

PAPER-INK INTERACTION IN NON IMPACT PRINTING

Seppo Juntunen & Jouko Virtanen
Technical Research Centre of Finland
Graphic Arts Laboratory

Abstract: In conventional printing technology the ink transfer is characterised by the effects of roughness and absorption, and by film split. Such phenomena as wetting, spreading and capillary absorption are well-recognised mechanisms of the paper-ink interaction. These mechanisms are also important in non impact printing although not in the same way as in impact printing. The effects are strongly related to quality. The relations of the various mechanisms in electrophotography, thermography and ink jet printing are analysed in this paper. The experimental results indicate that the effects of roughness dominate the formation of print quality in these processes. The surface energetic relations and absorption behaviour of the paper are also important. The evaluation of compatibility should also include determination of the polarity of the components. Absorption affects the fastness of the dots and controls the final dot size in ink jet printing. The paper summarises some of the latest results obtained in the laboratory tests and non impact printing trials concerning the basic mechanisms and the final quality of the prints.

Introduction

In non impact printing (electrophotography, thermal transfer, ink jet) the role of paper-ink interaction is in a way clearer than in conventional printing. In these processes the effects of additional pressure are minimal compared to the effects in conventional processes. This means that surface-physical/chemical interactions are very important mechanisms in NI printing.

The papers used in NI printing are mainly high-quality grades. The surface topography and the pore structure of the paper affect the print quality. The term "plain paper" means in practice "high quality, not specially treated paper".

This presentation deals with the results of some non impact printing trials carried out by the three main processes. In the trials, representative paper grades from newsprint to art paper were printed and the results were analysed with respect to print quality. Conventional and novel testing methods were used to estimate the paper-ink interaction.

Interaction mechanisms in non impact printing

Of the NI processes, thermal transfer resembles conventional printing most and ink jet printing least (which is the only truly non impact method). The familiar film split takes place not even in thermal transfer but the whole thickness of the ink film is transferred when the process is adjusted correctly. Some mechanical dot spread takes place in all the main processes. For example, in ink jet printing the ink drop has a fast phase of mechanical spreading. In the NI processes the penetration of ink is very dependent on the natural surface-chemical relations.

Electrophotography

In electrophotography, the toner has to be fixed onto the paper. Today, the hot roll fusion is the main fixing method. In this unit process the control variables are the fixing time, the temperature and the pressure. In commercial printers, the fixing time is 10-50 ms, the temperature 130-200 C and the pressure 40-55 kPa. The thermoplastic toner and the paper-ink interaction have the following phases /1/:

1. The toner is heated above its glass temperature, T_g (60-70 C).
2. The toner particles are sintered together.
3. The melted toner spreads on the paper surface.
4. The melted toner partly penetrates into the paper structure.
5. The toner cools down below its T_g .

Phases 2 to 4 obviously depend on the surface tension and viscosity of the melted toner and on the surface energy of the paper as well as on the equivalent pore radius and roughness of the paper.

Thermal transfer

In thermal transfer, the ink adhesion to the paper is enhanced by certain surface roughness. The viscosity, η , of the melted ink may be modelled by the equation

$$\eta = \eta_0 \cdot \exp(k/T)$$

where T represents the temperature and k the activation energy.

The ink transfer is controlled by the length or by the intensity of the heating pulse (the whole cycle is about 5 ms). A slight pressure is applied to enhance the transfer. The behaviour of the ink after the transfer is principally similar to phases 3 to 5 of the fixing in the electrophotographic process.

Ink jet

The inks used in the ink jet process are very fluid. In this case only the water-based inks are taken into account, which dry mainly by absorption (a water content of about 80 %).

The appearance of the printed dot is affected by the surface tension, the density and the viscosity of the ink, the drop size and the velocity, and by the surface energy, roughness and pore structure of the paper. The paper-ink interactions may be considered in two phases /2/:

- mechanical phase, and
- capillary phase.

Mechanical phase

The greater the velocity and mass of the drop when it hits the paper the more it spreads. The cohesion inside the drop and the mechanical roughness of the surface resist spreading. Immediately after the impact the drop oscillates for a moment. The mechanical phase may take a few milliseconds.

Capillary phase

The paper surface must wet before the capillary forces begin to act. The so-called wetting delay depends on the hydrophilicity of the paper. It may vary from 5 ms (chemical masses) to over 50 ms (mechanical masses) or several seconds (coated grades). It is clear that the ink jet papers should have a very short wetting delay and fast absorption.

