Papermaking

OVERVIEW AND INTRODUCTION

1. Introduction and Overview

Papermachine quick facts:

- 10m wide
- 100m long
- 100 km/hr
- $250,000,000++

2. Unit Operations

The unit operations of papermaking are shown in Figure 2. Each is described below in some detail.

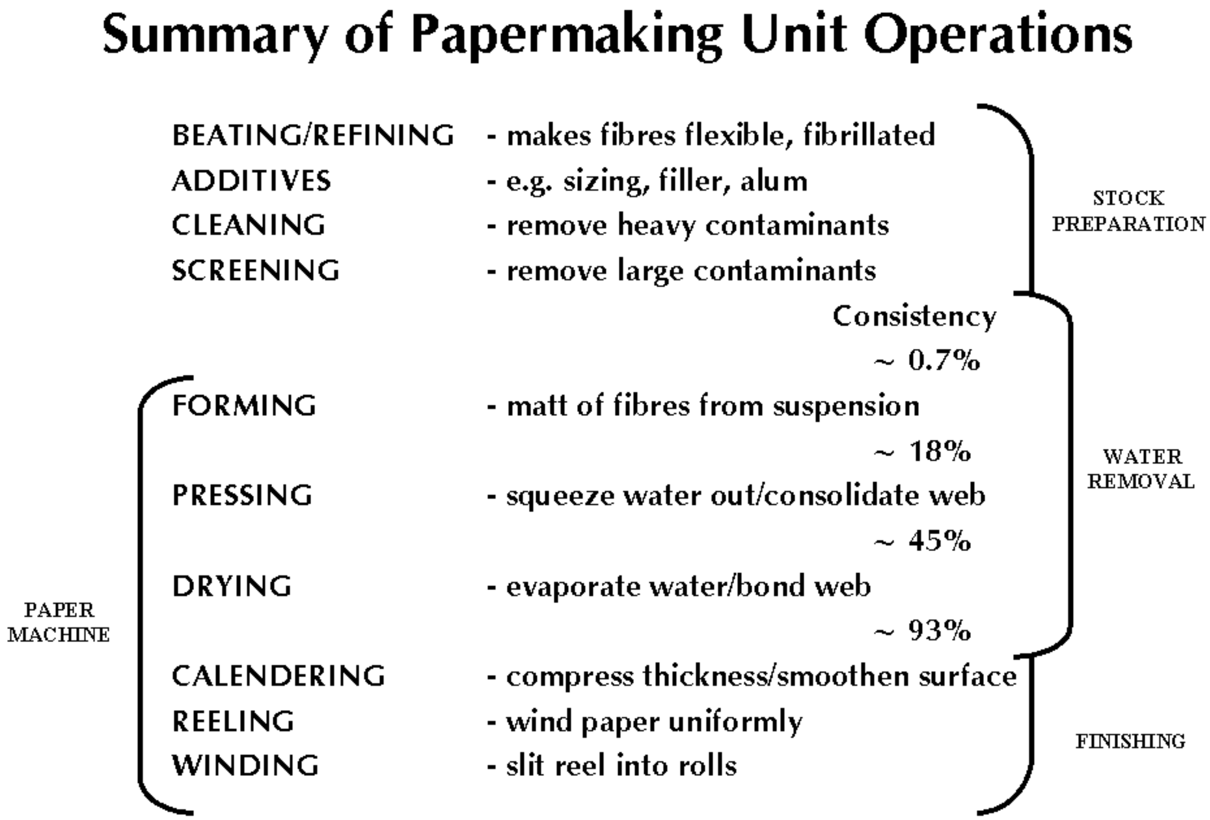


Figure 2

2.1Stock Preparation

In this step, pulps are repulped (if delivered to the mill in dry form), refined, and blended to give the desired furnish for the particular grade of paper. This blended stock is then pumped to the machine chest. From here it is pumped as thick stock through a tickle refiner, stuff box, and lastly the basis weight valve which controls the fibre delivery to the paper machine.

2.2 Approach Flow

At the fan pump, the thick stock is diluted with whitewater filtrate from the forming section. The mixed stock is pumped by the fan pump to the paper machine. It passes through centrifugal cleaners (to remove heavy material), a pressure screen (to remove large material), and then to the paper machine. There is sometimes a secondary fan pump between the cleaners and screen to assist in pumping.

After the pressure screen, the stock enters a manifold where it is drawn off over the width of the paper machine into the headbox. Stock leaving the headbox is made into a sheet by filtration. The fibrous mat is called a wet web, which is pressed, dried, and wound into a reel of paper on the paper machine.

