# Insight into Set-off Phenomenon in Coldset Web Offset (CSWO) Printing

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Abstract: During the last decade the number of 4-colour pages in newspapers has increased rapidly. Concurrently, the print density level has risen to achieve better print quality. These developments have increased ink volume on paper and smearing. Smearing deteriorates print quality. Different explanations have been given for the smearing defined as set-off. The study concentrates on finding different parameters important for the set-off phenomenon. In the presentation the following factors are discussed: 1) location of printing ink on and in the surface structure of paper, 2) setting of ink during the time period between printing nip and set-off situation, and 3) creation of the contact between facing paper and ink layer on printed sheet.

## Introduction

As one of the main paper grades the total production of newsprint was globally over 37 million metric tonnes in 1999 (James et.al., 2000). The large majority of that was for newspapers and their supplements printed using coldset web offset (CSWO). Some books and also newspaper type periodicals are also acceptable as coldset offset printing matter. Standard newsprint is largely used but a lot of special uncoated newsprint grades (MFS) have been launched onto the market. Only few coated grades are acceptable in coldset offset. The main reason for that is smearing of non-drying ink in the CSWO process.

In the middle of the last decade IFRA launched the quality competition emphasising good quality, colour printed newspapers. During recent years the number of 4-colour pages has increased rapidly in newspapers. At the same time the print density level has risen to achieve better print quality. These developments have

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increased ink volume on paper and smearing, too. For environmental and economical reasons, paper development has decreased the consumption of raw materials and increased the use of recycled pulp (DIP) leading to lower basis weight and a different paper structure. DIP based newsprint has been found to smear less than a virgin fibre based one (Fuchs et.al. 1996 and 1997, Jäättelä, 1996, Brinkman 1997, Haapoja, 2000). Smearing deteriorates print quality by giving a dirty character to the printed matter.

Definition of the Set-off Phenomenon in CSWO Process

Smearing is a common term for any kind of unacceptable ink transfer from and to the printed paper. Also, elements of a printing machine can be smeared by ink and paper based materials. Terms like rub-off, set-off and second impression set-off describe more exactly the type of smearing.

Set-off is one of the biggest problem limiting the development of CSWO print quality. Set-off takes place when a printed sheet is pressed against a facing paper and wet ink is transferred onto the surface of another sheet which is called 'counter paper', or 'facing paper', fig. 1.

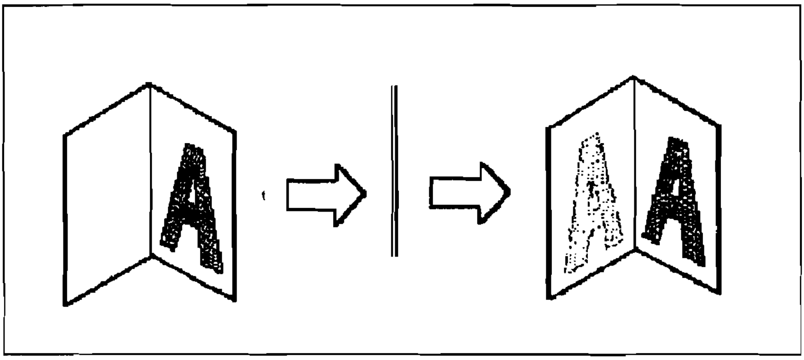


*Fig. 1. Set-off takes place when printed sheet with wet print is squeezed against another sheet (Haapoja, 2000).*

Measuring and predicting methods for set-off can be divided into two categories: 1) set-off printing, and 2) testing paper properties and ink from a set-off point of view. Measuring set-off is defined, e.g. in SCAN standard P 36:96. The standard does not give any time called set-off time between printing and the set-off nip. It tells only how to measure the results of set-off. In lab scale some printing devices like IGT or Prüfbau are commonly used. With these lab presses it is possible to vary the set-off time. When paper, ink, printing conditions and set-off time are chosen in lab scale printing one can see the set-off resulting from certain printing conditions. However, the printing nip geometry and use of fountain solution in lab scale printing, differ from full scale printing. The results are only loosely related to production printing, however, they are generally of the same order. The properties measured from paper and printing ink are often correlated with set-off results, and mathematical models can be developed. It is relevant, however, to understand in which way the parameters affect the phenomenon and what to do for developing better materials and printing processes.

