Ink Gloss Dynamics: Effect of Ink Emulsification and Coating Structure

Yang Xiang and Doug W. Bousfield*

Keywords: Ink, Emulsification, gloss, Coating, Testing

Abstract: Many laboratory methods involve pure ink and dry surfaces, but actual presses require that we understand the interaction of emulsified inks with dry and wetted coating surfaces. In a previous paper, we found that on coated papers ink tack buildup of emulsified ink is faster than the pure ink and pre-wetted surface by fountain solution sets ink faster than the dry surface. Here, the effect of ink emulsification on gloss dynamics on plastic film, clay-based coated papers, and a series of well-characterized model coatings varying in pore volume, pore size, and binder type is examined. A novel glossmeter is used to measure the dynamics of the ink gloss right after printing. Emulsified inks differing in fountain solution content from 1% to 30% are prepared in laboratory. ESEM (Environmental Scanning Electron Microscope) is used to examine the microstructure of emulsified inks, which is found to be a more useful way to view the real droplet size of the emulsion compared with the conventional method with optical microscope. In the initial stages ink emulsification enhances the film leveling. In the final stages, ink setting increases for emulsified ink and final gloss decreases. The leveling speed of the ink film depends on the content of fountain solution and coating properties. Increasing the content of fountain solution increases the leveling of ink film. Finer pore coating sets ink faster and can reduce the difference between pure ink and emulsified ink in film leveling. The gloss is lower on pre-wetted surfaces than dry surfaces for both pure ink and emulsified ink. Ink films level faster on the coated paper than on the plastic film even when ink penetration into paper can slow down the leveling.

---

*Paper Surface Science Program, Department of Chemical Engineering, University of Maine, 5737 Jenness Hall, Orono, ME 04468

Introduction

Print gloss is one of the most important attributes of printed matter for most of coated papers. In most printing processes, final print gloss is determined by the smoothness and binder level of ink film, which are not only a function of the ink, but also the coating and the interaction between the coating and the ink (Fetsko and Zettlemoyer, 1962; Oittien, 1980; Aspler and LePoutre, 1991;Zang and Aspler, 1995; Donigian, *et al*, 1997). The binder level at the top of ink film depends on the balance between the rate of absorption of ink mobile phase into the coating and the rate at which tack builds up as a result of the loss of solvent and polymerization of the binder. The smoothness of ink film depends on the roughness of the coated paper and the leveling characteristics of the ink film after splitting in the nip. Previous work by Glatter and Bousfield (1997) showed that the ink filamentation in the nip and ability of ink film leveling on coating before drying has a tremendous effect on the final print gloss by measuring the evolution of wet ink gloss right after printing. Further work by Desjumaux *et al* (1998a, 1998b, 1998c) on a number of model coatings with different pigment sizes and latex types has demonstrated that coating layers which promote rapid ink setting stop the leveling of ink film and often result in low print gloss. The rate of ink setting is related to removal of ink mobile phase into the coating. This rate is also a function of latex binder of the coating layer, because the latex itself can absorb ink solvent (Kelly, *et al*, 1971; Purfeest, *et al*, 1994). Therefore, the pore structure and the surface chemistry of the coating are considered to be two controlling factors of ink setting on coated paper. At similar pore volume level, coating with smaller pores sets ink faster and in turn has a lower ink gloss than the coating with larger pores (Desjumaux, et al, 1998a). Interactive latex binder with ink solvent sets ink faster and results in lower gloss than the non-interactive latex binder. However, previous work concentrates on pure ink and dry coating surfaces; the actual conditions of wetted surfaces and emulsified ink in multi-color offset printing have not been reported. The effect of two important aspects as in "real life" of multi-color offset printing was not considered, but is the focus of this work.