The penetration is a viscous flow, which is driven by the surface-chemical forces. The surface tension of the ink and the surface energy of the paper, the viscosity of the ink as well as the pore structure of the paper affect this mechanism. Due to different pore sizes the speed of the absorption in the radial direction is different from the speed in the z-direction.

Fig. 1 illustrates the mechanisms of paper-ink interaction in non impact printing.

The surface-chemical mechanisms (surface energy/tension, contact angle) between the ink and the paper provide the driving force for adhesion, penetration and spreading. The roughness and the void structure of the paper, which are usually considered to be disturbing factors in the surface-chemical measurements, have to be taken into account in the interaction models.

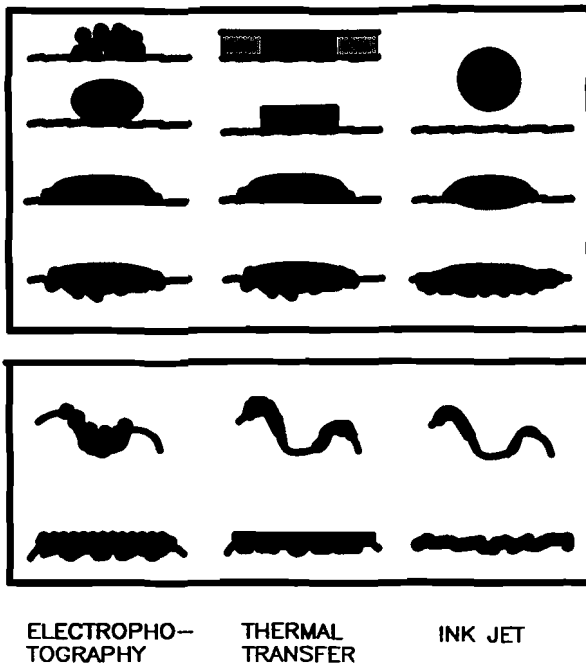


Figure 1. Interaction mechanisms in non impact printing.

Wetting

The relative importance of wetting in different non impact printing processes has not been of general interest, even though some significant studies have been reported /2,3,4/. There are few theoretical and experimental methods to characterize and use wetting to estimate the paper-ink interactions. We have used the very basic components of the adhesion theory /5,6/.

Driving force

According to the second law of thermodynamics, a free system spontaneously seeks a condition in which it expends the least energy, W . The free energy of a

system in which a smooth and compact solid surface is in contact with a liquid may be characterised by the surface energy or the surface tension of the components, γ . In general terms the driving force of wetting may be estimated by the energy level W .

Wetting may be examined in three subprocesses with different levels of free energy. There are spontaneous effects when the level of the driving force is positive.

Adhesion

The work of adhesion of a liquid to a solid describes the work required to remove the liquid from the surface. Principally it is for a solid, smooth surface (surface energy γ_s) in contact with a liquid (surface tension γ_l)

$$W_a = (\gamma_s - \gamma_l) + \gamma_l$$

where γ_l is the interfacial tension in the solid-liquid contact.

In reality, solid surfaces are rough. A rather usable roughness factor has been defined by Wenzel

$$r = A_c/A_p$$

in which A_c represents the rough contour area in the contact, and A_p is the projected smooth area.

We may also assume that wetting is not always complete. If we now define the relative contact area in wetting A so that $a = r$ in a complete contact, we may write

$$W_a = (a/r) * [r * (\gamma_s - \gamma_l) + \gamma_l]$$

Penetration

If the solid has capillaries, and their roughness is defined by r and the relative wetted area by a , the work of penetration into a single capillary gets the form

$$W_p = (a/r) * [r * (\gamma_s - \gamma_l) + [\gamma_l * (a-r)/a]]$$

Spreading

In spreading a duplex liquid film flows out over a solid surface. The film is supposed to be thick enough so that there are two independent interfaces (liquid - air and liquid - solid). The work of spreading is correspondingly

$$W_s = (a/r) * \{r * (\gamma_s - \gamma_l) + [\gamma_l * (a - 2r) / a]\}$$

Thus, all the energies W_i (<driving forces) depend on the extent of the contact between the liquid and the solid (a/r). Penetration seems to depend on the term $(a - r)$, which is negative until the wetting is complete. In the case of spreading, the term $(a - 2r)$ remains negative even after the complete wetting.

The various effects may be seen in Figure 2. Two practical examples are given in Fig. 3.