## Characterising Surface of Newsprint for CSWO printing

Standard newsprint is an uncoated and slightly calendered paper grade. Newsink does not dry but it only sets by absorption. That is why the newsprint has to have certain properties. The most important properties for CSWO printability are roughness, compressibility, and surface pore structure. Newsprint is made of mechanical pulp or deinked pulp or their mixture. Chemical pulp is seldom used in standard newsprint production. The pulps contain fibres and fines fraction. Thus the surface of uncoated newsprint contains also these pulp fractions. In the micro scale the surface can be divided to two different kinds of areas: 1) fibre area and 2) fines area located between fibres.

## Roughness of Newsprint vs. Set-off

Newsprint is a relatively rough paper grade. The depth of the whole roughness profile is about 20 μm but you can find deeper voids as well. Roughness of paper plays an important role both in the printing nip when ink is transferred, and in the set-off situation. In transferring ink to a rougher surface more ink or more impression pressure is needed to produce a target print density and even print. In the set-off situation the rougher surface of both the printed and the counter sheet allows less contact for ink to transfer. Ink can also 'hide' in the roughness profile. A higher ink amount generally causes more set-off but roughness helps to have a cleaner sheet after printing. Roughness is thereby a contradictory property of paper.

Fig. 2 shows that the roughness profile could be divided into four parts:
1) the contact area where the blanket without ink can contact the paper surface,
2) the upper void area where ink can be transferred and also set-off can take place,
3) the lower void area where ink can be transferred but no set-off can take place, and
4) the deepest voids with no ink. They form an insufficient area (white spots), which should be avoided in paper making.

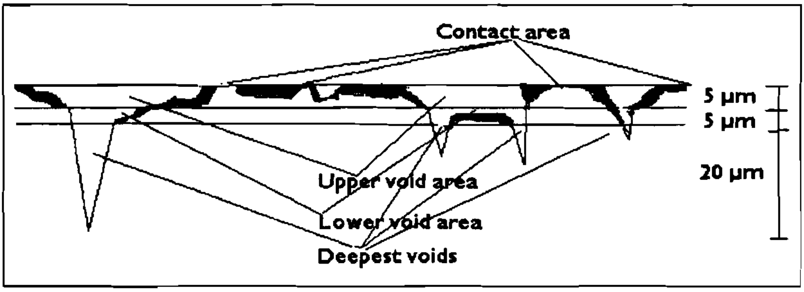


*Fig. 2. A model drawing of newsprint roughness profile with ink distributed on it.*

The dimensions shown in fig. 2 give an approximate idea of the scale. The actual values depend also on printing conditions. It is for example to find ink at a depth of 10 µm. The depth where you can see ink depends on the distance from the topmost fibre. The further sideways the location is from a local peak, the deeper one can find ink. If a void in the paper surface is very steep and deep it cannot take ink at all. (Helle, 1994, Jäättelä, 1996).

Compressibility of Paper Surface

Not forgetting that an offset blanket is compressible, the paper surface is compressed by the printing nip pressure and it compresses also in situations where the set-off takes place. The printing nip situation is very dynamic and the duration is only ca. 1 ms. Obviously, the paper surface behaves viscoelastically, or time depending, in such a situation. The longer the time, the more compression takes place. There have been experiments by Lyne (1976), and Heikkilä (1997) to develop methods for measuring the dynamic compression of paper, especially the dynamic contact area, but the methods have not been developed for practical use.