During the offset printing process, fountain solution in the non-image area of the printing plate is emulsified into the ink in the image area. A proper emulsification is desired to improve the stability of ink on press and maintain ink-and-water balance on printing plate (Koniecki, *et al*, 1984)). In full-scale offset printing, freshly emulsified ink transferred to the paper surface can contain up to 30% fountain solution (Aspler, 1993). Several studies concerning fountain solution/ink emulsion have previously been reported. These work focused on stability and rheology of emulsified ink and the effect of fountain solution and ink binder composition on ink emulsification. Bassemir *et al* (1987, 1988, 1989) conducted many studies on the stability of ink/fountain solution emulsion and have found that a good stability of ink/fountain solution emulsion is generally desirable for optimum lithographic performance and in particular, shear and thermal stability. Ink and fountain solution emulsion with lower interfacial tension tends to perform better on offset press because of the tendency to form micro-emulsions, which this condition encourages (Bassemir *et al,* 1987, 1988, 1989). Hayashi and Amari (1992) investigated the dynamics of transfer and splitting of emulsified ink and found that emulsified water lowered the apparent tack of the ink and the filament break-up length and increased the elasticity of the ink in the low frequency range. A recent study by Aurenty *et al* (1995, 1998) showed that the emulsification of water droplets affected the viscoelastic properties of alkyd resin principally in the low frequency range and at higher frequency emulsification did not change the elastic/viscous ratio of alkyd resin. Wickman *et al* (1995, 1997) found that addition of isopropyl alcohol to the aqueous phase resulted in smaller droplets and higher concentration of isopropyl alcohol gave smaller droplets. The interfacial tension between water and alkyd resin-containing oil decreased with alkyd resin concentration and polarity. However, no work to our knowledge has been published, to understand the setting mechanism of emulsified ink on coated paper and how ink emulsification influences the filamentation, film leveling and final print quality.

During offset printing, while ink transfers onto paper, the fountain solution (water) transfers from the plate via the blanket to the paper. The absorption of fountain solution can compete with the absorption of ink vehicle ingredients by the paper surface and affect the ink setting and in turn the print quality. Printing on a wetted paper surface may be different from printing on the dry paper. Previous work has shown how water and ink interact separately with coated paper. However, little is known about how they interact together on coated paper surfaces.

In a recent paper (Xiang and Bousfield, 1999a), we have found that on coated papers ink tack buildup of emulsified ink is faster than the pure ink and pre-wetted surface by fountain solution sets ink faster than the dry surface. Here, the effect of ink emulsification on gloss dynamics on plastic film, clay-based coated papers, and a series of well-characterized model coatings varying in pore volume and pore size was examined to further understand the setting mechanism of emulsified ink on coated paper.

Experimental

Samples

A plastic film (Mylar, DuPont) and a series of coated samples with different surface properties were used in this study. A brief description of coating ingredients for the coated samples is shown in Table 1. The clay-based coated paper has 22g/m^2 coat weight on each side and was on-line finished with softnip calendering. More details of this paper are found in Xiang *et al* (1999b). The four model coatings are part of the same samples used by Desjumaux *et al* (1998a) in their study of ink gloss dynamics and by Xiang and Bousfield (1998 and 1999a) in their study of ink tack development.

Table 1 Clay-based coated paper and model coating

Sample	Clay-based	SN30	BN30	BN150
Binder	14 pph 1800 Å S/B Latex and 2 pph Starch	30 pph Non-interactive Latex	30 pph Non-interactive	150 pph Non-Interactive
Pigment	50 Parts High Brightness Clay, 10 Parts Calcined Clay, and 40 Parts UFGL	0.10 μm Plastic Pigment	0.23 μm Plastic Pigment	0.23 μm Plastic Pigment
Setting Rate	Medium	Fast → Slow		

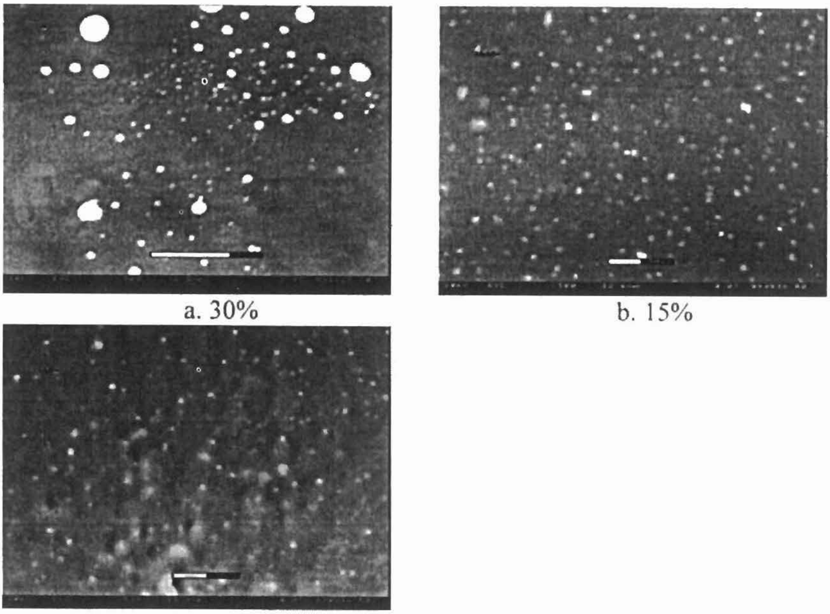
Preparation of Fountain Solution/Ink Emulsion

Fountain solution/ink emulsions were prepared on a mixer. This mixer is equipped with a 1" (2.54 cm) saw-tooth impeller and a double wall container with an inside diameter of 5.0 cm and a height of 7.0 cm. The double wall container is connected to an oil thermostat to keep the temperature constant during the emulsification process. The same procedure is used as described previously (Xiang and Bousfield, 1999a).

