

Transfer Characterization of UV Flexo Inks

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Abstract : The aim of this study is to examine the transfer characteristics of free-radical UV flexographic inks on coated paperboard, with a special emphasis on the solid print ink lay. Printing tests were carried out in laboratory on two printing testers (IGT) : F1, specially dedicated to flexo inks and C1-5, usually dedicated to offset ink. UV Inks with different rheological properties were analyzed. Then corresponding tests were carried out on a flexographic press (narrow web). The results were analyzed by optical densitometry, gloss and surface energy measurements. The effect of the ink properties is studied. Finally, a first step towards modelling of ink transfer between plate and paper is proposed.

Introduction

During the past ten years, UV flexo printing became an interesting alternative to offset for printing folding cartons, in the context of packaging. It combines the advantages of flexo printing with the rapidity of UV curing. The inks for this process are radically different from solvent or water-based inks, traditionally used. The aim of this study is precisely to analyze the transfer characteristics of UV flexo inks.

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Literature cited

Ink transfer in traditional flexography

Although flexography is now considered as a major printing process, relatively few studies are dedicated to flexo transfer, compared to the offset process. The first studies concerned water-based and solvent-based inks. Control of ink transfer in flexo requires measuring ink amounts on the anilox, plate and paper.

In the recent literature, interesting studies are reported on the influence of surface energetics on ink transfer in flexo printing (Lagerstedt and Kolseth, 1995; Lavelle et al., 1996; Quinn et al., 1997). Most of them agreed on the fact that the surface energy of the plate would exert little or no influence on ink transfer.

Aspler and his co-workers have particularly concentrated their effort on the influence of the paper surface properties on the transfer and setting of water-based inks and on the ensuing print quality (Aspler et al., 1992).

In the same context, searchers of IMT measured the ink film thickness in a flexo press, by IR-technology (Lindholm and Ström, 1997) and by X-ray fluorescence (Lindholm et al., 1996). But few results are reported concerning the influence of ink properties on the transfer.

Ink transfer in UV flexography

In the case of UV flexo inks transfer, the NPIRI's Task force (1996) studied the influence of ink viscosity (ranging from 0.048 to 0.59 Pa.s, at 890 s^{-1}), anilox cell volume, anilox screen ruling and printing speed on optical density and dot gain on a UV flexo press. The main conclusions about the study of optical density were that the solid print density increased with decreasing ink viscosity, decreasing press speed and increasing anilox cell volume.

Laksin and Parris (1997) examined the influence of the anilox screen ruling, the inking and printing pressures on optical density, print gloss, and ink lay on a IGT F1 printing tester. The printing speed was constant and the ink of the study was a cationic UV flexo ink with an apparent viscosity of 0.5 Pa.s at 250 s^{-1} and 25°C . They determined an area of optimal density, gloss and ink lay as a function of the tester parameters. One of their observations was that an excessive ink pressure turned out to be a negative factor. Again, a systematical study on the influence of the UV ink characteristics on the transfer is still lacking.

Theoretical considerations

Ink transfer modelling in offset

In the present work, the idea is to apply to UV flexo inks transfer (between the plate and the paper) the models developed in the context of offset inks transfer. Though many authors proposed some valuable modifications of the Walker-Fetsko model (1955), this model still remains a good solution for the modelling of ink transfer from an elastomer surface (the blanket, in offset) on coated paper or board. In its complete form, the Walker and Fetsko model is described by equation (1) :

$$y = (1 - \exp(-kx)) \times [b(1 - \exp(-x/b))(1 - f) + fx] \quad (1)$$

where : y [g/m^2] represents the amount of ink transferred on paper
 x [g/m^2] represents the amount of ink available on plate
 k [m^2/g] is the paper smoothness parameter. k depends on the paper roughness and on the ability of ink to cover the paper surface by flow at the beginning and middle part of the printing nip,
 b [g/m^2] is the immobilization parameter. It represents the fraction of ink immobilized in the paper mass.
 f (dimensionless) is the splitting coefficient. It represents the fraction of the free-ink film transferred. It is an evaluation of the asymmetric splitting of the ink film.

