Inkjet Printing: Effect of Paper Properties on Print Quality

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Abstract

A set of papers of various grades were characterized both on the optical and physico-chemical points of view. Then, they were all printed with the same color ink-jet printer by the use of a quadrichromic set of inks. Their performances were compared to one another by both densitometric and colorimetric measurements:

- Classical densitometric quality criteria (solid density, dot gain, relative contrast index, …) were evaluated;
- Color gamuts were determined;
- Print-through properties were also measured.

With the help of some theoretical considerations, we recognized a possibility to classify the behaviors of the papers at least qualitatively. The print-through determinations allowed to evaluate the penetration of the colorants into the paper and to confront the results with print rendering criteria. The final target is to derive an evaluative method for further investigations.

Introduction

In non impact printing, ink-paper relations are of primary importance : surface physico-chemical interactions govern print quality. In the case of the ink jet process, the dynamics of the impaction, spreading and penetration of the ink together with the surface topography and pore structure of the paper largely influence the printed result. These questions have been studied for a long time (see, for instance, Oliver,[1] Lyne and Aspler[2]), and useful analyzes of the corresponding mechanisms may be found, at least, in the papers of Juntunen and Virtanen,[3] Sami Selim et al.[4] or von Bahr et al.[5]

Taking the development of low-end color printers into account, we decided to focus this presentation on the results of a series of experiments carried out with an Epson Stylus Pro XL+ device. This printer, using water based inks for a quadrichromic printing process, was utilized on various papers including a classical office paper on which further measurements were done to quantify ink penetration.

Paper Characteristics

Measurements on our set of papers were performed on both the optical and physico-chemical points of view. Four grades: a classical office paper (a), a mate coated paper (b), a glossy coated paper (c) and a yellow pigmented paper (d). The results are gathered in Table 1.

Table 1. Paper Characteristics

Paper	a	b	c	d
Grammage G ($g.m^{-2}$)	78.7	101.4	136.4	159.7
R_0	100.7	98.9	104.0	63.0
$R_{\bullet}$	108.2	104.5	109.3	63.1
Opacity	93.2	94.6	95.1	98.9
Rugosity PPS10 (µm)	5.9	5.0	2.2	5.6
Porosity	51	48	47	46
Permeability to air	4.85	0.61	1.48	1.51
Cobb Index (sizing)	18.6	67.4	55.5	19.8

The office paper (a) yields the lowest values for grammage, opacity, Cobb index and the highest ones for rugosity, porosity and permeability to air. These last two figures indicate that its structure offer room enough to welcome a liquid. Except the pigmented paper (d), all these paper are filled with fluorescent whitening agents. Except for the glossy paper (c), the order of magnitude of rugosity is 5 micrometers, which shows that roughness may be sufficient to avoid an excessive spreading.

The Cobb index values are also interesting to consider. On the one hand, papers (a) and (d) are well sized but uncoated and on the second hand, papers (b) and (c) are less sized but coated: it may be assumed that the coating will behave like a barrier against the penetration of a liquid deposit like water based ink.

Optical Measurements on Prints

Densitometry

It is widely accepted that densitometry remains a very good tool to quantitatively evaluate quality indexes. In the usual case, it is assumed that the densitometer is set to zero on the unprinted paper; then, the following criteria are the most classical:
- Solid Optical Density D_S (100% coverage),
- Standard Dot Gain (DG_{50}, corresponding to a percentage value using the well-known Murray-Davies formula, by reference to a 50% screened area), and
- Contrast Index (NCI, according to the definition given by FOGRA, by reference to a 80% screened zone).

The results were obtained by means of an X-Rite densitometer (equipped with polarization filters); they are presented in Table 2.

Table 2. Densitometric Characteristics of Prints

Paper → Primary ink	a	b	c	d
Solid density				
Cyan	0.97	1.19	1.27	1.00
Magenta	0.93	1.15	1.26	0.96
Yellow	0.73	0.80	0.84	0.60
Black	1.23	1.74	1.88	1.25
Dot Gain				
50%	11.4	5.1	8.8	15.1
Cyan	18.4	9.0	15.9	21.0
Magenta	21.4	11.5	14.8	20.4
Yellow	25.9	19.1	23.2	27.1
Black				
Contrast NCI				
Cyan	27.4	39.4	37.0	23.8
Magenta	20.0	28.9	28.4	18.8
Yellow	13.1	17.2	17.0	13.2
Black	28.3	41.7	43.5	25.2

It may be seen that the two coated papers (b, c) exhibit the best solid density and contrast: this is an awaited result. It is more surprising to find so low values of the standard dot gain (except for the black ink) for these two papers, specially in the case of the cyan ink. To find at least one reason why the papers b and c yield such values of DG_{50}, we were led to test the papers by the Bristow's wheel experiment, in order to determine the so-called "wetting delay" t_0.[6] This delay is considered to correspond to the time taken by any liquid to begin to penetrate into the paper; thus, it is likely that t_0 may be in relation with the time interval during which the liquid can spread on the paper surface. The results are given in Table 3. They clearly show the behavior difference between coated and uncoated papers and confirm the observations about dot gain.

