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STRUCTURE AND BEHAVIOUR OF A PAPER'S SURFACE IN PRINTING

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Synopsis Print quality criteria are classified and listed from the point of view of paper printability. The theoretical background of such important print quality characteristics as print density and gloss, evenness, contrast and sharpness are presented. The effects of the components of ink transfer—coverage, immobilisation and splitting—on the resulting ink film structure are discussed. The connection between roughness distribution of paper and coverage in ink transfer are examined and an improvement is proposed for the previous coverage theory of Hsu. The use of laboratory test printing and full-scale press runs are recommended for printability evaluation of paper and the methods used in determining various print quality numbers are reviewed.

Introduction

THE concept of printability can be defined as a combination of those paper properties that influence the print quality under any given conditions of printing production. According to this definition, the print quality criteria are of primary importance in any consideration of printability. The most ambitious aim in print quality research has been to develop a single and unique numerical value for the quality of printed pictures that would be independent of the printing process used.

The most promising attempt was that of Wolf,[1] who in his thesis proposed a relative print quality number based on theoretical considerations of the data. Essentially, this entails a quantitative comparison of the transinformation content of the print with the information content of the original photographic picture and with the so-called irrelevance, which is the content of disturbing information introduced by the reproduction and printing processes used. Information content is supposed to be measured in fragments per image element, which in practice would require a scanning device, capable of measuring and digitising screened prints dot by dot and original pictures having a

Under the chairmanship of Dr J. A. Van den Akker corresponding resolution. The existing digital picture scanners could be modified to do this, but up to now such measurements have not been made.

In routine printability studies, the problem of print quality is approached by using several quality numbers that perhaps are not very unique, but cover the many features of print appearance and behaviour more completely than any single number can do. In a recent review,[2] print quality was divided into two groups—

Solid prints	*Half-tone prints*
Print density	Density range
Coverage (speckle)	Evenness
Evenness (mottle)	Contrast
Gloss	Saturation (of colour)
Print-through	Sharpness (of dot edges)
Set-off	
Rub-off	

This list is (more or less) a compromise between the general and specific requirements of any printed product, but most of these criteria can be clearly defined and objectively measured. Test printing with solid (that is, unscreened) printing plates, as it is usually done in laboratory printability testers, gives us the column on the left and this can be completed with half-tone print criteria when necessary. Any mutual comparison of the importance of these quality numbers is difficult, but some of them are certainly more important than others.

The print density of solids and the density range of half-tones are closely interrelated. Their importance is caused by the fact that the maximum information content of a print depends on the binary logarithm of the number of distinct tones resolvable with the human eye between the darkest and lightest parts of the print. They depend also on other criteria such as coverage, evenness and gloss; their dependence on the ink film structure has even been theoretically explained.

Tollenaar & Ernst[3] have shown how the mottle (or thickness variation of a continuous ink film and speckle (incomplete coverage of paper by ink) decrease the average print density. They pointed out the relationship between their simple solid print density model (Table 1), which gives the print density as a function of the average ink film thickness and the more accurate models derived from the Kubelka–Munk equations by dealing with a specific ink film thickness distribution functions instead of constant layer thicknesses. This was the first attempt to connect the macro-appearance of solid prints with the microstructure of paper and ink layer. A similar approach was published later by Wahren & Norman.[18]

Frøslev-Nielsen[4] studied the effects of the relative dot areas of half-tone prints, the ink layer structure of the half-tone dots and the ink film thickness on the half-tone print densities and showed that the microgranularity and blur of the individual dots can be related with certain parameters of the half-tone density models of Yule & Nielsen (see Table 1).

TABLE 1—INK TRANSFER AND PRINT DENSITY MODELS

Ink film thicknesses		*Print densities*	
on the plate x	*transferred on paper* y	*Solid print* D	*Half-tone print* D_r
Walker-Fetsko (1955) $y = A[Bb+f(x-Bb)]$ in which $A = 1-e^{-kx}$ $B = 1-e^{-x/b}$		**Murray-Davies (1936)** $D_r = -\log_{10}[1-a(1-10^{-D})]$	
Rupp-Rieche (1959) $A = 1-e^{-(kx)^2}$		**Yule-Nielsen (1951)** $D_r = -n\log_{10}[1-a(1-10^{-D/n})]$	
Laraignou (1960) $B = 1;\ A = \frac{x^2}{x^2+k^2}$			
Karttunen-Kautto-Oittinen (1971) $y = Afx+(A-A_0)Bb(1-f)$ in which $A = 1-(1-A_0)e^{-kx}$		**Schirmer-Tollenaar (1971)** $D_r = -\log_{10}[1-F^{1-(D/D_\infty)^s}(1-10^{-D})]$ in which $F = f[a, n]$	
	Tollenaar-Ernst (1962) $D = D_\infty(1-e^{-my})$		
	Hermanies (1968) $D = (1-e^{-m_1 y})[D'_\infty(1-e^{-m_2 y})+D_q e^{-m_2 y}]$		
	Lovasz (1971) $D = D_p e^{-by}(1-e^{-my})+D''_\infty(1-e^{-by})$		
	Oittinen (1971) $D = D_\infty(1-3^{-my^p})$		
Sweerman-v.d. Plas (1965) $D_r = D_\infty(1-e^{-m \cdot a \cdot x})$	in which in transfer was assumed to be linear and in spreading to be large		
Karttunen-Oittinen (1972) $y_2 = A_2[b_2B_2(1-f_2)+f_2x-A_1tf_1(1-f_2)x]$	for wet-on-wet ink transfer		
Oittinen (1972) $y = F^{1-e^{-s/x}} A[bB(1-f)+fx]$	for half-tone ink transfer		

These observations bear some resemblance to the results of Yule[21] on the effects of light scattering at the dot and line edges on print densities.

The effects of ink film microstructure on the print densities are interesting, because the ink transfer mechanism[5–7] is adequately known and what happens in the printing nip largely determines the ink film structure.