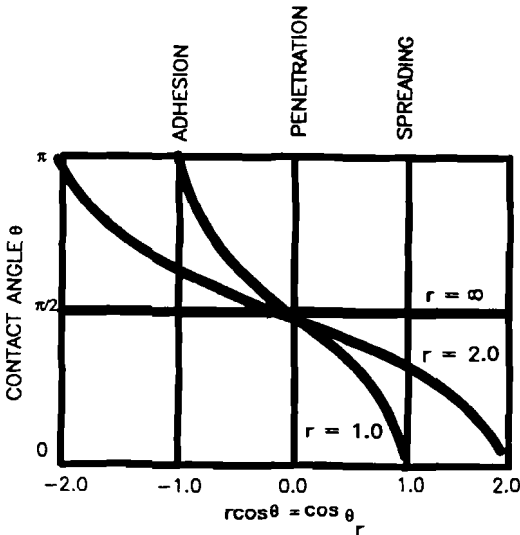


Figure 2. Wetting mechanisms and their functional regions.

Some interesting conclusions may be drawn:

- The energy of adhesion is always positive (it is always spontaneous).
- For the absorptive materials, the driving force of penetration is greater than the driving force for spreading (absorption takes place and spreading is minimal).
- The effectiveness of wetting is directly proportional to the fractional area contacted by the liquid (a/r).
- The incompleteness of the contact has a very adverse effect on penetration and spreading (the second term in the expressions).

With a complete contact ($r=a$) the equations get the forms

$$W_a = r \cdot (\gamma_s - \gamma_l) + \gamma_l$$

$$W_p = r \cdot (\gamma_s - \gamma_l)$$

$$W_s = r \cdot (\gamma_s - \gamma_l) - \gamma_l$$

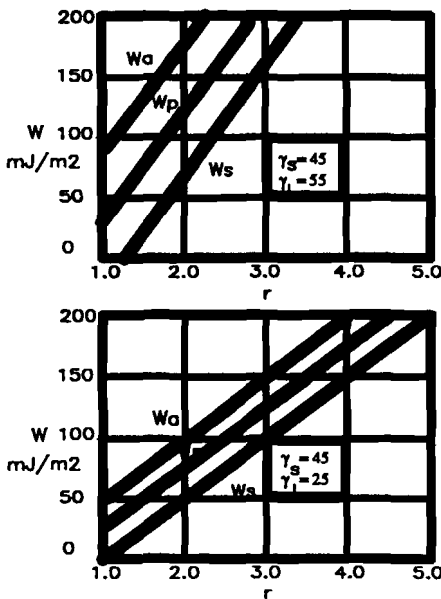


Figure 3. Energies of adhesion, penetration and spreading in two practical cases.

Cohesion

When two faces of the same liquid come into contact and neutralise each other there is a decrease in the free surface energy . This cohesion energy is

$$W_c = 2\gamma$$

From the previous equations we see that in a complete contact

$$W_a - W_s = 2\gamma = W_c$$

or

$$W_s = W_a - W_c$$

We may also see that

$$W_s = W_p - 0.5W_c$$

and

$$W_p = W_a - 0.5W_c$$

It seems clear that in practice with absorptive materials the penetration effect hides over the spreading effect.

Interaction parameter

The surface energy/surface tension is divisible into two components:

$$\gamma = \gamma_d + \gamma_p$$

where γ_p is the polar component and (due to the dipole forces)

γ_d is the dispersive component (due to the dispersive forces)

The better the components match the stronger the interaction. The interaction parameter is defined by the expression / 6/

$$\Phi = \sqrt{(\gamma_s \cdot \gamma_l / \gamma)} + \sqrt{(\gamma_p \cdot \gamma_l / \gamma)}$$

In normal conditions this parameter has a value between 0.5 and 1.0.

Roughness parameter

The roughness parameter defined by Wenzel plays a very essential role in wetting because there is roughness in all actual solid-liquid contacts. This parameter describes the "surface chemical roughness", which in fact, may be due to the

surface topography and/or the chemical heterogeneity. It characterises the surface in a way which is significant in the printing process.

Cox [7] analysed solid-liquid contacts mathematically examining surfaces with parallel grooves, surfaces with periodicity in two perpendicular directions and general non-periodic surfaces. The general non-periodic surfaces are of interest in printing. The analysis showed that moderate surface roughness causes a change in the contact angle from the value α_0 by an amount

$$\beta = \alpha_0 - 0.5 \cdot \epsilon^2 \cdot \cot \alpha_0 \langle (d_1)^2 + (d_2)^2 \rangle$$

where ϵ is the characteristic surface slope and (d_1, d_2) are squared derivatives, independent of the position. The brackets $\langle \rangle$ denote an area average.