Compressibility of the paper surface also seems to be important for ink transfer in the set-off situation. It decreases total roughness volume and increases the probability of the ink layer to have contact with the paper surface on the micro scale. The greater the compressibility, the deeper the ink can be transferred into surface voids. In the set-off situation the surface compressibility increases the probability of sufficient ink contacting the facing paper when set-off can take place. Compressibility is, like roughness, a contradictory property of newsprint. Higher compressibility gives a better printing density but increases the probability for set-off.

Compressibility is usually measured with roughness meters using an air flow method like Parker Print Surf or a Bendtsen tester set at different pressures.

## Penetration of Ink vs. Ink Setting

Pore structure on the paper surface is not homogenous. The surface fibres form a matrix oriented more or less in the machine direction (MD). Between the fibres there are larger or smaller areas of fines which are commonly on a lower level than the topmost fibres.

In fibre areas there are some fibre pits but these do not dominate the surface pore structure. Most of the surface area of fibres is virtually closed for ink components. Conversely, fines areas are porous. The porosity depends on the properties of fines and possible mineral fillers. Luukko (1999) classified the fines into two groups: flakes and fibrils. Basically, we can say: the finer the material the better the bond ability and the finer the pore structure. The matrix of fibres and fines material between fibres dominates the pore structure of the whole surface. Water removal in the paper making process can leave some fines in a surface void or it can strip fines away when the void becomes open. Table 1 illustrates the fractionation in size for the surface holes of newsprint. In practise, the holes are not normally round in shape.

*Table 1. A fractionation in size of diameter for the surface holes of newsprint.*

| | | |
|---|---|---|
| Capillaries: | < 4 µm | exist in fines area. The pore structure is not well known. |
| Voids or cavities: | 4 - 40 µm | exist often in the angle formed by adjacent fibres. Often non-inked area. |
| Recesses: | 40 - 400 µm | often fines area, between long fibres or shives. |
| Specialities:<br>• the gap width round a fibre is about 1 µm or even less, and is probably formed by the shrinking of fibres and fines during drying. It does not exist around every fibre.<br>• fibre pits can allow some ink/solvents to flow into lumen.<br>• larger recesses between fibre flocs are more porous than the average of the paper surface because of weaker local calendering. | | |

It is assumed that ink can be squeezed by nip pressure into the surface pores of paper during printing. Fig. 3 shows the situation of one pore. It is possible that ink could be squeezed into the capillary not only from above it but also around the opening of the capillary. To make the calculation easier it is assumed that the ink can be penetrated from the 60 degree half cone above the capillary.

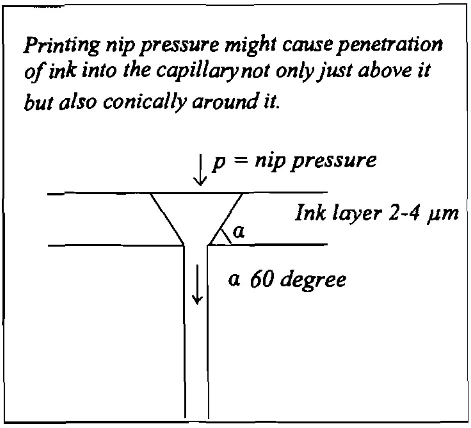


*Fig. 3. Imagined picture of penetration by nip pressure.*

Using the situation described in fig. 3 the penetration depth is drawn in fig. 4. One can see that only the capillaries smaller than 1-2 μm radius are filled by ink so much that we can say that significant penetration takes place. Larger capillaries can be filled only a little.

