A New Model to Predict Ink Transfer on Coated Paper in Multiple Nips

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Abstract: A model relating the ink transfer in multiple nips to the ink/paper setting rate is proposed. The model differs from previous work in that the effects of ink/paper interaction in multiple nips and printing speed are included. In addition, the model is based on physical properties of the ink and substrate that can be measured independently. The model is based on the idea of a filtercake on the paper surface during the process of ink setting. The thickness of free splitting film in a printing nip depends on the growth rate of the filtercake. Laboratory printing tests can be used to characterize the ink/paper setting rate. This model predicts the correct trends of the experimental data and agrees with experimental observations that a fast setting surface receives more ink than a slow setting surface. The model is important to predict ink density differences from point to point, related to variation in coating properties. Therefore, the occurrence of backtrap mottle may be predicted.

Introduction

For coated papers with a similar surface finish, the print density was solely determined by the amount of ink transferred on to the surface [Zang & Aspler, 1998). This suggests that print mottle problems with coated paper are caused by the non-uniform ink film deposited on paper surface and the importance of accurate prediction of ink transfer in evaluating how paper properties and their interactions with ink affect the final print.

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.

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Traditionally, experimental data of ink transfer are often interpreted with the Walker-Fetsko model [1953]. In this model, ink transfer is divided into three partly components-coverage, immobilization and splitting. They considered that there was incomplete contact at low ink levels and that there was insufficient ink to satisfy the ink-immobilizing capacity of paper. In addition they suggested that the non-immobilized free ink between the plate and the paper surface could be divided with any constant fraction, depending on the ink-paper-press interaction. Based on these assumptions, following equation was proposed by Walker-Fetsko:

$$y = A[bB + f(x - bB) \qquad (1)$$

where y is amount of ink transferred to paper, x is amount of ink on plate, A is the coverage function $A= (1-e^{-kx})$, B is the immobilization function $B=(1-e^{-x/b})$, and k, b and f are empirical constants that need to be found by printing trials. This equation or its simplified model has been widely used to interpret ink transfer phenomena in *single color printing*. Later on, many modified models on this equation have been proposed by other researchers (Karttunen *et al*, 1971; Bery, 1978; Yamazaki, 1991; Zang, 1993] to better interpret the ink-paper interaction during printing, mainly by modifying the coverage function or introducing other new features. Mangin et al (1982) did a critical review on major ink transfer models and found that all were able to fit certain experimental data, but none of them accurately described the physical phenomena involved in ink transfer. Zang (1993) proposed a modified Walker-Fetsko model by introducing a new splitting function that not only fitted the experimental well but also yielded realistic ink-transfer parameter.

Recent studies (Xiang & Bousfield, 2000a) have demonstrated the importance of ink-paper interaction/ink-setting rate in determining the amount of ink transferred onto paper surface. Ink-setting rate does not significantly influence the print density in single color printing but significantly influences final print density on the surface in multi-color printing. In a multi-color printing, paper with faster setting rate has a higher print density than the paper with slower setting rate. The paper surface may receive a uniform ink film in single color printing, but non-uniform distribution of ink-setting rate in surface will create a non-uniform ink film in multi-color printing because of backtrap in the upcoming printing nips. This findings suggest that the amount of ink transferred to paper changes in the coming nips of multi-color and the final ink kept on the surface depends not only on the amount of ink on the plate but also on the ink-paper interaction/ ink setting rate. However, in the Walker-Fetsko equation or other modified equations, the effect of ink setting rate and the dependence of time ink transfer are not separately included. The immobilization function in these models is a complex quantity that combines the effect of the dwell time, paper porosity, pore size, and ink viscosity in a single nip. They cannot be applied to interpret ink transfer phenomena in multi-color case and to evaluate the effect of ink-paper interaction/ink setting rate on ink transfer.

In the course of this work, a new model, relating the ink transfer to the ink/paper setting rate and fundamental properties of ink and paper, is proposed. These physical properties are possible to measure in the laboratory, such as volume fraction solids of the ink, ink surface tensions and coating pore size. Application of the model to analyze the ink transfer in multiple nips is discussed. Compared to the previous experimental observation on a wide range of coated papers with different ink setting rates, the new model seems to predict the correct trend.