A typical quick-set offset ink (Capiplus III Process Cyan, Flint Ink Corp.) is used in this study. This particular ink has been used in other ink gloss dynamics studies and tack development tests. Emulsified inks with fountain solution content 1%, 5%, 10%, 15%, and 30% were prepared using above method. A Substifix HD fountain solution by Hostman-Steibbers was used. The ratio used was 74g concentrate to 2000 ml water. For a comparison with pure ink with shearing before test, a pre-sheared pure ink which experienced same process as other emulsified inks was prepared.

ESEM Observation of Emulsified Inks

Optical microscope was widely used for droplet size characterization of many emulsions in previous work. However, for emulsified ink, it is very difficult to get the real droplet size with this tool. This is because extra force put on the glass slide for have good image will change the droplet size.



a. 30%

b. 15%

c. 5%

Figure 1 ESEM Micrographs of Emulsified Inks with Fountain Solution Level of 30% (a), 15% (b), and 5% (c), respectively. Beam Energy is 20 keV and Magnification is 500X.

A new effort is made in this study by using Environmental Scanning Electron Microscope (ESEM). ESEM has been widely used to view the real surface of solid materials because surface coating of the sample is not needed compared to the conventional SEM. However, to view the liquid like emulsion using ESEM is still a new area of interest in many application fields. It is known that the signals collected by the Environmental Secondary Electron Detector (ESD) fitted to ESEM is a combination of secondary electrons which is generated from the surface of the sample (surface information) and backscattered electron (BSE) which is generated from a large volume and greatly affected by the material of the sample (material information). Increasing the working distance between the detector and sample surface increases the backscattered electron signal and gets more material information. Through using a Peltier stage (cooling stage) sample temperature inside the chamber can be controlled around 5 °C to reduce the evaporation of ink solvent and emulsified water. In this study, a E-3 ESEM (FEI Company) is used and the working distance is controlled around 12 mm. Figure 1 shows some ESEM micrographs of emulsified ink with a fountain solution content of 30%, 15%, and 5%, respectively. The method to obtain a good image is still under investigation. However, preliminary results obtained so far have shown that ESEM will be an useful tool of imaging emulsified ink. At same energy consumption level, droplet size is smaller and more uniform with decreasing the fountain solution content.

Printing and Measurement of Ink Gloss Dynamics

The samples were printed on the KRK printability tester with an ink thickness 3.0 μm, a printing speed of 2.0 m/s, and a printing load of 100kg. A novel glossmeter as described in detail by Glatter and Bousfield (1997) was used to measure the dynamics of the ink gloss every tenth of a second right after printing. The gloss dynamics was measured with a laser reflecting off the sample at 75° from the vertical. Print density of the dry prints was measured 24 hours after printing.

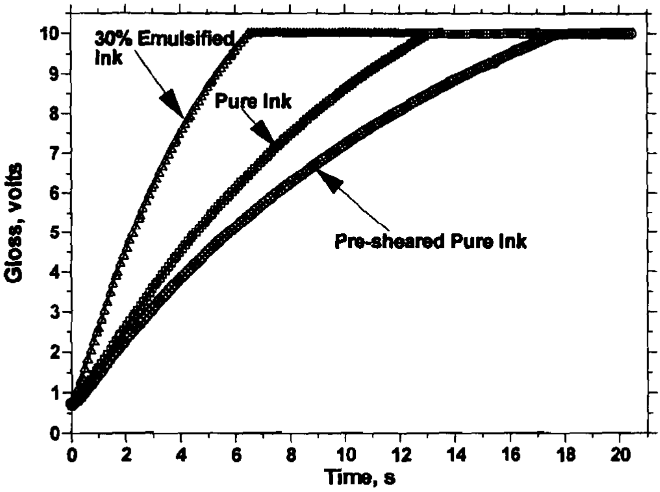


Figure 2 Effect of Ink Emulsification and Pre-shearing: on Plastic Film (Mylar)

Results and Discussion

Effect of Ink Emulsification

Right after printing, ink gloss increases with the leveling of ink film on the substrate. Figure 2 shows the gloss dynamics of pure ink, pr-sheared pure ink, and emulsified ink with 30% fountain solution on plastic film (Mylar). We see here that emulsified ink has faster film leveling right after printing on the plastic film than the pure ink and pre-sheared pure ink. This is probably due to a decrease in viscosity of ink and an increase in elasticity in the low frequency range as found by other researchers (Hayashi, et al, 1992; Aurenty, *et al*, 1998). Pre-shearing causes a loss of ink solvent and results in a slower film leveling because of a higher viscosity compared to the pure ink without pr-shearing.