Paper machines may vary in width from about 5 to over 30 feet, and operate at speeds up to 1800 m/min. They may produce from a few tonnes to 1000 tonnes per day. The paper basis weight may vary from light tissue (about 10 grams per square metre) to paper board (up to 500 grams per square metre).

Paper machines may be divided into three general types:

- Fourdrinier machines
- twin-wire formers
- multi-ply formers

By far the most common type of paper machine in use today is Fourdrinier. In this former, stock is drained on a moving horizontal screen called a fabric. The various parts of a typical Fourdrinier machine are illustration in Figure 3. The full machine is shown in Figure 4. It consists of a stock distribution system; headbox; forming section; press section; dryer section; calender stack; and reel.

In twin-wire formers, the stock is filtered between two fabrics.

Multi-ply formers are used in the production of paperboard. The most common type is cylinder formers. These consist of a series of screen-covered cylinders, each rotating in a vat of dilute paper stock. Web formation occurs on the screen as a result of suction inside the cylinder which removes the filtrate.

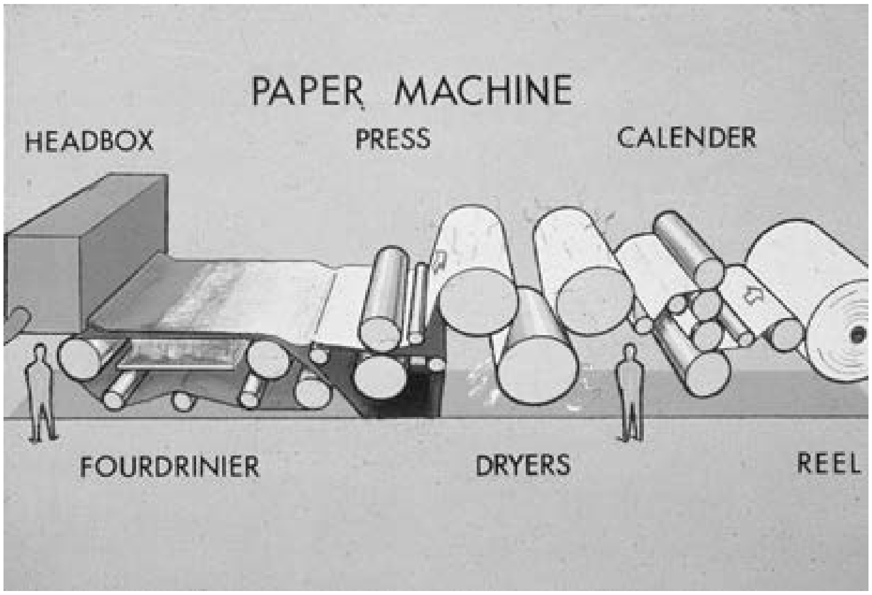


Figure 3

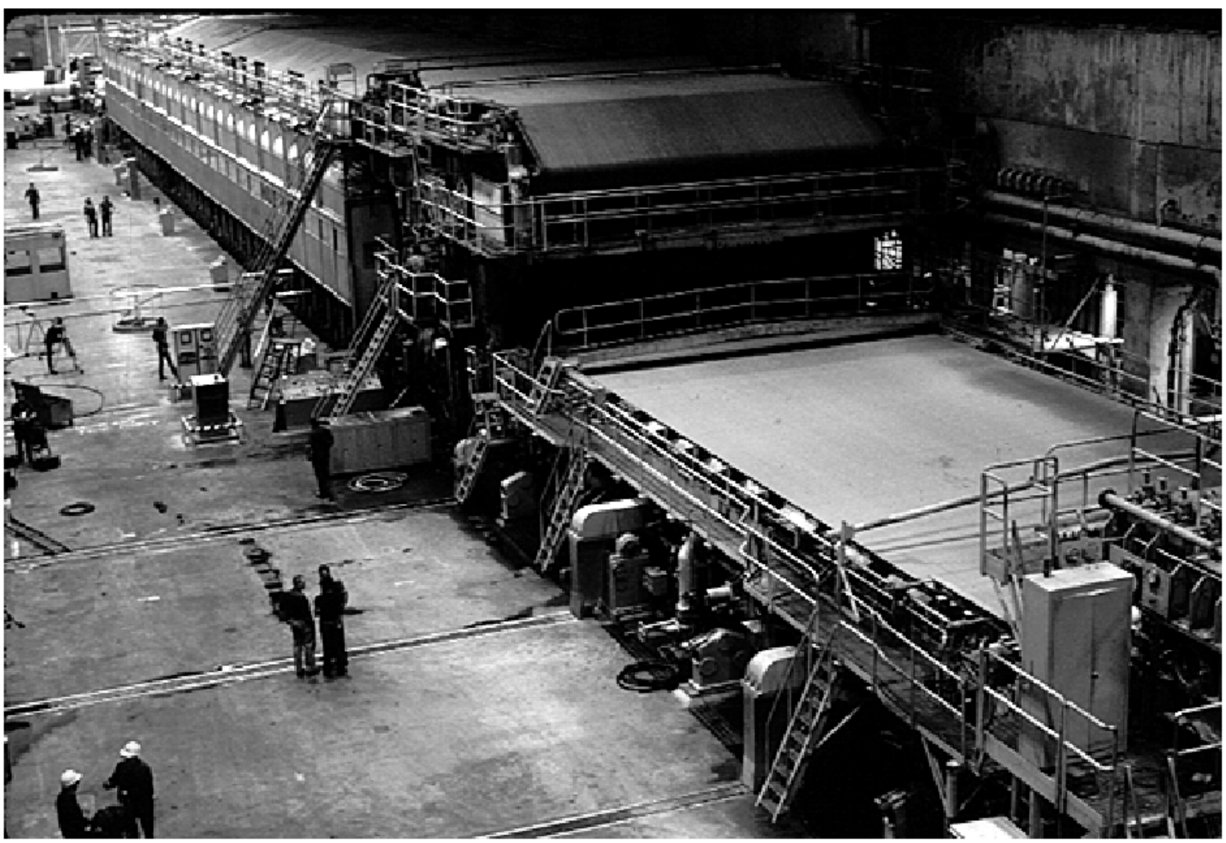


Figure 4

2.3 The Headbox

Stock leaving the flow distributor passes through a headbox before the filtration process begins. The major functions of the headbox are: to assure uniform distribution of flow across the paper machine; to provide velocity control of the jet leaving the headbox by the pressure in the headbox; and break up of pulp flocs by turbulence within the headbox. These functions are achieved by causing the stock to flow through several rotating perforated rolls within the headbox or, in modern headboxes, past stationary flow elements. After passing through these turbulence-generating elements, the stock is accelerated in a sharply converging orifice called a slice. On leaving the slice, the stock becomes a free jet, which then impinges upon the forming screen to begin the filtration process of forming.

2.4 Forming Section