The characterization of these parameters and their relevance were widely discussed in literature, especially the dependency of the splitting coefficient with the thickness of ink available on the plate (De Grâce and Mangin, 1984, 1987). Therefore, Zang (1992) proposed an extended version of the Walker and Fetsko model. This new equation introduces a splitting function F (equation (2)) in order to characterize this dependency.

$$F = f_{\infty} + (f_0 - f_{\infty}) \times \exp(-cf_{\infty}x) \quad (2)$$

where f_{∞} is the splitting coefficient at high ink amounts,
 c is a constant,
 f_0 the splitting coefficient of the free-ink film when the amount of ink on plate tends to zero. Assuming that the two rollers which form the printing nip have similar surface speeds, the free-ink film should be divided equally between the plate and the paper. So, it can be assumed that f_0 equals to 0.5.

Moreover, Zang fixed the constant c ($c = 2$), in order to minimize the computer calculation time.

Experimental

1. Characterization of the materials

1.1. Inks

In order to determine the influence of ink properties on transfer, seven free-radical UV flexo inks were analyzed : A, B, C, E, F, G and H. The pigment content and nature were the same for all the samples. The inks C, E, F, G and H had the same chemical nature, and differed only by the molecular weight of the oligomer (however the proportion of monomers and oligomers in the ink composition is not known). Most of the properties of the inks were analyzed and reported in a previous study (Fouché, 2000) : rheological properties and their variations with temperature, and surface tensions. Complementary results were obtained : viscoelastic properties, specific gravity and glass transition temperature (T_g). Table 1 summaries these results.

Rheological and viscoelastic properties were obtained on a cone-plate rotating rheometer (TA CSL₂⁵⁰⁰). The plastic viscosities were evaluated with the Bingham Exponential Decrease model, at 20°C. The loss tangent (tan δ) was measured at 20°C and 10 Hz (for a stress of 1000 Pa).

Surface tensions were measured on a Krüss tensiometer with a Du Noüy ring at room temperature. Glass transition temperatures were determined by the method of differential scanning calorimetry (Setaram DSC).

Specific gravities were determined empirically by a comparative method.

Inks	A	B	H	C	G	F	E
Plastic Viscosities (Pa.s)	1.7	1.5	0.7	1.7	2.2	2.8	3.8
Specific gravities (g/cm ³)	1.08	1.17	1.14	1.16	1.17	1.18	1.21
T _g (°C)	-64	-59	-62	-58	-56	-55	-53
Surface Tension (mJ/m ²)	23.9	38.0	35.3	35.6	38.0	38.2	38.7
tan δ	18.1	14.5			75.1	46	31.8

Table 1. Ink properties.

A large panel of viscosities is obtained for the series HCGFE (a ratio of 1 to 5).

These inks do not have a marked elastic character (liquid inks). However, in the series CGFE, the decrease of oligomer molecular weight is expressed by an increase in the loss tangent values which reveals a lower elastic contribution.

In this series, the ranges of T_g values were as expected : the more oligomers in the composition the highest value of T_g. Literature reported values of T_g for acrylate oligomer ranging from -40 to -5°C and T_g for acrylate monomer ranging from -120 to -70°C (Pezron and Magny, 1996).

According to the Flory-Fox relation (1968), it is not surprising to find a glass-transition temperature of inks examined located between this two extremities. To summarize, the properties of inks HCGFE, reported in Table 1, depends strongly on the oligomer molecular weight.

Apart from the inks examined, ink A had specific characteristics. The composition of this ink includes surface agents based on silicon derivatives which explains a lower value of T_g and, above all, the lowest value of surface tension.

1.2. Substrate

The coated paper board selected was provided by Iggesund paperboard. Its characteristics are presented in Table 2.