Ink transfer models

INK transfer models deal with the basic problem of how much of the ink on the printing plate before the moment of the impression is transferred on to paper. Ink transfer can be divided into three partly independent components—*coverage*, *immobilisation* and *splitting*. These will be discussed in the following pages, together with some accompanying phenomena such as penetration and roughness distribution of paper in a printing nip. In the text, diagrams and tables the following nomenclature is used—

x = amount of ink on plate (g/m² or μm)
y = amount of ink transferred to paper (g/m² or μm)
k = smoothness parameter (m²/g or μm^{-1})
A_o = smoothness parameter depicting an initial value of the coverage function A, when $x = 0$[6,7]
b = immobilisation parameter (g/m² or μm)
f = splitting parameter
A = coverage function, fractional area covered by ink
B = immobilisation function
D = density of solid print = $\log_1 : \left(\frac{\text{luminous reflectance of paper}}{\text{luminous reflectance of print}}\right)$
D_∞ = density of solid print at infinite ink film thickness
m = parameter in solid print density model[3] depicting the steepness of the curve (m²/g or μm^{-1})
a = printing area of half-tones
D_r = density of half-tone print
F = effective printing area of half-tones[19]
s = measure of filling-in tendency of half-tone dots[19]
x' = depth of ink penetration at the moment of transfer (g/m² or μm)
x'_o = ink film thickness on the flattened fraction A_o of paper surface before transfer (g/m²) or (μm)
$\phi(x')$ = roughness distribution of paper in a printing nip

The transfer of ink from solid printing surfaces to paper is normally presented as an equation between the amount of ink transferred (y) and the amount of ink on the plate before impression (x).

These quantities are measured as mass per unit area (g/m²) or as ink film thicknesses (μm). The basic idea of ink transfer was presented by Walker & Fetsko[5] in the following equation—

$$y = A[bB+f(x-bB)]$$

in which the coverage function $A = 1-e^{-kx}$ and the immobilisation function $B = 1-e^{-x/b}$, where k, b and f are constants.

Verbally, this equation means that the amount of ink transferred is the sum of a constant amount of ink immobilised (b) and a constant fraction (f) split from the remaining amount of free ink ($x-b$). At lower ink film thicknesses, this occurs only in the area of ink-paper contact A. In addition, the immobilisation may be incomplete by a factor B.

Table 1 gives the mathematical fomulas for the existing ink transfer models (left column), the print density models for solids (middle column) and for half-tones (right column).

As can be seen from Table 1, many researchers have developed ink transfer models, mainly by modifying the coverage function or introducing other new features. In this paper, only the newest modifications of Karttunen *et al.* [6, 7] will be examined in detail.

By introducing a new smoothness parameter A_o, called the flattened fraction, the model becomes as follows[6]—

$$y = (A-A_o)bB+f[Ax-(A-A_o)bB]$$

or

$$y = Afx+(A-A_o)bB(1-f)$$

in which $A = 1-(1-A_o)e^{-kx}$ and $B = 1-e^{-x/b}$.

Solving the four parameters (b, f, k and A_o) from experimental test printing data is slightly more complicated than the computation of three parameters, but the resulting accuracy of the fit is better.[7] The role of two smoothness parameters k and A_o is connected with the coverage function A.

Coverage and immobilisation

THE interpretation of A and A_o is illustrated in Fig. 1 & 2, which show that the paper surface is deformed or flattened very close to the plate surface (rubber blanket surface in offset printing) when compared with the original ink film thickness. From the flattened area (A_o), the ink thus has to flow into the recesses and pores of paper. The interpretation of the second smoothness parameter k is connected with the average steepness of the recesses, in their compressed state in the nip and at the areas ($1-A_o$) between those considered to be flattened.[7]

The point in dividing the coverage function A into two components A_o and k is that they may—

1. Have different dependences on the structural properties of the raw materials (fibres and fillers in newsprint)
2. Have different dependences on the papermaking process variables

3. Cause different local phenomena during the ink transfer in the printing nip and during the setting of the ink film after printing. This may cause different dependences on the printing conditions.

For example, A_o decreases more than k with increasing ink viscosity at a range of news inks of 5–45 P/30° C (see Fig. 3), which means that a viscous ink evens the pressure between the plate and the paper surface; this in turn reduces the surface deformation (A_o). The total effect is that the paper seems smoother when printed with a fluid ink.[16] Similar effects may be observed when a hard metal printing plate is replaced by a soft plate: rubber and plastic plates in letterpress and a rubber blanket in offset.