Model Development

One picture of ink setting process in the multi-color printing is the motion of ink vehicle or mobile phase into the coating layer, as depicted in Figure 1. Because the ink pigment particles are on average too large to penetrate the finer coating pores, they are filtered out on the coating surface. Recent work by Ström *et al* (2000) verifies this assumption. As the mobile phase penetrates into the coating, the thickness of filtercake increases, and in turn, the thickness of the free ink layer would decrease. This decrease results in an increase transfer of ink to the sample because more ink pigments are transferred to the paper.

In Figure1, V_0 is the initial volume of ink per unit area, and V_s, V_f and V_p are the volume of free splitting film per unit area, the volume of filtercake per unit area and volume of mobile phase per unit area absorbed by the coating, respectively. From mass balances, we have

$$V_s = V_0 - (V_f + V_p) \tag{2}$$

and

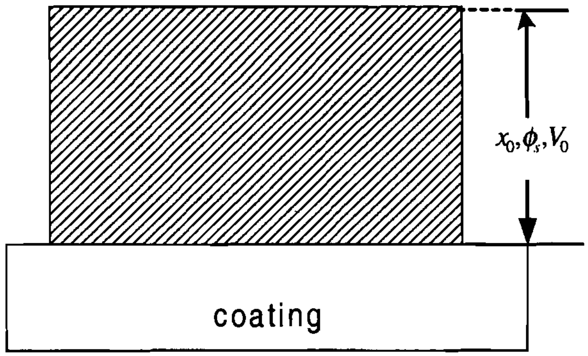
$$V_f = \frac{V_p \phi_s}{(\phi_f - \phi_s)} \tag{3}$$

where ϕ_s and ϕ_f are the volume fraction of solid in the ink and ink filtercake, respectively, and λ is the thickness of the filtercake. The volume of the ink per unit area transferred to the paper *V(t)* is

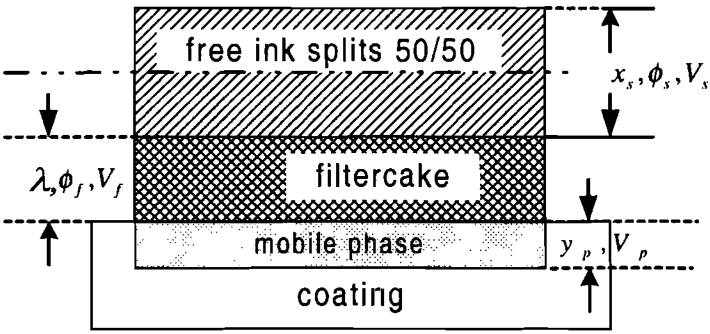
$$V(t) = V_p + V_f + (V_0 - V_f - V_p)f \tag{4}$$

where t is time and that f is the split ratio of the free ink. Eq (3) and Eq(4) combine to give

$$V(t) = V_0 f + \frac{\phi_f (1-f)}{\phi_f - \phi_s} V_p \tag{5}$$



a. Initial Ink Film at Time $t = 0$



b. Time $t = t_i$

Figure 1 Formation of filtercake and free ink splitting

From our previous paper (Xiang & Bousfield, 2000b), we have found that volume of mobile phase per unit area absorbed by the coating is

$$V_p = \sqrt{\frac{4Kt\gamma\phi_f(1-\phi_s)\cos\theta}{\eta\phi_s R}} \tag{6}$$

where K is Darcy coefficient, R is the radius of the capillary, γ is surface tension, θ is the contact angle, and η is the viscosity of the fluid phase. Combining Eq(5) and Eq(6) and replacing the volume of ink per unit area with the thickness of ink, we obtain the thickness of ink layer transferred to coating surface $y(t)$as

$$y(t) = fx_0 + C\sqrt{t}(1-f) \tag{7}$$

where x_0 is the initial thickness of ink film on the printing plate and $C = \sqrt{\frac{4Kt\gamma\phi_f{}^3(1-\phi_s)\cos\theta}{\eta\phi_s R(\phi_f - \phi_s)}}$ can be defined as the ink-paper interaction parameter which is a measure of ink setting rate. Eq(7) is the main result of our theoretical work which states that the amount of ink transferred on to the paper is proportional to the amount of ink on the printing plate, the ink-paper interaction parameter/ink-setting rate, and the square root of the dwell time in the nip or the contact time before splitting. If we assume a 50/50 split of the free ink ($f = 0.5$), the equation (7) becomes

$$y(t) = \frac{1}{2}(x_0 + C\sqrt{t}) \tag{8}$$

For simplicity, Eq. 8 is used in the cases discussed below.

