Gloss Dynamics of Inks on Porous Surfaces

Jong Suk Sonn
Douglas W. Bousfield
Paper Surface Science Program
Department of Chemical and Biological Engineering
University of Maine
Orono, ME 04469 bousfld@maine.edu

Presented at the 15th International Coating Science and Technology Symposium
September 13-15, 2010. St. Paul MN[1]

Abstract

The leveling of coating defects and filament remains is important in a number of products, especially for printing of high quality publication grades. In printing, ink is applied to a porous substrate. Oils in the ink are pulled into the substrate due to capillary pressures. This oil removal can stop the leveling event, resulting in low print gloss. The model that best describes the ink setting process is not clear in the literature.

The gloss of a freshly printed sample was measured with a custom made laboratory device described by Glatter and Bousfield (1997) with a cyan offset ink that was diluted with mineral oil at 10 and 20% by weight. The viscosity of the ink and various dilutions of the ink with oil were obtained by a controlled stress rheometer (CVO, Bohlin). The absorption rate of the oil-ink mixture into a ceramic filter was characterized gravimetrically.

The leveling of a Newtonian fluid is described in the linear limit by Orchard (1962). The film profile h, is described as

$$h(x,t) = h_o + \varepsilon_o \sin(2\pi x/\lambda) e^{-\alpha t}$$

$$\alpha = \frac{16\pi^4 h_o^3}{3\mu\lambda^4} \tag{1}$$

Where h_o is the leveled film thickness, ε_o is the initial disturbance, λ is the wavelength of the disturbance, σ is surface tension, and μ is the fluid viscosity.

Now, when a fluid phase is removed from the ink, the viscosity of the film may increase. In addition, a filtercake of particles may form at the substrate surface, reducing the effective leveled film thickness. In the literature, it is not clear what mechanism actually occurs. One goal of this work is to test if one model of ink setting better predicts the gloss dynamics results.

With the absorption rate behavior of the system and the viscosity-oil content data, we can estimate the increase in viscosity of the ink film as a function of time. For suspensions, an approximate expression is

$$\mu = K(1-\phi/\phi_m)^{-2} \tag{2}$$

Where ϕ and ϕ_m are the solids volume fraction in the ink and the maximum value, respectively. For this ink, the value of K is adjusted to match the current viscosity level compared to the current solids level. The maximum

---

[1] Unpublished. ISCST shall not be responsible for statements or opinions contained in papers or printed in its publications.

solids volume fraction was measured by scraping the sample from a filter and should be close to 0.6. The solids fraction of the initial ink is estimated to be 0.5. In theory, these value can be measured exactly, but in the laboratory, it is not easy to measure these solids because all of the oil does not evaporate. Figure 1 shows the viscosity-oil content behavior.

By inserting this viscosity in Eq. (1), a prediction for surface roughness as a function of time is obtained. Ma et al. (2008) give an expression that links the roughness of a surface to the 75° gloss value of $gloss = 100exp(-2.5h_r)$, where h_r is the roughness in microns. . Therefore, Eq. (1) in combination with expressions for viscosity increase can be used to predict gloss dynamics of the system.

If a filtercake is forming on the substrate as oil is pulled removed, the viscosity of the bulk ink layer does not change, but the final leveled film thickness h_o does. The expression for the volume absorbed, based on this filtercake model is

$$V/A = \sqrt{\frac{2\Delta P t}{\mu_L\left(\frac{\phi}{(\phi_m-\phi)K_f}+\frac{1}{\varepsilon K_p}\right)}} \qquad (3)$$

Where V/A is the volume of oil removed per unit area, μ_L is the oil phase viscosity, K_f and K_p are the permeabilities of the filtercake and the substrate, respectively. The capillary driving force is assumed to be given by the Laplace equation. This equation links to the filtercake thickness through a mass balance given as

$$h_f = \frac{V}{A}\frac{\phi}{(\phi_m-\phi)} \qquad (4)$$

The effective value of h_o to use in Eq. (1), therefore, is the initial value of h_o minus the filtercake thickness. As the filtercake thickness grows, the rate of leveling slows as expected. Both of these methods to include absorption into the leveling rate equation are approximate and may not hold for all situations and throughout the consolidation process, but they lead to simple expressions that can be compared to the experimental results.

