

# *Liquid penetration into paper*

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Typeset in Times by T<sub>E</sub>X and L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub>.

To get the necessary image quality it was necessary to print this thesis one page to a sheet.

Except where otherwise indicated, this thesis is my own original work.

Raymond John Roberts  
10 August 2005

Rags make paper

Paper makes money

Money makes banks

Banks make loans

Loans make beggars

Beggars make rags

Author unknown, circa Eighteenth century

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# Abstract

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The origin of this thesis lay in the production of defects associated with manufacturing LPM impregnated panels. The causes of these defects were unknown as was their exact nature. In identifying the actual nature and cause of these defects, it is necessary to research the fundamental mechanisms of fluid flow into paper as well as identifying how certain structural characteristics of paper, as well as characteristics of the penetrating liquids, affected fluid flow within paper.

To understand the affect of different liquids on impregnation into porous media, simple isotropic micromodels are used to quantify the effects of surface tension and contact angle on the rate of fluid flow. The use of the Lucas-Washburn equation is questioned.

Using cryo-SEM and a newly developed technique of cryo 2-photon confocal laser scanning microscopy, the actual mechanisms of fluid flow in unsized paper are identified. These are due primarily to the advance of the wetting fluid in the form of bulk liquid films along channels formed by fibre overlaps. This is in contrast to the common description of fluid penetration, where the primary flow mechanism is based on the bulk filling of pores. These channels, formed by fibre overlaps are shown to form a highly interconnected dense network of flow paths which efficiently transport the wetting fluid. The flow rates associated with penetration along a number of potential flow paths within the fibre web are calculated. The experimentally observed penetration rate is consistent with a film flow process through inter-fibre channels which is significantly slower than a penetration process dominated by meniscus flow through pores. In addition the mechanism of fluid flow in internally sized papers is presented.

The effects of different fillers on paper structure, flow path morphologies and imbibition rate are also quantified. Laboratory papers with different types and amounts of filler are studied using SEM and cryo-SEM and a newly developed technique of high speed video microscopy to quantify such effects.

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