Application of Ultrasonic and Porometric Techniques to Measure Liquid Penetration in Digital Printing Papers

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Abstract

This investigation sets out to develop a more quantitative understanding of how paper structure impacts printing ink development. Two instrumental approaches are compared to monitor liquid penetration under: (i) capillary driven flow using an ultrasound method; and (ii) forced flow using liquid porometry. Commercial printing papers including xerographic, ink jet and newsprint grades, were evaluated using swelling (water) and non-swelling (polydimethylsiloxane) probe liquids. On the basis of these experimental studies the latest progress in developing a more realistic theoretical model to describe liquid penetration in paper and better quantify its behavior will be presented.

Introduction

Liquid absorption represents a critical property in the performance of many printing papers. For example, for ink jet grades the rate of ink absorption into the bulk structure dictates surface ink holdout, which in turn affects print quality, ink drying and paper dimensional stability.[1] Over the past decade significant progress has been made in improving the properties of ink jet grade papers. Despite this from the papermakers perspective much remains to be learnt and understood in terms of being able to define the ideal structure in which one can for example modulate surface wetting, and at the same time, control ink absorption into the bulk structure. This is especially challenging in the case of plain office grade papers where economic as well as aesthetic factors restrict the use of coating and special chemical additives.

A major underlying problem for both papermakers and printer manufacturers is the need to develop more meaningful characterization methods which help demarcate subtle differences between key surface and bulk properties of paper.[2] One recent example in this regard has been the application of the ultrasonic-based dynamic penetration instrument.[3] As part of our ongoing research program in this area, we are attempting to calibrate this instrument using well defined model pore structures and delineate major structural complications arising in paper, notably its ill-defined pore structure and fibre swelling. The following presentation describes some of the latest progress in this area.

Experimental

Materials Characterization

Commercial Papers:

Samples included: ink jet 'plain' paper ('C', 'W'); electrophotographic color copy ('H'); and a newsprint: roto' grade. Some relevant physical properties of these papers are given in Table I.

Dynamic Liquid Penetration:

The papers were evaluated with an EMCO DPM 30 ultrasound-based instrument using *swelling* (deionised water, 0-100% aqueous methanol), and *non-swelling* (1cSt polydimethysiloxane [PDMS]) probe liquids. Among the various parameters derived from generated penetration curves, this study focuses on: *L* (%) the difference between the initial and maximum acoustic transmission; and the corresponding elapsed *wetting* time t_B prior to the onset of liquid penetration.

Capillary Flow Porometry:

A second instrument, a PMI capillary flow porometry (model AF 18), was used to characterize pore size distribution and permeability using a *non-swelling* low surface tension (< 20 mN/m) probe liquid. The measuring principle of this instrument is based on flow of an inert gas through the dry, and subsequently, completely wetted porous material.[4] Compared with other techniques e.g. Hg porosimetry, use of the high wetting probe liquid requires less pressure and hence less pore modification in deformable structures such as paper.

Print Quality:

The paper samples were printed with a solid/line/dot/text test pattern on an Epson Stylus Color 740 and Hewlett Packard 1150C ink jet printer. Print quality metrics (line width/raggedness, inter-color bleed, solid optical density/showthrough) were determined using an ImageXpert print quality analyzer equipped with an automated motion-controlled x-y stage.[5]

Table I. Physical properties of test papers

Sample/ Property	Color copy H	IJ Plain C	IJ Plain W	Newsprint Roto
Basis Wt (g/m^2)	99.4	75.3	85.6	48.0
Density (g/cm3)	0.88	0.75	0.78	0.58
Thickness (µm)	113	101	109	82
Filler (%)	?	?	15.5	?
Bendtsen Porosity (mL/min)	345	908	621	293