The Fourdrinier table of a paper machine consists of foils, table rolls, breast roll, couch roll, suction boxes, wire rolls, and other parts. The fabric on which the sheet of fibre is formed is a finely woven synthetic fabric of strands made of specially fine drawn and filaments, woven into a screen. Various types of weave are used to obtain maximum fabric life and to reduce wire marking on the wet sheet.

The foils are located under the forming wire. In addition to supporting the wire, the negative pressure created in the expanding nip on the underside of the fabric, causing drainage of the water through the wire. Older paper machines sometimes use table rolls for this purpose. However, most modern paper machines now use foils.

After the foil section on the forming table, the moving fabric passes over a series of vacuum boxes and then over a couch roll. Often, a dandy roll is located on top of the forming fabric over the suction boxes. This is a light open structured roll covered with wire cloth, resting lightly upon the surface of the sheet. Its function is to flatten the top surface of the sheet and improve the finish. A pattern on the dandy roll may leave translucent patterns on the wet paper, in the form of names, insignia or designs. These are called watermarks.

The last roll over in the forming section is called the couch roll. It is a suction roll to remove further water.

2.5 The Press Section

The press section mechanically squeezes water from the wet web, increasing the solids content of the sheet of paper. It also reduces the bulk or thickness of the paper. This compaction assists in subsequent bonding of fibres.

2.6 The Dryer

Paper leaves the press section and enters the dryer at a consistency of 40-45%. The dryer causes further water removal by evaporation. A typical dryer section consists of from 40 to 70 steam-heated dryer cylinders. The sheet is held in intimate contact with the heated surfaces by means of dryer felts.

2.7 Calendering

After the dryer, the paper web is passed through a calender stack. This is a vertical stack of solid iron rolls which impart successively higher compression cycles to the paper as the paper passes downward through the stack. The function of the calender stack is to reduce the thickness and to impart a smooth surface to the paper web for good printability.