Grammage (g/m ²)	Thickness (μm)	Bekk Smoothness (s)
231	400	174
Stiffness L&W 5° (mNm)	Stiffness Taber 15° (mNm)	Gloss (60°)
CD 12.2 MD 24.9	CD 6.5 MD 13.8	14
Surface energy (mJ/m ²) - Owens Wendt approach		
γ _s ^p 3.5	γ _s ^d 28.1	γ _s 31.7

Table 2. : Characteristics of paperboard

1.3. Printing plate

The printing plate was a thin polyvalent flexo plate (1.14 mm) provided by Dupont de Nemours. Its hardness was equal to 65 shore A.

According to the Owens-Wendt approach (1969), its surface energy was 27.9 mJ/m² (polar component = 3.5 mJ/m², dispersive component = 24.4 mJ/m²).

2. Transfer tests

Printing experiments were carried out on two types of IGT testers : C1-5, usually dedicated to offset tests and F1, specifically dedicated to flexography.

C1-5 tester

Tester description

The major elements of this tester are an printing cylinder covered by the photopolymer plate with a compressible adhesive (provided by TESA), an inking unit with an elastomer distribution roller, and the printing unit. The printing pressure can be gradually adjusted from 100 to 1000 N. The printing speed is constant on this tester (0.3 m/s).

Tests procedure

1. Inking of the distribution roller (1 minute)
2. Weighing of the printing cylinder (without ink)
3. Inking of the printing cylinder (1 minute)
4. Weighing of the printing cylinder after inking and before printing
5. Printing on substrate and drying (power of the UV lamp : 240 W/cm)
6. Weighing of the printing cylinder after printing

Thereby, the different weights allowed to determine the amount offered on the plate by surface unit, x (g/m²) and the amount transferred to paperboard, y (g/m²). Twenty data points had been obtained and the reproducibility of the experiments were very good. A preliminary study had been made to evaluate the influence of printing pressure. The optical density and print gloss were less affected by printing pressure than was ink transfer. The printing pressure selected for our experiments was 300 N.

Reprotest F1

Tester description

The tester is composed of a ceramic anilox roller, a doctor blade with an angle of 60°, a printing cylinder covered by the same plate and adhesive than the C1-5 experiments, a rubber printing cylinder and, finally, a substrate carrier.

The following parameters can be adjusted on the tester :

- The printing speed, from 0.3 to 1.5 m/s
- The inking pressure (between the anilox and the plate), from 30 to 500N
- The printing pressure (between the plate and the substrate) with the same range of pressure available.

Tests Procedure

Preliminary studies had been made to confirm the Laksin and Parris results (1995). Optical density and print gloss were less affected by the pressures settings than print quality. The pressures settings of the tests were 300 N for both printing and inking pressure. Following are the anilox roller engravings experimented :

- 87 l/cm and 20 ml/m² cell volume
- 140 l/cm and 10 ml/m² cell volume
- 187 l/cm and 4 ml/m² cell volume

Finally the following printing speeds were used to carry out the experiments : 0.3, 0.8 and 1.2 m/s. The power of UV lamp was 240 W/cm.

3. Measurements

The quality of the printed samples was analyzed by the following parameters :

- Optical density measured with a Gretag D-194 densitometer
- Print gloss, measured with a REFO 3 glossmeter at 60°.
- Surface energy of the cured ink films, obtained by the measurement of contact angle and the approach of Owens-Wendt.

Results and Discussion

1. Influence of printing speed on print gloss and optical density (Tests on F1 tester).

Figures 1, 2 and 3 represent the evolution of the optical density with the printing speed at different anilox cell volumes.

