From fibres to paper – A journey through a multiphase state space

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The basic components used to produce a paper sheet are cellulose fibres and water. Here the secret of paper production prevails. Cellulose fibres dissolved in water do not bond, but as water is removed, chemical bonds form naturally between the fibres. The pulp fibre suspension used in paper manufacturing is however not at all as well behaved as an idealised fibre suspension consisting of a Newtonian liquid with non-buoyant rod-like stiff particles (cylinders). The reason being the complex morphological properties of the cellulose fibres and the chemical environment see e.g. Kerekes (2006).

One feature of most pulp fibre suspensions is the capability to form flocs when diluted in water, so called fibre flocculation. This is a feature closely connected to concentration and fibre properties. It has been shown that the main mechanism of fibre flocculation is the mechanical bonding of fibres to each other.

The first step in the paper manufacturing process is to modify the properties of the cellulose fibre to improve strength properties and surface smoothness of the final product. This is performed in a refiner, which in principle consists of one stationary and one rotating disc with the suspension in-between. The distance between the bars on the two discs are usually 0.1-0.2 mm. The process is characterized by high shear rates, suspension heterogeneity and fluid-structure interaction. Average concentration lies in the range of 3%.

In order to optimize the final product the present development is to separate the pulp in different fractions depending on morphological properties such as surface structure, flexibility and length. The fractionation based on fibre length is presently done using screening but for flexibility and surface structure fractionation using hydrocyclones is the focus of present research. In this process stage the suspension has to be diluted down to less than 0.5% in order to obtain sufficient fractionation efficiency. Presently the fractionation is believed to be the result of several mechanisms; volume forces, density variations, local mobilization of single fibres through shear and the hydrodynamic drag.

The Chinese started to make paper 2000 years ago by handsheet forming where a mix of water and fibres is put on top of a permeable surface (i.e. the wire) and due to the gravitational force water passes through the wire whilst the fibres are trapped. In modern paper manufacturing the sheet forming process is continuous. The fibre suspension is shaped as a plane liquid jet by a nozzle, which is called a headbox. The jet from the headbox lands on one or between two permeable forming fabrics (wires). The homogeneity of the suspension in the headbox and jet is of vital importance to the material structure of the final sheet. Thus the mechanisms to homogenise and break up the fibre flocs in the suspension are of primary interest. The flow in the headbox is characterized by turbulence, re-laminarisation, elongation and fluid-floc interaction. The flow conditions determine the homogeneity of the suspension the jet impinging on/between the wires and concentration lies in the range 0.5% - 1.0%.

When the jet impinges on or between the wire(s) dewatering of the suspension starts immediately. During the dewatering process pressure and shear pulses are used to influence the floc structure as well as the flow of smaller pieces of fibres (fines) and other materials inside the developing network structure on the wire(s). Thus this represents a transition from a flowing fibre suspension to a multi-phase flow in a network structure where the suspended particles are not any longer fibres, see *Figure 1*. After this structuring process the concentration has increased to 15-20%.

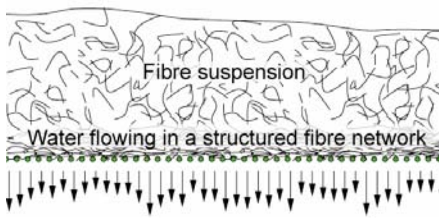

Figure 1: Water is drained from the suspension in the forming zone of a paper machine, which involves a phase transition from a flowing suspension to flow in a fibre network.

After the fibre network has been formed the web is a mix of fibres, water and air and the next step in the manufacturing process is to remove water through mechanical dewatering, i.e. the web is compressed between permeable felts, which compress the fibre network while allowing water to flow out from the web. However, water is not only trapped in-between the fibres in the network but also in the hollow core of the fibres, the lumen, and inside the fibre wall. Thus the pressing process is characterized by the flow in hierarchical porous structures and the result is a web with a concentration of up to ~50%. The final step in the paper manufacturing process is to dry the web using heat in the drying section.

References

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