2.8 Reel

After the calender stack, the paper web is wound into a large roll at the end of the paper machine, called a reel. The calendering and reeling operations are the last part of the continuous paper machine.

2.9 Winder

When reels are wound to full size, the web is transferred to a new spool, without machine shut down. The full reel is transferred by a crane to a winder where it is unwound and slit into rolls based on customer specifications. In newsprint mills, the rolls then goes to the wrapping station, and then into storage.

2.10 Coating

High gloss papers are produced by coating the paper surface with a pigment-binder compound, either on-machine or off-machine. The pigment consists of mineral particles having platelet shapes, e.g. clays.

2.11 Supercalendering

Coated papers are passed through an off-line supercalender made up of hard and soft rolls. These impart gloss to the coated surface.

2.12 Converting

This term describes further operations after papermaking to make products from paper. Usually these are carried out in separate converting plants, but some converting may be done in a paper mill, e.g. production and packaging of sheets from continuous webs.

Water Removal

As is evident, much of the paper machine is devoted to water removal, taking consistency from 0.5-1% to greater than 90%. The relative amount of water removed in each section is shown in Figure 5. The cost of water removal at each section is shown in Figure 6. As is evident, the cost of water removal increases down the machine, with a particularly large increase at the dryer. Accordingly, as much water as possible must be removed in the forming and pressing sections.