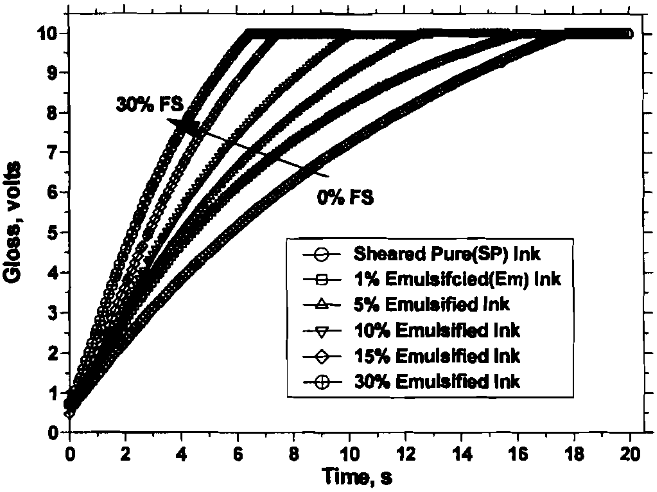


Figure 3 Effect of Fountain Solution Level: on Mylar

Effect of fountain solution content on ink gloss dynamics on Mylar is shown in Figure 3. The leveling speed of ink film on the Mylar is consistently increased with increasing fountain solution level of emulsified inks. On the absorbent clay-based paper, the same trend was found as shown in Figure 4, but the difference in ink gloss dynamics between the pure ink and emulsified inks is smaller than on the Mylar. One possible reason is that the filament size formed on coated paper is smaller than on the Mylar as in previous work (Ercan, 1998; Xiang and Bousfield, 1999a). Smaller filaments are expected to level faster than larger filament based on the theoretical models of film leveling (Desjumaux and Bousfield, 1998c; Toivakka and Bousfield, 1999) and thus can reduce the effect of ink emulsification on film leveling. As shown in Figure 5, the final gloss for both pure ink and emulsified ink is higher on Mylar than on the coated paper, but in the initial stage both two inks level faster on the coated paper than on the plastic film even though ink penetration into paper can slow down the leveling of ink film as found by Desjumaux *et al* in their work (1998a).