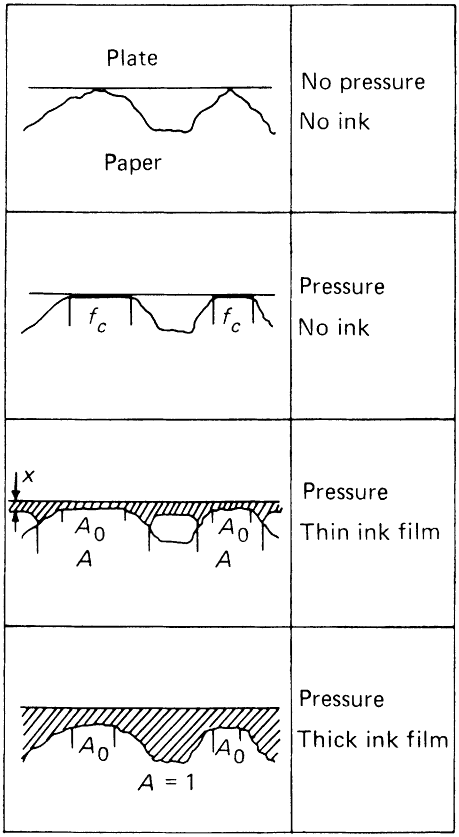
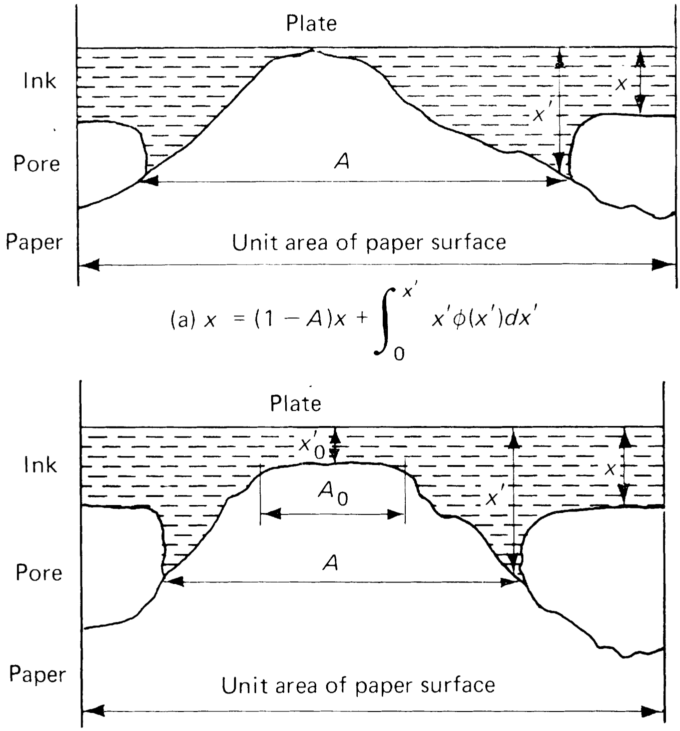


Fig. 1—Deformation of paper surface in four different situations: the quantities f_c, x, A_o and A are described



$$\text{(a) } x = (1 - A)x + \int_0^{x'} x'\phi(x')dx'$$

$$\text{(b) } x = (1 - A)x + A_0 x_0' + \int_{x_0'}^{x'} x'\phi(x')dx'$$

Fig. 2—Coverage A, flattening A_o penetration x' and roughness distribution φ (x') in the printing nip with the ink film thickness x on the plate—
(*a*) according to Hsu[8]
(*b*) according to Karttunen *et al.*[7]

Other important dependences of ink transfer and its parameters on the printing conditions are presented in Table 2.

TABLE 2—THE DEPENDENCE OF INK TRANSFER ON PRINTING CONDITIONS [7, 16]

Printing factors	*Ink transfer parameters* A_o	k	b	f	*Coverage* A	*Total amount transferred* $y = y(x)$
Printing pressure	++	++	++	0	++	++
Printing speed	–	–	–	– –	– –	– –
Ink viscosity	– –	–	–	– –	–	– –

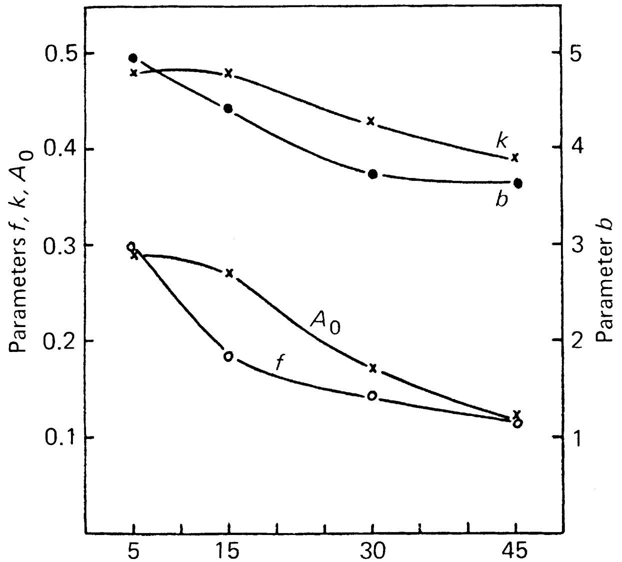


Fig. 3—Ink transfer parameters A_0, k, b and f as a function of ink viscosity (poises at 30°C) determined with IGT printability tester, speed 4 m/s and pressure 20 kp/cm

The ink transfer models are linear at high ink film thicknesses, when the coverage and immobilisation functions (A and B) tend to unity. Then the Walker & Fetsko model reduces to—

$$y = b+f(x-b) = b(1-f)+fx$$

This equation shows that there is an extrapolated intercept on the y axis and that a constant amount of ink (b) is immobilised by the paper at high ink film thicknesses. At low ink film thicknesses, this is not so because of the immobilisation function B, which tends to zero when x tends to zero. Rough and porous uncoated papers give b values of up to 5–10 μm; coated papers less than 1 μm and films and foils practically zero. The actual ink pigment penetration depths (into pores) reach values of up to 15 μm.[10]

Immobilisation tends to increase with increasing printing pressure. Particularly with rough papers, this is a disadvantage, because full coverage is attempted by increasing printing pressure, which increases immobilisation at the same time. The resulting ink film is rather uneven if, say, 5 μm has been transferred by immobilisation (and penetrated even deeper—say, 10 μm) and only 2 μm by splitting. Such very uneven ink films are not optically effective.

The same situation applies to ink viscosity. By decreasing the ink viscosity, both the coverage (the smoothness parameters A_o and k) and the immobilisation (b) increase, the latter effect being unfavourable. Penetration of fluid news inks into a well wettable substrate such as paper makes it impossible to obtain a completely even ink film. On the other hand, viscous inks are not split adequately.

The depth of immediate penetration (x'), the average amount of ink immobilised (b) and the coverage A depend on each other at the moment of ink transfer in the nip. Fig. 2 shows the volumetric relationships between the coverage, roughness distribution and penetration.