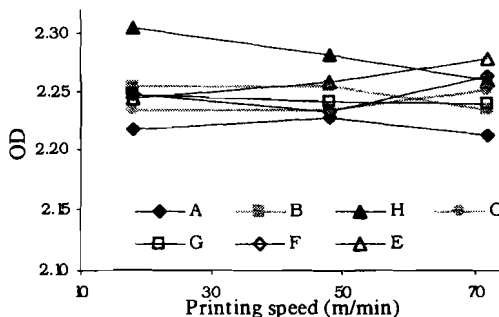


Figure 1. Evolution of optical density with printing speed.
Anilox cell volume : 20 ml/m² (87 l/cm).

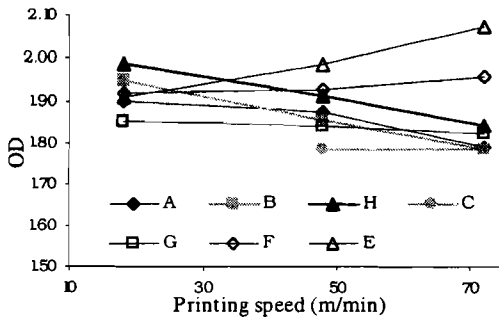


Figure 2. Influence of the printing speed on optical density.
Anilox cell volume : 10 ml/m² (140 l/cm).

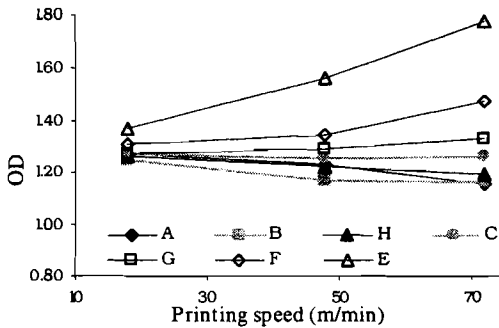


Figure 3. Influence of the printing speed on optical density.
Anilox cell volume : 4 ml/m² (180 l/cm).

As expected, the major parameter which influences optical density is the anilox cell volume. An increase in anilox cell volume leads to a significant increase of optical density.

At high inking level (20 ml/m²), there is no significant changes in optical density with printing speed, except for ink H, whose density decreases with printing speed.

At medium inking level (10 ml/m²), two evolutions can be distinguished : a decrease of optical density with speed for inks A, B, H, C and G and an increase for the most viscous inks F and E.

Finally, at low inking level (4 ml/m²), the optical density slightly decreases with printing speed for inks A, B, H while the optical density of ink C is quite constant. On the other hand, the optical density of inks G, F and E increases with printing speed, and this increase rises with the viscosity and the elastic character of the ink.

This study emphasizes the existence of a critical oligomer molecular weight which determines the evolution of inks optical density with printing speed : beneath these conditions, optical density decreases with printing speed and beyond, optical density increases with printing speed. This critical ink composition decreases with a decreasing ink thickness. The first experiments made on press at EFFG tend to confirm this result. With finer anilox roller the optical density obtained with ink H increases with printing speed. This part of work is still in progress.

When the speed increases, in the case of positive angle doctor blade, overfeeding of the anilox roller may occur, and, as a consequence, the optical density increases. This phenomenon depends also on the viscoelastic characteristics of the ink : when the ink is more elastic, a normal stress may appear under the doctor blade. This is coherent with the values of $\tan \delta$ measured (see Table 1). This situation is also observed in the coating of paper.

Figures 4, 5 and 6 show the evolution of print gloss with printing speed.

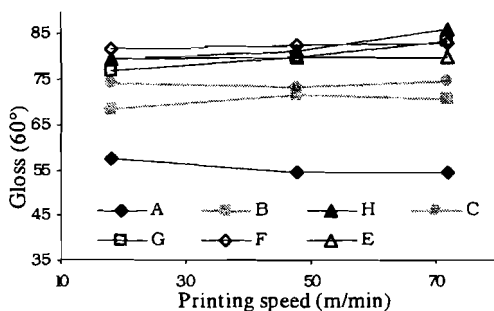


Figure 4. Evolution of gloss with printing speed.
Anilox cell volume : 20 ml/m^2 (87 l/cm)

