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Forming

This chapter is about sheet formation, forming fabrics, and the forming section of the paper machine. The general mechanism for sheet formation is described. Forming fabric design, manufacturing, properties, and testing are explained in detail. Finally, forming section configurations of paper machines are summarized.

Formation of the sheet is the most critical phase of paper manufacturing. If the sheet is not formed properly in the forming section, there is little that can be done to correct it in the remaining sections of the paper machine. Many sheet properties such as opacity, smoothness, tensile and tear strength, and formation are directly controlled by the forming section of the machine. The manner in which the fillers, fibers, and water flows are handled in the forming section controls sheet properties and contributes to the way the press and dryer sections will react to the fiber mat. The way the sheet behaves in the paper converting operations, particularly in the areas of roll condition and converter runnability, is a function of the operation of the forming section of the paper machine.

Pulp dewatering and drying machines deserve a special mention. Pulp is the final product of a pulp mill, which papermakers will "re-hydrate" and use on a paper machine to produce a specific final product for their customers' needs. This can include high quality pulp for upscale magazine papers, photographic grade papers, and high quality writing papers as examples. The forming process on a pulp machine is very similar to that of a paper machine for most purposes and functions. The main differences between a pulp machine and a paper machine in terms of process include:

- Machine speeds
- Basis weight (pulp = 820-1100 gsm or 168 - 225 lb/1000 ft^2)
- Headbox consistencies (pulp = 0.5-1.3% for softwood and 1.4-1.8% for hardwood)
- Air dry targets, which can be variable for pulp

Paper machines, in contrast to pulp machines, run at higher speeds, with lower basis weights, lower headbox consistencies, and generally with lower final sheet moistures. See more details in Section 2.3 Application of Forming Fabrics/Forming Fabric Application Examples by Grade.

2.1 Sheet Formation Mechanism

There are various forming section configurations of paper machines and pulp machines. Although the principle of sheet formation is the same, the process of sheet formation depends on the machine configuration. Therefore, sheet formation process and equipment may differ from machine to machine. Forming section configurations are described in Section 2.5, where a rather detailed analysis of sheet formation on Fourdrinier type machines is also included. This section provides a more generic description of sheet formation. Formation as a paper property is discussed in Chapter 6.

There are five basic processes which take place in the forming section of the paper machine. The processes are interrelated. Each process is necessary for good operation of the machine [1].

TABLE 2.1. Typical Papermaking Consistencies at Headbox.

Paper Grade	**Headbox Consistency Range** (%)
Tissue	0.15 - 0.50
Groundwood	0.45 - 0.70
Newsprint	0.80 - 1.50
Freesheet	0.45 - 0.75
Linerboard	0.35 - 0.90
Bleached Board	0.60 - 0.80
Corrugated Medium	0.80 - 1.20

1. The first basic process is to take the properly prepared furnish (mixture of water, fibers, fillers, fines, and additives) from the stock preparation plant and dilute it to a low consistency for easy relative motion between all the particles in the furnish, particularly the fibers. Consistency is a measure of the percent solids in the stock slurry. The typical consistency at the headbox is around 0.5-1.0%. The turbulence developed in the piping, pumps, cleaners, and the headbox results in very uniformly dispersed stock slurry. Typical consistencies of paper grades at the headbox are given in Table 2.1 for North American paper machines.

2. Next, the slurry is distributed across the width of the machine by the headbox and slice. A good headbox will distribute the fibers uniformly while maintaining good dispersion. The uniformity of the distribution directly affects the uniformity of the sheet basis weight in both machine and cross directions, as well as the micro scale weight uniformity of the final sheet.

3. The uniformly distributed and diluted slurry is delivered onto the forming fabric through the headbox slice or nozzle in such a way as to promote the formation of a uniform fiber mat on the top surface of the fabric. At the same time, water must begin to drain through the forming fabric, which further develops the fiber mat (Figure1.6, Chapter 1).

4. As the free water is drained through the fabric, and while the fiber mat is still in a wet compressible state, it is consolidated and compacted in a controlled way to increase fiber-to-fiber contact and gradually close up the porous structure of the web. Compactness and thickness of the fiber mat increase as it travels down through the machine. The main factors affecting filtration of the furnish are temperature, forming fabric properties, fabric tension, stock consistency, refining degree, fiber properties, additives, and the type of machine drainage elements [2]. Flow rates must be controlled to give acceptable levels of fines, fillers, and fiber retention. Fiber-to-fiber contact and pore structure greatly affect the final sheet properties.