Roughness distributions

FIG. 2 also points out the very important deduction of Hsu,[8,9] which states that so long as the coverage is incomplete ($A \leqslant 1$), the penetration depth x' is governed by the roughness distribution of the paper surface $\phi(x')$ and the ink film thickness on the plate x. Hsu originally calculated the situation as shown in the upper block of Fig. 2.[8] Later, he proposed a model [9] in which x' was assumed to be equal to x. This makes the determination of roughness distribution easier (by means of test printing with different ink film thicknesses and optical coverage measurements), but gives only an estimate of the real penetration depth. Therefore, a more general approach on the penetration problem is given in Fig. 2, based on the reasoning that led to the ink transfer models of Karttunen *et al.*[6, 7]

We must perhaps accept that a deformable solid structure such as the fibre structure of a paper surface does not penetrate through the whole ink film thickness even in the middle of a printing nip. On the flattened fraction A_o, there must be a thin ink film (x_0') between the paper and the plate. By assuming that the splitting takes place in a similar way throughout the covered area A, it would be possible to solve x_0' numerically together with the ink transfer parameters. Consequently, a determination of roughness distribution as a by-product of ink transfer measurements would be possible. Unfortunately, experimental verification is difficult. Splitting may be different—like immobilisation is—at the flattened areas (A_o), where the ink is highly pressurised in the nip, then suddenly released at the outlet of the nip. Further uncertainty is caused by the possible separation of ink components such as pigment filtration in the nip and immediately after it. This problem has been studied by Larsson *et al.*[11]

Schaeffer *et al.*[10] could not completely explain the unexpectedly high ink pigment penetration depths (7–15 μm for newsprint) compared with the corresponding amounts of ink immobilised. It is important to remember that the penetration can reach only the pores and recesses of the surface, whereas the immobilisation b is an average amount of ink over the unit area[5] or recess area.[6, 7] Based on optical contact measurements, the porosity of newsprint surface layers—to, say, less than 2 μm depth—is roughly 80 per cent.

Deeper in the recesses there is, however, less porous volume to be penetrated during the contact time in the nip. A large part of the total relative porous volume of newsprint consists of closed voids such as fibre lumens, which do not necessarily collapse under the printing nip pressures. Most of the decrease in total pore volume in the printing nips probably occurs in the pores between the fibres. All these factors together explain the unexpectedly deep penetration of ink that occurs during ink transfer on newsprint. The ink vehicle separation after printing is not discussed here.

It is interesting to compare the smoothness parameters of the ink transfer models (k and A_o) with standard smoothness values measured by the Bendtsen airleak method and the FOGRA optical contact/smoothness method[12]—an improved Chapman contact smoothness principle. The correlation between the flattened fraction A_o and FOGRA contact smoothness (f_c) could have been expected, if f_c could have been measured under dynamic conditions resembling the printing conditions used in the determination of A_o (Fig. 1). No dynamic smoothness measurements have so far been made by us, although devices have been developed by Bliesner[13] and Blokhuis.[25]

Table 3 gives the ink transfer parameters k and A_o as determined at a speed of 4 m/s and pressure of 20 kp/cm in an IGT printability tester and computed from the two A_o modifications of the Walter-Fetsko model.[7] The corresponding standard smoothness values measured for the papers are also shown. Measuring pressures are 1 kp/cm² (Bendtsen) and 50 kp/cm² (FOGRA).

TABLE 3

Paper grades		*Newsprint*			*Uncoated*			*Coated*		
Sample No.	1	2	3	4	6	10	11	12	13	14
W–F/1 k	0·48	0·35	0·39	0·47	0·48	0·77	0·48	0·73	0·83	1·35
A_o	0·09	0·16	0·05	0·06	0·10	0·25	0·26	0·0	0·29	0·33
W–F/2 k	0·67	0·72	0·48	0·60	0·68	1·73	1·35	0·73	2·7	3·2
A_o	0·17	0·31	0·20	0·15	0·16	0·34	0·35	0.0	0·46	0·32
Bendtsen roughess, ml/min	65	105	125	70	70	22	34	28	20	14
FOGRA contact smoothness, f_o	0·19	0·21	0·20	0·18	0·19	0·23	0·24	0·13	0·34	0·41

Fig. 4 shows that the dependence of A_o on f_c is fairly consistent. The Bendtsen roughness does not correlate with A_o, but does so to some extent with the k parameter. It is obvious therefore that the smoothness parameters depict two independent aspects of the paper surface structure—flattening (A_o) and steepness of recess slopes (k).

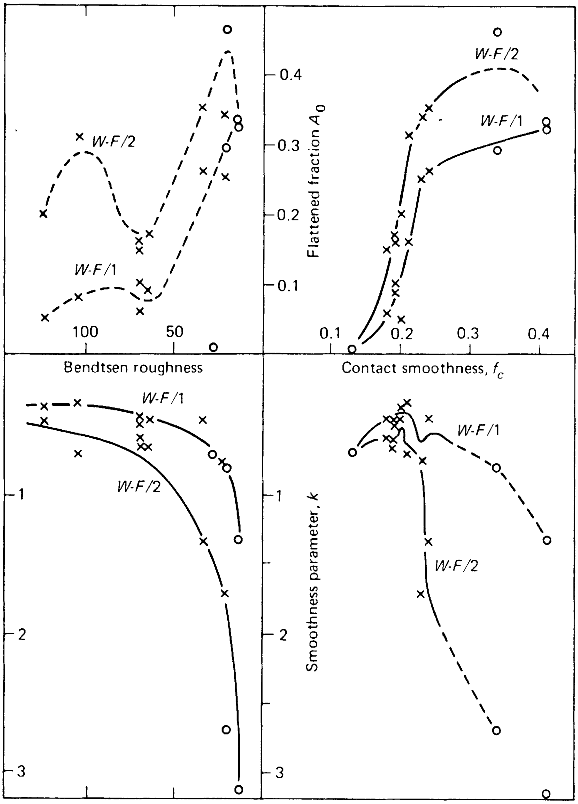


Fig. 4—Correlations between the smoothness parameters of ink transfer (A_o and k), FOGRA contact smoothness (f_c) and Bendtsen air-leak roughness

As pointed out by Brecht & Rothamel,[14] the size distribution of non-contact areas of paper is a very important factor in contact smoothness evaluations. In attempts to correlate the contact smoothness values with the flattened fraction A_0 of the ink transfer experiments, we must remember that the 'contact' involves distances of some tenths of a micron. Small recesses from this level to about one micron in depth are registered as non-contact areas in f_c measurements, though they might be included in flattened areas in the ink transfer tests.