We can see that the resultant contact angle is smaller or larger than α_0 depending on whether α_0 is smaller than or greater than $1/2\pi$. A comparison with Wenzel's relation of the form

$$\cos \beta = r \cdot \cos \alpha_0$$

shows that there is a possibility to replace the simple roughness parameter (r) by two parameters ($\epsilon, \langle \rangle$) if this information is relevant.

Spreading coefficient

The term spreading coefficient is used in the literature. It is not a multiplying factor (as the term coefficient usually implies) but refers to the work of spreading defined previously. With smooth, solid surfaces it gets the form

$$W_s = \gamma_s - \gamma_l - \gamma$$

This equation indicates that there is never any spontaneous spreading on solid, smooth surfaces if $\gamma_l > \gamma_s$ ($W_s < 0$). However, if the surface is rough, the term $r \cdot (\gamma_s - \gamma_l)$ may be greater than the surface tension of the liquid, γ_l . It is reasonable to state, that the interfacial tension γ_l gets a value that is somewhere between zero and γ_l . Assuming that the interfacial tension $\gamma_l = \gamma_l - \gamma_s$ when $\gamma_l > \gamma_s$, the spreading coefficient of a rough, absorptive surface gets the value

$$W_s = r \cdot (2\gamma_s) - (r+1) \cdot (\gamma_l)$$

and the "penetration coefficient" the value

$$W_p = 2\gamma_s - \gamma_l$$

Thus it is possible that W_s exceeds W_p (when $r*(2\gamma_s - \gamma_l) > \gamma_l$), but absorption dominates in most cases.

A simplified interaction model

Fig. 4 illustrates the wetting conditions where the edge of a droplet of liquid is depicted as retracting over an irregular solid surface of roughness r that has been completely wetted. The work of retraction is equal to

$$dE = E_1 - E_2 = r*\gamma_l + \gamma_l*\cos\theta_r - r*\gamma_s$$

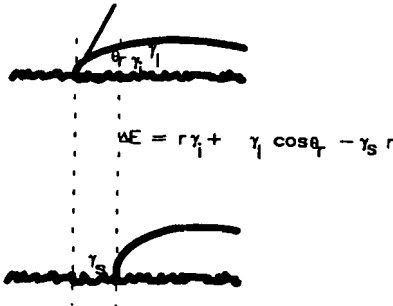


Figure 4. Energy change in retraction.

In a state of equilibrium corresponding a stable contact angle, the droplet does not tend to retract or to spread. This is the case when $dE = 0$:

$$\gamma_l*\cos\theta_r = r*(\gamma_s - \gamma_l)$$

For a completely smooth surface we may write

$$\gamma_l \cos \theta = \gamma_s - \gamma_l$$

We see that

$$r = \cos \theta_r / \cos \theta$$

And the equations for the wetting work may be written:

$$W_i = (r \cos \theta + N) \gamma_l$$

or

$$W_i = (\cos \theta_r + N) \gamma_l$$

Where N is +1 for adhesion, 0 for penetration and -1 for spreading.

This equation shows that spreading is less probable with an absorptive material. We have based our considerations of the paper-ink interactions on the following model (see Fig. 5):

Penetration/radial spread

1. When a drop of liquid is applied to a rough, absorptive surface, it immediately gains the width and height determined by the adhesion energy and roughness effects.
2. Absorption which consumes the volume of the drop begins at the same time.
3. The width of the drop cap remains constant during the process, only its height changes with time.
4. Absorption takes place in both radial and vertical directions.
5. The speed of the penetration/radial diffusion is determined by the equations

$$L_r = K_r (T - T_0)^n$$

$$L_z = K_z (T - T_0)^m$$

where T_0 is the wetting delay and K_r , K_z , n , m are coefficients which characterise liquid-paper system.

6. After a certain penetration time the radius $r(t)$ and height $h(t)$ of the drop indicate the relations of the rate constants K_r , K_z and the exponents n and m as follows (penetrated volume = $V(t)$)

$$V(t) = f_1(r(t), h(t))$$

$$V(t) = f_2(R_0, \varepsilon, L, K_z, K_r, n, m, T_0, t)$$

where the parameters ε (void fraction) and L (thickness) characterise the paper and the parameters K_z , K_r , n , m and T_0 the paper-ink interaction.

7. Depending of the volume of the drop and on the rate constants, following conditions are found the end of the process:
- a minor penetration and a minor radial diffusion (evaporation dominates)
 - a mainly radially spread drop
 - a mainly penetrated drop
 - a moderate penetration and a moderate radial spread and the liquid volume is sufficient to fill the paper structure.