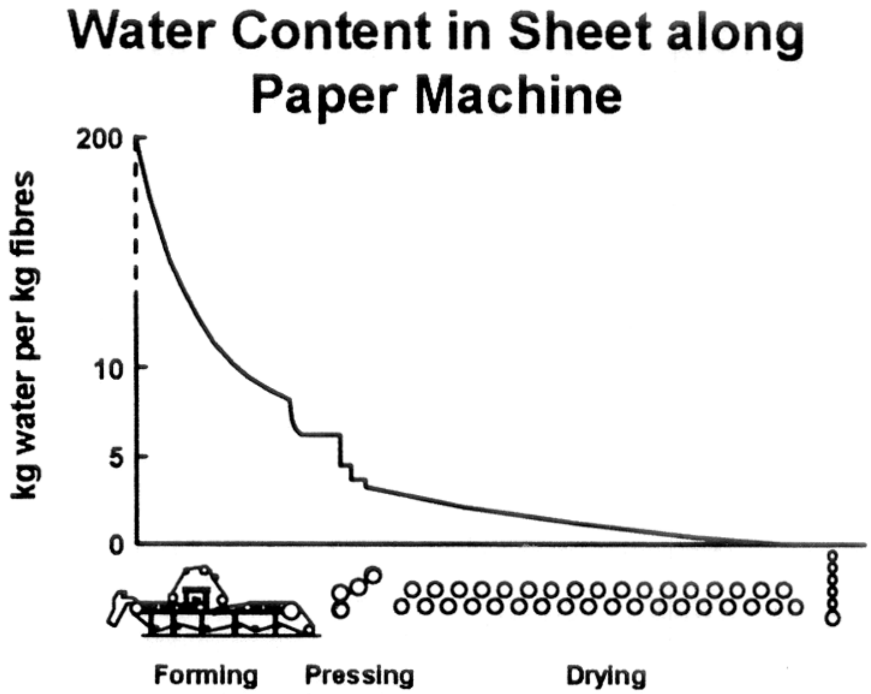


Figure 5

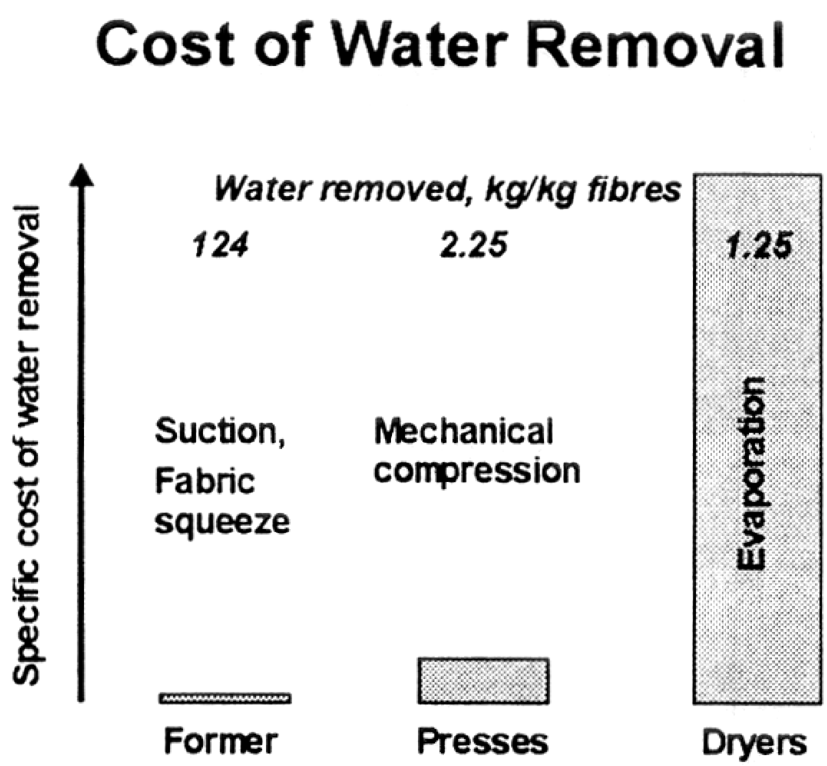


Figure 6

3. Pulp Quality Measurements

A number of analytical tests can be performed on pulp samples. Some measure chemical characteristics while others measure physical attributes. Most provide information that is useful in predicting the properties and performance of the end product made from that pulp. The most common tests are described below. Many of the following descriptions will relate to TAPPI (Technical Association of the Pulp and Paper Industry) standard test procedures. It is important to recognize, however, that there are many European standards which are equally applicable and, in some cases, more widely practiced.

Moisture Content. For pulp that has been formed into sheets, moisture content is determined by weighing a representative sample collected from several locations within a bale and then oven drying to remove all water. The difference between the original sample weight and the oven dried sample weight represents the amount of moisture present in the original sample. A percentage is determined by dividing the amount of moisture by the original sample weight. For dry pulp sheets, moisture content is usually between 5-15%. For wet lap pulp, moisture content is typically 50%-60%.

Consistency. This test measures the dry solids concentration of a suspension of fiber in water. A representative sample of pulp is collected, it is filtered to remove free liquid, and then oven dried to remove all remaining water. In stock preparation refining systems, consistency is normally between 2% and 6%. This permits relatively easy pumping of the slurry using conventional centrifugal pumps.

Kappa Number. The result of a quantitative chemical analysis, the Kappa number of a pulp indicates the extent to which lignin has been removed in the chemical pulping process. A high Kappa number, indicating a greater amount of retained lignin, is common for unbleached pulps used in the production of linerboard or bag paper. If the pulp is to be bleached, the Kappa number of the pulp before bleaching predicts the bleachability of the pulp. Low Kappa pulps are easier to bleach. High Kappa pulps usually require more energy in refining, but often produce stronger paper or board (particularly with regard to tear strength).

Viscosity. There are a number of standard tests in which a sample of pulp fibers is dissolved in a suitable solvent, and the viscosity of the resulting solution is measured. This viscosity indicates the degree of polymerization of the cellulose and is a measure of the degradation of the cellulose in the pulping and bleaching process. The lower the molecular weight (or degree of polymerization), the more degraded is the cellulose and, in general, the lower the physical strengths of the paper or board produced.

Fiber Length. The average fiber length of a pulp has a direct bearing on many of the important physical characteristics of the paper produced. In particular, tearing resistance is very closely related to average fiber length: the longer the fiber, the greater the tear strength of the sheet produced. Screening classifiers (e.g. Bauer McNett) have been used in the past to determine the weight percentage of fibers collected on various screen sizes, but these have largely been replaced by computer automated optical devices. The most commonly used of these optical instruments are the Kajaani FS-200 and the Optest FQA. The data output of these devices can provide information such as the average length and length distribution curve for the fibers in that pulp.

Fines Content. An additional measure of pulp particle size is the percentage of fines. This consists of particles measuring less than 0.2 mm in length as measured by an optical analyzer, or the weight percentage of the P200 fraction obtained from a Bauer McNett classifier. Fines can have a significant impact on processing, particularly with regard to filtering or drainage operations. Fines content of a kraft pulp may be in the range of 5– 15%. For a groundwood mechanical pulp, the fines content may exceed 40%.

Coarseness. This is a measure of the average weight of fiber per unit length, often reported in units of mg/m. It is most conveniently measured using an optical analyzer. For fibers of a given average length, it is a measure of the cross sectional area of the fiber. For a given average diameter, it is measure of wall thickness. Coarse fibers are considered to be less conformable than fine fibers and do not bond as readily. Coarser fibers also result in fewer fibers per mass of pulp, which has a significant impact on sheet formation and light scattering potential.

