

A Study of the Dynamic Spreading of Inks onto Various Ink-jet Substrates

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Abstract

The aim of this paper is to present some results concerning ink/substrate interactions in the context of ink-jet printing. During the impact of an ink drop onto the substrate, the interface properties of the materials play a crucial role, which may determine, to a certain extent, the spreading of the ink droplets, and therefore the ensuing print quality.

In this study, several substrates, including papers of various quality levels and a polymer film, were analysed. Classical methods of porosity determination were applied, together with roughness measurements. The surface energy of these substrates was calculated from measurements of contact angles with various liquids.

A series of commercial ink-jet inks, and the corresponding model solvents were analysed. Their surface tension was measured by the DuNouy ring method and then, their spreading kinetics onto the different substrates were examined using a high-speed camera coupled with an image analysis system. Various situations were observed. These results were correlated to quality tests conducted with commercial ink-jet printers using the same inks/ substrates systems.

Introduction

The initial stages of ink drop impact during ink jet (I-J) printing play an important role in the image development and the subsequent print quality. The major difficulty in this type of study is to identify and characterize the successive stages of the interactions between the ink and the substrate. Le¹ has described succinctly the behavior of a water-based ink droplet landing on the surface of a paper sheet: the ink tends to spread, then penetrates into the bulk of the paper, if the latter is porous enough, and thereafter, evaporation drying takes place, which is often a relatively slow mechanism. In this context, the surface properties of the substrate are of prime importance, as they will determine the spot resolution and the color density.

Bristow² suggested that the penetration process demands a certain wetting time (up to 0.4 s), before the liquid begins to penetrate into the paper. Oliver³ studied the different stages of impaction, spreading and wetting of an ink-jet drop on different papers, and emphasized that the

initial wetting is an important variable, with other factors, such as liquid permeability and drop coalescence.

The present work is essentially focused on the wetting stage.

Experimental

Materials

Substrates :

Five commercial I-J substrates with different surface properties were employed, namely two photographic quality papers (G and PG), two high-quality papers (HR and EQ) and one transparency polyethylene terephthalate (PET film) (T). G and PG are highly coated papers, compared with HR and EQ which were uncoated or only slightly coated ones.

Inks :

A series of four commercial aqueous I-J inks (Cyan, Magenta, Yellow and Black) was selected for this study. Their exact compositions are not known.

Characterization of the Materials

1. Surface tension of the inks

Surface tension measurements were carried out at room temperature with a Krüss tensiometer equipped with a Du Nouy ring. The surface tension is given by the equation $\gamma = P/U * F$, where γ is the surface tension in mN/m, P is the maximal force exerted on the ring, F a correcting factor which takes into account the density of the fluid and U a characteristic of the geometry of the ring. Table 1 gives the results obtained for the inks.

Table 1 : surface tension (mN/m) of the inks

	Surface tension
Yellow	33.6
Magenta	34.4
Cyan	34.0
Black	34.4

These values are relatively low, given the high water content of the inks (about 60 %). This feature can be explained by the presence of co-solvents such as diethylene glycol, glycerol and diethylene glycol monobutyl ether.

2. Surface morphology of the substrates

Figures 1a-e show the electron micrograph, at 350 magnification, of the surfaces of substrates PG, G, HR, EQ and T, respectively. It can be observed that EQ and HR papers presented similar features, but with a higher porosity for the latter (pore diameter ca. 30 μm , regularly spread over the surface). The other substrates had a very low roughness and PG and G papers displayed surface aspects very close to those of the polymer film T.

3. Surface energies of the substrates

It is difficult to have access to reliable values of the surface energy of a solid (γ). Most of the methods involve contact angle measurements, but none gives an absolute value of the total surface energy.