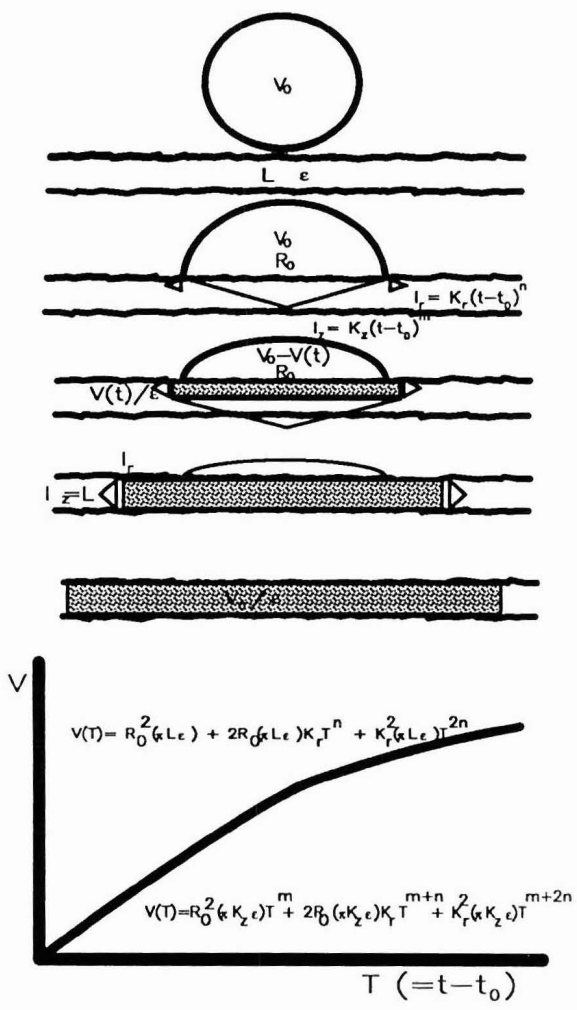


Figure 5. Simplified drop absorption model.

The effects of roughness

Roughness affects the adhesion phase and the values of the corresponding contact angle. To find out the roughness factor we measured contact angles with a tilted drop (Fig. 6). We tried to take advantage of the fact that the drop slip is hindered by a force which is a function of ($r \cdot A \cdot \gamma_i$ or $r \cdot R \cdot \gamma_i$). In the procedure, drops of different sizes were applied onto a tilted paper specimen. Advancing and receding contact angles θ_a , θ_r and also the contact length, R , were measured as a function of the drop size, V . The model is of the form

$$r = f_4(\theta_a, \theta_r, \theta_y, V, R)$$

The roughness parameter measured in this way differs from the conventional roughness estimates, such as Printsurf or Fogra-KAM. We call it surface-chemical roughness (SCR). It is an area average, which characterises the physical and/or chemical heterogeneity on the scale matching the interactions in the printing processes.

Surface-chemical characteristics

Conventional measurements of the contact angle are useful when estimating the compatibility of paper and ink. The interaction parameter can be determined by using model liquids and surfaces with different surface energies/tensions and polarities. Kaelble's approach is to divide the adhesion energy into components as follows /8/

$$W_a = \gamma_i \cdot (1 + \cos\theta) = 2(\sigma_l \cdot \sigma_s + \delta_l \cdot \delta_s)$$

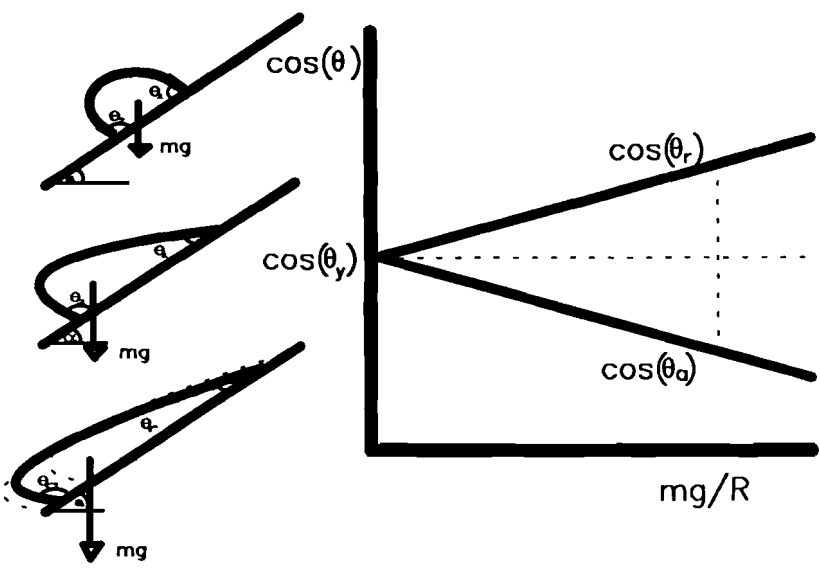
where σ_l , σ_s are the square roots of the dispersive components of the surface tension (liquid and solid) and δ_l , δ_s are the square roots of the corresponding polar components. For a series of known liquids on a solid surface to be characterised we may write