Splitting

COVERAGE and immobilisation govern ink transfer at the inlet and middle parts of the printing nip. After the middle parts of the nip, high shear and pressure gradually change to negative pressure in the ink film. Even though this happens very quickly—in fractions of milliseconds—cavitation usually occurs in the 'free ink layer' x–Bb, which then starts to split. Cavitation bubbles increase too from filaments and breaking of the filaments finally terminates the splitting. The phenomena at the outlet region of the nip are depicted by a splitting constant (f), which is a measure of the proportion of the free ink layer that transfers to the paper. The most important variables of f are printing speed and ink viscosity (Table 2). The effects of paper on splitting are relatively small, except in the case of picking or linting.

The splitting constant f varies from about zero to 0·5 so that the lower limit corresponds to high speed and viscous ink, the conditions for the higher limit being the reverse. A plausible explanation is that a higher speed increases the pull of ink and this drags the immobilised ink layer more efficiently from the recesses to take part in the splitting, thus resulting in a smaller amount transferred and higher splitting forces.[(16)] This can even cause pointwise (linting) or areawise (picking) reverse transfer of paper particles on to the plate and poor trapping in multi-colour wet-on-wet printing.[(16)] In fact, a new laboratory method as proposed by Kuvaja[(26)] is based on disturbances in splitting at high speeds and used to predict linting and picking for newsprint.

In conclusion, the ink transfer tests give valid information of what happens at the paper surface in the printing nip, but the models and their parameters—even those depending mostly on paper smoothness—also depend on the properties of ink. This must be remembered when printing behaviour is explained with the aid of physical measurements such as optical contact smoothness,[(12–14, 25)] contact size distribution[(13, 14)] and pore size distribution under pressure.[(15] Many of these physical measurements have become very complicated in their attempts to approach the pressure conditions in a dynamic nip without using ink. When using ink transfer methods, the role and effects of the ink must be considered and, if possible and necessary, separated from those of the paper.

Print density and gloss

PRINT density and gloss will be discussed together, because they are closely related. Print density D is a relative measure of the average darkness of print (logarithm of the ratio of paper and print luminous reflectances). Print densitometers usually measure with 45°/0° or 0°/45° geometry, but occasionally diffuse illumination photometers such as Elrepho are also used. The 45°/0° geometry corresponds to viewing conditions in which the observer holds the print at such an angle that the light source does not disturb the viewing by its specular reflection from the glossy print. Under such conditions, the print density depends on the following factors—

1. The diffuse and specular reflectance of paper (unprinted).
2. The coverage of paper by the ink film.
3. The optical changes due to ink vehicle spreading on the areas not covered in the print.
4. The diffuse reflectance of the ink layer, which depends on the thickness and thickness distribution of the ink film, on the saturation reflectance and on the scattering coefficient of the ink and reflectance of paper under the ink film.[3]
5. The specular reflectance of the ink film, which depends on its surface smoothness.[17]

For a continuous ink film, the second and third points do not apply, nevertheless print density remains a very complicated concept. An ideal printed surface is an even and glossy ink layer on a matt substrate. Because of the randomly distributed angles of the reflecting surface elements, a rough and matt print cannot be darker than about 1·4 in density units. This means that, for reproducing originals with a higher density range, the smoothness requirements for paper are very high, independent of the printing methods and ink. Paper can be matt, but it should be smooth and not too absorbent. High absorbency requirements set up by other print quality criteria such as set-off and half-tone contrast contradict the 'gloss hold-out' requirement. Much can be done by correct ink formulation when aiming at an ink film that has high enough vehicle retention and that thus results in a glossy surface, even if the paper is absorbent.[17] The role of paper absorbency, however, is one of the last unknown areas in printability research. So far, almost no general testing methods and recommendations can be given in spite of the large number of methods proposed. Paper gloss—though it is usually appreciated by the printers and their advertiser customers—is not theoretically necessary. Paper gloss may, however, correlate with the print gloss, because it indirectly measures that kind of smoothness (in an uncompressed state) required for the resulting print gloss.

Print density and gloss evaluations for a paper/ink combination are usually made by measuring laboratory test prints prepared with varying ink film thicknesses. Print gloss may depend in very many ways on the ink film thickness.[17] Print density as a function of the ink film thickness transferred on to paper behaves more consistently. The first and simplest of the solid print density models presented by Tollenaar & Ernst is as follows—

$$D = D_{\infty}(1-e^{-my})$$

As was pointed out later by the same authors,[3] this model does not necessarily fit all kinds of experimental data and therefore many other proposals for the same dependence have been presented (see Table 1, middle block). Parameters of print density models can be computed and used as printability numbers. They can also be used for computing other values such as ink requirement—that is, the ink film thickness needed for a given print density level, It is also usual to determine ink transfer, print-through, set-off and rub-off values for the same series of test prints.

The evenness of solid prints—usually expressed as the coefficient of the variation of reflectance—can also be measured and examined as a function of ink film thickness. Wahren & Norman[18] proved theoretically what has been previously observed by others that, with increasing ink film thickness transferred to paper (but with constant relative non-uniformity of ink film), the unevenness of print reflectance increases to a maximum, then decreases. Wahren also presents the experimental and interpretational difficulties with the unevenness scanning and refers to earlier work carried out in many institutes—PPRIC in Canada, Pira in England, IPC in Wisconsin, U.S.A. and ours and FPPRI in Finland.