Table 3. Bristow's Wheel Experiments

Paper →	a	b	c	d
Wetting delay t_0 (s)	0,039	0,010	0,008	0,048

In general, the office and pigmented papers behave similarly, except the low solid density of the yellow ink on the yellow paper: this is also an awaited result. Let us add that, globally, the contrast values are rather high, except systematically for the yellow ink.

It is also important to notice the peculiar shape of the curve representing the dot gain variations with the reference relative dot area. The typical example presented in figure 1 shows that the maximum dot gain is shifted around the 40% reference coverage (it is the case almost whatever the ink and the paper).

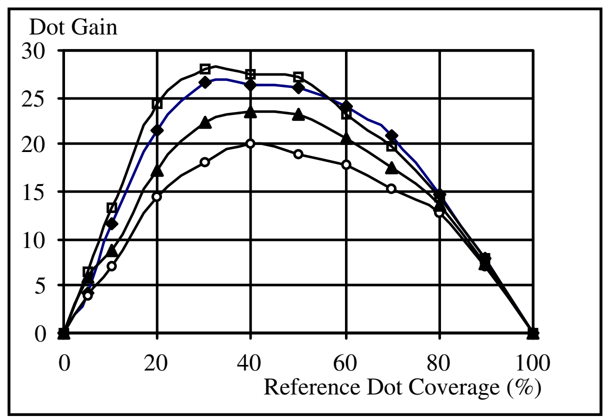

Figure 1. Dot Gain versus Reference coverage

Colorimetry

Colorimetry is the best tool to quantitatively evaluate fidelity indexes and performance of any color printing process. In our case, the goal was to characterize the inks themselves; thus, it was necessary to avoid any deviation which should be the result of the use of any kind of profile. Taking this requisite into account, it was possible to determine the color gamuts of the set of inks under consideration by printing each of our four papers.

The figure 2 is a projection of the color gamuts in the plane (a*, b*). It was obtained from measurements on printed solid areas by the 4 primary inks (C, M, Y, K), their binary combinations (R, G, B) and "trichromic black". This figure shows some awaited results: the two coated papers (b, c) yield larger gamuts than the two uncoated papers (a, b). In comparison with the office paper (a), the hexagon of the yellow paper (b) is completely shifted in the b* direction. It is also interesting to compare the volumes of the four dodecahedra (corresponding to each paper) in the L*a*b* space.[7] Due to the linearized nature of this space, this technique allows to get an estimate of the relative number of reproducible colors, which is an evaluation of the performances of our papers. Choosing the office paper (a) as an arbitrary reference, we obtained the results which are gathered in Table 4.

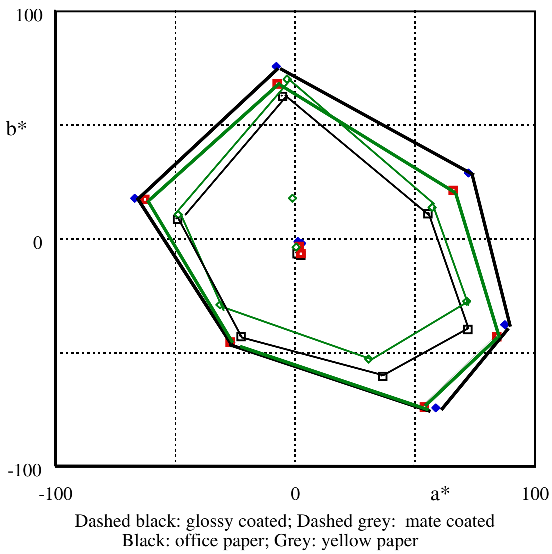

Figure 2. Color gamuts of the four papers

Table 4. Relative Volumes of Gamuts

Paper →	a	b	c	d
Gamut vol.	1	1,70	2,11	0,88

It can be seen that the two coated papers yield quite better ratios than the reference. Due to the shift of its gamut towards the yellow domain (a feature which may be noticed in figure 3), paper d has the worst performance of the four.