$$W_a/2\sigma_l = \sigma_s + \delta_s \cdot (\delta_l/\sigma_l)$$

and for an unknown ink on a series of model surfaces we may write

$$W_a/2\sigma_s = \sigma_l + \delta_l \cdot (\delta_s/\sigma_s)$$

Finding the correlation between (δ_l/σ_l) and $W_a/2\sigma_l$ gives a linear relationship and its parameters give estimates to unknown components σ_x , δ_x . We use ten model liquids and seven model surfaces in our tests.



$$r = (\cos(\theta_a) + \cos(\theta_r)) / 2\cos(\theta_y)$$

Figure 6. Tilted plate method.

Experiments

Paper tests

To examine the effects of the paper-ink interactions in non impact printing we carried out special laboratory tests with a number of papers which are characterised in terms of conventional measurements in Table 1. The additional tests included determination of following characteristics:

- Printsurf roughness and compressibility (surface volume and its compressibility) , PPS (μm), s1
- Fogra contact smoothness and its compressibility, KAM(%), s2
- Surface chemical roughness, SCR
- Surface energy γ (J/m²)
- Polarity PPO(%)
- Radial spreading coefficient for water, K_r ()
- Penetration coefficient for water, K_z ()
- Power of radial spreading , n
- Power of penetration, m
- Void fraction, ϵ

Ink tests

The surface chemical properties of the inks were determined by the Kaelble's method. These include

- Surface energy/surface tension of the inks, γ (J/m²)
- Polarity, IPo (%)

The interaction parameter, Φ was also calculated on the basis of the polarities of the paper and ink.

Printing trials

Printing trials were performed using commercial printers:

- Canon LBP-4 (300 dpi, electrophotography)
- Intermec 8646 (100 dpi, thermal transfer)
- Hewlett Packard Paintjet (180 dpi, bubble jet, four colours)

Test lay - outs included both compact, text and halftone areas.

Table 1. Paper grades with their characteristics measured by the conventional methods.

	Grammage (g/m ²)	Thickness(um)	Moisture content (%)	ISO-Brightness (%)	Opacity (%)	Gloss (%)	Bendtsen roughness (ml/min)	Bendtsen porosity (ml/min)	Oil absorptivity (g/m ²)
Ordinary copy paper	78	101	4.9	92.0	89.0	8.5	176	920	37.0
LWC	59	52	4.2	71.5	91.0	64.5	14	23	5.5
Newsprint	45	71	8.3	58.5	93.5	13.0	85	175	24.5
Pre-printed form paper 1	90	113	3.2	87.5	91.5	5.6	265	665	33.0
Pre-printed form paper 2	86	103	3.6	88.5	93.0	9.7	122	615	37.0
Art paper	137	115	6.2	83.5	97.0	77.5	3	24	7.5
Thermographic paper 1	165	154	5.2	81.5	91.0	15.5	67	12	16.0
Thermographic paper 2	218	267	5.9	88.5	97.0	46.0	7	19	6.0
Thermographic paper 3	172	145	4.7	76.5	92.0	18.0	62	12	6.5
Coated ink jet paper 1	95	107	5.4	83.5	88.0	8.5	41	255	13.5
Coated ink jet paper 2	97	114	3.5	90.0	88.5	10.0	44	128	19.0
Uncoated ink jet paper	66	81	4.8	91.5	88.5	6.0	190	250	13.5

Print quality tests

Dot quality

The quality of the prints was evaluated by new methods. The characteristics included:

- raggedness of the dots, DRa
- void rate of the dots, DVR
- blur of the dots, DBI
- edge gain of the dots, DEG
- mean radius of the dots, DMR
- coverage of the dots, DCo

Filing feasibility

The prints were analysed with official tests to characterise their

- water resistance, PWR
- alcohol resistance, PAR
- fastness to rubbing, PRR
- fastness to light, PLR

These properties were evaluated by densitometric measurements. The accepted performance was achieved in the tests when the density of the test print was at least 50% of its original level.