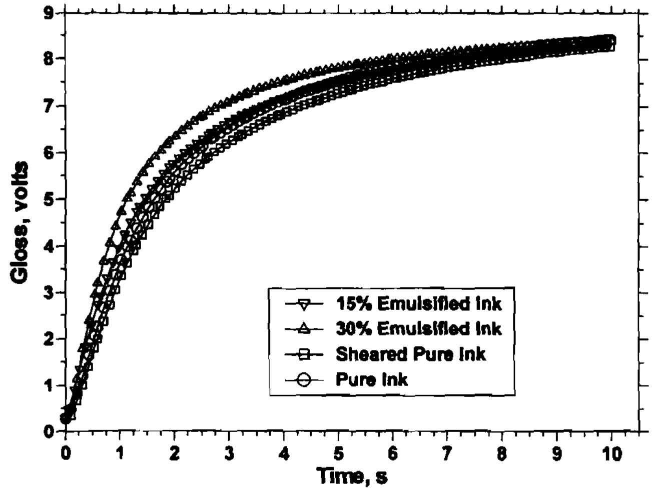


Figure 4 Effect of Ink Emulsification: on Clay-based Coated Paper

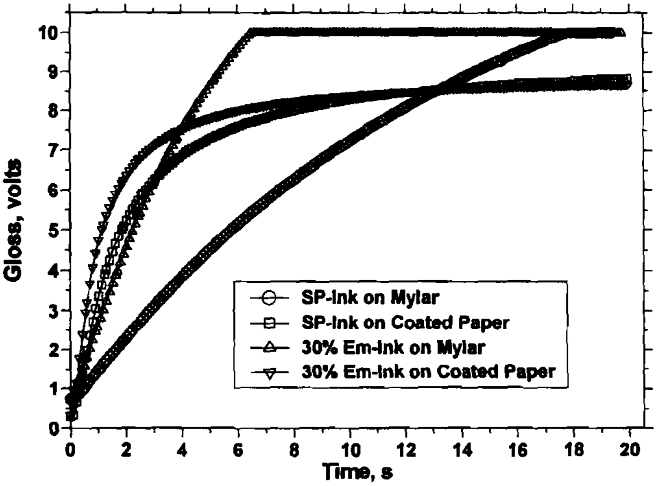


Figure 5 Ink Gloss Dynamics: Coated Paper vs. Mylar

Effect of Coating Pore Volume and Pore Size

The effect of coating pore volume on gloss dynamics of emulsified inks is shown in Figure 6. Both coatings have same pigment system but different latex binder level. Sample BN30 contains 30pph latex and has a porous surface. Sample BN150 contains 150pph latex binder and has a closed surface. We would expect the more open surface, BN30, to set ink more rapidly than the closed surface and give lower gloss, but the opposite result occurs, be again because of the filament size. We see again that in the initial stage emulsified ink levels faster than pure ink on both two coatings. In the final stage, ink setting increases for emulsified ink as shown in our previous paper (Xiang and Bousfield, 1999a) and final ink gloss decreases.

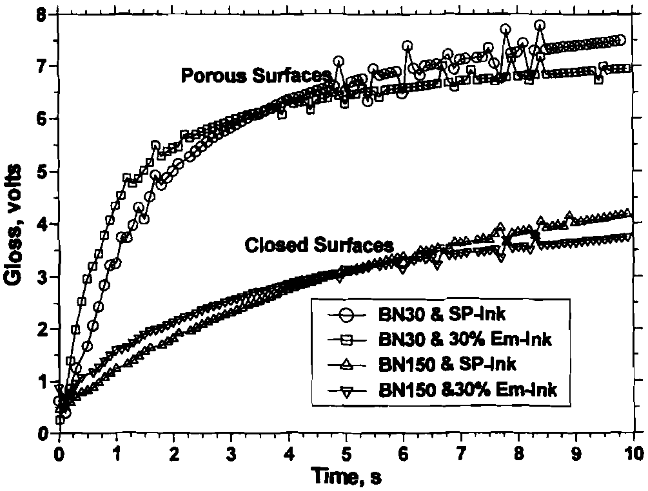


Figure 6 Effect of Coating Pore Volume

Coating pore size has been found to be the most important factor affecting ink setting on coated paper. Coating with smaller pores sets ink faster and has lower final ink gloss because ink film leveling stops earlier than the coating with larger pores. This is demonstrated in Figure 7. Both coatings have same level of latex binder (30pph) but have different size pigments: 0.10 μm and 0.23 μm, respectively. On sample BN30, which has large pores and sets ink slowly, we see same trend as in Figure 6 that in initial stage emulsified ink levels faster than the pure ink. However, on sample SB30, which has small pore and sets ink fast, Little difference in initial leveling was found between two inks. Pure ink has a slightly higher final gloss than the emulsified ink.