The ink film thickness ranges used in practical laboratory test printing are chosen according to the ranges used in production conditions, which are approximately 2–10 microns for uncoated and 1–5 microns for coated papers. For complete ink transfer tests, these ranges should be extended to about 20 microns of ink on the plate. Other printing conditions can be chosen according to the possibilities of the tester used and the production conditions imitated.

The existing laboratory presses such as IGT, FOGRA or GFL are sufficient for letterpress printing, whereas there is as yet no standard laboratory equipment for the imitation of lithographic offset printing. Gravure printability testers have been developed in many laboratories, but so far only the GRI/Huck press has been used in several laboratories, mainly in U.S.A. Many laboratories use pilot-scale presses[23] for gravure printing.

Half-tone density models

PRINT quality criteria of half-tones—in letterpress and offset printing—cannot be reliably tested with the laboratory presses that have a separate inking unit. The phenomena of half-tones are very sensitive to the way ink is applied on to the printing plate. For lithographic offset, the only reliable method is testing at full scale. This has been the motivation for the development work on the evaluation of full-scale test prints.[19, 20, 22, 24] This work has been carried out in connection with the new half-tone density models[19] recently developed.

In Table 1 (right column), the basic half-tone density models are shown.

The Yule & Nielsen model explains the effect of light absorption by the ink-covered areas and by the edges of the screen dots where the light is scattered sideways and absorbed by the ink layer from beneath. Later, Yule *et al.*[21] have shown that this effect, which occurs at all optical edges in the print, depends on the scattering power of the paper surface. By measuring very sharp edge projections with a microdensitometer, they obtained spread function widths ranging from 10 μm to about 70 μm for titanium dioxide coated and uncoated papers, respectively. This means that, by increasing the scattering coefficient of the paper surface, the sharpness of line and dot edges of a print can be improved independently of the mechanical sharpness of the ink film edges. They conclude by stating that the flatter contrast of dark half-tones commonly obtained with uncoated papers appears to be due to the spreading of light rather than the spreading of the ink image.[21]

Schirmer & Renzer[20] and later Schirmer & Tollenaar[19] explained the mechanism of ink spreading in half-tones that occurs at excessively high inking levels and leads to the dark half-tone areas filling in. Between the low and high inking levels, there is a level—called normal inking—where the contrast of dark half-tones is at its highest. It may be concluded that both optical spreading[21] and mechanical spreading are important and their effects are demonstrated in the newest half-tone density model.[19] This model is directly applicable in the interpretation of full-scale press runs, because it gives a method of determining objectively—so far only afterwards—which inking was the optimum in the sense of maximum contrast for each of the samples. Hence, papers to be compared in the test can be evaluated at their optimum levels.

This method has been used in our laboratory in a number of tests during the last two years.[24] The procedure is as follows—

1. Papers to be tested are run through the press by adjusting all the press variables at their normal production levels as well as possible.
2. Only the inking level is changed in a stepwise manner from low to clearly excessive inking. Depending on the amount of sample, a steady state situation is aimed at in each inking step and their number should be about 10. In lithographic offset, this means a run of about 2 000 sheets; in letterpress, fewer sheets.
3. From each inking level, ten printed sheets are sampled and the print densities of solid and dark half-tone areas are measured.
4. This data is then used to compute the best fitting Schirmer-Tollenaar curve and its parameters F and s. The standard programme used in our laboratory gives a print-out of the normal inking level and the maximum contrast. This is completed by plotting the half-tone densities D_r as a function of the corresponding solid densities D and by checking that the computed result is reasonable.

5. Other measurements and evaluations of the print quality criteria are finally carried out from the sheets printed at the normal inking level.

A more complete description of this method, its accuracy and applicability is given by Säynevirta & Karttunen.[24] The projects in which this method has been successfully used vary from comparison tests of printing papers in the development of new grades of comparisons of inks and printing plates.

In conclusion, the print density models—both for solid and half-tone prints—can be effectively used in interpretation of the test printing results. Though they do not have any direct connection with the paper surface structure, as ink transfer models have, they may help paper technologists to get a more consistent understanding of the basic variables of the printing processes.

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* APST (Advances in Printing Science and Technology), editor W. H. Banks is published every two years and contains all papers read at IARIGAI conferences; publisher up to vol. 6 is Pergamon Press

Transcription of Discussion

Discussion

The Chairman The next contribution is rather unusual. It is the presentation of illustrations by Dr J. Mardon, who has studied the interrelationship between a number of factors that relate to the things we are talking about this morning and to other areas covered by the symposium. He has offered to supply copies of the charts to anyone who approaches him for them.

Dr Mardon is associated with Mr George Williams in describing these results as important. They state that it is not accurate to discuss the sheets produced by two-wire formers as if they were identical. Each two-wire former has its own characteristics. Results obtained during a paper structure investigation carried out over a long period are shown in Fig. L. It should be noted that the results of the Bel Baie former are for the Bel Baie mark 1.

Fig. M relates papermaking technology and those papermaking characteristics important in printing to sheet structure.

Fig. N illustrates uniformity of sheet strength and printing quality as related to furnish, system and papermachine characteristics.

Fig. O illustrates the interrelationship of surface and internal structure characteristics, which together determine the total sheet structure. The vital areas of study of sheet structure are given.

Fig. P–T illustrate typical sheet structural characteristics as described from sheet cross-sections.