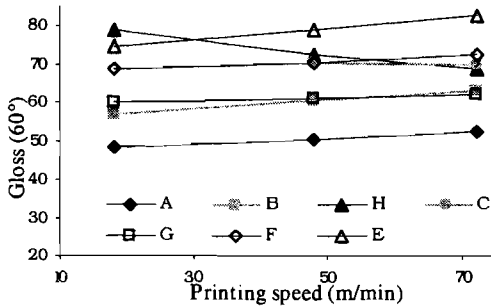


Figure 5. Evolution of gloss with printing speed.
Anilox cell volume : 10 ml/m² (140 l/cm)

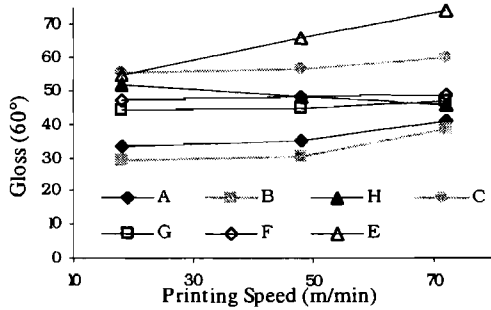


Figure 6. Evolution of gloss with printing speed.
Anilox cell volume : 4 ml/m² (180 l/cm)

As expected, print gloss decreases when anilox cell volume increases. An increase in anilox cell volume is accompanied by an increase in ink film thickness, that generally leads to an increase of print gloss (Fetsko and Zettlemoyer, 1962).

Print gloss values for ink A are low. There is no doubt that print gloss is affected by the silicon derivatives which migrate to the ink film surface when ink is cured.

At high inking level, printing speed does not influence the print gloss. For the lowest inking level, two behaviors can be distinguished : for all the inks, print gloss rises with printing speed and ink E - the most viscous ink, but also the ink which presents the most pronounced elastic character - seems to be more affected by an increase in printing speed. The explanation of this result may be also a problem of overfeeding encountered with positive doctor blade angle. Then gloss of ink H decreases with printing speed. This phenomenon is probably due to the rate of curing which depends on the ink composition.

Tests on C1

2. Influence of ink amounts on the properties of the cured ink film

*Surface Energy

The approach of Owens-Wendt had been used to determine the surface energy of the cured ink films at different ink amounts. The results are presented on figure 7.

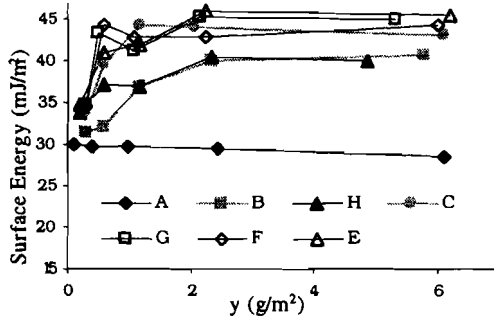


Figure 7. Evolution of the surface energy of cured ink film with y (g/m^2), ink transferred on paperboard.

The inks surface energy rises with y (except for A), and tends to a limit value. Till a certain value of ink film thickness, the paperboard surface influences the determination of the cured ink film surface energy. Since the surface energy of paperboard (31.7 mJ/m^2) is lower than surface energy of cured ink films, a critical ink thickness must be reached to counter this influence. Then the surface energy determined is an intrinsic characteristic of the cured ink film (cf. table 3).

The evolution of the surface energy of ink A is quite different. Its surface energy does not vary with y (around 30 mJ/m^2). This value is very close to the surface energy of paperboard, which explains that surface energy of paperboard has no visible influence on the determination of ink A surface energy.

Moreover, the value of this surface energy is the lowest. This result confirms the explanations made previously, namely the migration of the silicon derivatives to the surface during the exposure to UV lamps. Generally, silicon derivatives have a very low surface energy (around 20 mJ/m^2).