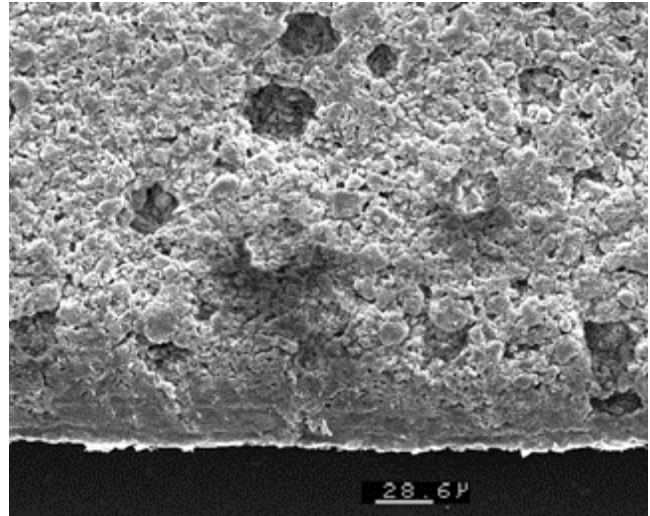


Figure 1c. SEM micrograph of paper HR

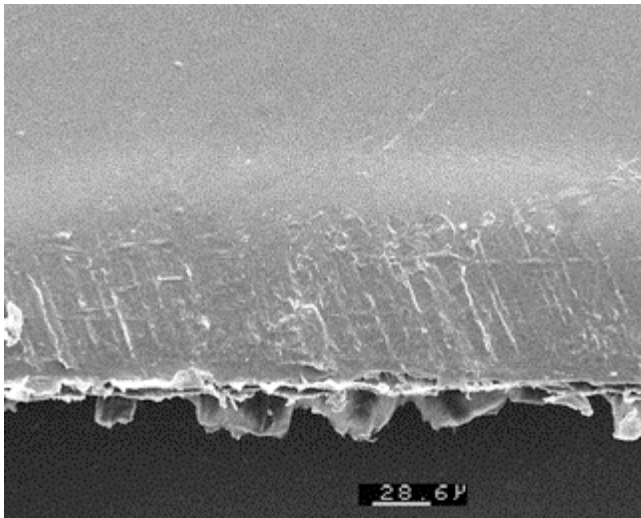


Figure 1a. SEM micrograph of paper PG

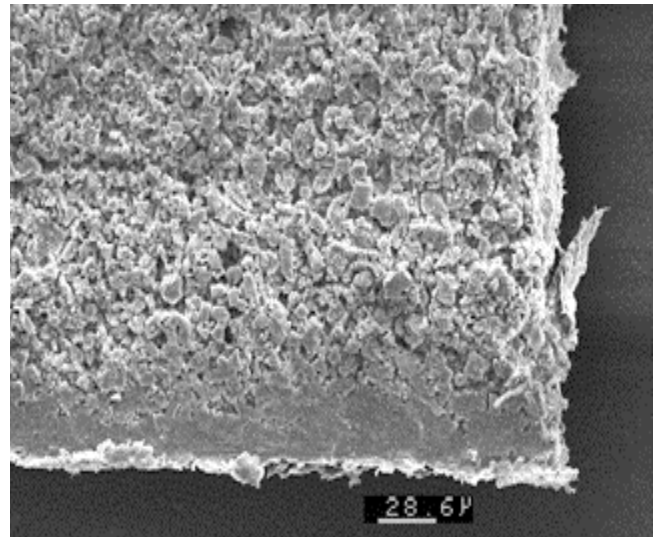


Figure 1d. SEM micrograph of paper EQ

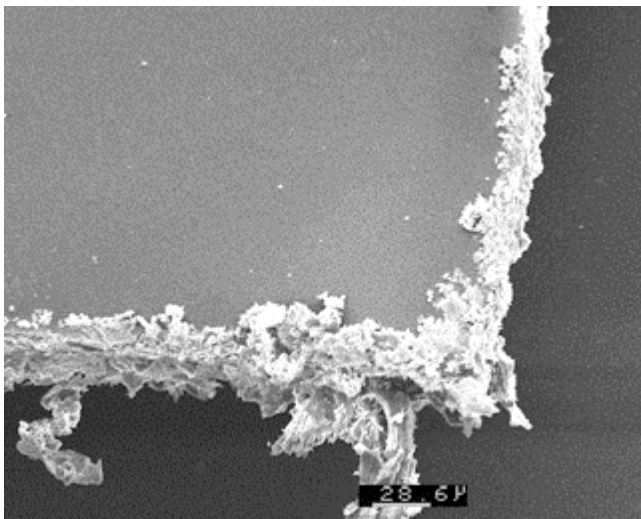


Figure 1b. SEM micrograph of paper G

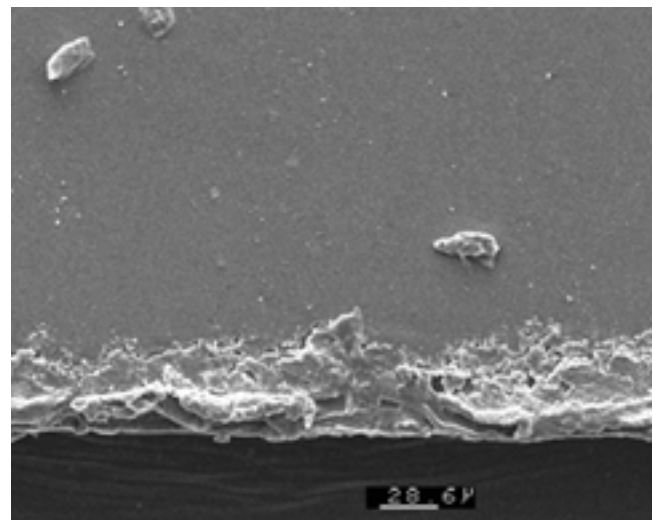


Figure 1e. SEM micrograph of PET film

The surface energies of the substrates were calculated from the values obtained of the contact angles of different liquids on their surface, according to Owens-Wendt's theory^x. This approach is derived from Fowkes, who defined a "geometric mean" for the dispersive forces contribution to solid/liquid attraction :

$$W_{sl} = 2(\gamma_s^d \cdot \gamma_L^d)^{1/2} \quad (1)$$

where γ_s^d is the dispersive component of the surface energy of the solid and γ_L^d the dispersive component of the surface tension of the liquid.

From this equation and the Young-Dupré relationship, equation (2) is obtained :

$$\gamma_L(I + \cos\theta) = 2(\gamma_s^d \cdot \gamma_L^d)^{1/2} \quad (2)$$

where γ_L is the surface tension of the liquid ($\gamma_L = \gamma_L^d + \gamma_L^p$, γ_L^p being the non-dispersive component), and θ is the contact angle between the liquid and the solid.

Owens and Wendt extended the hypothesis of the geometric mean to the non-dispersive (or polar) forces, viz:

$$\gamma_L(I + \cos\theta) = 2(\gamma_s^d \cdot \gamma_L^d)^{1/2} + 2(\gamma_s^p \cdot \gamma_L^p)^{1/2} \quad (3)$$

From the contact angle values of two liquids, a system with two equations and two unknowns leads to γ_s^d and γ_s^p , and thus $\gamma_s = \gamma_s^d + \gamma_s^p$