Zero-Span Tensile. This test is a measure of the intrinsic strength of individual fibers. For normal tensile strength tests (described in the next section), the jaws of the tensile machine gripping a paper sample are spaced about 7” apart. As the sample is pulled apart, many fibers pull out of the sheet by breaking fiber-to-fiber bonds. The resultant breaking load is a measure of both fiber strength and bond strength. For the Z-Span test, the gripping jaws are moved together until they are touching so that, in principle, all fibers in the tensile zone are gripped by the jaws. The fibers are then stressed to the breaking point and a measure of fiber strength is obtained.

Freeness. Freeness is a measure of the drainage resistance of a pulp slurry. In the Canadian Standard Freeness (CSF) test, one liter of dilute slurry (0.3% consistency) is drained through a standard screen which captures the fibers to form a mat. The amount of water overflowing a weir and collected from a side orifice is then a measure of how fast the water drains through the mat. CSF values may be as high as 750 ml for an unrefined, unbleached softwood kraft, and as low as 30-40 ml for a fine groundwood mechanical pulp. Stock prep refining of kraft pulp will typically reduce freeness to between 600 and 250 ml depending on the starting freeness and the paper grade being produced. Freeness is a good general predictor of sheet density and, as such, is routinely used to predict strength, opacity and other physical properties of paper. Freeness is the most widely used control test in the stock preparation area of the paper mill, at least in North America. Other standard measures of pulp drainage include Schopper-Riegler (SR^{o}), Williams slowness, and TAPPI drainage time. All of these measures can be roughly converted to equivalent CSF values.

Beating Response. There are a number of standardized bench top beating devices that can be used to refine small pulp samples. The Valley Beater and the PFI Mill are two such commonly used devices. The nature of the fiber treatment in these devices is very different compared to each other and to industrial refining, and it is not possible to directly compare the results of one type of test to results of another. As beating takes place, samples are withdrawn from the test device to generate a refiner curve. In the case of the Valley Beater, samples are typically collected at 5 or 10 minute intervals over a period of 20 to 40 minutes depending on the ease of refining for a given pulp. Pulp samples taken during the beating cycle are typically tested for freeness, fiber length, fines content, and handsheet properties.

Handsheet Testing. To test for sheet properties, pulp is diluted and formed into handsheets using a sheet mold and a very specific forming procedure. The wet sheets from the handsheet mold are carefully removed and pressed under standard conditions. Pressing is performed on several sheets at a time, with thin highly polished steel plates between them. The pressed sheets adhere to the steel plates which are placed on separator rings and stored in a temperature and humidity controlled room. After a specified period of drying and conditioning, the handsheets are peeled from the polished plates and set aside for physical testing. One very important factor to remember when using handsheet test results to predict machine made paper is that handsheets are fully restrained by the polished plates during the drying process. In other words, they are able to shrink in the thickness direction but cannot shrink in the X-Y plane. Machine-made paper, on the other hand, shrinks considerably in both the machine and cross directions. Consequently, sheet properties and the trends observed from beating can be very different for differing conditions of restraint during drying.

Physical and optical tests – such as tensile strength (or breaking length), tear strength, burst strength, caliper and light scattering - are performed on pieces of the handsheets cut to specification. The results of these tests are typically plotted against beating time, freeness, and/or density in order to demonstrate the beating response of the pulp being tested. Tests performed on handsheets are similar to those performed on samples of machine made paper, as described in more detail in the following section.