Results

Electrophotography

The effects of roughness

We can see in Table 2 that the known estimates of roughness/smoothness (Bendtsen, Printsurf, FOGRA KAM and even gloss) are useful when predicting the print result in electrophotography. The edge gain and the mean dot radius depend in this technique on the mechanical and optical roughness. The compressibility of the surface roughness (s_2) is of particular interest. The smoother and more compressible the paper in hot roll fixing the better paper-ink interaction.

The effects of absorption

In Table 2 three parameters describe the absorptivity of the paper. Porosity estimates by the Bendtsen device correlated with the mean dot radius. The effects of the oil absorbency are seen in the computational values of the dot area and coverage. The estimates of the void fraction provided by the drop absorption model correlated with the rub resistance of the prints. The radial spreading coefficient, K_r , was related to the raggedness of the dots.

Surface-chemical effects

The parameters used to estimate the surface-chemical characteristics of the papers seemed to affect the quality rather strongly. The values of the surface energy correlated with the dot quality and polarity with the tone-rendering parameters.

Table 2. Correlations between the paper state variables and the main print quality parameters in electrophotography.

	Roggedness	Area	Mean radius	Edge gain	Rub resistance
** SIGNIFICANCE LEVEL 95 %					
X: SIGNIFICANCE LEVEL 99 %					
Oil absorptivity	*	X			
Bendtsen porosity			*		
Surface energy	*		*		
Bendtsen roughness	*				
Gloss			*	*	
Printsurf 1		*	*	*	
Printsurf 2		*	*		
Fogra KAM 1				*	
Fogra KAM 2			*	*	
Fogra KAM 3			*	*	
s2				*	
Spreading coefficient Kr	*				
Void fraction					*

Thermography

The effects of roughness

The surface roughness of the paper significantly affected the void rate and rub resistance of the printed dots. The compressibility of the roughness seemed to be important, too (see Table 3).

The effects of absorption

Oil absorptivity and void fraction of the paper correlated with the void rate of the printed dots. Also the moisture content of the paper had a strong effect on the quality.

Surface-chemical effects

In thermal transfer printing, the surface-chemical relations play an important role as seen from Table 3. The interaction parameter correlated strongly with the

quality of the dots, density formation and the water/alcohol resistance of the prints.

Table 3. Correlations between the paper state variables and the main print quality parameters in thermal transfer printing.

	Raggedness	Void rate	Area	Mean radius	Edge gain	Density	Water resistance	Alcohol resistance	Rub resistance
Oil absorptivity		X							
Bendtsen porosity		*							
Moisture content	*		X	*	*	*	*	*	
Surface energy	X	X	X	X	X				
Interaction parameter	X	X	X	X	X		X	X	
Bendtsen roughness		X							
Printsurf 1		X							X
Printsurf 2		X							X
S1	X								

*: SIGNIFICANCE LEVEL 95 %

X: SIGNIFICANCE LEVEL 99 %

Ink jet

The effects of roughness

In ink jet printing the roughness (Bendtsen and Printsurf, measured under a low pressure) depicted density formation and detail rendering. Gloss correlated with the tone rendering and the surface-chemical roughness with the dot quality (see Table 4).

The effects of absorption

The penetration coefficient, K_z , correlated with the edge gain of the dots printed by the ink jet. The moisture content of the papers seemed to affect the absorption behaviour of the papers because the dot properties and the alcohol resistance were dependent on this parameter.

Surface-chemical effects

The surface-chemical properties of the papers were the dominant group in ink jet printing. Surface energy level of the paper correlated with the density formation, detail rendering, rub, and the water/alcohol resistance of the prints.

Table 4. Correlations between the paper state variables and the main print quality parameters in ink jet printing

	Raggedness	Void rate	Area	Edge gain	Density	Water resistance	Alcohol resistance	Rub resistance
Moisture content	*	*						
Surface energy						X	*	*
Bendtsen roughness								
Printsurf 1					**			
Surface chemical roughness			*	*	*			
Penetration coefficient Kz			*	*	*			

*: SIGNIFICANCE LEVEL 95 %
 X: SIGNIFICANCE LEVEL 99 %

Interrelations between the state variables of the papers

Table 5 describes the correlations between the parameters used to characterise the papers (state variables). The intercorrelations indicate that the effects of roughness distort the results of conventional porosity and absorptivity tests. On the other hand the roughness values received by air blow techniques (Bendtsen, Printsurf) are affected by the porosity of the structure. This may explain the correlations between the roughness estimates and the parameter m of the penetration equation.

