Evaluation of Ink Transfer Theory

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Abstract: The ink transfer process has been a subject of interest for many years. Walker and Fetsko created an equation for the process in 1955. According to theory the three parameters controlling the ink transfer are immobilisation, splitting, and ink coverage (smoothness). Later, new equations have been developed, almost all based on the same theory. During recent years, some researchers have argued against the theory, because of correlation between the parameters. Also, some visual observations have created criticism against the theory. This study has concentrated on ink transfer in coldset offset printing using a rough uncoated newsprint surface. Some earlier results will be referred to also. During multi colour printing the earlier printed inks are influenced by subsequent ink coverage such that the first printed ink can flow readily under the surface fibres. This is not common if only one colour is printed, but the situation seems to be very sensitive to the amount and viscosity of the inks printed.

Introduction

This study is concentrated on the ink transfer mechanism in coldset web offset (CSWO) printing on relatively rough newsprint, and its simulation on the laboratory scale using a Prüfbau laboratory printing device. Generally, ink transfer in a printing nip has been discussed widely. Reviews for the item have been published (Parker 1973 published 1976, Oittinen and Lindqvist 1981, Mangin et al. 1982, Lyne and Aspler 1982, De Grace and Dalphond 1989). Ink transfer has often been presented in a form of mathematical equations. The oldest and best known equation for the ink transfer was created by Walker and Fetsko (W-F) (1955), as presented equation (1):

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$$y = A[bB(1-f)+fx] \quad (1)$$
$$A = 1 - e^{-kx}$$
$$B = 1 - e^{-x/b}$$

with

- y: the ink amount on paper (g/m^2)
- A: the 'coverage function', or the fraction of the area covered by ink
- k: a 'printing smoothness' parameter (m^2/g) indicates how fast full contact is reached between the substrate and an in-creasing ink film x
- B: the 'immobilisation function', or the fraction of the immobilised ink
- b: the immobilisation capacity of the substrate under a given set of printing conditions (g/m^2)
- f: the splitting factor
- x the total ink amount on the printing plate or blanket (g/m^2).

For smooth printing substrates k >0.5 and b<1, while for rough papers k <0.5 and b> 5. These figures can vary considerably depending upon ink rheology, and especially viscosity. Because A is the fraction of the area covered by ink and B is the fraction of the immobilised ink, it could be assumed that $B \leq A$. However, such a relation is not always found e.g. Chou and Tasker (1994).

As in equation (1) ink transfer is commonly divided into the following stages; coverage, immobilisation, and splitting. During splitting it is considered that the portion of ink penetrated into capillaries could 'rise away' from wider capillaries (Oittinen 1976). In addition, at the end of the splitting the compressed paper could revert to its original form thereby creating widening of capillaries which creates further ink absorption (by suction). However, penetration by aspiration after the printing nip may only be theoretical and as Oittinen and Lindqvist (1981) have noted, over that period measurements of the magnitude of the penetration have not been possible.

The mathematical parameters and related functions should describe paper properties such as smoothness and absorption. The difficulty in establishing such a relationship with paper properties has been one reason for doubting the theory. It has been found also that the parameters describing coverage, immobilisation and splitting have either been too high in variation, or the parameters inter-correlate (Mangin et al. 1982, Chou and Tasker 1994).

Evaluation of the ink transfer process has often been achieved using sheet fed offset inks and coated paper grades. Letterpress newsinks and newsprint paper grades have been used also in these studies. Today the coldset web offset printing (CSWO) method dominates newspaper printing. From the ink transfer perspective these printing processes differ from each other. Low shear viscosity, which is important for ink coverage, is much higher in the case of sheet fed inks than for CSWO, e.g. 20-50 Pas and 10-15 Pas respectively. In sheet fed offset printing, it is usual to use anti set-off powders to prevent set-off. Thus, it is possible to print with higher amount of inks to reach a required high print density. Letterpress newsinks have a lower viscosity than CSWO inks.