An Analysis of Ink Transfer in Multi-Color Press

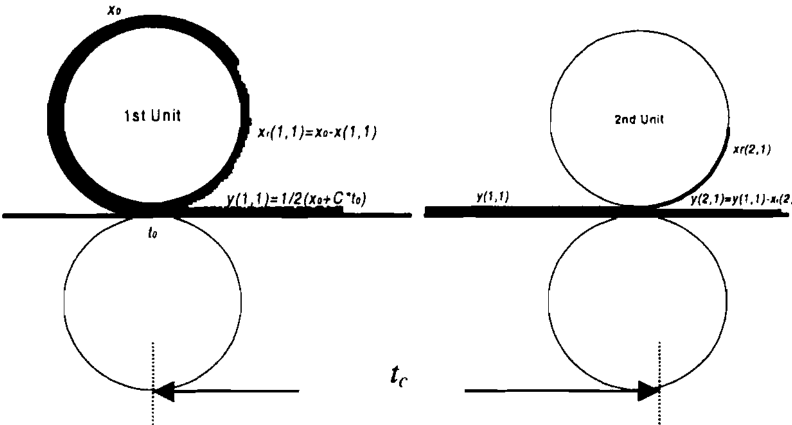
As illustrated in Figure 2, if x_0 is the ink film thickness on plate or blanket of the first unit before printing and t_0 is the nip dwell time of the paper, from Eq. 8 the ink thickness transferred onto the first sheet can be expressed as

$$y(1,1) = \frac{1}{2}(x_0 + C*\sqrt{t_0}) = \frac{1}{2}(x_0 + B_1) \tag{9}$$

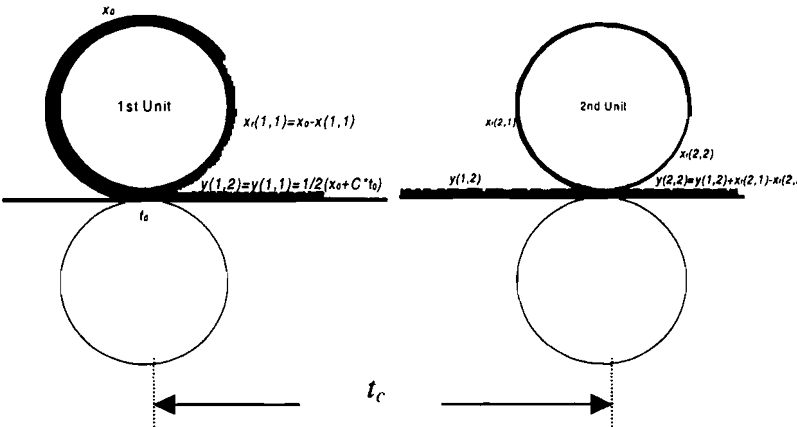
where C is the ink-paper interaction parameter and B_1 equals to $C*\sqrt{t_0}$.

If we assume that the ink thickness on the first unit is held constant from one impression to another through a continuous ink feeding by the inking system, the ink transferred to the sheet will be the same for a certain paper:

$$y(1,1) = y(1,2) = y(1,i) = \frac{1}{2}(x_0 + C*\sqrt{t_0}) = \frac{1}{2}(x_0 + B_1) \tag{10}$$



(a) First sheet



(b) Second sheet

Figure 2 Ink transfer in the 1st unit and 2nd unit for the first sheet (a) and second sheet (b).