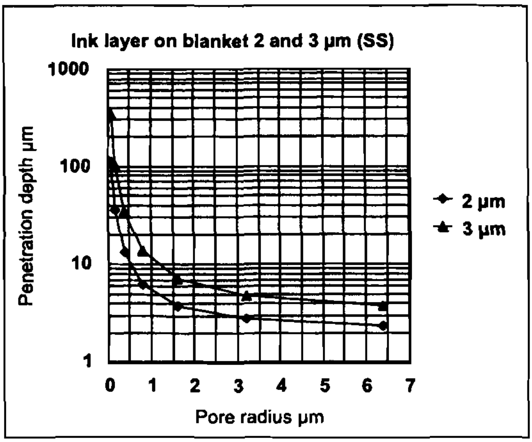


*Fig. 4. Calculation from fig. 4. Maximum possible penetration depth in μm if all the ink from 60 degree half cone above the capillary pore is penetrated into it.*

From the Poiseuille's equation of the flow through a capillary the equation (1) for calculating the penetration's depths caused by external pressure can be developed :

$$l = \frac{r}{2}\sqrt{\frac{p \cdot t}{\eta}} \qquad (1)$$

where $l$ is penetration depth in given time $t$, $r$ is capillary radius, $p$ is external pressure and $\eta$ is viscosity of liquid.

In Prüfbau lab printing with 50 mm printing disc, 10 kN/m line pressure and a 5 mm nip width, the average nip pressure is 2 MPa and the nip time 5 ms with 1 m/s printing speed. The same pressure on a commercial press can be calculated with 20 kN/m nip pressure, 10 mm nip width, and printing speed 10 m/s when nip time is 1 ms. Because nip pressure is not constant over the nip width these average figures are rough approximations. The 2 MPa pressure and 1 ms time have been used in fig. 5 where the penetration by nip pressure has been drawn in function of pore radius calculated by equation 1.

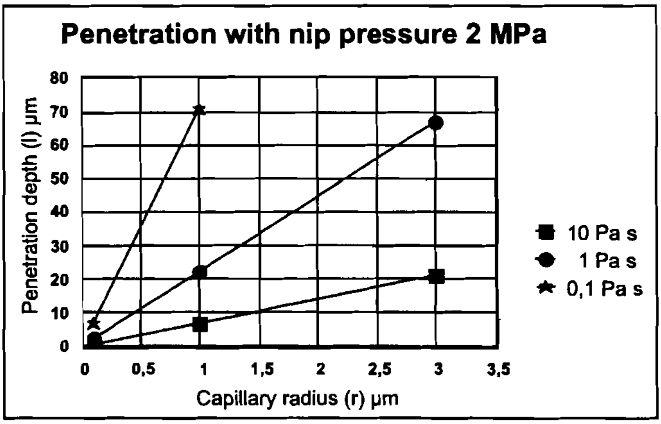


*Fig. 5. Penetration depth calculated by equation 1.*

The penetration depth is strongly dependent on the viscosity of the liquid. Viscosity of commercial CSWO inks is about 10 Pa.s depending upon shear rate. The flow speed into a capillary is surprisingly low, about 10 mm/s and thus the flow is laminar.

The topmost fibres take care of most of the pressure. At lower levels of the roughness profile the pressure is smaller depending on, for example, the viscoelastic compressibility of the paper surface. In addition the pressure pushes the ink to flow a little sideways, away from topmost fibres where one can see non-inked fibres.

There is no external pressure after printing nip. Only capillary forces can take care of absorption. Because there is a lack of ink in larger pores the flow can continue only into the smaller pores completely filled by ink. There is enough time after the printing nip for capillary absorption. That is why it is surprising that clearly penetrated ink within microtome cross sections and microscope studies is seldom seen (Helle 1994, Jäättelä 1996). Several reasons for this can be found:

1) The flow caused by the capillary forces can continue only as long as the flow is continuous.

2) Ink flow into capillaries is limited in a steric way by larger particles of ink components especially ink pigments and fillers. The mineral filler particles, and the real ink pigment particles formed by crystals' aggregation can be several micrometers in diameter, Breslin et al (2000), that can restrict penetration into smaller pores.

