Handbook of Paper and Board

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Herbert Holik
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Handbook of Paper and Board

*Edited by*

*Herbert Holik*
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Preface

“Paper is out”... and “paper flood increases”...
Is paper now dead or alive?

Paper is reality in our life. This book informs on the technical, economic and social importance of paper and board. The authors give a concise description of the fascinating art and technology of paper making, providing laymen, students, politicians and others with most recent information and on the state-of-the-art technology. It shows the relevance of paper and board today as well as the historical background and economic aspects. The chapter on raw materials for paper and board manufacture contains an overview and summary of what is described in Volume 1 on fibrous material, followed by more detailed description of pigments as fillers and for coating. Paper chemistry has found an adequate scope covering this important area by basics and practical application. The process of stock preparation first describes the unit processes which are then combined to systems for primary and secondary fiber preparation. Water circuits with loop designs and circuit closure follow. The chapter on paper and board manufacture covers the different sections in the paper machine as well as fabrics, rolls and roll covers, and describes the different types of machines producing the various paper and board grades. The high technical standard of the control, information and analysing systems in the paper industry is described in the chapter of control systems. Coating is dealt with in a separate chapter covering color formulation and preparation as well as the actual coating application. Paper finishing gives an insight in what happens at roll slitting and handling. The chapter on environmental aspects includes waste water treatment as well as handling, utilization and disposal of solid waste. The following chapters describe the main paper and board grades and their properties, followed by testing of paper and board. The paper and book preservation chapter points at an area of burning interest of mankind. The appendix includes latest papers on state-of-the-art as well as earlier ones giving basics in certain areas.

This wide knowledge field of paper and board – the big elephant – could only be eaten by cutting it into smaller pieces. This was successfully done by the readiness of more than 20 authors, all professionals with detailed knowledge in their areas, to contribute to this project. The variety of their points of view are certainly one of
the advantages of this book. My thanks go to my colleagues for their cooperation, to the individual companies for providing the pictures, to BASF, OMYA and Voith for enabling the handbook to be printed in colors and to Ullmann for the support during the preparation of this book.
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Introduction

1.1

Paper and Board Today

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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
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
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.
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]

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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.