Results and Discussion

1. Ultrasonic Penetration Analysis

Figures 1-3 show liquid absorption profiles for the various paper/liquid systems selected for this study. Significant parameters derived from these curves are included in Table II. For paper structures the change in ultrasound attenuation with penetration time is attributed to as many as eight discrete sequential processes.[6] Most notably in this study these include: (i) surface wetting during which there is an initial increase in acoustic transmission, as the retained air is displaced from surface pores by liquid; (ii) liquid absorption into the bulk structure subsequently resulting in fibre swelling with aqueous liquids; and (iii) liquid saturation and equilibration of bulk interaction processes (i.e. fibre swelling and inter-fiber bond breaking). In the latter stage it should also be noted that the presence of pigment filler (found in most of the current test papers) also plays role in so far as it functions as a fiber de-bonding agent which will influence both the rate of swelling and overall absorption.

On the basis of the short time wetting regime curves (Figure 1), samples C and W exhibit similar (t_B 902 and 1102 msec, respectively) levels of surface sizing. In contrast the other ink jet paper sample, H, exhibits a much shorter wetting time hence a lower level of sizing (tB 40msec) which is identical to the highly calendered mechanical pulp fiber based commercial rotogravure newsprint sample. Differences in the magnitude of acoustic attenuation (%L) and the corresponding rate of decay, following the initial surface wetting regime, are indicative of the relative levels of sizing which impede the rate of penetration into the bulk structure, the degree of swelling, and overall, the acoustic transmission**?** Figure 2 shows a clearer delineation of this bulk absorption behavior over a *long* time regime. Further resolution in the contribution of swelling, to the magnitude and rate of change in acoustic transmission, can be derived from Figure 3 which shows penetration of a non-swelling liquid. Compared with water penetration (Figure 2), with PDMS oil, samples H and C exhibit similar bulk absorption (swelling) behavior. The marked differences in curves H and C in Figure 2 are largely attributed to the degree of sizing.

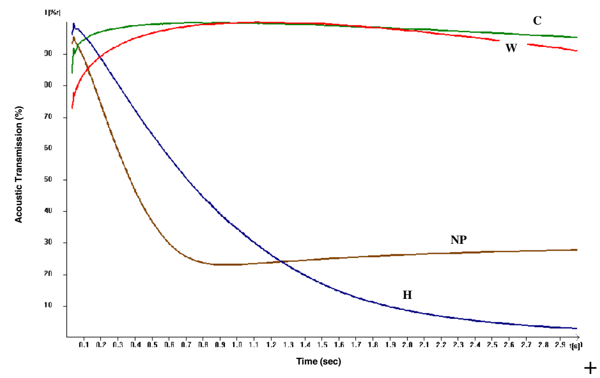

Figure 1. 'Short' time regime ultrasonic penetration of water (swelling liquid) in various digital papers.

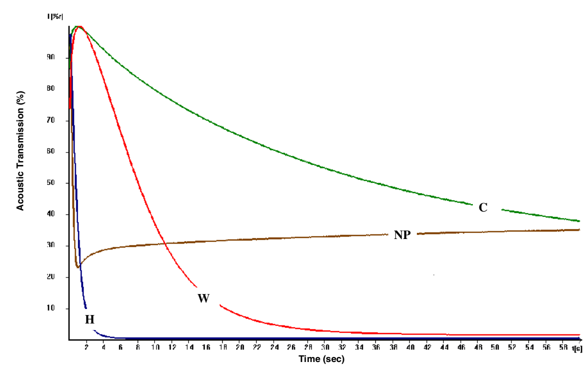

Figure 2. 'Long' time regime ultrasonic penetration of water (swelling liquid) in various digital papers.