After a time interval of t_c, the printed sheet with an ink thickness of $y(1,1)$ passes the second nip (unit 2). If 50% of the free ink is transferred to the blanket of the second nip, for the first sheet the ink thickness remained on the sheet after the second nip is

$$y(2,1) = \frac{1}{2}\left[y(1,1) + C * \sqrt{2t_0 + t_c}\right] = \frac{1}{2^2}(x_0 + B_1) + \frac{1}{2}B_2 \qquad (11)$$

where $B_2 = C * \sqrt{2t_0 + t_c}$.

The ink thickness transferred to the blanket of the second unit from the printed sheet is

$$x_r(2,1) = y(1,1) - y(2,1) = \frac{1}{2^2}(x_0 + B_1) - \frac{1}{2}B_2 \qquad (12)$$

For the second printed sheet, ink thickness remained on the sheet after the second nip is expressed as

$$y(2,2) = \frac{3}{2^3}(x_0 + B_1) + \frac{1}{2^2}B_2 \qquad (13)$$

For sheet i,

$$y(2,i) = \frac{2^i - 1}{2^i}(x_0 + B_1) + \frac{1}{2^i}B_2 \qquad (14)$$

Where $a_i = 2a_{i-1} + 1 = 2^i - 1$.

Similarly, we can obtain the ink thickness remained on the sheet after nip 3 and nip 4.

After nip 3:

$$y(3,i) = \frac{2a_i - i}{2^{i+2}}(x_0 + B_1) + \frac{1}{2^{i+1}}B_2 + \frac{1}{2^i}B_3 \qquad (15)$$

where $B_3 = C * \sqrt{3t_0 + 2t_c}$, $b_i = (2b_{i-1} + i)$ and $a_i = 2^i - 1$.

After nip 4:

$$y(4,i) = \frac{(c_{i-1} + b_i)}{2^{i+3}}(x_0 + B_1) + \frac{d_{i-1} + i}{2^{i+2}}B_2 + \frac{i}{2^{i+1}}B_3 + \frac{1}{2^i}B_4 \qquad (16)$$

Where $B_4 = C * \sqrt{4t_0 + 3t_c}$ and $d_i = c_i - 2c_{i-1}$.

Correspondingly, if sheets are printed in the first nip, the ink amount (x_r) transferred onto the blanket in nips 2, 3, and 4 can be calculated.

On the second nip:

$$x_r(2,i) = \frac{a_i}{2^{i+1}}(x_0 + B_1) - \frac{a_i}{2^i} B_2 \quad (17)$$

Where $a_i = 2^i - 1$.

On the second nip:

$$x_r(3,i) = \frac{b_i}{2^{i+2}}(x_0 + B_1) + \frac{i}{2^{i+1}} B_2 - \frac{a_i}{2^i} B_3 \quad (18)$$

Where $b_i = (2b_{i-1} + i) = 2(2^i - 1) - i$.

On the fourth nip:

$$x_r(4,i) = \frac{c_i}{2^{i+3}}(x_0 + B_1) + \frac{d_i}{2^{i+2}} B_2 + \frac{i}{2^{i+1}} B_3 - \frac{a_i}{2^i} B_4$$

Effect of Ink-Paper Interaction on Ink Transfer

The new ink transfer equation makes it possible to predict the effect of ink-paper interaction on ink transfer in multiple nips.

Figure 3 and 4 show the effect of ink-paper interaction parameter on ink amount on paper after second nip and after fourth nip, respectively, when the paper is printed in the first nip with ink thickness of 5 μm (x_0) on the blanket. In the calculation, the nip dwell time of the paper (t_0) is 0.25s and the time interval (t_c) is 0.5s. For given paper, ink amount remained on the paper surface increases initially with the running of the press and reaches equilibrium after around 8 or 9 revolutions. Note that this number to reach the equilibrium seems to be very close to practical number observed from the printing trial. More important thing shown in Figure 3 and 4 is that ink amount remained on paper before and after the equilibrium increases with increasing the ink-paper interaction parameter (C). This indicates that ink transfer onto the paper after multiple nips increases with the ink setting rate and non-uniform ink setting over paper surface will result in a non-uniform ink film, and in turn, a print mottle problem. Figure 5 shows the changes of ink remain through the nips for the first paper printed in the first nip. We see that the difference in ink remain between papers with different ink-paper interaction parameters increases with the nip number and the biggest difference is found after last nip (4th nip) for the 1st paper. However, for given paper, this difference in ink remain after each nip is reduced with the running of press as shown in Figure 6 for a paper with C=0.1.