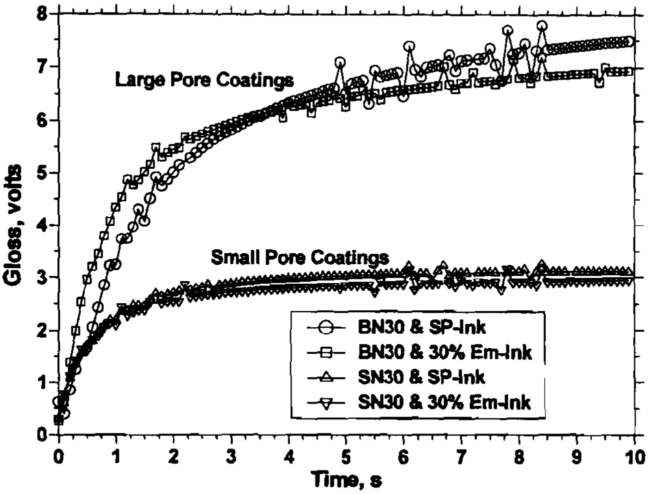


Figure 7 Effect of Coating Pore Size

Effect of Fountain Solution Pre-Wetting of Paper Surface

To examine the effect of fountain solution pre-wetting on ink gloss dynamics, 15mm^3 fountain solution is distributed in the damping unit and transferred to a 20X200mm area of the paper surface with a rubber-coated disc before printing. As shown in Figure 8 and 9, ink gloss is lower on pre-wetted surfaces than on the dry surfaces for both pure ink and emulsified ink. In multi-color offset printing, effect of fountain solution transferred on paper surface is always linked to the "wet repellence", a poor ink transfer in coming units. Therefore, lower ink transferred on the pre-wetted surface might be one important reason of lower ink gloss. Another important reason might be the difference in ink setting rate between dry and pre-wetted surfaces. In a previous study (Xiang and Bousfield, 1999a), we have found that for some coatings, ink sets faster on pre-wetted coating surface than on the dry surface. The underlying mechanism is not understood, but a change in surface chemistry can be brought about by wetting the coating surface with fountain solution. Fast ink setting stops film leveling and in turn results in a lower final gloss. On dry surface of clay-based paper, emulsified ink has a slightly higher leveling speed in initial stage and but a lower final gloss. On pre-wetted surface, a large difference exists in the initial leveling between two inks compared to the dry surface, but not much difference in final gloss. For sample BN30 shown in Figure 9, we see same trend on both dry and pre-wetted surfaces as observed on other model coatings (Figure 6 and

7), that is, emulsified ink levels faster in initial stage and has lower final gloss than the pure ink.

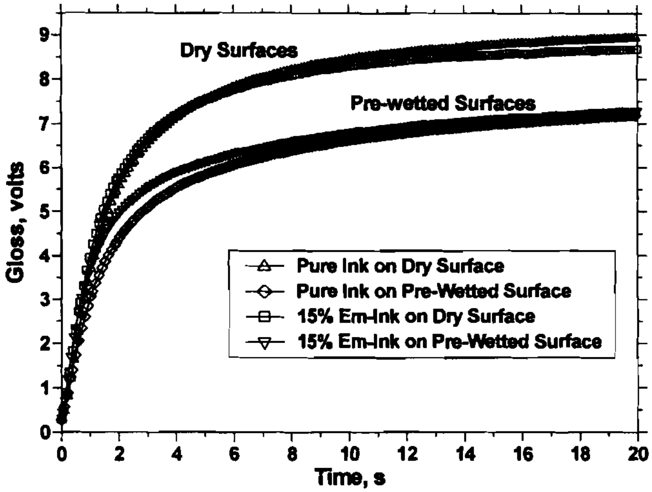


Figure 8 Effect of Fountain Solution Pre-Wetting: on Clay-Based Coated Paper

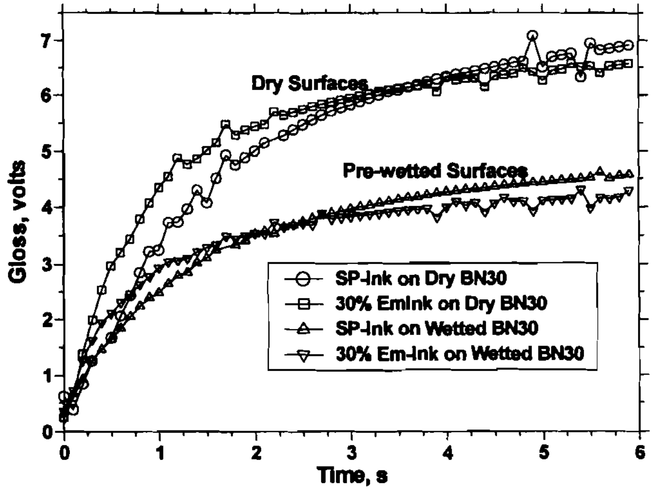


Figure 9 Effect of Fountain Solution Pre-Wetting: on Sample BN30 (a Model Coating)

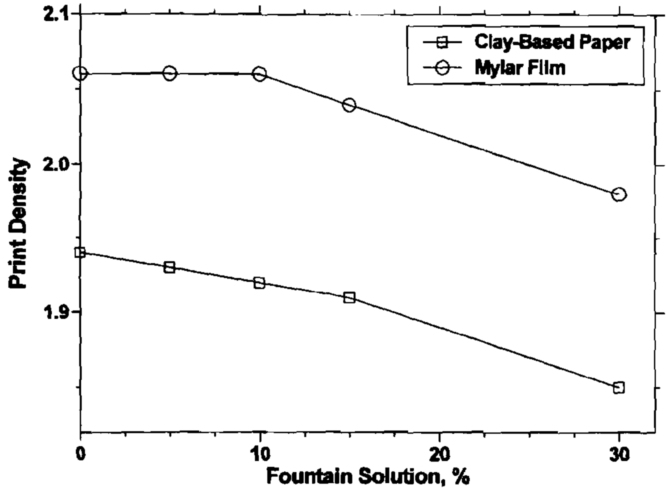


Figure 10 Effect Fountain Solution Levels on Print Density

Effect of Ink Emulsification and Fountain Solution Pre-Wetting on Print Density

Effect of fountain solution levels on print density is shown in Figure 10. As one expects, on the clay-based paper print density decreases with increasing fountain solution level of emulsified inks. On Mylar film, because of a better ink coverage, print density does not change until fountain solution reaches 10%. In most case, pre-wetted surface by fountain solution has a lower print density because of lower ink transfer caused by "wet repellence" as shown in Figure11, 12, and 13. Fast setting surface can take the solution fast and reduce the difference in print density.