Let us also observe the unusual shape of the dodecahedra in figure 3 with the neck at the L* = 50 level.

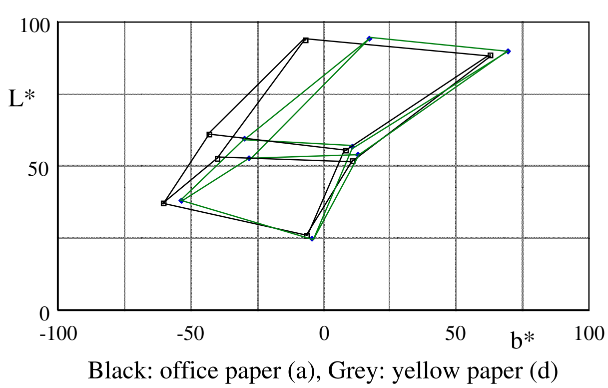

Figure 3. Color gamuts of uncoated papers

Print Through Measurements

According to the accepted definition of Print Through, this phenomenon depicts to which level a print on the one side of a sheet is visible on its unprinted reverse side. The most basic article on the subject was written by Larsson and Trollsas.[8] In the case of the offset process, these authors consider different effects the superposition of which build up Print Through PT:

- insufficient opacity of the printed sheet, leading to the Show Through component (ST),
- ink vehicle and/or pigment entering the paper structure, that is expressed by the ink penetration (IP) component.

PT is obtained in a decimal logarithmic form, like an optical density, by the equation (1):

$$PT = -\log \frac{R_r}{R_\infty} \tag{1}$$

where R_r is the reflectance of the reverse side of the printed sheet and R_∞ is the intrinsic refelectivity of the paper, provided the reverse side of the print be lain on a thick set of unprinted sheets and no “two-sidedness” be detectable. In turn, the right hand part of equation (1) may be divided into two terms, as presented in equation (2):

$$PT = ST + IP = \log \frac{R_\infty}{R_X} + \log \frac{R_X}{R_r} \tag{2}$$

where R_X is the reflection coefficient of an unprinted sheet which should be lain over the first side of a print. In the right hand part of equation (2), the first term corresponds to ST and the second to IP. The requirement for non “two-sidedness” was only fulfilled by the office paper (a).

In the office ink-jet process, the dyes (C, M, Y, K) are usually dissolved in an aqueous phase; thus, they are carried into the paper by the liquid and may reach a large depth. Let us call d this depth and t the total thickness of the paper. It has been proposed elsewhere[9] that an estimate of the ratio d/t may be calculated by equation (3):

$$\frac{d}{t} = 1 - \frac{G'}{G} \tag{3}$$

G is the grammage of the paper and G’ a so-called “reduced grammage” corresponding to the remaining part of the paper sheet where the ink did not penetrate. In turn, it is possible to calculate G’ by optical measurements. The principle is to consider a printed sheet on its reverse side like an unprinted “reduced sheet” covering a print on its first side. Under this assumption, it is easy to show that the reflectance R'_0 (over a black background) of the reduced sheet may be calculated by equation (4):

$$R'_0 = \frac{R_r - R_S}{1 - R_S (R_\infty + 1/R_\infty - R_r)} \tag{4}$$

in which R_s is the reflectance of the solid print which, in turn, is given by a measurement of its optical density D_s. Finally, by applying the Kubelka-Munk theory, we are lead to relation (5):

$$\frac{G'}{G} = \ln \frac{1-R'_0 R_\infty}{1-R'_0 / R_\infty} \cdot \left[\ln \frac{1-R_0 R_\infty}{1-R_0 / R_\infty} \right]^{-1} \quad (5)$$

Expression (5) gives access to the evaluation of d by (3). It is worth to add that this analysis may be applied to any ink (provided the reflectances R_0 and R_∞ be chosen in the right wavelength range) in screened and/or solid areas.

On the experimental point of view, we used it successfully in the case of our office paper (a). Typical Print Through results are presented in Figure 4 on the example of the cyan ink. It can be seen that the value of PT and ST increase very rapidly in the range of low reference dot area, a behavior which was also observed with the other three inks (M, Y and K).