5. In the last step of the formation process, the web must be as dry as possible at its point of removal from the forming fabric to achieve high wet strength. Wet strength increases with increased dryness. From the headbox to the point of transfer to the press section, gravity and induced drainage forces work together to drain as much water from the fiber mat as possible to reach maximum dryness. The forming fabric itself, due to its structure, will contribute to the dryness of the sheet by enabling water drainage while providing support for the fiber mat being built on the top of the fabric.

The formation of the sheet is the result of physical interactions during the forming process. Factors involved in sheet formation are fiber dispersion, fiber orientation, and degree of packing. The reactivity that cellulose fibers have with water (swelling and softening) is crucial to sheet formation and structure. Hydrodynamic variables of the sheet forming process are the viscosity of the slurry, drainage, turbulence, and

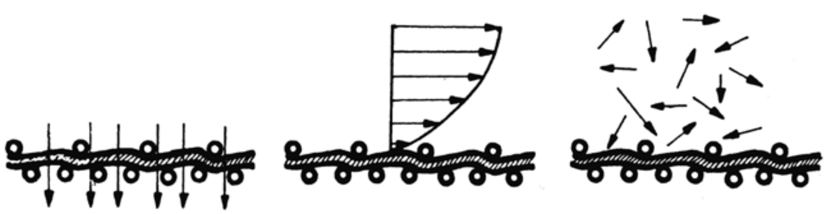

FIGURE 2.1. Hydrodynamic forces in sheet formation [3].

shear (Figure 2.1). Oriented shear is the result of the difference between fabric speed and headbox jet speed (known as the "jet-to-wire ratio").

A measure of drainage ability is the freeness or slowness of the pulp. Freeness is the rate at which the water drains from the slurry. The amount of debris and fines in the slurry impacts freeness. There are two types of measurements: 1) Canadian Standard Freeness (CSF), which measures freeness (higher number indicates faster draining slurry) and 2) Schopper-Riegler (SR°), which measures slowness (higher number indicates slower draining slurry). TAPPI test method T227 is designed to measure the freeness using the CSF tester. It should be noted that the freeness measurement does not predict the drainage on the paper machine. Drainage time of pulp is measured with TAPPI method T221.

In the forming section, and later the press section, suction and compression forces consolidate the sheet web. These forces also cause the fibers on the web surface to conform to the topography of the forming fabric. Sometimes this results in a "wire mark" in the sheet. Due to the contact between surface fibers, fabrics and metal surfaces during manufacturing, the structure of the paper surface is different from the rest of the sheet structure. In addition, the two sides of the sheet may also be quite different. In general, pulp properties that give a denser sheet structure also result in a smoother surface [4].

During formation, fibers tend to orient in the direction of the motion of the forming fabric, i.e., along the machine direction (MD). The tensile strength of the sheet increases with the increase in fiber orientation. Therefore, the tensile strength in the MD may be different than that of the cross machine direction (CD).

Flocculation, which is the tendency of fibers to agglomerate, results in poor formation. Sheet formation quality requires that fibers are randomly oriented in the headbox and fibers and fillers are uniformly distributed. Constant turbulence is generated in the headbox to disperse flocs. Then, dewatering should be done fast enough to prevent the formation of new flocs.

It is generally accepted that traditional sheet forming methods produce a layered structure where fibers lie approximately parallel to the paper surface. However, in high consistency forming, fibers are arranged as a three-dimensional network structure, oriented to some extent in the thickness direction [5]. Table 2.2 shows the comparison of low and high consistency handsheet mechanical properties. A high consistency sheet has a drastically higher Scott Bond value than that of a low consistency sheet. Thickness and bending stiffness are also increased. Compression strength slightly increases in high consistency forming while tensile strength decreases.

Various paper properties such as strength, appearance, amount of directionalism, and dimensional stability are affected by formation. Therefore, some of these factors are used to evaluate formation.

While the fibers are formed into a sheet, non-fibrous materials such as fillers in the furnish should be retained in the sheet structure as well. Certain fillers are used to give different properties to the paper. Table 2.3 shows the typical size range of some filler materials. Fillers should be retained on the first pass on the forming fabric. For best retention of fillers, fines should form flocs, which contradict the prevention of fiber flocculation for good formation. To increase retention, retention aids are used. High retention allows for lower headbox consistencies, which improves formation. Increased retention increases the basis weight and strength of the paper.

TABLE 2.2 Mechanical Properties of Low Consistency (LC) and High Consistency (HC) Formed Handsheets [6].

	Density (kg/m^3)	**Bending Stiffness Index** (Nm^7/kg^3)	**Tensile Index** (kNm/kg)	**Compression Index** (kNm/kg)	**Scott Bond** (J/m^2)
LC Sheet	650	1.00	60	18	75
HC Sheet	500	1.30	50	20	380
Ratio HC/LC	0.76	1.30	0.83	1.11	5.06