Concluding Remark

From above results obtained, the conclusions can be summarized:

- Emulsified ink levels faster than the pure ink. The leveling speed depends on the content of fountain solution and surface properties of the substrate.
- Increasing the content of fountain solution increases the leveling speed.
- Finer pore coating sets ink faster and can reduce the difference between pure ink and emulsified ink in film leveling.
- In the initial stage, film leveling of both pure and emulsified inks is faster on the coated paper than on the plastic film.
- In most cases, pre-wetted surface by fountain solution has a lower gloss and print density.

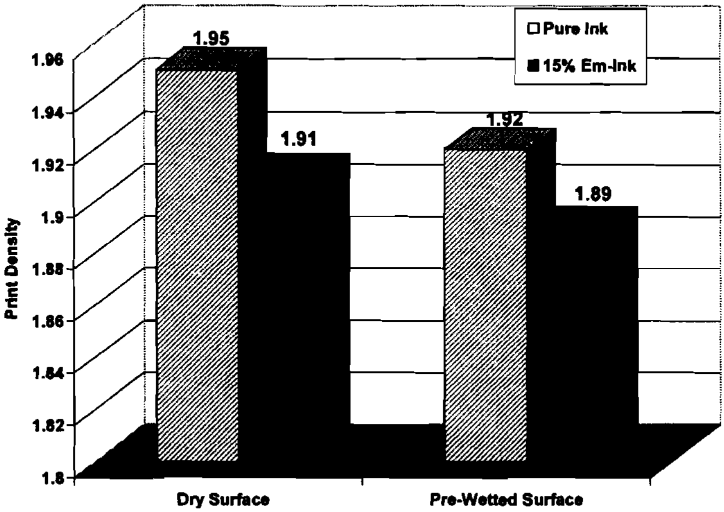


Figure 11 Effect on Print Density: on Clay-Based Paper

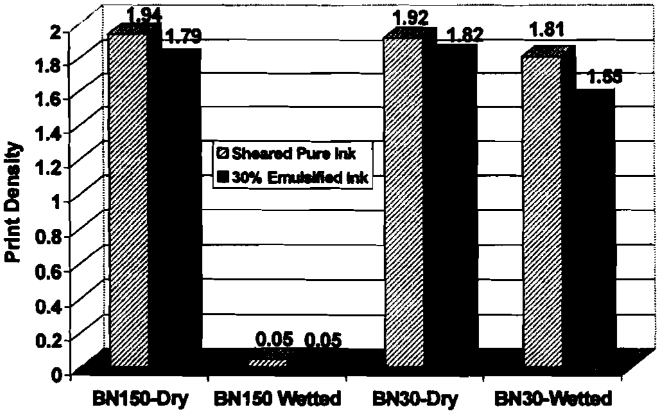


Figure 12 Effect on Print Density: Closed Surface (BN150) vs. Porous Surface (BN30)

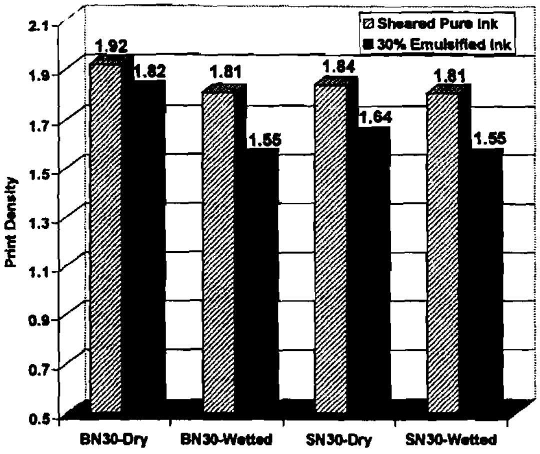


Figure 13 Effect on Print Density: Large Pores (BN30) vs. Small Pores (SN30)

Acknowledgement

This work was supported by the industrial sponsors of the Paper Surface Science Program at the University of Maine.

Literature Cited

Aspler, J.S. and Lepoutre, P.
1991 "The Transfer and Setting of Ink on Coated Paper", Progress in Organic Coating, vol. 19, pp.333-357.