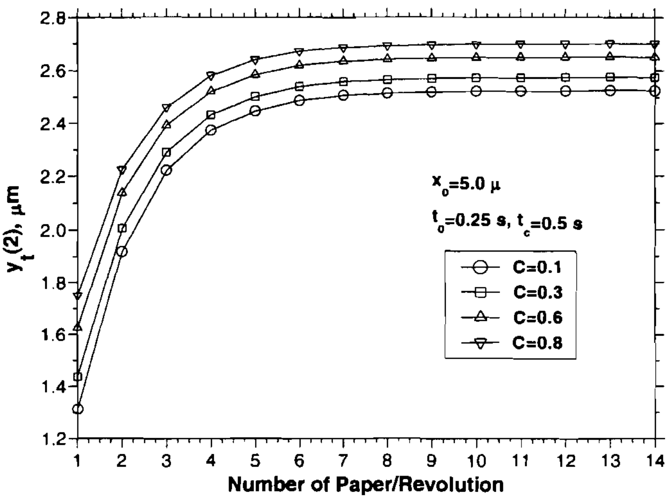


Figure 3 Effect of ink-paper interaction after 2nd nip

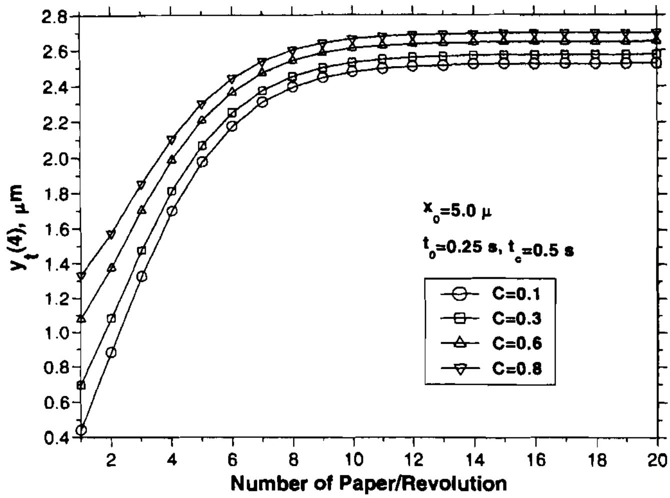


Figure 4 Effect of ink-paper interaction after 4th nip

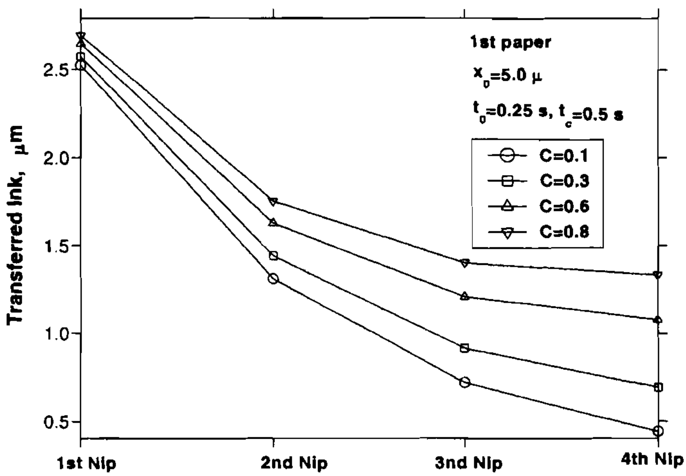


Figure 5 Effect of ink-paper interaction in different nips for the 1st paper

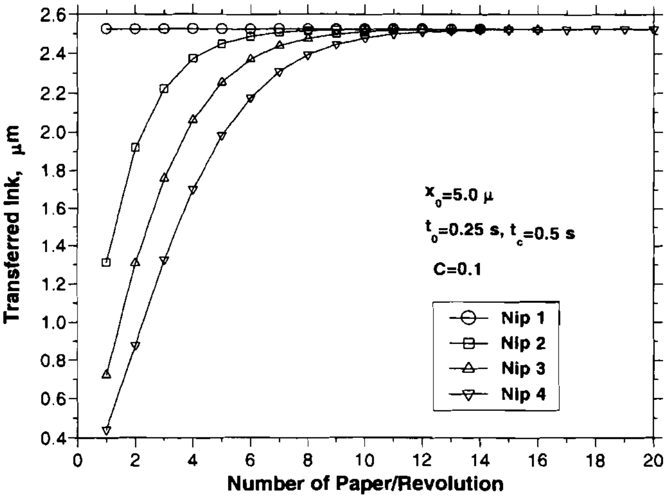


Figure 6 Effect of ink-paper interaction in different nips for the paper with C=0.1

Verification of The New Ink Transfer Model

Direct data to test the validity of the derived new ink transfer equation is not available. However, a previous study (Xiang & Bousfield, 2000a) on a number of model coatings with different ink setting rates has provided an indirect experimental evidence of the validity of new model in predicting the effect of ink setting rate on ink transfer in multiple nips. In that study, model coatings were printed on a laboratory press using the printing conditions similar to commercial presses. Print density after multiple nips was measured and related to the ink setting rates of the coatings. Since some of these model coatings set ink too fast to measure their initial rate of tack buildup, a time which tack force starts to go down in the tack development curve (T_d) was determined. The shorter down time (T_d), the faster ink tack build or ink-setting. As shown in Figure 7, a good correlation between T_d and print density after multiple nips was found for a wide range of samples. It is known that print density is solely determined by the ink amount on paper. Therefore, it can be implied from the result shown in Figure 7 that faster setting coating keeps more ink on paper surface after multiple nips as predicted by our new ink transfer model.

