13.1 Water removal in papermaking compared with conservation drying

Any paper drying in general concerns two simultaneous and overlapping objectives: the removal of water and the development of a dimensionally stable planar sheet. On contemporary paper machines, a ~0.5% aqueous dispersion of papermaking fibres is processed until a ~95% solids content is reached (see Chapter 7). It takes a continuous process of only a few seconds to bring a fibre from a free-floating state to a fixed position anchored within the sheet. The point at which the process becomes comparable with conservation drying lies beyond the wet end and press section, where, by drainage, suction and pressure, 50% of water has been removed from the fibre web. When it enters the dryer section and undergoes heat-induced evaporation, its solids content increases from about 50% to about 95% (**Fig. 13.2a**).

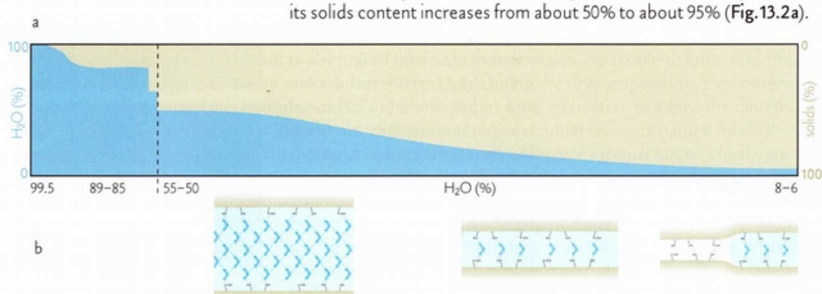

Fig. 13.2 Water removal on the papermaking machine. (a) As the fibre solids content increases (beige), the water content decreases (blue). The drying in papermaking and conservation only shows some similarities below 50% solids content (dotted line). A rewetted paper sheet contains roughly 50% water when drying begins. (b) In both cases, the sheet structure is established through interfibre bonding created by water molecules that form bridges between fibre surfaces by hydrogen bonding. Excess liquid water (not shown) that fills interfibre pores in wet paper does not destroy the sheet coherence. See also Fig. 7.2.

During drying, inter- and intrafibre pores are continuously shifting, narrowing and collapsing while water is removed. Drying is a non-reversible process because some pores in the highly swollen fibres close permanently (see Chapters 4 and 7). When subsequently the finished paper sheet is wetted, it never returns to the highly swollen state of the pulp before its first drying on the papermaking machine. In other words, even as the paper sheet takes up about 50–70% water, its fibres remain less swollen compared to the fibres in never-dried pulp at comparable solids content. Soaking paper in water is not sufficient to cause the fibres to re-disperse, as they are held firmly in place by hydrogen bonding and friction within the fibre mass (**Fig. 13.2b**). The wet strength of paper is determined almost entirely by these forces.

At the extreme, conservation drying involves lowering the water content of paper from maximally 50–70%, when soaked, to 5–10% at ambient conditions through the use of drainage and evaporation. These processes are, however, administered far less intensively and rapidly than in papermaking and usually do not involve a continuous

line process. Quite often, drying is conducted stepwise, with intermediate waiting periods that overall may take several hours, days or even weeks. In two respects, however, paper manufacture and conservation drying are fully consistent. First, the drying treatment can only be considered complete if the sheet has reached a moisture content that is in equilibrium with the surrounding environment. Second, all drying processes seek uniformity so that the shrinkage of millions of papermaking fibres is orchestrated as much as possible in a simultaneous fashion. This objective is complicated by the fact that the fibres are never distributed in ideal uniformity, and that they occupy both exposed as well as recessed regions in the paper. Drying therefore does not occur uniformly in all parts of the paper. In the case of washing and deacidification, we have already seen that the fibre interior was the rate-limiting factor because respective diffusion processes occur most slowly within the fibre (Chapters 9 and 12). The fibre interior is also the rate-limiting factor in drying.

13.2 Principles of drying

For describing the process of paper drying such as it pertains to conservation, let us assume that we place a sheet of absorbent, fully wetted paper on a table and observe how it dries without interfering with this process, recalling an experiment conducted by Sugarman and Vitale (1992). They were the first to propose a systematic differentiation of seven drying stages of wet paper (**Fig. 13.3**). First, the saturated paper lies flat on the table (stage 1). Its surface is glossy because the pores are flooded and the surface is coated with a water film that, in the first moments after pulling the paper out of the bath, envelops the paper evenly. All of the water removal occurs along this surface as long as the water film is intact. Then, the water surface recedes into the paper matrix, and water begins to evaporate from the interfibre pores (stage 2). The surface tension of the water (Campbell forces, see page 180) causes the fibres to associate more closely so that the

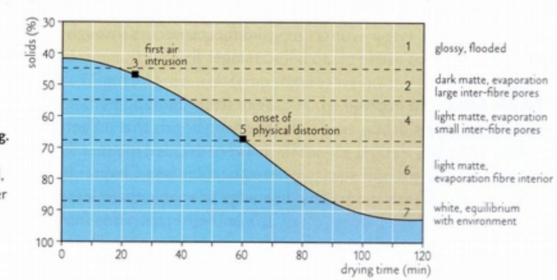

Fig. 13.3 Solids increase (beige) of wet paper during observable stages of drying. Water first evaporates from interfibre pores (stages 1–3); as these are emptied, intrafibre evaporation gradually takes over (stages 4–7). This is associated with the onset of distortion (stage 5).
Source: Sugarman and Vitale (1992).