Table 5. Interrelations between the state variables of the papers.

	Oil absorptivity	Surface energy	Polarity	Interaction parameter	Moisture content	Bendtsen porosity	Bendtsen roughness	Gloss	Printsurf 1	Printsurf 2	s1	KAM 1	KAM 2	KAM 3	s2	Kr	Kz	E	m	T0	Surface chemical roughness	
Oil absorptivity																						
Surface energy			X X																			
Polarity		X X																				
Interaction parameter																						
Moisture content																						
Bendtsen porosity						*																
Bendtsen roughness							X X X															*
Gloss							X X X															*
Printsurf 1							X X															*
Printsurf 2							X X															*
s1							X															*
KAM 1												X X X										*
KAM 2												X X X										*
KAM 3												X X										*
s2												X										*
Kr																						*
Kz																						*
E																						*
m																						*
T0																						*
Surface chemical roughness																						*

Interrelations between the state variables of the prints

The correlations between the main print quality parameters are in Tables 6 to 8. In the case of electrophotography (Table 6), the interrelations are rather low and predictable. It was found that void rate and blur are not so easy to separate in the electrophotographic prints by the optical measuring techniques we used.

In thermal transfer printing, roughness, void rate and rub resistance were the most independent quality parameters (Table 7). The other parameters had rather strong correlations with one another.

The quality parameters of the ink jet prints (Table 8) had also some interrelations. The mean dot radius and the edge gain seemed to be the most independent parameters.

Table 6. Interrelations between the main quality parameters in electrophotography.

	Raggedness	Void rate	Blur	Area	Mean radius	Edge gain	Density	Water resistance	Alcohol resistance	Rub resistance
•: SIGNIFICANCE LEVEL 95 % X: SIGNIFICANCE LEVEL 99 %										
Raggedness										
Void rate										
Blur										
Area										
Mean radius										
Edge gain										
Density										
Water resistance										
Alcohol resistance										
Rub resistance										

Table 7. Interrelations between the main quality parameters in thermal transfer printing.

	Raggedness	Void rate	Blur	Area	Mean radius	Edge gain	Density	Water resistance	Alcohol resistance	Rub resistance
•: SIGNIFICANCE LEVEL 95 % X: SIGNIFICANCE LEVEL 99 %										
Raggedness				X	X	X	X	X	X	
Void rate										
Blur										
Area					X	•	X	X	X	
Mean radius						X	X	X	X	
Edge gain							X	X	X	
Density								X	X	
Water resistance										X
Alcohol resistance										
Rub resistance										

Table 8. Interrelations between the main quality parameters in ink jet printing.

	Raggedness	Void rate	Blur	Area	Mean radius	Edge gain	Density	Water resistance	Alcohol resistance	Rub resistance
Raggedness		X *								*
Void rate			*							*
Blur										
Area					X					
Mean radius						*				
Edge gain							*	*	*	
Density								*	*	
Water resistance										*
Alcohol resistance										
Rub resistance										

*: SIGNIFICANCE LEVEL 95 %
 X: SIGNIFICANCE LEVEL 99 %

Conclusions

Paper roughness is the first factor to be minimised in order to reach an optimal printing result in non impact printing. Conventional estimates of roughness are useful when estimating the performance of papers in NI printing.

The compressibility of surface roughness is important in thermal transfer printing. Measurements of the contact smoothness with various pressures show the compressibility that affects the paper performance in electrophotography.

Surface-chemical roughness is an important factor in ink jet printing. This result is rather straightforward as ink jet technique is truly non impact.

It is very difficult to estimate the surface-chemical roughness of an absorptive material, such as paper. Even though a good correlation with the print results was found in ink jet printing, we realise that much more work is needed to develop a reliable routine to estimate this parameter.

Conventional absorptivity tests describe the paper structure rather restrictively. Void fraction and penetration/spreading coefficients are valuable additional data

when estimating the absorption properties of the paper. In electrophotography the spreading coefficient and in ink jet printing the penetration coefficient were found to be relevant.

The parameters that describe the surface-chemical properties of the papers or the interaction between the paper and the ink were important in all three processes. The surface energy of the paper and the interaction parameter may be used to estimate paper performance.

The simplified model for drop absorption seemed to correlate rather well with the practical results. This model facilitates the estimation of the penetration/spreading coefficients and the void fraction of the paper recognised by a test liquid. The test liquid may be chosen according to the surface-chemical properties of the ink or the toner.

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