3) The lowest viscosity components tend to flow quickest in such a pore structure (compare paper chromatography). That is why it is expected that the higher viscosity concentrate near the capillary openings prevents absorption.

Both theoretical evaluation and practical findings prove that CSWO ink does not penetrate significantly into paper pores. Another reason for ink setting should be found.

## Ink Setting by Solvent Separation

Setting of ink via solvent separation is well known in sheet fed offset printing. Offset ink contains low viscosity, often non-drying oil which escapes in a few seconds from the ink into the pores of the paper or board coating. It is also possible to fine-tune the setting by manipulating coating pore structure. The pore structure of newsprint is not as homogenous as it is in coated grades. There are, however, capillary pores in the fines area. Set-off decreases remarkably in a few seconds after printing. CSWO inks contain such low viscous oil components as solvents. The solvents can leave the ink layer by surface forces of the paper, and by capillary forces in the fines area.

Lab set-off test printing is often done by transferring different amounts of ink onto paper. If a smooth coated grade is used as the set-off counter paper the set-off print can be analysed using a microscope. With a lower amount of ink transferred the set-off print contains mainly imprints of the topmost fibres. The imprints are often double lines from fibre edges. Greater volume of ink creates more set-off also from fines areas. So, it is understandable that the pore structure of the fines areas is very important for reduction of set-off.

Falter (1975) found that set-off of mill papers after 15 s delay time correlated significantly with the specific surface area (BET, low temperature nitrogen or argon gas adsorption method of Brunauer, Emnet and Teller), the higher the BET value the less the set-off. In the study of Jäättelä (1996) the specific surface area of the newsprint surface was measured using scanning electron microscope stereo pictures. The papers giving less set-off had the larger specific surface area. The amount of oil in the ink able to penetrate into pore structure is small. It can fill only the smallest capillaries when capillary forces take care of absorption. Another way is flow principally along the surface of the pores and paper materials. In this case oil does not need to fill pores. Then the specific surface could be more important than capillary structure itself. On the other hand the finer capillary structure gives the higher specific surface area.

Solvent separation from the ink composition is obviously a complex process. Basically, it is a competition between cohesion forces of the ink components and adhesion forces between solvent and paper component parts. A common rule is: the easier a solvent can dilute binder the more difficult the solvent separation is. The solvent with low molecule weight and no functional groups can move easier from the ink layer.

## Connecting set-off to rub-off

Rub-off and set-off have often been investigated together but not always with parallel results. Basically, in both cases ink is removed from the paper surface. In the set-off case ink has not set completely whereas in rub-off it has. The strength of the ink layer in set-off is very weak, while in rub-off it is stronger but still weak. Rub-off should be imagined as the work of fingers of a reader.

## Process Analysis of Set-off Phenomenon

In table 2 the set-off phenomenon is summarised into three stages: 1) location of printing ink on and in the surface structure of paper, 2) setting of printing ink by solvent separation and absorption prior to set-off, and 3) creation of the contact surface between counter paper and ink layer, and ink transfer onto pressing paper during set-off situation.

The main components of the phenomenon seem to be:

- Roughness and surface compressibility of newsprint.
- Specific surface area of paper surface.
- Capillary structure in fines area.
- Ink properties for solvent separation.
- Time delay after printing nip.
- Pressure in set-off situation.

Less ink is required to achive a specific print density if the paper has higher brightness, and less ink gives lower set-off. If brightness differences need to be compensated within the measurement of set-off, the absolute scale of a densitometer could be used.

Printing process design varies from site to site. Papers and inks can have different raw materials. The time delay from printing nip to set-off situation depends on printing speed, press layout and the mailing operation. These variations mean that the final solutions for controlling set-off problems have to be unique to every printing house. The ideas presented in this paper can function as an initial path for creating better newspapers for advertisers and readers.