In letterpress printing, higher ink amounts are used because the inks are less pigmented (about 12%) compared with CSWO inks (about 20%). The higher pigmentation of CSWO inks and the higher tack and viscosity help in printing with a lower ink transfer to paper. Approximately 1.5-2 g/m^2 is sufficient for achieving the target print density. This ensures less dot gain, lower print through, and less set-off. Less than 4 g/m^2 in the printing nip is needed as the amount of ink transferred is above 50%. However, much higher ink amounts up to 25 g/m^2 have often been studied. It might not be a surprise that the ink transfer mechanism is different for lower and higher amounts of ink. It is concluded e.g. (Walker and Fetsko 1955, Chagas and Baudin 1996, and Nordstöm and Grön 1998)) that with low ink amounts, ink coverage dominates the ink transfer, followed by immobilisation, and splitting which covers the larger ink amounts.

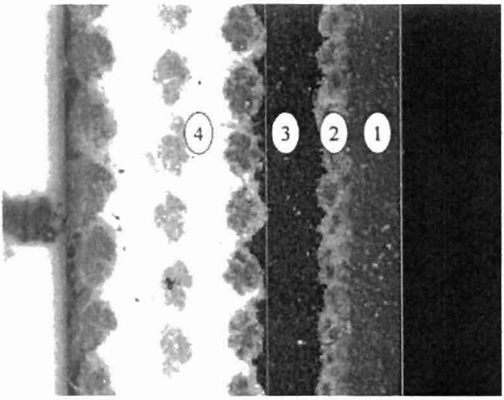
Ink transfer in CSWO printing to uncoated, rough paper

Compressible rubber blanket

For analysing ink transfer it is necessary to study the materials performance in the printing nip. Oittinen and Lindqvist (1981) have pointed out that the distribution of pressure in the nip is dependent upon the ink, the paper, and the rubber blanket. However, the overriding factor is the behaviour the rubber blanket in the input and middle of the nip. The reason is that the blanket is the most compressible material of the three.

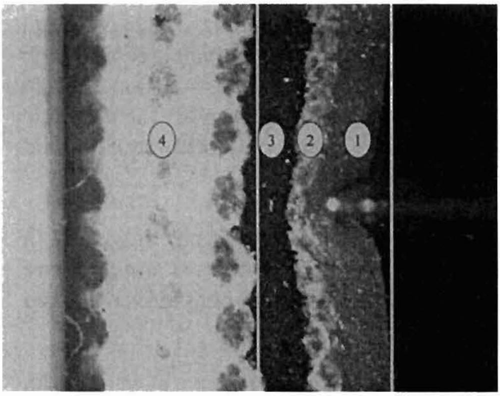
The offset blanket is not only compressible but also conformable. As an example, Figures 1-3 illustrate a range of performance behaviour for an offset blanket. Figure 1 shows an offset blanket in its original form; while Figure 2 shows the ease of deformation under the action of 50 µm wide screw driver. Figure 3 illustrates the compressive behaviour of the blanket and the resilient nature of the rubber surface under the action of a 1 mm screw driver.

Figures 1-3 illustrate that the rubber surface can accommodate a small scale roughness variation, while the compressible nature of the blanket controls the larger thickness variation of paper. The rubber can 'penetrate' into the surface voids of paper carrying ink to the surfaces located on the lower level of the roughness profile. The deepest and steepest voids avoid this penetration.



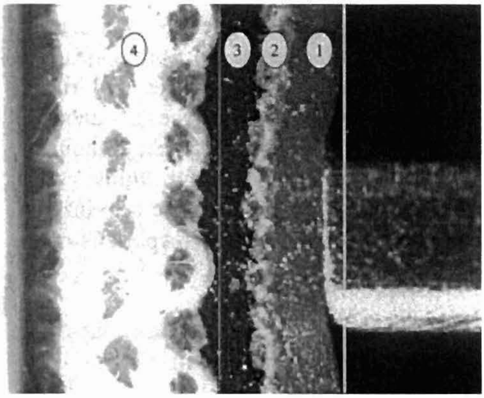
1. Surface rubber layer, 2. Stabilizing fabric ply, 3. Compressible layer, 4. Base fabric ply

Figure 1. Cross section of a compressible offset blanket.



1. Surface rubber layer, 2. Stabilizing fabric ply, 3. Compressible layer, 4. Base fabric ply

Figure 2. Cross section of a compressible blanket, with localised deformation arising from a 50 μm wide screw driver. The rubber layer is not damaged.



1. Surface rubber layer, 2. Stabilizing fabric ply, 3. Compressible layer, 4. Base fabric ply.

Figure 3. Cross section of a compressible blanket, as deformed by 1 mm wide screw driver.

