Drying: Theory and Techniques

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Drying causes problems for all papermakers. There are many variables and it is an area that will always be challenging. I would like to make some observations on this process that I hope will help you determine how you choose to dry your paper.

The objective during the drying process is to make the moisture content of the sheet equal to the relative humidity of the air. This water is held in the spaces between the fibers of the sheet. After the initial pressing, the moisture content of the sheet is about 50%. When the sheet is dry, it will contain between 8 and 10% water. As the paper dries, it can cockle or develop edgewaves, ripples that form along the outside of the sheet and sometimes fold over during pressing. Cockling occurs in the interior of the sheet and can take the form of large donut-shaped wrinkles.

Removal of the water allows the fibers to interlock. The Campbell effect describes how this happens. Water spans gaps between the fibers and the fibrils (short hair-like extrusions off the main fibers). As the water evaporates, surface tension acts to pull the fibers closer together. This internal compacting force pulls at all the intersections of fibers. This force can be equal to the surface tension of the water and pulls toward the center of the sheet. A sheet of 18 × 24 inch paper can easily shrink ¼ of an inch if left unrestrained during the drying process.

Hydrogen bonding occurs between cellulose molecules when they are in contact with each other. Hydroxyl groups of different cellulose molecules share electrons. Hydrogen bonding gives more strength to the paper than does the mere entanglement of the fibers. Cockling is caused by uneven moisture removal and consequent uneven bonding. If the paper dries unevenly, the edges before the center, sections of the paper will contract more than others. Simultaneously they will form hydrogen bonds sooner. These bonds then lock contractions in place. The wet fibers move to alleviate the stress. This process causes sheet distortion. These ripples or cockles are then locked in place by hydrogen bonding.

The type of fiber and how it is processed affects bonding. In a well beaten pulp, the inner layers of the fiber are allowed to move in relation to the outer layers. This flexible fiber will lie in closer proximity to the other fiber in the sheet and more hydrogen bonds will be formed. An example of this would be a hard crisp sheet of linen paper. It will be more difficult to dry flat than a softer linter sheet. This is because well beaten linen fibers are more flexible and able to form more bonds than the linters. Because there are many more bonds being formed, the magnitude of forces involved is greater and therefore more ability to lock into place any uneven contractions.

Cockling and sheet distortion begin at the point where all of the water has been removed from between the fibers of the sheet. The remaining moisture is now within the structure of the fiber itself. As this is removed, hydrogen bonding occurs. If the sheet is left unrestrained, distortion will quite suddenly begin.

There are two techniques for minimizing distortion: very slow drying and restraining methods. Air drying and blotter exchange are two methods of slow drying and an air dried sheet has a unique surface. No other drying method produces the same characteristics. The disadvantage with this method is that it is very time consuming and you have to watch the paper very carefully. The paper must be dried slowly and evenly. The simplistic nature of blotter exchange makes it a little easier and quicker though more labor intensive. Felts or blotters are interleaved with the newly pressed sheets and repressed. This exchange continues until the sheets are dry. It requires several extra sets of felts or blotters that will then also require drying before being reused.

The second method deals with restraints. This procedure can speed drying time which is one of its biggest advantages. A simple restraint that has been around since the beginning of papermaking is the drying of the sheet in the paper mould. The bonding that occurs between the mould and the sheet acts to keep the paper restrained and flat. Look carefully at a mould on which a piece of paper has dried. Because of the contracting forces within the drying sheet, the screen actually becomes tighter. Another traditional method of restraint is board drying. Damp paper is brushed onto a flat surface and adheres. When the paper dries, it is peeled off. Drying boards can be made of wood, formica or coated masonite. Certain pulps can be dried in the sun. Others require shade to prevent excess shrinkage which results in peeling. Hot metal plates, walls and window glass will also work as drying surfaces. Drying paper in spurs (a group of 5 to 10 sheets) is another common method of restraint used to control cockling during air drying. Drum drying is another successful method. There is a problem involved in drying the felt that holds the sheet to the surface of the drum. A separate drying roll is usually required to dry this felt. Single roll print driers do not work well for production papermaking. In general, most papermakers use drum drying in conjunction with an air drying process as the last step before storing the finished sheets.

An important characteristic of a sheet of paper is its ability to remain flat under a variety of circumstances. Printers require a sheet that will remain flat after redampening and will not distort upon drying. This is sometimes a problem. As paper dries and bonds occur, fibers become aligned in a specific way. Simple distortions within a sheet can be removed by dry pressing and curing although the fibers themselves will retain a memory of their original position. For example, a paper dried on a hot curved drum drier can be made to lie flat during curing. When the paper is dampened, however, the edges will curl and try to regain the curve of the drum. An air dried paper can regain its cockles. Paper that has been dried flat under restraint will have a greater tendency to remain flat.

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Glen Wark and I have developed a dryer that allows paper to be dried flat while under restraint. This machine is now in use at Leaf Papers in Seattle Washington for daily production.

There are other methods of paper drying which might someday have applications to hand papermaking. These remain mainly untested and include vacuum and solvent drying. At present, they are not practical for the hand papermaking application.