Dr J. Marton My one comment is on the basic difficulty in printability assessment of fine papers and boards, namely, that the customer may have minimum requirements in most properties, but they have a preference. Their variety may make it very difficult (if not impossible) to express printability of a paper in one given number. Nonetheless, certain properties might be more generally sought after than others—one group of customers will prefer matt paper, others glossy paper. It seems usual for one common demand to be for high printed gloss. A good understanding of the printed gloss measurements or the development of printed gloss would be quite useful and generally applicable: it necessarily depends *inter alia* on the gloss of the unprinted

Under the chairmanship of Dr J. A. Van den Akker

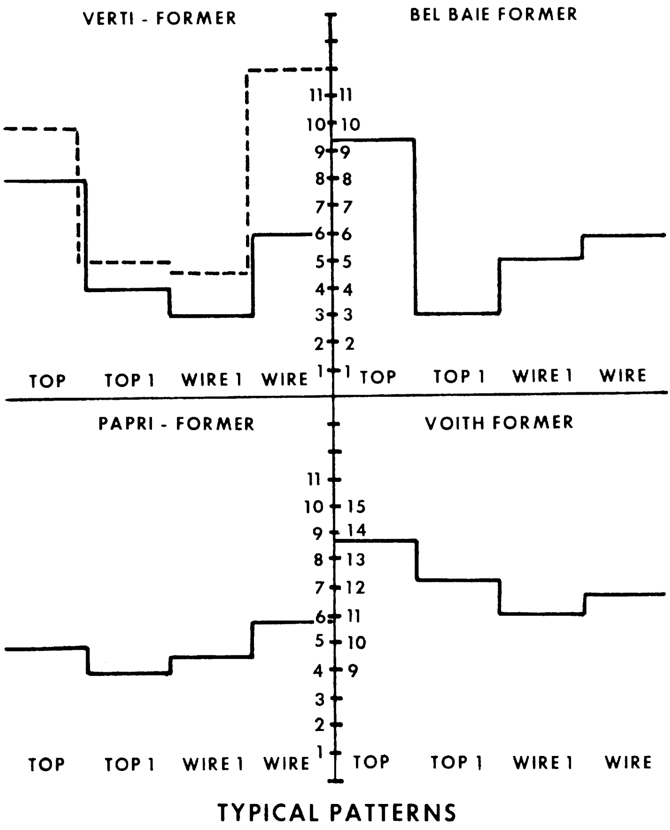

Fig. L—Table and drainage resistance for four types of two-wire former for four successive layers of the sheet

paper, on the smoothness of the surface and on the ink absorbency. Taking a homogeneous group of samples of coated board, our study indicated that, in a homogeneous group in which the variance comes mainly from production, both from changing formulation or conditions, 60–70 per cent of the printed gloss variance was caused by the variance of the unprinted gloss of the board and the rest by variance of surface roughness. This means that, although the level of expected printed gloss cannot be predicted from the unprinted gloss alone, it would be a challenging task—to keep production more uniform—and it would be very useful if one could measure the unprinted gloss of the paper or the smoothness or both, continuously and directly on-line. Our greatest challenge is to maintain consistency of product quality.

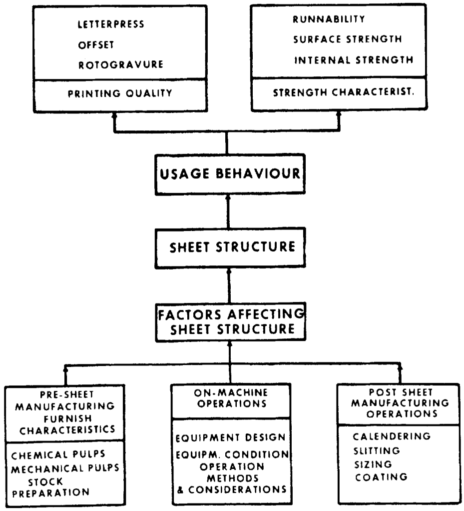

Fig. M—Sheet structure as the focal point in a study of papermaking technology

Mr J. R. Parker Just before this conference, I spoke to Dr Larsson by phone and his comment on my paper was about the term printability. He said, 'It's very misleading, for it conveys the idea of just one number.' Printability is a term that we realise embraces a number of very different properties. It is impossible to express the idea of printability in any one number and paper must quite clearly be tailored to the requirements of certain customers. With newsprint, those running fast presses want one thing and those with old slow presses want another.

Dr H. G. Higgins I should like to refer to your conclusion or thesis that it is not merely the compression of the projecting parts of the paper surface, but also the flexing of the paper that is responsible for the decrease of roughness with pressure. Just before I left Melbourne, Dr Colley completed some Print-Surf experiments on a range of hardwood kraft handsheets beaten to 2 000, 4 000 and 8 000 rev in the PFT mill. We were prepared for the effect of roughness either to decrease or to remain constant (based on our experience with de Yong's profiler). What happened in fact was that the roughness decreased with beating in some cases, but there was a highly significant increase in the Print-Surf measurement with beating in others. I think this to be consistent with your thesis. We have not yet measured the elastic modulus of these papers, but it may be interesting to see how the trends with beating in relation to the roughness changes fit in with your hypothesis. I should mention also that compressibility measurements were taken as the ratio of the Print-Surf readings at 10 kgf/cm^2 to that at 20 kgf/cm^2 (soft backing, gloss side of the sheet). The compressibility figures ranged 1·03–1·08.

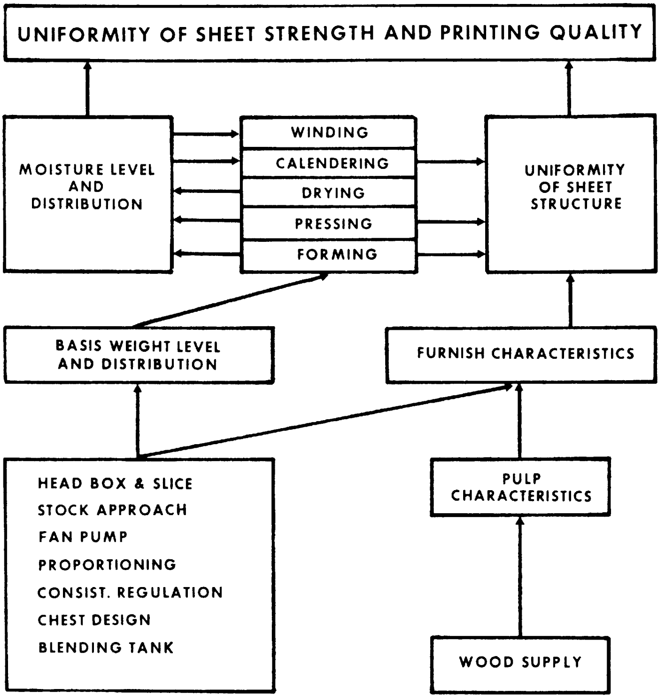

Fig. N—Relationship of papermachine system characteristics to uniformity of sheet strength and printing quality

(*Submitted addendum* The variation of stiffness with beating—an initial increase arising from increase in Young's modulus, followed by a decrease because of reduction in thickness—was discussed by Gallay in his symposium contribution. Different positions of the stiffness maximum, with beating, could help to determine whether there is a rise or fall in Print-Surf roughness.)