Inks	A	B	H	C	G	F	E
Surface Energy (mJ/m^2)	29.4	40.4	38.5	42.5	43.4	43.6	44.6

Table 3. Surface Energy of cured ink films.

These values must be compared to those obtained on the liquid inks (cf. table 1). The evolution of these two series of values with the inks specific gravities is similar, as shown in Figure 8.

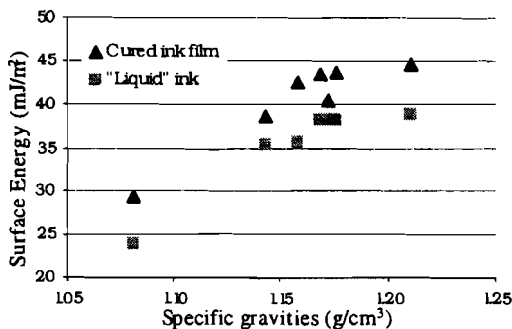


Figure 8. Comparison between surface energy of the cured ink film and surface tension of the liquid ink.

However surface energy of the cured ink film is higher than the surface tension of the liquid inks. This result could have two origins :

- first, the incertitude of the surface energy determination which is based on a calculation and not a direct measure,
- secondly, the expand of molecular weight due to the photopolymerization of the ink film.

*Optical density

Since the printing speed is constant, there is no significant difference between the optical densities of the inks.

However, the approach of Tollenaar (Tollenaar and Ernst, 1971) had been used to determine the values of optical density at infinite film thickness for the different inks examined. Following is the model of Tollenaar (eq. 3) linking the optical density to the thickness of the ink film transferred on coated paper.

$$D = D_{\infty} [1 - \exp(-my)] \quad (3)$$

where D is the optical density, y the ink film thickness, D_{∞} the limit value of optical density, and m represents the increase of relative density D/D_{∞} per unit of ink thickness at low values of y.

The results of this correlation are summarized in Table 4.

Inks	A	B	H	C	G	F	E
D_{∞}	2.34	2.32	2.39	2.36	2.34	2.32	2.32
m	1.18	1.03	1.10	1.09	1.03	1.15	1.18
Correlation coefficient	0.9973	0.9981	0.9981	0.9977	0.9983	0.9983	0.9991

Table 4. Determination of the Tollenaar's model parameters

*Print gloss

Figure 8 shows the evolution of the print gloss with the amount of ink transferred on the paperboard (y).

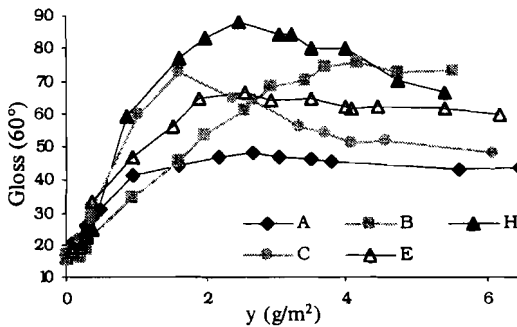


Figure 9. Print gloss vs. the amount of ink transferred on paperboard.

Print gloss increases with the amount of ink transferred up to a maximum value and then :

- stabilizes for inks A and B
- slightly decreases for inks E, F, G (only ink E is presented on Figure 9 for simplicity)
- significantly decreases for ink C and H

Maximum gloss is higher for inks with lower viscosity. Lowest viscosity improves ink levelling and leads to a better gloss.

This difference of evolution can be explained by the variations of curing rate, related to the ink composition. This phenomenon needs further investigations but it probably emphasizes the existence of a critical oligomer molecular weight which may slow down curing.

3. Transfer modelling between plate and paper.

Figure 10 presents the evolution of the percent of ink transferred (y/x) vs. the ink available on plate (x).