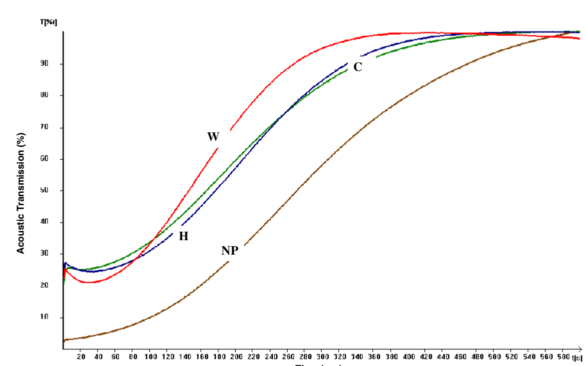

Figure 3. 'Long' time regime ultrasonic penetration of PDMS oil (non-swelling liquid) in various digital papers.

Table II. Comparison of ultrasonic penetration and capillary porometry data.

Paper	Mean flow pore dia. (μm)	Darcy perm-eability constant	EMCO Water L (%)	EMCO Water T_B (msec)	EMCO PDMS L (%)	EMCO PDMS T_B (msec)
W	1.77	0.0250	27.3	1120	75	426
C	2.44	0.0233	16.2	902	79	563
H	1.51	0.0159	4.0	40	70	551
NP roto'	1.437	0.0067	1.0	40	97	596

2. Capillary Flow Analysis

Figure 4 shows a comparison of the pore size distributions for the test papers derived from porometric analysis using a low surface tension liquid probe. Corresponding values for the mean flow pore diameter and permeability are included in Table II. According to this evaluation the structures of samples W and C reveal similarly higher permeability but with sample C having distinctly higher average pore size.

3. Print Quality Analysis

Table III summarizes data for single and six pixel horizontal black lines printed with two commercial printers on the three test papers. With the Epson printer, sample C revealed the highest line width, line width growth (black/yellow) and line raggedness. In contrast, with the HP printer it produced the lowest line width and line raggedness for black only. However this trend was reversed with the neighbouring yellow/black print. In terms of solid areas, sample C exhibited the highest optical density (EPSON) and with both printers resulted in the highest showthrough. The line width/ raggedness (black/yellow) and showthrough trends for sample C are consistent with its higher pore size and permeability (see Table II and Figure 3). For the other samples, H and W, with narrower line width, lower raggedness and lower showthrough, while there are some consistencies, e.g. higher sizing for sample W, but at the same time there are obvious inconsistencies, e.g. sample H, with low sizing. However one can argue in the latter case that the higher print quality performance of sample H is attributable to its lower pore size and permeability. Clearly these examples serve to demonstrate the contribution and complexity of different paper structural aspects. Presently we are trying to clarify some of these structural ambiguities further on a more theoretical basis using Lucas-Washburn capillary kinetics and Darcy permeability to interpret fluid flow in well-defined model porous structures characterized by these techniques. We expect to complete this study later this year.