In offset newspaper printing, paper, ink, and blankets enter into the printing nip with a speed of about 10 m/s at an average pressure about 2 MPa. The schematic is shown in Figure 4. The nip time duration is about 1-2 ms.

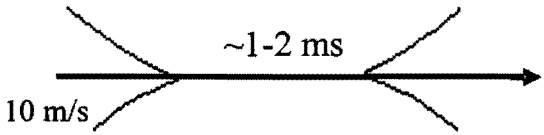


Figure 4. The elements entering the printing nip: ink, paper, and blanket.

When printing with an IGT laboratory printing press, using small ink amounts with both coated and uncoated papers Singh et al. (1996) found that the best fit for the coverage results (with $r^2 > 0.97$) was reached using Hsu's (1962) coverage equation $A/(1-A) = kx^n$, where A is the covered area and x is thickness of the ink film on a printing form; k and n are constants which do not cross-correlate, while k correlated with roughness of the papers studied. In the same study the coverage function of the W-F equation, and that also for Karttunen's (1970) equation did not fit the printed results.

It is known that the changes taking place within the printing nip involve both movement and compression. Within this 'violent' regime, it is important to establish which of the elements is the weakest to respond to both movement and compression.

The easiest moving element is the printing ink, due to its liquid form. Ink can move away easily from, say the gap between a topmost fibre and blanket. Hsu (1962) has calculated the effect of paper roughness on the changes in ink film thickness within a printing nip. Also, the topmost fibres are often seen clear of ink while the ink has been seen to locate on both sides of the fibre edges. The second moving element is the rubber surface of the offset blanket. The rubber can conform to the roughness profile of paper. The surface of uncoated newsprint has a steep shape profile. That is why the rubber can not contour the profile completely, but moves towards the wider gaps and voids (width approximately 20-100 μm) located between fibres, transferring the thin ink film to the lower parts of the surface profile. In this way the le s steep walls of the voids can be covered by ink.

During the nip dwell time, compression of blanket and paper takes place. The behaviour of rubber is similar to a liquid in that it maintains its volume under pressure, unlike the compressible layer and support fabric of the blanket. It is obvious therefore that the bulk of the blanket, about 2 mm thick, cannot be deformed to conform to the roughness profile. However, it can accommodate the wider areas like the thickness variation in the millimetre scale. In the area of 0.1-1 mm, there are the roughness variation of newsprint, along which both the rubber surface and the whole compressible blanket might conform.

Both the body and surface of newsprint are able to compress. The space between layered fibres contracts first when the topmost fibres transfer the pressure to the fibre matrix. The compression of fibres themselves is negligible. When the pressure against the topmost fibres increases, the fibres start to intrude into the paper body. This generates further pressure in the paper body creating movement of both fines and fibres without breaking bonds. In this way the surface becomes smoother and better contact can be reached with the ink film on the blanket.

During the time of compression of blanket and paper, and movement of the rubber surface, ink flows in the direction corresponding to the lowest counter pressure. This flow is controlled also by the viscosity of the ink. The counter pressure is mainly created by surface forces. It is also said (De Grace and Mangin 1984 and 1987) that air between the ink layer and the paper running into the nip, and especially the air in the surface voids of the paper, could also generate counter pressure preventing ink intrusion to the surface voids. On the other hand, the good air permeability of newsprint reduces the influence of air.

The ink film on the bottom of the voids has been found to be as thin as on the higher level of the roughness profile. This situation does not tell about a remarkable ink flow to the surface voids. That is why it is also concluded that the capillary spreading into offset printed newsprint paper surfaces is over-estimated in many studies (Gregersen et al. 1994).

Coverage in multi-colour printing

In newspaper printing a solid 4-colour black consists of 240-280% tonal coverage depending, inter alia, upon the level of under colour removal (UCR). The printing sequence can vary from one printing site to the other. Generally, the colour and black inks are printed on top of each other, and more ink is transferred to the paper surface than in single colour printing. The ink transfer in the first printing unit is aided by nip pressure and the surface contour of both blanket and paper. The new ink transfer to the paper surface has the ability to push the first ink further into the surface voids.

From the cross sectional images, there is clearly greater penetration with multi colours than with mono colours (Figures 5 and 6). On the other hand, we can not see the coloured inks as separate films as it appears for rotogravure 4-colour printing (wet-on-dry). In the printing nips during wet-on-wet multi-colour printing the inks appear to be ‘more or less’ mixed with each other. The portion of the ink which lays deep within the surface voids does not split further due to a lack of contact with the blanket of the subsequent printing unit. This type of ink flow to the larger surface voids is not simply the capillary penetration as caused by hydraulic pressure, but rather a mass flow caused by kinetic energy of the subsequent transferred ink.