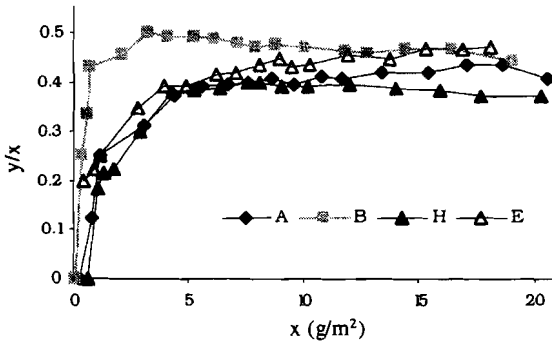


Figure 10. Percent transfer curves for inks A, B, H and E.

The tendencies are different depending on the inks. Ink B curve reached a maximum value and then slightly decreases. Ink B had the best transfer properties. Ink H had similar behavior.

On the contrary, the transfer curve of ink E increases rapidly at low ink amount till a certain value and then still increases but slowly. This could be explained by the low printing speed of the experiment. The similar behavior was observed for ink G and F, with intermediate values between H and E.

For inks A and C, as represented on Figure 10 by ink A, the curve reaches a maximum value and then remained constant.

These results suggest again that the transfer curves are strongly related to the ink composition and nature, and more precisely to the oligomer molecular weight.

Table 5 presents the ink transfer parameters of the Zang's model and the correlation coefficient, R^2 .

Inks	A	B	H	C	G	F	E
k (m^2/g)	0.214	0.684	0.200	0.257	0.261	0.201	0.222
b (g/m^2)	1.320	0.645	2.113	1.629	0.991	1.252	1.163
f_{∞}	0.385	0.434	0.301	0.385	0.420	0.421	0.435
c	1.037	2.144	0.944	2.102	1.148	0.859	0.878
f_0	0.500	0.500	0.500	0.500	0.500	0.500	0.500
R^2	0.9990	0.9995	0.9999	0.9998	0.9994	0.9990	0.9994

Table 5. Determination of the Zang's equation parameters.

The Zang's model (eq. 1 and 2) fits the data quite well, with an average value of R^2 of 0.9994. This equation is suitable for the study of UV flexo ink transfer between a photopolymer plate and a coated paperboard.

The printing smoothness parameter (k) does not depend on the ink composition. k depends rather on the paperboard properties and on the printing conditions which are constant in this study.

Figure 11 presents the variation of the splitting coefficient, f_{∞} as a function of the immobilization parameter, b .

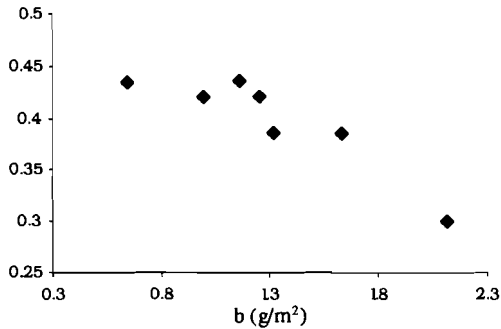


Figure 11. Parameters of transfer model : f_{∞} vs. b

f_{∞} decreases as b increases. For coated paper, these two parameters are strongly correlated. Here, the correlation coefficient is -0.9021 . Physically, it means that if the amount of immobilized ink increases, the ink film splitting occurs closer to the substrate.

Figure 12 presents the evolution of the splitting coefficient as a function of the plastic viscosity for the series HCGFE.

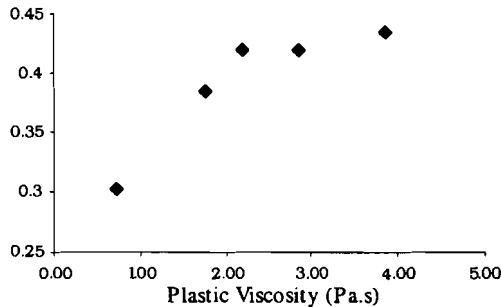


Figure 12. Evolution of the splitting coefficient with the plastic viscosity for the HCGFE series.

f_{∞} increases with the plastic viscosity. Inks with low viscosity splits closer to the substrate. This result is consistent, considering that b increases when ink viscosity decreases. The amount of ink immobilized in the paper during its compression in the nip is higher when the ink viscosity (and obviously the specific gravities) decreases.

