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Drying

Drying is the last major process on a paper machine. The sheet, which is formed in the forming section, and consolidated and dewatered to a certain extent in the press section, enters the dryer section for the removal of the remaining water in its structure. At the entrance to the forming section, the paper stock is ~99% water. A significant amount of this water is removed in the forming and press sections, with typical moisture content after the press section at 56% (46-50% for shoe presses). The remaining water in the sheet has to be evaporated in the dryer section. During the drying process, the loose network of fibers is consolidated into a more compact, continuous web structure. The moisture content of the sheet after drying is approximately 5-10%.

Although the effect is not very pronounced, the drier the sheet is coming to the press, if all other things remain constant, the drier the sheet will be going to the dryers. A dry, well compacted sheet from the forming and pressing sections will help the dryer section run more efficiently and will consume less energy (steam). Since drying is a costly process (responsible for over 55% of the energy consumed on a paper machine), every effort should be made to remove as much water as possible from the sheet prior to the dryer section. A 1% increase in sheet dryness before the dryers results in about a 4% reduction in steam consumption (calculated by the change in water-to-fiber ratio entering the dryer section).

Dryer cleanliness and fewer sheet breaks are also advantages of a drier and well-formed sheet coming from the press section, but the biggest impact comes from better heat transfer and easier drying. Better contact between a smooth, well-formed sheet and the dryer cylinders will result in easier and more efficient drying.

Significant improvements in sheet runnability in the dryer section have been accomplished in the last twenty years. These have not only increased the efficiency of existing machines, but have made ever increasing machine speeds and sheet quality improvements possible.

Dryer fabric quality and design have had to keep up with the innovations in machine design. Dryer fabrics are a crucial element in successful machine operation.

4.1 Paper Drying Theory

Figure 4.1 shows the schematic of a typical dryer configuration. The sheet is pressed against the heated cylinder by the dryer fabric. The drying of paper is accomplished by two interdependent actions: heat transfer and mass transfer. Heating of the water in a sheet of paper is accomplished by conduction (contacting the sheet with the hot surface of a steam-heated dryer cylinder). This contact first results in energy (heat) transfer from the dryer to the sheet, and then progresses to mass transfer of the water into the surrounding air with evaporation.

Heat transfer takes place from a hot dryer to a cooler sheet. As a result, the water in the sheet is warmed up. The evaporation of water under any drying condition requires heat to be transmitted to the water in the sheet to raise the temperature of the water to the evaporating temperature. Once the water molecules absorb enough energy so that they leave the sheet to be carried away by the surrounding air, the second activity, known as evaporation or mass transfer, begins.

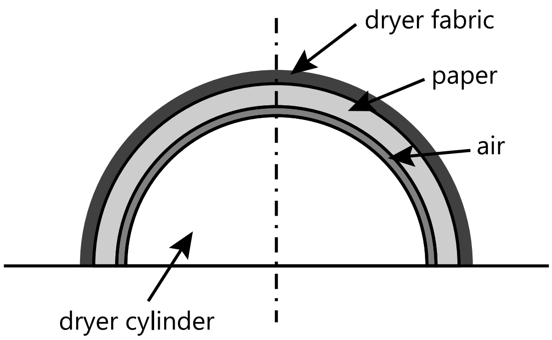

FIGURE 4.1. Drying configuration.

When the water molecules absorb enough energy to leave the sheet, they must be allowed to enter the surrounding air. The rate of evaporation from the sheet is due to the difference in vapor pressure of the water vapor in the sheet and the vapor pressure in the surrounding air. Therefore, if the air around the sheet is dry enough to hold the moisture evaporating from the sheet at an adequate velocity, the air will carry the moisture away. This makes the ability to supply dry air to all areas around the sheet, and to eventually exhaust the moisture-laden air from the machine a critical capability.

If the capability to supply dry air and exhaust wet air is inadequate, the air surrounding the sheet becomes saturated. As air humidity in this "pocket" around the sheet increases, the "driving force" for evaporation of moisture from the sheet reduces as well, due to the reduction in the vapor pressure differential.

Pocket Ventilation (PV) systems are employed on the machine to feed hot, dry air into the dryer pockets over the entire width of the machine. This air picks up evaporated water and carries the air and water vapor through the dryer screen body and also to the sides of the machine where it is, in turn, picked up by the exhaust fans and removed from the machine.

As moisture evaporates from the sheet, the sheet is cooled by this evaporation. The cooler sheet is then heated again by the next dryer cylinder and the process starts over. The closer the sheet temperature gets to the dew point temperature of the surrounding air, the better the heat transfer from the following dryer cylinder will be. This is due to the increased temperature differential between the sheet and the dryer cylinder surface. This advantage is seen in "Single Tier" dryer configurations, where the increased path distance between dryer cylinders creates a greater sheet temperature drop due to a longer evaporation time.