*Table 2. Parameters and process analysis of set-off phenomenon. The following aspects need to be taken into account for assessing paper, ink and printing conditions from a set-off point of view.*

| 1. Location of printing ink on and in the surface structure of newsprint and influence on set-off. | |
|---|---|
| Parameters | Influence on set-off and other remarks |
| Roughness of paper surface and its reduction via compressibility in a printing nip: | The more paper compresses during printing nip time the deeper ink transfers into roughness profile and the less small non-inked areas exist. Less ink is needed for target print density. Less set-off. Print through + and -, because less ink but deeper. |
| Dwell time in printing nip and viscoelasticity of paper surface: | The longer time in printing nip the more compression of paper surface and the deeper ink is transferred into roughness profile. Less small, non-inked areas exist. Less set-off. Print through + and -, because less ink but deeper. |
| Impression pressure in printing nip: | Same influences as dwell time. |
| Flexibility of offset blanket: | Compressible part of blanket follows variations of paper formation and thickness decreasing the need of nip pressure. It gives more even print in the scale of formation and thus decreases ink requirement. The topmost rubber layer of blanket is elastic in small scale roughness variations giving more even ink coverage in fibre width scale thus decreasing ink need. Conclusion: compressible blanket has more + than - influences on set-off. |
| Ink rheology, especially viscosity: | Lower viscosity adds the probability that the whole ink would penetrate into larger surface capillaries decreasing set-off (see scaling of capillaries in table 1). Obviously the nip dwell time is too short for solvent separation. |

*Table 2 cont.*

| 2. Setting of printing ink by solvent separation and absorption prior to set-off: | |
|---|---|
| Parameters | Influence on set-off and other remarks |
| Dense elements like collapsed fibres, shives and hard calendered spots located on the topmost surface: | Having easy contact with counter paper and preventing solvent separation the elements increase set-off and its unevenness.<br>The hard calendered spots depend on formation of paper and calendering type. |
| Fines area between surface fibres, and fillers: | The porous areas speeds up ink setting by solvent separation decreasing set-off.<br>Fines areas contain capillaries. Strongly bound fines form tighter areas where the capillary absorption of solvent is weaker.<br>Fillers increase porosity. |
| Setting time of ink before a set-off situation: | The longer setting time the less set-off. It is possible that a little set ink is more prone to smear. As a rule in beginning of setting time set-off propensity decreases the quickest. |
| Binder/resin solubility into solvent of ink: | The weaker the solubility the easier solvent separation leading to quicker ink setting, and to less set-off. |
| Viscosity of ink solvent: | Lower viscous solvent can move easier in ink layer by diffusion, progressing solvent separation and thus decreasing set-off. |
| Viscosity of ink: | A solvent can move quicker by diffusion in lower viscose ink giving faster solvent separation thus decreasing set-off.<br>Nip pressure can push lower viscous inks deeper into roughness profile and into larger capillaries thereby increasing print through. |
| Ink pigment: | Ink pigment influences mostly in steric way on solvent separation. Spherical particle shape inhibits less the separation than plate shape of ink pigment particles. |
| Interaction of ink components: | One component can interact with others in the multi component system of a CSWO ink. This interaction is not well understood, especially in the case of solvent separation. |

*Table 2. cont.*

| 3. Creation of the contact surface between counter paper and ink layer, and ink transfer onto pressing paper during set-off situation. | |
|---|---|
| Parameters | Influence on set-off and other remarks |
| Compression of the printed paper surface in set-off situation: | The ink layer can reach more contact with fibre matrix and fines area of counter paper if the printed paper surface compresses. This increases set-off. |
| Roughness of counter paper | Less contact with ink, less set-off. |
| Compression of the counter paper: | Adds contact surface and thus set-off. |
| Pressure and dwell time in set-off situation: | Both increase contact area and set-off. |
| The stage of ink setting; shrinking and hardening of ink layer | Solvent separation makes ink layer thinner decreasing probability to contact counter paper giving less set-off. Well set ink does not necessarily adhere, although it contacts the surface of counter paper. |

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