In this study, four liquids were selected, displaying different structural features interms of their relative polar/non-polar contributions, namely water, hexadecane, formamid and ethylene glycol.

The results obtained are summarized in Table 2.

The value obtained for the transparency film (T) was consistent with the value of the surface energy of PET (about 40 mN/m). Also, the value for the PG paper was comparable to the value of that of polymers used in paper coating operations, namely 35-40 mN/m.

Table 2 : Surface energies of the substrates

Substrates	Surface energy (mN/m)	dispersive component	non-dispersive component
T	42	18	24
G	56	38	18
PG	44	31	11
EQ	72	16	56
HR	40-45		

The determination of the surface energy of the uncoated papers was much more difficult, because of the relative roughness of the substrates and the rapid absorption of the test liquids by the surfaces by. However, these values are close to the surface energy of the cellulose (about 40-50 mN/m). As already observed in the SEM micrographs, the cellulose was perhaps more "apparent" for substrate HR than for EQ. The relatively high surface energy of EQ can be attributed to a larger contribution of inorganic pigments used in the finishing operations of papermaking.

Study of the Dynamic Spreading of Ink-Jet Inks Onto The Substrates

A video analysis system was used to follow the changes of the contact angle θ of an ink drop on the substrates. These contact angles were measured with a CCD camera and processed by an image analysis video card which calculated θ using equation (4) :

$$\tan(\theta/2) = 2h/D \quad (4)$$

where h is the height and D the diameter of the drop.

The liquid drops had an average volume of no more than 3 μ l, in order to avoid problems related to gravity.