3. Paper Quality Measurements

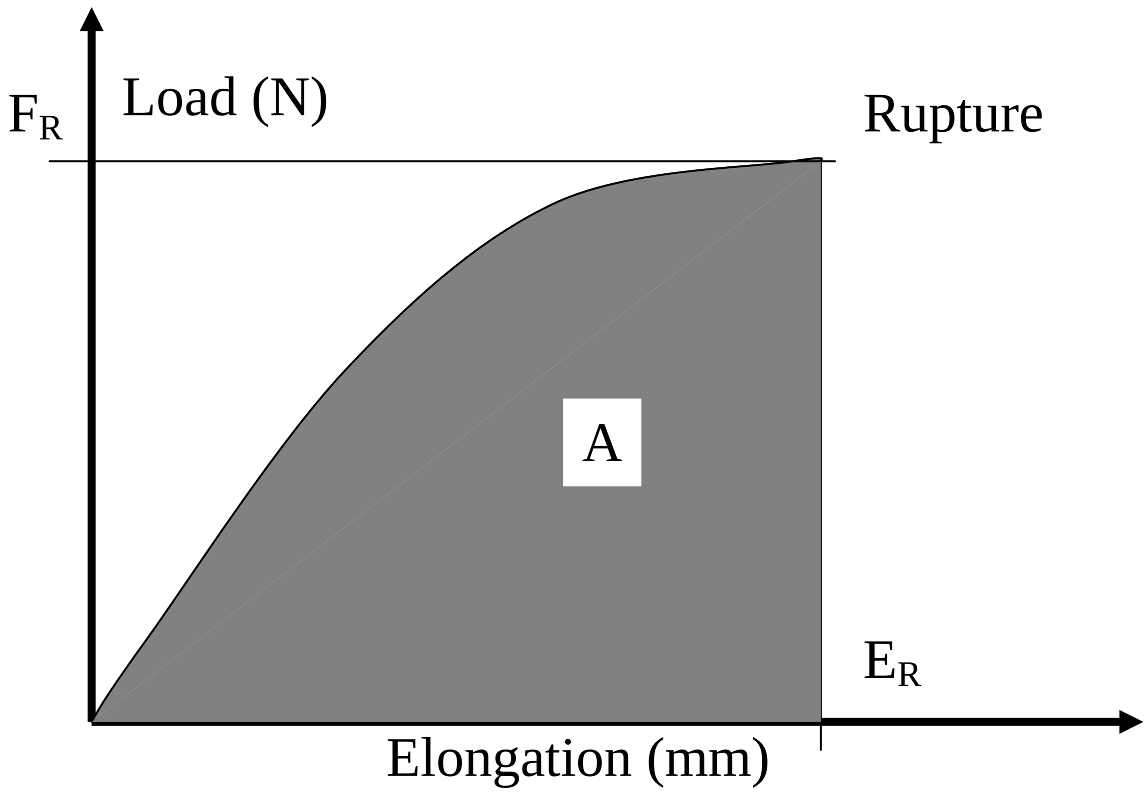
There are a variety of tests that can be performed on paper samples. Some measure strength or toughness, others measure surface properties such as smoothness or coefficient of friction, and still others measure optical properties such as opacity or brightness.

Nearly all paper properties are a function of the density of the paper which is, in turn, largely a function of refining. In evaluating processing alternatives, it is therefore generally appropriate to examine how refining affects the sheet properties of interest at a given density. More importantly, density can have a direct economic impact since many paper and board grades are sold not by weight but by area, subject to a set of test criteria. If a producer can meet sheet specifications at a lower density (i.e. at higher bulk), there is a significant profit incentive to do so.

It is important to recognize that machine made paper will exhibit significantly different properties in the direction of travel of the web (machine direction or MD) compared with the perpendicular direction (cross-machine direction or CD). As mentioned earlier, tests performed on standard Tappi handsheets are not dependent on direction.

Density. Density of paper is determined by measuring the weight and thickness (or caliper) of a sheet of paper of known area. Basis weight and caliper are usually measured using several sheets of paper in order to reduce local variations. The inverse of density is a measure of specific volume, most commonly referred to as sheet bulk.

Tensile Strength. Tensile strength is measured by clamping a strip of paper between two jaws of a tensile testing machine and recording the resulting load as the moving jaw stretches the paper to its breaking point. The maximum total force applied is called the breaking load. The elongation (or strain) of the strip is also measured, and the machine usually provides an output plot of load versus elongation as well. The area under the load-elongation curve represents the tensile energy absorption (TEA), and the slope of the curve is called the elastic modulus.



From this we can define a Tensile Index, as

$$T = \frac{F_R}{wR}$$

Where,

Fr is the force to rupture the paper

w is the width of the paper (standard is 1.5cm)

R is the basis weight of the specimen.

One of the most common means of expressing tensile strength of paper which is given as the length of paper that the paper can hold up without breaking. This is called ‘Breaking Length’

That is,

$$L = \frac{10^3 F_R}{wRg} = 101.97\frac{F_R}{wR} = 101.97T$$

<u>Tear Strength</u>. Measurement of the out-of-plane tearing strength (or tearing resistance) is done using a pendulum type device that measures the energy absorbed in tearing a paper sample. A starting slit is cut into the sample to initiate the tear, and the load is applied to simulate a piece of paper being torn by grabbing it with two hands and ripping it down the middle. Tear strength is a function of fiber length, fiber strength, and the degree of bonding in the sheet.