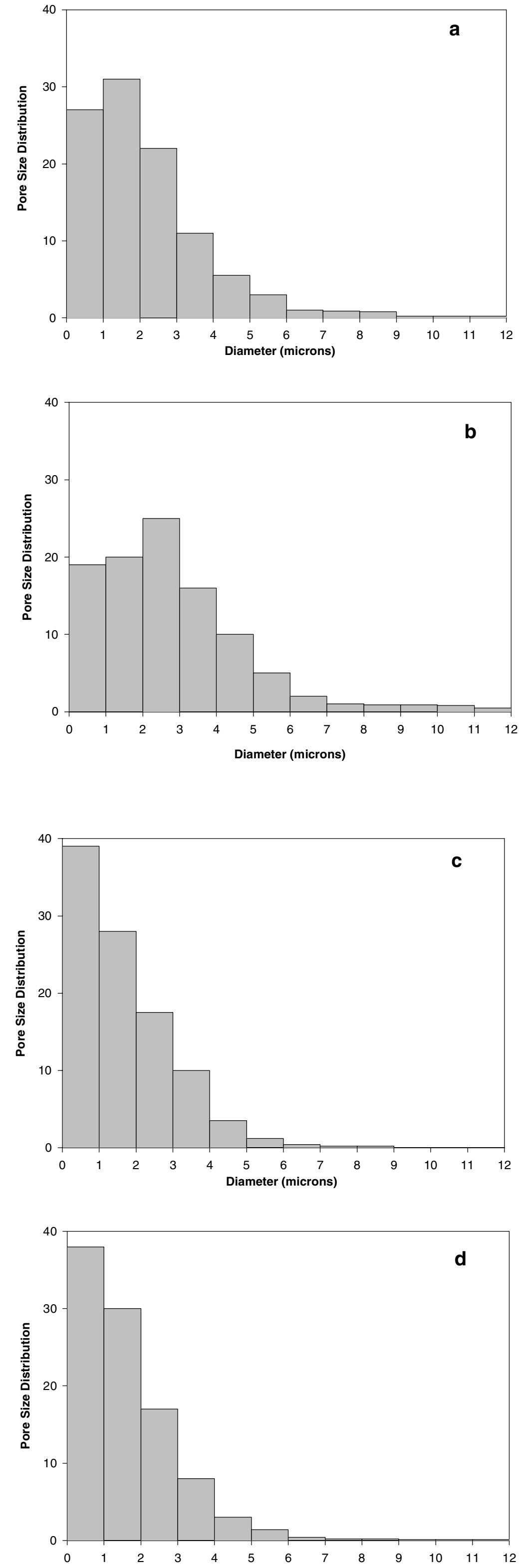

Figure 4. Pore size distributions derived from PMI (low surface tension/viscosity) liquid capillary flow porometry for: a) paper 'W'; b) paper 'C'; c) paper 'H; and d) paper 'NP''.

Tabl eIII. Print quality analysis for ink jet and electrophotographic papers.

Printer:	Epson Stylus 740	Color		HP	1150C	
Metric/Paper:	H	C	W	H	C	W
Single pixel line:						
Raggedness (B)	11.9	15.8	13.3	11.7	7.0	8.2
Raggedness (B/Y)	26.3	32.6	21.3	16.4	20.3	16.5
Difference	14	17	7	6	13.3	8.3
Line width (Black)	114.0	149.0	113.0	104.0	76.0	75.0
Line width (B/Y)	163.0	207.0	161.0	175.0	187.0	165.0
Difference	49	58	58	71	111	90
Six pixel line:						
Raggedness (B)	12.5	16.6	13.5	11.3	6.3	7.7
Raggedness (B/Y)	20	27	25	12	19	18
Difference	8	10	11	1	13	10
Line width (Black)	289.0	341.0	283.0	326.0	293.0	299.0
Line width (B/Y)	415	485	414	406	438	414
Difference	126	144	131	80	145	115
Solids: (Black)						
Optical density	1.50	1.54	1.45	1.40	1.39	1.36
Showthrough	0.06	0.20	0.08	0.06	0.14	0.08

Conclusions

This study has attempted to quantify structural characteristics of paper in terms of identifying more meaningful parameters to better define print quality performance. Among the set of ink jet plain papers investigated some clear print quality correlations are demonstrated in terms of specific physical properties derived from ultrasonic penetration and liquid porometry analysis. It is hoped that through our ongoing research in this area, using geometrically well-defined model pore structures and a range of liquid penetrants, that this will further aid quantification of key properties and development of ink jet grade plain papers.

Acknowledgements

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Biography

John Oliver received his PhD in Physical Chemistry (McGill University) in 1976, BSc Chemistry (Surrey University, UK) in 1968. and holds an adjunct professorship at the University of Alberta. He has published over 40 technical articles in his field and co-authored 20 patents relating to specialty papers and inks for ink jet printing and xerography.

He joined the Alberta Research Council in 1997 as a Senior Research Officer prior to which he worked at Xerox Research Centre of Canada, studying ink-paper interaction fundamentals in ink jet and xerographic printing processes and development of specialty paper grades and novel inks.
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