Aspler, J.
1993 Interactions of ink and water with the paper surface in printing, *Nordic Pulp and Paper Research Journal*, No. 1: 68-74 (1993).

Aurenty, P., Schrödewr, A. and Gandini, A.
1995 "Water in Alkyd Resin Emulsions: Droplet Size and Interfacial Tension", *Langmuir*, 11 (12): 4712-4718.

Aurenty, P., Palierne, J.F. and Gandini, A.
1998 "Viscoelasticity of Water/Ink Emulsions at Low and High Frequency", *1998 TAGA Proceedings*.

Bassemir, R. and Krishnan, R,
1987 "Optimizing Lithographic Performance - A Physical-Chemical Approach", *1987 TAGA Proceedings*, 560-573.

1988 "A Study of Lithographic Performance: Mechanical vs. Thermodynamic Consideration", *1988 TAGA Proceedings*, 339-351.

1989 "Prediction of Litho Press Problems from/Phase Equilibria of Ink and Fountain Solutions", *1989 TAGA Proceedings*, 240-256.

Desjumaux, D., Bousfield, D.W., Glatter, T.P., Donigian, D.W., Ishley, J.N., and Wise, K.J.
1998a " Influence of Pigment Size on Wet Ink Gloss Development". J. Pulp & Paper Sci., vol.24, no. 5, pp.150-155

Desjumaux, D., Bousfield, D.W., Glatter, T.P., and van Gilder, R.L.
1998b "Influence of Latex Type over a Range of Pigment Volume Concentration, *To appear, Prog. Organic Coatings,* or *Proceedings of the 1998 Coating Conference*, pp. 875-895, TAPPI Press, Atlanta, GA

Desjumaux, D., Bousfield, D.W.
1998c "Modeling of Ink Film Leveling with Mobile Phase Removal", Preprint of the 1998 Pan-Pacific and International Printing and Graphic Arts Conference, CPPC, pp.103-109.

Donigian, D.W., Ishley, J.N., and Wise, K.J.
1997 "Coating Pore Structure and Offset Printed Gloss", Tappi J., vol.80, no.5, pp.163-172.

Fetsko, J.M. and Zettlemoyer, A.C.
1962 "Factors Affecting Print Gloss and Uniformity", Tappi J., vol.45, no. 8, p. 667

Glatter, T.P. and Bousfield, D.W.
1997 "Print Gloss Development on a Model Substrate", Tappi J., vol. 80, no.7, pp.125-132.

Hayashi, T. and Amari, T.
1992 "Dynamics of Transfer and Splitting of Emulsified Ink", *Proceedings of 1992 International Printing and Graphic Arts Conference*, 75-80.

Kelly, J.M., Russell, P.J., and Graham, F.H.
1971 "Result of an Investigation into Ink Setting Behavior on Coated Paper", Proceedings of the 14th EUCEPA Conference: paper no. 28.

Oittinen, P.
1980 "Surface Reflection of Coated Paper and Prints", Adv. Print. Sci. Technol., vol.15, p.344

Toivakka, M.O. and Bousfield, D.W.
1999 "Leveling of Coating Suspensions", J. Pulp & Paper Sci., vol. 25, no. 5, pp.183-188.

Wickman, M., Hallstensson, K. and Ström, G.
1995 "Interactions between Printing Ink Binders, Printing Oil and Fountain Solutions", *1995 TAGA Proceedings,* vol. 2: 978-992.

1997 "Effect of Printing Ink Binder Composition on Emulsification of Fountain Solutions", *Journal of Pulp and Paper Science,* Vol.23, No.4: J167-J173.

Xiang, Y. and Bousfield, D.W.
1998 "The Influence of Coating Structure on Ink Tack Development", Preprint of the 1998 Pan-Pacific and International Printing and Graphic Arts Conference, CPPC, pp. 93-101, accepted for publication by J. Pulp & Paper Sci.

Xiang, Y. and Bousfield, D.W.
1999a "Effect of Fountain Solution on Ink Tack Development and Print Quality", Proceedings of 1999 TAPPI Coating Conference.

Xiang, Y., Bousfield, D.W., Hassler, J., Coleman, P., and Osgood, A.
1999b "Measurement of Local Variation of Ink Tack Dynamics", J. Pulp & Paper Sci., vol. 25, No. 9, pp.326-330.

Zang, Y.H. and Aspler, J.S.
1995 "The Influence of Coating Structure on the Ink Receptivity and Print Gloss of Model Clay Coatings", Tappi J., vol. 78, no. 1, p.147-154.