The Dynamics of a Roll Press Nip

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ABSTRACT

The press section of a paper machine is designed to remove by mechanical means the maximum possible amount of water from a just-formed paper sheet. The paper sheet is carried by a textile fabric conveyer belt through a series of roll nips, which cause water to be transferred from the sheet to the fabric. In the most general case the problem to be considered at each press nip involves transient fluid flow at high speed in two contacting, partially saturated, anisotropically porous media undergoing non-linear compression. Though a great deal of empirical information concerning press performance has been accumulated over the years, there is no generally accepted theoretical treatment available, and new insight into the physics of the water movement could lead to valuable process improvements.

THE PAPERMAKING PROCESS - OVERVIEW

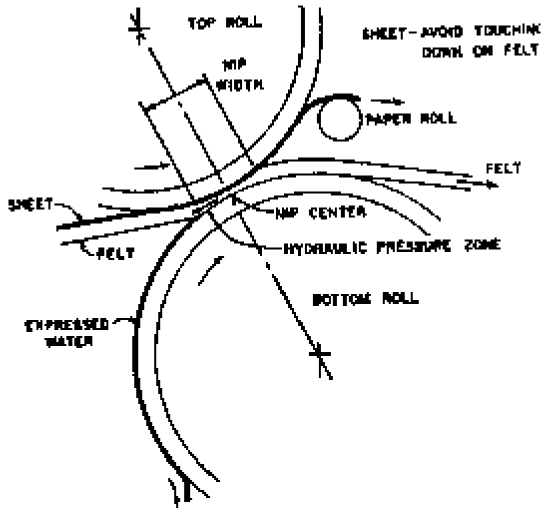
The modern papermaking process consists of three distinct coupled stages: forming, pressing, and drying. In the forming stage a dilute suspension of individual wood fibers in water, typically at a concentration of around 1%, is evenly distributed onto a porous conveyer belt known as a forming fabric, and a substantial fraction of the water is removed by the action of various forces. In earlier times, most of the water removal relied on gravity drainage, but in modern high–speed machines the pressure gradients are enhanced by a variety of mechanisms according to the detailed configuration of the paper machine. In all cases, however, water is filtered through the forming fabric as it moves through the machine, and wood fibers are retained at the surface of the fabric to form the paper sheet. At the end of the forming section the paper sheet typically has a consistency of approximately 20% fiber and 80% water, and has just enough mechanical integrity to permit its transfer to the next stage of papermaking, the press section.

The press section continues the process of water removal that was started in the forming section. The just-formed sheet is transferred to a second conveyer belt known as a press fabric, which is both porous and compressible, and is carried by this belt through the nip formed by two press rolls. The rolls apply considerable pressure at the nip zone, and water is expressed from the saturated sheet and is transferred to the porous press fabric. At the exit side of the nip the sheet, now at a typical consistency of 40% fiber and 60% water, is separated from the press fabric and moves onto the dryer. The expressed water is carried off by the press felt and is removed by vacuum before the fabric reenters the nip.

Modern press sections are capable of working close to the limit of water removal by purely mechanical means and the final stage of papermaking relies on thermal energy to produce a fully dried sheet. In the dryer section the sheet is carried over a series of heated cylinders by another porous belt known as a dryer fabric and the remaining water is removed by evaporation. At the end of the dryer section the sheet consists of about 95% fiber and 5% water, which is the typical consistency of the paper of commerce.

The three stages of papermaking all share problems associated with the high speed of the modern process, the statistical variations of the sheet material, and the uncertainty of the boundary conditions, and a detailed understanding of the various processes is an elusive goal. Of the three stages, however, the press section is probably the least understood at a fundamental level, and since improvements in this process can produce considerable economic benefits, it continues to attract theoretical attention, but with little agreement among the various schools of thought. The brief description given above does not do the problem justice: the more detailed discussion given in the next section will make clear some of the theoretical difficulties of this deceptively simple process.

THE PRESS SECTION – DETAILED DISCUSSION



The essential features of a typical roll press nip are given in figure above, copied from the *Paper Machine Wet Press Manual*, published by the TAPPI Press. In commercial practice there are a wide range of additions to, and modifications of this simple configuration, but this is sufficient to define the core issues and process parameters. The two steel rolls defining the nip geometry are typically 1 m in diameter, and may be considered to be incompressible. The paper sheet is about 0.5 mm thick on the entry side of the nip, and is probably close to saturation. It is carried through the nip by the press fabric, which is an assembly of textile fibers, typically 20 micrometers in diameter, needled to a base fabric to give it structural integrity. The press fabric is typically about 3.0 mm thick in the unloaded state, with a solid volume fraction of about 50%, which increases to up to 80% under mid-nip loading. The press fabric approaches the nip at a velocity of about 20 m/s with a water content of about 50%, with air as the continuous phase of the three part mixture, and fiber and water phases being discontinuous. As the sheet and the fabric enter the nip region, both are compressed and both eventually become saturated with water, which becomes the continuous phase in both components. As the compression proceeds the mechanical deformation of the fabric structure and the displacement of the water within the structure require substantial force, which is supplied via the rolls, which operate at a fixed load per linear length. Beyond midnip some further redistribution of water takes place, and at the exit side of the nip the sheet and press fabric are separated, with the net result that some of the sheet water is permanently transferred to the felt and is ultimately removed from the process.

This outline provides a framework for a catalog of the major problem areas associated with the process. Firstly the time frame of the various events is quite short, typically of the order of 10 ms, so the loading is essentially impulsive and inertial effects can not be ignored. The press fabric is markedly non-linear in compression, and exhibits anisotropic permeability, which changes throughout the compression and recovery load cycle. The interstices of the press fabric are small enough that the viscosity must be properly accounted for, and since both the sheet and the press fabric are multicomponent assemblies, they are subject to significant statistical variations of their mechanical properties from place to place. Finally the redistribution of the water between the sheet and the fabric on the exit side of the nip probably involves some surface tension controlled processes. In summary the problem within the nip region involves the solution of the full Navier-Stokes equations in a non-uniform, anisotropically porous non-linear compressible medium with moving boundary conditions, with some additional complications in the entry and exit regions.

In view of these difficulties, it is not surprising that the distribution of pressure and velocity within the nip should be the subject of intense debate, and the debate is rendered more intense by the extreme difficulty of making meaningful confirmatory measurements in this hostile environment. The problem has been treated as an example of Bernoulli's theorem on one extreme to an example of hydrodynamic lubrication on the other extreme, and a rational appraisal of the issues by a skilled but non-involved group could be extremely beneficial to all the workers in this field.