Figure 5. A typical picture of CSWO 1-colour newspaper printing (black)

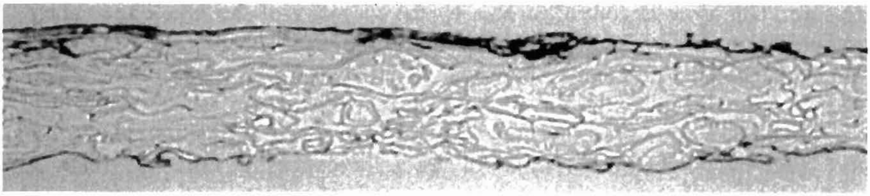


Figure 6. A typical picture of newspaper CSWO 4-colour printing.

Evaluation of the immobilisation

The immobilisation parameter of the W-F equation correlates well with the splitting factor with newsprint grades (Mangin et al. 1982), and the smoothness parameter for smooth coated grades (Chou, and Tasker 1994). In both examples the immobilisation factor could have been neglected and compensated by the other parameters. The main emphasis in the literature is that the term immobilisation is equal to penetration. However, e.g. Walker and Fetsko (1955), and also Nordström and Grön (1998) have combined it also with surface roughness.

For the case of 1.5-2 g/m^2 ink transfer to paper, roughness has a big influence on ink location on the surface of newsprint together with possibility for ink immobilisation. The high viscosity of ink prevents the penetration into smaller capillaries with insufficient ink to fill any larger surface voids (Särelä 2001). This phenomenon restricts real penetration for mono printing. However, the soft conformable rubber surface of a blanket can spread ink on a wider area via penetration to the larger surface voids. This may also increase the part of the immobilised ink.

Immobilisation in multi colour printing

During multi colour printing the first printed inks are pushed deeper into the surface voids by any subsequent printed inks, and therefore do not participate in any ink splitting. More ink can be seen under the surface fibres with some vehicle separation from the ink film taking place during the time interval between the printing units. All these processes increase the amount of immobilised ink.

Back transfer from larger voids may take place which could decrease the immobilisation of the inks (Oittinen 1976). In CSWO newspaper printing, the ink amounts are so small resulting in minimal back transfer, even for 4-colour printing.

Evaluation of splitting

Ink splitting is influenced by printing nip conditions. If a printing nip is symmetric in terms of geometry and surface properties, or both surfaces of the nip are similar with ink evenly spread on both surfaces, then ink splitting should be symmetric. However, ink splitting is seldom 50/50 between paper and blanket in practice.

For smooth papers, the ink fraction transfer to paper is often less than 50%, compared with more than 50% for rough papers. The higher values are due to penetration of ink into the paper structure while for lower values due to smoothness of non-penetrating papers; this transfer is influenced by the counter pressure of air (De Grace and Mangin 1987).

Studies of printing blankets as a partner in ink transfer are not often published except for Chagas and Baudin (1996). However, there is considerable information in the www home pages of blanket producers. The roughness values of the blankets vary considerably between 2-12 µm whereas Ifra has proposed a value for newspaper printing of 1 µm. The difference may be symptomatic of the measuring method. However, the rough surface is able to accommodate a high share of ink compared with a smoother one.

At the end of the nip, both paper and blanket are in a compressed and conformed state. Nip pressure and the rubber blanket ensure the progression of ink to the widest possible extremity. The flattened surface of newsprint and the rubber surface of the blanket separate from each other and the ink film between them splits. As more ink film remains on the paper surface than on the rubber surface, the rubber release from the paper departs without any ink splitting taking place in a part of the transferred ink film area. Some share of the ink not in contact with the rubber surface may well progress deeper into the paper voids.

