquaintances, safe in their familiar circles, not forced out into the world. The desire to create buffers against inevitable vicissitudes or even life's shocks that await them can cause a social flocculation that can prove hard to break. But it almost always does.

1.5.6
Fibers Ready for the World, Part 1

Well prepared in the preformation process and suitably buffeted in the turbulent headbox, the fibers reach the lip of the headbox, ready for their placement in the world of the sheet. This is the moment of truth for the quality of the fibers and thus the eventual quality of the final sheet. On exit from the headbox, the fibers must have acquired the right amount of kinetic energy to achieve the proper throwing length and the compact shape of the free jet, and enough turbulent energy to maintain the mobility required to avoid renewed flocculation. Only then will the sheet form properly. The equivalent for young people is at the end of their training when they will have acquired three basic essentials: knowledge, values, and desires. These they take out into the world, into their social and professional lives. Now comes their first landing in reality – a true reality check – but hopefully one as gentle as possible.

1.5.7
Sheet Formation as the Basis of the Fiber's Society

With the grand moment of impact of the fiber jet on the forming fabric, everything is suddenly different. Water is not the natural environment for wood fibers; they like it dry, and now they can finally get the water out. As water is drained through the fabric, everything moves quickly as each fiber must soon find and settle into its final position because of this rapid drainage. There is a delicate balance between the kinetic energy to keep flocs from forming and the final placement of fibers through drainage, just as there are always things that people want to do and things they have to do.

Simultaneously with the rapid drainage, energetic pulses will be generated in the suspension above the first layer of fibers by the elements of the formation table. This helps to equalize the fibers' distribution in the undrained suspension and improve the nascent sheet's formation. This application of energy needs attention and care not to disrupt the fibers already laid in place. Additional energy is imparted to the fiber suspension from the difference in speed between the wire and the jet. There is an aligning of fibers in the incoming suspension along the direction of the machine, a final adjustment of the sheet in its transition from individual fibers to an interconnected society. This characteristic is expressed as the ratio of alignment of the fibers in the MD/CD ratio. One might interpret the degree of alignment in the MD to be those things that you are obligated to do and the degree of alignment across the machine to be those things you would like to do. Finding and maintaining the right balance between these two is the critical path that fibers and people alike must achieve. Without doubt, the journey along the forming section is a complex process laden with chaotic features.

There is, however, a conceptual divergence at the end of the forming process: the fiber's position and function are effectively locked in permanently while people have (hopefully) only begun their lifelong formation processes. A proper foundation of formation must be laid down as the person continues this formation development throughout his life.

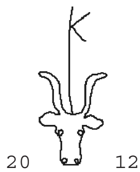
1.5.8
Fibers Ready for the World, Part 2

When the sheet has left the forming section, and completed its trip through the presses to reach the dry end, it is fully formed and ready to embark on its career as a newspaper, a page in a book, a poster, or any of a number of other possibilities. So it is with young people: they are full of energy and potential, their hopes and dreams intact and undiminished by failure or the possibly unrealistic nature of their desires. Their sheet is not folded, spindled, or mutilated by the vicissitudes of life. But as one ages, it can happen that desires, visions, and goals have often proven to be dreams, a reality to which the properly formed person will adjust accordingly. It begins to dawn on a sheet of paper that it is not here forever. In the later phases of life, a sheet serene and standing apart from adversity, perhaps honored to be a page in a Shakespeare folio – a most suitable stance from which to enjoy its stature – and perhaps the equivalent is to be the honorable chairman of the choral society in Posematuckel village.

1.5.9
In Summary – Toward the End

Paper gives us pause to dwell on these matters; and for some, it leads to an analogy with the world that one may have been seeking for a long time, a world that one is more inclined to say does not exist or that one will never find. The author must admit that, whenever he holds a piece of paper in his hands, he is astonished that such a thin sheet of paper is actually such a large book that can teach one so much about the universe. The reader will now hopefully understand why, for this author, formation stands at the center of his worldview: a sheet of paper is a silent philosopher if you look and listen closely enough.

Mit Gruß von wegen's Handwerk
(traditional German fellow papermakers greeting)



Dedicated to Dr Otto Kallmes, a masterful wet-end scientist and a true friend.
With translation assistance from Paul Kallmes.

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