The tear Index is given by

$$TI = \frac{F_t}{R}$$

Where Ft is the force required to tear the paper and R is basis wt.

<u>Bursting Strength</u>. This test is performed by clamping a paper sample between two steel rings over a rubber diaphragm. The diaphragm is then inflated, and the inflating pressure is measured at the moment that the diaphragm bursts through the sample. Burst strength is an indicator of sheet bonding and often trends with tensile strength.

We can define a Burst Index as,

$$B = \frac{P}{R}$$

Where P is the burst pressure (kPa) and R is the basis weight.

It has been suggested that Burst strength is related to Tensile strength as

$$P = KF_R E_R^{1/2}$$

Compressive Strength. There are several methods available to measure the edgewise compressive strength of a paper or paperboard sample. The Ring Crush Test is a traditional method in which a ½" x 6" strip of paper is rolled end-to-end to form a very short cylinder about 2" in diameter. The cylinder is then compressed axially between two plates and the maximum load is measured. In recent years, a short span compression test (STFI) has become more widely used. Other similar tests have been developed for corrugated board samples. Compressive strength increases with refining in a nearly linear relationship to density.

Internal Bond or Z-Direction Strength. There are several test methods, the most common of which is the Scott Bond test which measures the energy or force required to separate a paper sample in its thickness direction. This is a very important property for paper or board grades that are printed on high-speed offset printing presses, where high tack inks act to separate the paper into two layers at the exit of the printing nip.

Stiffness. As implied, the stiffness test measures the resistance to bending of a sample of paper. The Gurley type tester is the most common. It can be used for a variety of paper and paperboard grades by adjusting the length and width of the sample to keep the measurement within a specified range. Stiffness can be a very important characteristic of paper and is affected by refining in a complex way. It is increased as the amount of bonding increases, but decreased by the reduction in sheet caliper. Therefore, increasing the amount of bonding at a given sheet density always improves stiffness.

Porosity. Sheet porosity or air permeability is determined by measuring the air flow through a known area of paper. It can be reported in two ways: 1) as the time required for a known volume of air to pass through a sample of paper, in units of sec/100 cc (Gurley porosity); or 2) as the volume of air flow per minute, reported in ml/min (Sheffield or Bendtsen). Refining always acts to close up a sheet and make it less porous. Porosity is often used as an indicator of the potential absorbency of the paper, particularly for coated grades.

Smoothness. Smoothness (or, conversely, roughness) is often measured indirectly using a Sheffield, Bendtsen or Parker Print Surf (PPS) test. These tests measure the extent to which air flows between the land area of a smooth ring and the surface of a paper sample on which the ring rests. Both the air pressure and the contact pressure of the ring are carefully controlled. More sophisticated methods are available for measuring the microscopic topography of a paper sample, but none are in common use yet.

Folding Endurance. This test measures the number of double folds that a paper sample will endure while subjected to a fixed load in tension. The most common test device is the MIT tester. The effect of refining on MIT fold is not clearly predictable. Folding endurance is very dependant on fiber length and coarseness, where longer and less coarse is better.

Brightness. The brightness test is a measure of the reflectance of light by paper. It is indicative of the apparent whiteness of a paper sample. The brightness of pulp can also be determined by preparing pulp pads or handsheets according to standard methods.

Opacity. Opacity is a measure of the relative reflectance of light by paper on a pure black background compared with the reflectance when backed by several sheets of the sample paper (or a calibrated "white" backing). It is indicative of the usually undesirable tendency for printing on one side of the paper to show through to the other side. Opacity always decreases with refining due to the fact that the bonded area between fibers is nearly transparent. Any increase in the bonded area will increase the transparency and reduce the opacity.

Scattering Coefficient. Light scattering coefficient is an alternative form of presentation of the opacity test above, and it is often used as an indirect measure of the relative bonded area (RBA) in a paper sample.

Ash Content. This test measures the non-combustible portion of a pulp or paper sample which is primarily made up of filler or coating materials. Virgin pulps also have measurable ash content as a result of minerals absorbed into the wood of the source trees. In this test, a sample of known weight is placed in an oven at a temperature of 525 ^{o}C (or 900 ^{o}C depending on the nature of the fillers present) and fully combusted. The weight of the residual ash after combustion is reported as the ash content.