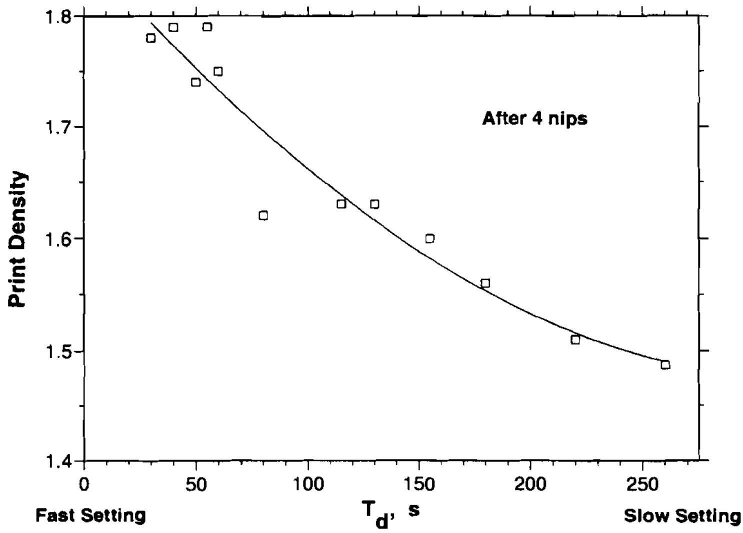


Figure 7 Effect of ink setting rate measured as the time that ink tack starts to decrease (T_d) print density after 4 nips.

In a detailed study those parameters in our model could be estimated carefully and ink remain after multiple nips could be precisely determined experimentally. Nevertheless, above result has demonstrated that our model predicts a correct trend of ink setting rate on ink transfer in multiple nips. We expect that the equation will also predict the correct trends as the initial ink thickness and time between nips are changed.

Conclusions

The new ink transfer model appears to provide a good tool for relating ink transfer in multiple nips to the ink setting rate of paper and more fundamental parameters of ink and paper. This model predicts the correct trend of the experimental observation that a fast setting surface receives more ink and has higher print density than a slow setting surface. Potentially the model can be used to predict the occurrence of backtrap mottle, variation in print density caused by the non-uniform ink setting, and the trapping of one ink on another ink in multicolor offset printing. It remains to be shown, however, how ink-paper interaction parameter in the model is influenced by the fundamental properties of ink and paper and how ink remain after multiple nips is changed by the initial ink thickness and printing conditions. This is the objective of a current project.

Acknowledgements

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