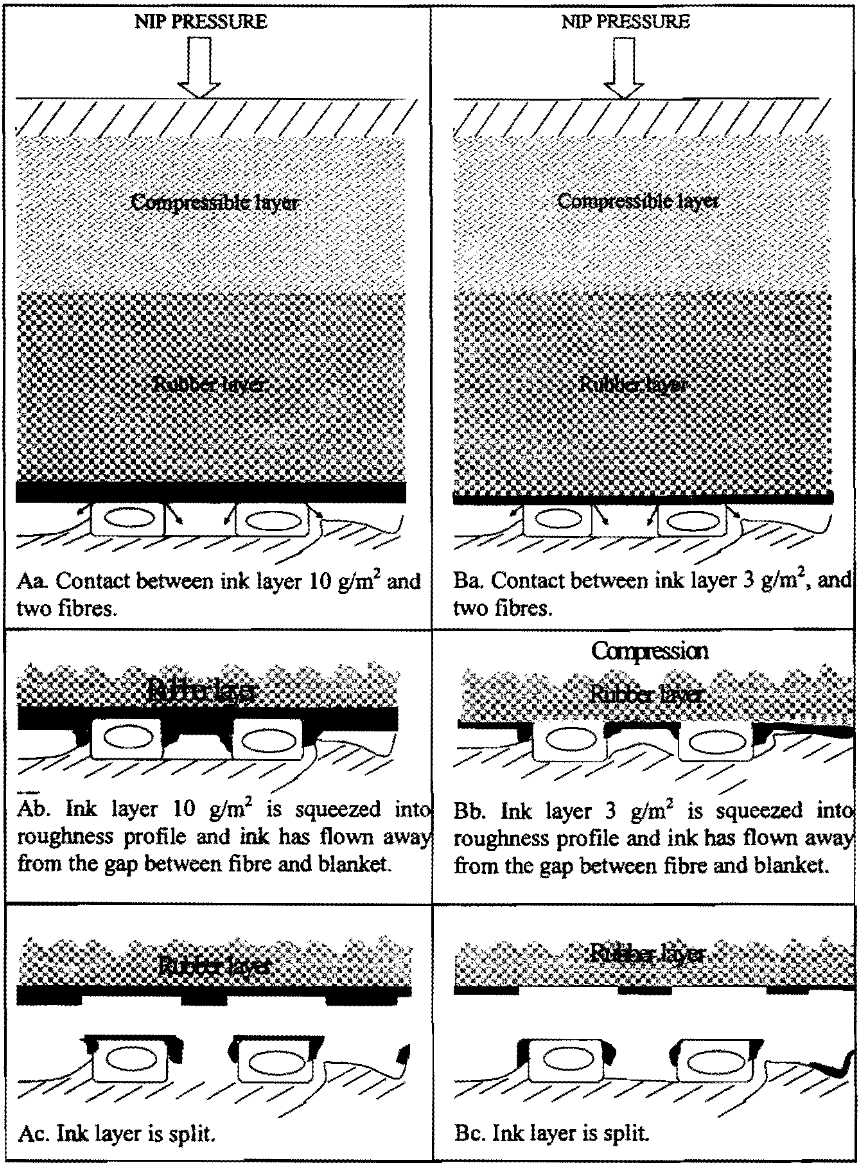
Figure 7 illustrates the ink transfer to the newsprint surface using different film weights 10 and 3 g/m^2. No compressibility has been taken into account on the left column. Instead, the pictures of the right column illustrate the impact of paper compression and conform of the blanket upon the contact between paper and ink film. Thus, during the splitting stage, more ink remains on the paper surface.

Larger surface voids (Figure 7) create non contact areas with no ink splitting. The amount of ink remaining without splitting may be smaller or larger depending upon the rheological properties of the ink. Higher speed will decrease the amount of transferred ink.

Pressure distribution in a printing nip on the rough newsprint surface

The surface of newsprint for CSWO printing can be divided into both fibre and fines areas (Särelä 2001). The fibre area consists of surface fibres and is practically closed for printing ink and its components. This is because the pores of the fibre walls can be opened only upon water saturation (Maloney 2001). The fines area can be porous and is located between the surface fibres. There is often a narrow gap around the surface fibres where ink or solvent could flow (Figures 5 and 6).

Newsprint surface is rough and the roughness is inhomogeneous. Surface fibres are commonly on the higher level of the roughness profile and the fines areas form in the lower level recesses. The surface fibres located on the upper level are referred to as topmost fibres. In a test (Haapoja 2000), the surface of a newsprint sheet was compressed between a glass prism and an offset blanket. The contact picture between the class prism and the paper surface could be taken with a CCD camera, and analysed by an image analyser. When the impression pressure was increased the contact area increased also. The first contact was made with the topmost fibres with an increasing surface contact dependent upon the applied pressure. It can be assumed therefore that the topmost fibres carry the highest load of the nip pressure. Essentially the whole body compression of paper is generated by the pressure applied to these fibres with a distribution throughout all the paper fibres. The fines area and the possible hydraulic pressure applied via the thin ink layer play a minor roll in the compression of the paper. This situation explains how surface compression impacts upon the smoothening of paper in a printing nip.