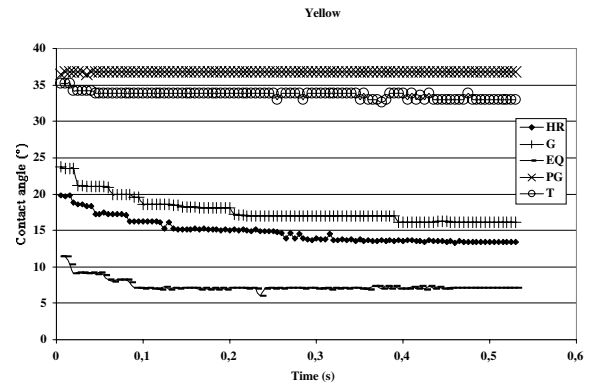


Figure 2a. Evolution of the contact angle of Yellow ink

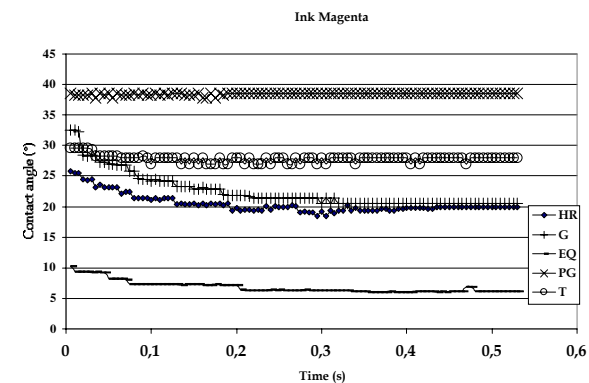


Figure 2b. Evolution of the contact angle of Magenta ink

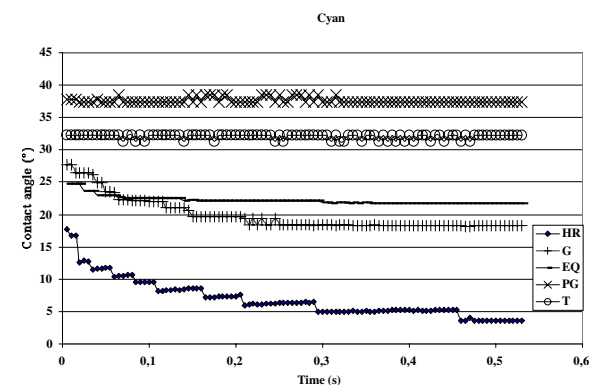


Figure 2c. Evolution of the contact angle of Cyan ink

Figures 2a-c show the evolution with time of the contact angles with time with the Yellow, Magenta and Cyan inks, respectively.

The three inks gave similar features, with some minor differences. As expected, the polymer film (T) and paper PG gave a very stable contact angle with the three inks. The values of the mean contact angles for each substrate were consistent with the values of the corresponding surface energies (Table 2). However, the contact angle of the inks on paper G decreased by approximately 10° during the first 0.4 s. Except for the Cyan, paper EQ gave the lowest contact angle, which implies the highest spreading. EQ had also the highest surface energy.

Correlation with the Printing Quality

These substrates were printed with a commercial EPSON printer. The quality of printing was evaluated by optical densitometry (which gave the dot gain information) and spectrophotometry (which gave color values). Measurements were performed on areas of halftones varying from 10% to 100% (solid).

Densitometry

The solid optical density and the printing contrast were the highest for HR and EQ, with all inks, which was not expected.

The dot gain was measured on the halftones. No clear-cut conclusion can be made on these results, as many other factors intervene when the measurement is made after ink drying. However, some tendencies were observed:

PG and G gave similar dot gain curves. PG displayed slightly better results, probably because of its lower surface energy and the stability of the contact angle of the ink drops on its surface.

For uncoated papers (HR and EQ), the dot gain was always lower on HR, although the stabilization time of the contact angle (wetting time) was shorter on EQ. Other phenomena, such as ink penetration, may take place within this time, which make it difficult to propose unambiguous interpretations.

Spectrophotometry

L*a*b* measurements were made in the solid areas and chroma values were calculated.

The substrates EQ and HR gave the highest chroma values for the three primary inks. Surprisingly, the papers with the best surface morphology and the transparency film gave the lowest chroma values, corroborating the observations made with the optical density. In fact, in solid areas, other interactions must be taken into account. Indeed, the ink drop interacts not only with the substrate, but also with other ink drops already present. The higher chroma values measured for EQ and HR result probably from a better spreading of the ink onto the substrate, compared with G and PG.

Conclusion

In this short study, the dynamic spreading of inks on various ink-jet substrates was investigated. The surface characteristics (morphology and energy) of four papers and one polymer film were analyzed and the spreading of inks was observed within the first stages of wetting. It is still difficult to correlate these measurements to the print quality, but the features observed permitted a better insight into the interactions between inks and substrates. Future work is needed to bring clear-cut conclusion, especially concerning the uncoated papers.

References

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Biography

Anne Blayo graduated from the French Engineering School of Papermaking and Printing in 1988 and received her Ph.D. at the National Polytechnique Institute of Grenoble in 1994. This thesis, based on rheological properties of printing inks, was supervised by Prof. Gandini and Prof. Le Nest. Since then, she has been working in the French Engineering School of Papermaking and Printing as a teacher and researcher. Her work is focused on printing inks (chemical composition, physico-chemical and rheological properties) and color-related studies.