There are several factors that affect heat transfer and mass transfer rates. Drying will take place at almost any sheet temperature and air moisture content. For example, if a sheet of paper is laid out on the floor on a very humid day, it will eventually dry. In fact, the very first sheets of handmade paper were dried this way. Certainly, today's drying technology produces fast and effective drying of the sheet.

4.1.1 Drying Rate

The term *drying rate* refers to the amount of water evaporated per hour per unit area of drying surface. Many paper machines are limited by drying capacity. Since most papermakers are interested in getting maximum production, an improvement in the drying rate without a negative impact on paper quality is a constant pursuit. Improving drying rate by focusing on the heat transfer side implies that the heat must get into the paper sheet more rapidly.

The law of heat transfer states that the amount of heat transferred varies directly as the temperature difference between the source of heat (i.e., the steam inside the dryer cylinder) and the material being heated (i.e., the paper sheet in contact with the dryer) increases [1]. Increasing the temperature difference will increase the amount of water evaporated or paper dried in direct proportion. The temperature difference can be increased by raising steam temperature (i.e., raising steam pressure) or decreasing the drying temperature of the paper.

4.1.2 Saturated Steam Pressure

The first step is to heat the sheet to get more of the water molecules to leave the sheet in a shorter time. This is done using steam-heated dryer cylinders. Saturated steam is supplied at pressures which generally range between -50 kPa(g) (-7.25 psig) for warmup dryers, and up to 1050 kPa(g) (152 psig) for main section dryers, depending on paper grade. The temperature of the steam at -50 kPa is 82° C, while at 1050 kPa, the steam temperature is 186° C. The drying rate does not increase linearly with increased dryer steam pressure. Table 4.1 shows this characteristic about steam.

TABLE 4.1. Change of Enthalpy with Steam Pressure and Temperature.

Saturated Steam Pressure (psig)/kPa(g)	**Saturated Steam Temperature** (°C)	**Enthalpy (latent heat)** (Btu/lb)/(kJ/kg)
0/0	100	970/2256
5/34	108	961/2235
10/69	115	953/2216
15/103	121	946/2200
20/138	126	940/2186
30/207	134	929/2161

As steam pressure increases, the condensing saturation temperature increases and the latent heat decreases. Therefore, the heat transfer rate increases with pressure, but more steam must be condensed for a given amount of heat transferred. In other words, the rate of increased drying capacity resulting from an increase in dryer pressure decreases as the steam pressure is raised. For example, the drying rate for a dryer with 1034 kPa (150 psi) of steam is only twice that of a dryer with 172 kPa (25 psi) of steam.

4.1.3 Superheated Steam

The purpose of superheated steam is solely to avoid the issue of saturated steam condensing in the pipework and causing internal erosion or corrosion. Superheated steam must first give up its heat to the dryer condensate layer before the latent energy of the saturated steam can be utilized. The amount of heat available above the saturation temperature is small compared to the latent heat. Typical value of superheat temperature in supply piping measured close to the machine is ~5° C.

Paper drying is not just a simple function of water removal. The use of high steam pressure is impractical if the result is unacceptable quality paper. High steam pressure accentuates or causes picking, puckering, and cockles. In addition, high steam pressures in the first dryer cylinders may actually retard drying (by sealing the sheet) and are detrimental to sizing.

4.1.4 Condensate

A given differential pressure between the steam supply and condensate siphon within the dryer must be maintained to remove condensed steam as it forms. Condensate removal must function properly or the dryer will fill up with hot water. The condensate buildup within the dryer acts as insulation, inhibiting direct heat transfer from the steam to the dryer shell. The thinner the condensate layer, the more efficient the heat transfer. There is a minimum required condensate layer for heat transfer to take place and the thickness of this minimum layer is determined by siphon design.

4.2 The Role of Dryer Fabrics in Drying

Another requirement for heat transfer is to maintain and/or improve the sheet contact with the dryer cylinder itself. This is a primary function of the dryer fabric. The evaporation of heated water from a sheet of paper creates a positive pressure, which will tend to lift the sheet off the dryer. This reduced contact with the dryer will result in poor heat transfer.

There is also a layer of air between the sheet and the dryer that is carried by the moving sheet (Figure 4.1). The dryer fabric presses the sheet onto the dryer cylinder, reducing the air layer and minimizing any sheet lifting due to heating the sheet.

It is very important to maintain adequate tension on the dryer fabric. The general industry tendency is towards increased tension. Studies and on-machine trials have shown that increased dryer rates correlate with increased dryer felt tension to a certain point. In North America, fabric tension is normally in the range of 1.4-2.1 kN/m (8-12 pli), compared with 2.5-3.5 kN/m (14-20 pli) for Asia. Fabric tensions of 3.5 kN/m (20 pli) are now standard on newer or rebuilt machines and grades to provide further heat transfer efficiencies. Tensions above 2.6 kN/m (15 pli) have a minimal improvement on drying rate.

Most of the dryer fabrics are woven textiles made of synthetic yarns. The fabrics are constructed so that air can pass through the fabric structure. This characteristic is called permeability. Permeability is expressed as the amount of air (cubic feet) that will pass through a square