Aa. Contact between ink layer 10 g/m^2 and two fibres.

Ba. Contact between ink layer 3 g/m^2, and two fibres.

Ab. Ink layer 10 g/m^2 is squeezed into roughness profile and ink has flown away from the gap between fibre and blanket.

Bb. Ink layer 3 g/m^2 is squeezed into roughness profile and ink has flown away from the gap between fibre and blanket.

Ac. Ink layer is split.

Bc. Ink layer is split.

Figure 7. Examples of ink transfer 10 g/m^2 (left) and 3 g/m^2 (right) on the rubber blanket. On the right drawing also compressibility of the paper and conformability of the blanket have been taken into account.

Fibres normally used for newsprint production are between 20-40 μm in width. In a microscope study of newspaper printing, the topmost fibres were practically devoid of ink. The ink between the fibres and blanket was squeezed to the edges of the fibres. The non-inked area was about 20 μm wide due to the rounded nature of the fibre. Some fibres had collapsed, but not calendered flat, and had a groove in the middle of the fibre surface. The depth of the groove was found to be 2-3 μm. This groove area was normally covered with ink, but the narrow line on both sides of the groove was clear of ink. Clearly in this case, the high pressure had squeezed the ink aside. In addition, smaller areas located on the top-level of the surface profile were not covered by ink with no clear indication as to where the ink was directed. The excess ink was located somewhere around the small surface. On the other hand, there were holes or voids and cavities not covered by ink. These holes were too deep to have contact with the ink layer. Overall, the ink film on the paper surface was not continuous.

An interesting question is how high the level of pressure has to rise to clear the ink from the topmost fibres. The following chapter illustrates mathematically the impact of nip pressure upon ink transfer. For a simpler solution the situation has been approximated to that of a fibre and a smooth incompressible plate.

Flow of the ink between fibre and a plate

The flow of the incompressible liquid with constant viscosity can be described by Navier-Stokes equation (2) (Bird et al., 1960).

$$\rho \frac{Dv}{Dt} = -\nabla p + \mu \nabla^2 v + \rho g \tag{2}$$

with,

ρ:	density
D:	substantial time derivative operator
v:	velocity
t:	time
∇:	nabla operator
p:	pressure
μ:	viscosity
g:	earth gravity acceleration

In order to apply this equation the physical circumstances must be clearly defined. In many cases it means that the existing geometry must be simplified and irrelevant terms be ignored from Equation (1) in order to allow the solution.

In our study the real geometry and the simplified geometry are shown in Figure 8.

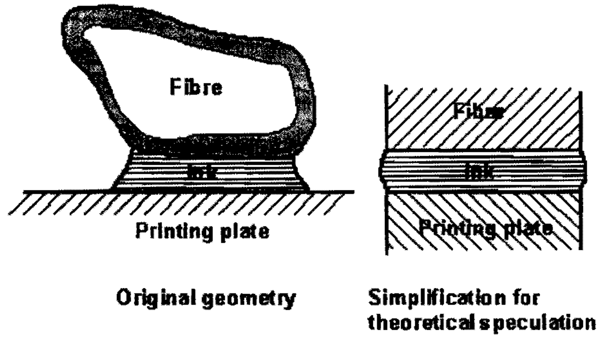


Figure 8. Schematic representation for the contact between fibre, ink and printing plate. The right hand diagram illustrates the simplified theoretical case.

The geometry of the contact between fibre, ink and printing plate is defined in Figure 9. The surfaces of printing plate and fibre are assumed to be parallel within a distance h. This space is filled by ink, which has a viscosity μ. The width of the contact zone between fibre and printing plate is 2L. The length of the contact zone is b. The fibre moves towards the printing plate at a velocity v_p.