However, the dependency of the splitting coefficient with plastic viscosity needs further investigations. Viscoelastic properties of inks should be included in the study of splitting coefficient.

Conclusions

In this work, transfer characteristics of a panel of UV-flexo inks were analyzed. The printed result was evaluated by different methods, such as densitometry, gloss measurements and surface energy on cured ink films. An equation well known in offset printing (Walker and Fetsko, modified by Zang) was used to model the transfer of the UV-flexo inks between the photopolymer plate and the paper. Similarly to the approach of Zang, two inking levels may be distinguished. At high inking level, there is no significant change in optical density, nor of gloss, with printing speed. On the contrary, subtle effects may occur when the ink films are thin, that is to say at low inking levels. These specific behaviors are probably related to viscoelastic properties of the ink. The different results pointed out the fact that the ink composition is of prime importance in the transfer phenomena. Further work is needed and is on the way in our laboratory, such as the study of curing conditions and extensive press tests on the flexo press at EFPG.

Acknowledgement

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Literature cited

Aspler, J.S., et al., *Taga Proceedings*, 207, 1992.

Berry, G.C., Fox, T.G., *Advances in Polymer Science*, 5, 268, 1968.

De Grâce, J.H. and Mangin, P.J., A mechanistic approach to ink transfer Part I : effect of substrate properties and press conditions, *Advances in Printing Science and Technology*, 17, 312, 1984.

De Grâce, J.H., and Mangin, P.J., A mechanistic approach to ink transfer Part II : the splitting behavior of inks in printing nips.

Fetsko, J.M., and Zettlemyer, A.C., Factors affecting Print Gloss and Uniformity, *Tappi*, 45, 8, 1962.

Fouché L., Rheological characteristics of UV flexo inks, *Taga Proceedings*, 774, 2000.

Lagerstedt, P., Kolseth, P., Influence of Surface Energetics on Ink Transfer in Flexo Printing, *Advances in Printing Science and Technology*, 23, 1995.

Laksin M. and Parris J., Optimization of ink lay in UV flexographic printing, *Taga Proceedings*, 861, 1997.

Lavelle, J.S., et al., Measurement of flexographic ink transfer on a modified Prufbau, International printing and graphic arts conference, Tappi Press, 199, 1996.

Lindholm et al., Ink transfer in flexo evaluated by X-ray fluorescence, *Taga Proceedings*, 102, 1996.

Lindholm, G., Ström, G., On-line measurements of the ink film thickness in a flexo press, *Advances in Printing Science and Technology*, 23, 1995.

Mangin, P.J., et al., *Advances in Printing Science and Technology*, 16, 180, 1982.

NPIRI Task Force, The effect of UV flexo ink viscosity, anilox cell volume, and press speed on print density and dot gain, *Taga Proceedings*, 86, 1996.

Owens D.K. and Wendt R.C., Estimation of the surface free energy of polymers, *J. Appl. Polym. Sci.*, vol. 13, 1741, 1969.

Pezron E., Magny, B., Modeling of UV oligomers and monomers properties : viscosity and shrinkage, *European coatings journal*, 9, 602, 1996.

Quinn et al., Does the surface energy of the plate affect ink transfer?, *Converter, Cartotecnica*, 10, 55, 135, 1997.

Tollenaar D., Ernst P.A.H., Optical density and ink layer thickness, *Iarigai*, 214, 1971.

Vinogradov G.V. and Malkin A.Ya., *Rheology of polymers*, Mir Publishers Moscow, 1980.

Walker W.C. and Fetsko J.M., A concept of ink transfer during printing, *American ink maker* 33 (12), 38, 1995.

Zang, Y.H., Asymmetric splitting and ink transfer : a new ink transfer model, *International Printing and Graphic Arts Conference*, 103, 1992.