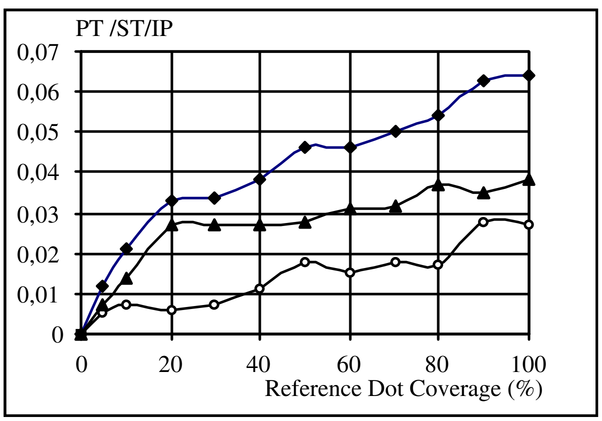

Figure 4. Print through variations with dot area (cyan ink)

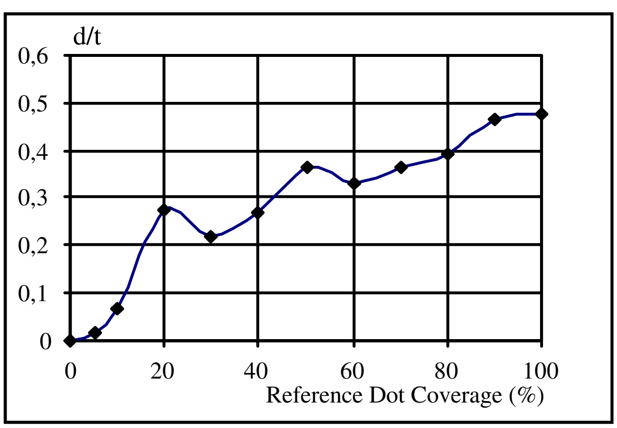

Figure 5. Penetration depth ratio versus dot area (cyan ink)

The ink penetration component IP is somewhat smaller than ST and seems to grow more progressively, but the precision of the measurements is not sufficient to insure this observation. In general, IP has the same order of magnitude as ST (see also Table 5), a feature which largely differ from what is occurring by offset printing on a similar paper.

On the same example of the cyan ink, we have represented in figure 5 the variation of the penetration depth ratio d/t with the reference dot area. Globally, the tendancy is similar to what is seen in figure 4: there is also a rapid increase of the ink penetration depth in the range of low dot areas. It is more important to observe that the ink may enter up to 50% of the total sheet thickness.

To verify this feature, we have repeated our calculations in the case of 100% coverage areas for the primary inks, their combinations (R, G, B) and the C+M+Y superposition. The corresponding results are gathered in Table 5. It can be seen that, in every case, more than 40% of the sheet is entered by ink.

Table 5. Print Through Data For Inks (Solid Areas)

Paper a	PT	ST	IP	d/t
Cyan	0,065	0,038	0,027	0,48
Magenta	0,051	0,028	0,023	0,45
Yellow	0,049	0,029	0,020	0,41
Black	0,063	0,035	0,028	0,44
Red (M+Y)	0,069	0,035	0,034	0,51
Green (C+Y)	0,085	0,043	0,042	0,52
Blue (C+M)	0,086	0,038	0,048	0,56
C+M+Y	0,114	0,050	0,064	0,62

It is not surprising to see that the penetration depth ratio increases with the number of printed colors, but the increase seems to become lower and lower, with the number of colors. Nevertheless, it remains worth to point out that more than 60% of the sheet thickness seems to be occupied by the use of the superposition C+M+Y.

In fact, we must also account for the precision of our measurements, which had to be done by the use of a reflectometer to insure their reliability. It is also correct to mention the relatively poor evenness of the color visibility on the reverse side of the printed samples, specially in the case of more than one printed ink.

Conclusion

A set of four different paper grades were printed with the same office ink-jet printer. The papers were characterized on both physico-chemical and optical points of view and the prints were tested by densitometry and colorimetry to determine classical quality criteria. Some peculiar behaviors of coated papers were explained by wetting properties.

On another hand, we considered Print Through, an important print quality parameter, on both its physico-chemical and optical points of view. A relatively simple model was developped; it turned out to allow us to develop a method for evaluating ink penetration into the paper in the case of the office paper. Nevertheless, we must stress the approximate nature of our calculations. It remains that our method seems to be valid at least as a qualitatively. Further experiments are needed to validate the method for different paper grades, provided their opacity be not too high.

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Biography

Gerard Baudin was born in 1944. He graduated from INSA-Lyon (France) in 1966 achieving Physical Engineering. He obtained his PhD from the Claude Bernard Scientific University of Lyon in 1970. Then, he was a teacher for Applied Sciences in scientific African universities. Since 1978, he joined the French Engineering Faculty for Papermaking and Printing (EFPG - Grenoble) where he became a Professor in Process Engineering applied to Graphic Arts, directing Master- and PhD theses, and teaching prepress and printing techniques.