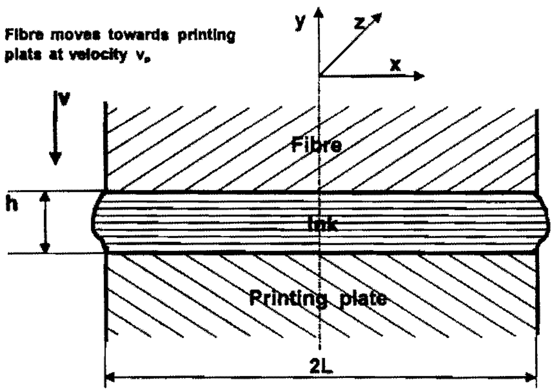


Figure 9. Definition of the geometry in contact between fibre, ink and printing plate.

The ink is compressed from the gap by the motion of the fibre towards the printing plate. The distance between fibre and printing plate is much smaller than the width of the contact area. Therefore in the theoretical speculation the influence of the flow of the ink in z-direction is ignored and the ink motion only in x-direction is considered. Navier-Stokes equation (2) for the motion in x-direction is as shown in Equation (3) (Bird, et al., 1960).

$$\rho(\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}+v_z\frac{\partial v_x}{\partial z})=-\frac{\partial p}{\partial x}+\mu(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}+\frac{\partial^2 v_x}{\partial z^2})+\rho g_x \quad (3)$$

with,

∂: partial derivative operator

x,y,z rectangular coordinates

Equation (3) is simplified further by ignoring the components caused by changes of v_x in other directions than the x-direction. The viscosity of the printing ink is high and therefore the influence of inertia forces is neglected. The effect of gravity is further ignored. This yields Equation (4).

$$\frac{\partial p}{\partial x}=\mu\frac{\partial^2 v_x}{\partial x^2} \quad (4)$$

From Equation (4) follows the Equation (5) (Yuan, 1967).

$$\frac{\partial p}{\partial x}=-12\mu\frac{v_{av}}{h^2} \quad (5)$$

with,

v_{av}: average ink velocity in x-direction

h: thickness of the ink layer between fibre and printing plate

Based on the continuity of mass flow, at the distance x from the centre line is valid

$$v_{av}=\frac{xbv_p}{hb}=\frac{x}{h}v_p=\frac{x}{h}\frac{dh}{dt} \quad (6)$$

with,

b: length of the contact area of fibre and printing plate in the fibre axis' direction

By combining the Equations (5) and (6) we get Equation (7).

$$\frac{dp}{dx}=-\frac{12\mu\frac{dh}{dt}}{h^3}x \quad (7)$$

The integration of the equation on both sides gives the pressure distribution between the fibre and printing plate.

$$p = \frac{6\mu \frac{dh}{dt}}{h^3}(L^2 - x^2) \qquad (8)$$

with,

L: half of the width of the contact area between fibre and printing plate

Because the distribution is parabolic, the mean value is 2/3 from the peak value. The integration of the pressure over the fibre surface gives the value of the total force acting via ink between printing plate and fibre.

$$F = 2b\int_0^L p\,dx = 8\mu b \frac{dh}{dt}\left(\frac{L}{h}\right)^3 \qquad (9)$$

with,

F: total force acting via ink between fibre and printing plate

Equation (9) illustrates how various factors influence the force acting between fibre and printing plate in a printing situation.

If we assume that force F is constant, we can develop Equation (9) further. By integrating the Equation (9) with respect of time we can calculate the time needed to change the thickness of the ink layer from h_1 to h_2. This is expressed in Equation (10).

$$\Delta t = \frac{4\mu b L^3}{F}\left(\frac{1}{h_2^2} - \frac{1}{h_1^2}\right) \qquad (10)$$

with,

Δt: elapsed time when the thickness of the ink layer changes from h_1 to h_2

h1: thickness of the ink layer at the beginning of the inspection period

h2: thickness of the ink layer at the end of the inspection period

Force F can be taken out from Equation (10) and it gives Equation (11).

$$F = \frac{4\mu b L^3}{\Delta t}\left(\frac{1}{h_2^2} - \frac{1}{h_1^2}\right) \qquad (11)$$

Force F can be replaced by average pressure in ink and it gives Equation (12).

$$P_{av} = \frac{2\mu L^2}{\Delta t}\left(\frac{1}{h_2^2} - \frac{1}{h_1^2}\right) \qquad (12)$$

with,

P_{av}: average pressure in ink layer.

Equation (8), (9), (10) (11) and (12) can be used to describe the ink-flow phenomenon between printing plate and single fibre. This helps to get a more comprehensive view of the printing process.