Dr S. Karttunen I would like to speak about Joe Marton's comment on print gloss and paper gloss. It is quite natural when trying to explain the variations in print gloss to use the paper gloss as the first argument. It is because paper gloss measures the paper smoothness indirectly in the same manner as print gloss is measured, since paper gloss is normally measured without using any pressure. Most current roughness or smoothness methods use pressure, which is another thing. Pressure comes into the picture at the printing nip, but it has nothing to do with paper or print gloss in its relaxed state after the ink film has been set and dried.

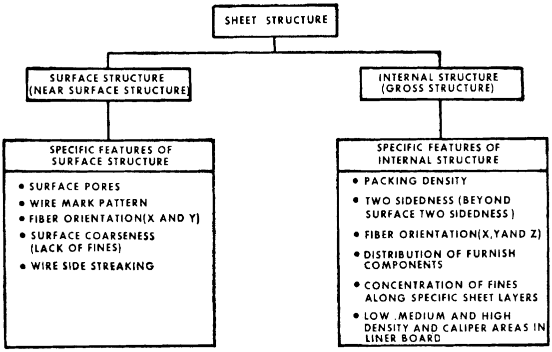

Fig. O—A breakdown of vital study areas when examining sheet structure

Mr J. A. S. Newman The oil penetration test measures the time it takes for an oil drop to penetrate the sheet completely. This time can be very different, depending on which side of the paper is tested; furthermore, it can be altered drastically by the action of the wet presses on the papermachine—for instance, a straight press increases the time that the oil takes to go from the wire side of the sheet to the top side. Thus, this change may occur through a change in the structure of the paper and particularly of the surface of the paper.

Has this change in structure ever been observed physically in any other tests on the porous structure of the sheet or of the surface of the sheet? Secondly, has it ever been considered as a possible reason for differences in printability on the two sides of the sheet?

Prof. D. Wahren Mr Graeme Robertson at STF, Stockholm has performed a long series of experiments that relate to this question. In general, the more wet pressing used and the higher the temperature in drying and the higher the drying wire tension, the more dense the paper and the rougher its surface measured with a Bendtsen surface roughness tester and a Print-Surf tester using various pressures.

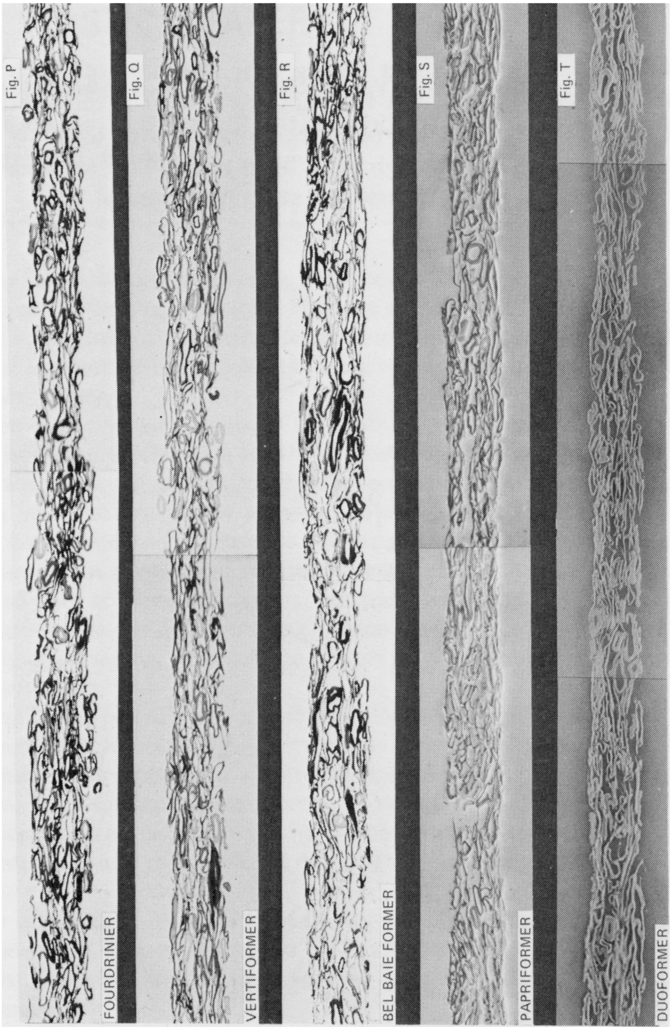
Fig. P
FOURDRINIER
Fig. Q
VERTIFORMER
Fig. R
BEL BAIE FORMER
Fig. S
PAPRIFORMER
Fig. T
DUOFORMER

Fig. P—T

Mr B. Radvan It was suggested that conformability is concerned rather than compressibility of the paper. This takes place over very small distances comparable with the thickness of the paper, so it is not really stiffness as measured by modulus or by any flexural test, but something rather more complicated.

Mr Parker I was talking about flexing over distances of the order of 100 microns. I agree with you, but I do not know what is the appropriate property. There is an empirical test by Paszkiewicz (referred to in my paper) in which the paper is pushed through small holes to find how far it has gone. This looks relevant, but it is of course not at all fundamental.