In the numerical examples the following values are used:
- The width of the contact surface between fibre and printing plate may vary from 10 to 40 μm.
- Length of the contact area is 0.5 mm
- The thickness of the ink layer at the beginning of the inspection period is 3 μm.
- The residence time in printing nip is app. 1 ms. As first estimate for the fibre velocity towards the printing plate it is assumed that the thickness of the ink layer approaches 0 in 1 ms. This gives the velocity 0.003 m/s.
- The viscosity of the ink is 10 Pas.

Example 1.
Pressure distribution in contact point is defined by Equation (8) and maximum value of pressure is reached when x=0. Mean pressure is 2/3 from that. Based on this equation the mean pressure is calculated and the solution is in graphical form as Figure 10.

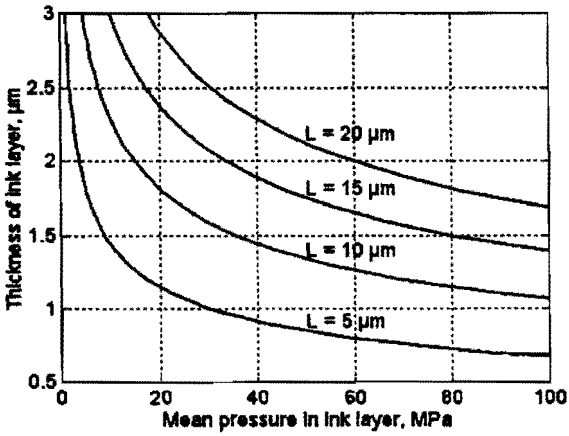


Figure 10. Mean pressure in the ink layer as function of the thickness of the ink layer. The half of the fibre width L of the contact area is a parameter. The thickness is reduced by speed 0.003 m/s.

Example 2.
Calculation of how the size of the average pressure influences on the thickness of the ink layer in printing nip.

From Equation (12) we can solve Equation (13).

$$h_2 = \sqrt{\frac{1}{\frac{P_{av} \cdot \Delta t}{2\mu L^2} + \frac{1}{h_1^2}}} \tag{13}$$

The solution of the Equation (13) is shown in graphic form in Figure 11. We know that app. 5% of the substrate surface is in contact with printing plate in the nip. We know also that the average pressure in the printing nip is app. 2 MPa. Thus the average pressure in the contact area is app. 40 MPa. This approximation gives the situation when almost all of ink is squeezed away from the surface of a topmost fibre as often seen in the microscope pictures.

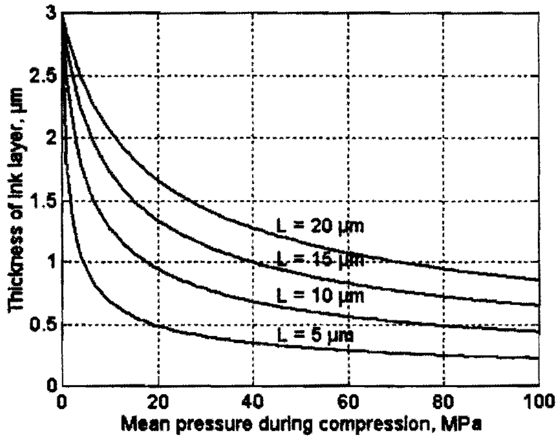


Figure 11. The thickness of ink layer as function of mean pressure during the compression. The chance happens in 1 ms. The half of the fibre width L of the contact area is as curve parameter.

Conclusions

The ink transfer within the printing nip in CSWO printing is dependent upon the properties of the printing surface; nip pressure and geometry; ink rheology and the amount on the blanket; blanket properties, and the printing speed. This is a very complex situation.

The parameter that has created confusion most towards the understanding of ink transfer is the amount of ink transfer within the printing nip. In CSWO printing, the ink film thickness is lower than with letterpress or sheet fed offset to minimise smearing. The penetration of ink within the printing nip appears to be dependent upon the ink amount on the blanket. In some cases (Gregersen et al. 1994, and Jäättelä 1996) as for mono printing, the amount of penetration was negligible. However, in this study with 4 colour printing, the ink penetration is clearly defined.

Roughness and compressibility of newsprint dominates ink transfer together with blanket properties. There is very little published work referring to the role of blankets other than within this conference.

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