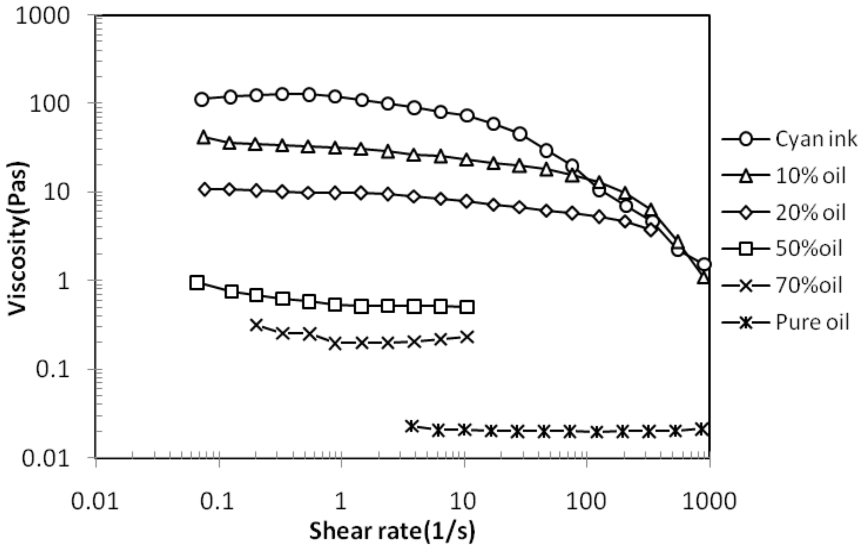

Figure 1. Ink-oil viscosity results for different oil content.

Therefore, there are two key approaches or models that can be used to predict gloss: 1) adjust the viscosity using Eq. (2) as a function of time by predicting the oil content using Eq. (3) or 2) adjust the ink film thickness in Eq. (1) by the predicted thickness of the filtercake. These models are referred to here as the thickening and filtercake models, respectively. Both will lead to a decrease in leveling rates, but describe different physical reasons. The value of the wavelength and the initial roughness in Eq. (1) are found by matching the "non-setting" case to the initial gloss curve.

Figure 2 shows the measured and predicted gloss behavior for the ink mixed with 20% oil printed on a slow setting paper. The initial solids fraction is 0.42. The initial viscosity is 10 Pas. The initial ink film thickness was measured, from gravimetric methods, to be 2.8 µm. The wavelength in Eq. (1) for this case was 55 µm . The initial roughness amplitude was 1.1 µm. The Darcy coefficient of the paper, the void fraction and the parameters that determine the capillary pressure all work to determine the absorption rate. In this case, these parameters are set to give a reasonable rate that causes the thickening and filtercake models to deviate from the no setting case.

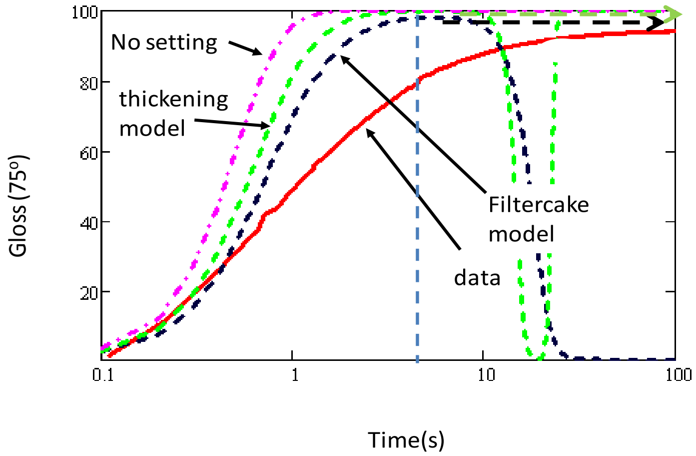

Figure 2. Measured and predicted gloss behavior of the mixture of 20% oil and 80% ink for parameters as noted in the text. Model predictions past the vertical line are non-physical.

As expected, due to the low viscosity and low solids, the gloss of this oil-ink mixture increases to a high value. The no-setting case is expected to predict 100 gloss because there is nothing to stop the leveling of the defect. Both the thickening model and the filtercake model predict a lower gloss, but these are higher than the measured value at modest times. Both models predict that the final gloss to be high. This result is seen in the experiments. The difference between the models for these parameters is minimal.

A disadvantage of using the simple linear equations becomes apparent in Fig. 2. At some point, the filtercake becomes larger than the ink film thickness or the solids of the ink increases higher than the maximum physically possible. When this occurs, near the dashed vertical line, the model predictions do not mean anything; a horizontal line drawn to the right would indicate the final gloss that is predicted. A non-linear model, not discussed here, does not have this problem, but it also predicts similar final gloss.

The fact that none of these models predict the exact shape of the gloss curve is not a serious concern. The model is based on a single sinusoidal disturbance but the experiment must have a distribution of filament sizes. The long wavelength filaments must dominate the gloss response at longer times, giving a lower value than the models. In addition, the base paper has a finite roughness that is not included in the model.

The results for the 10% oil and 90% ink case are shown in Figure 3. The final gloss is not as high as the 20% gloss, but the difference is not large. Because of the higher initial solids, both the thickening model and the filtercake model predict a stoppage of leveling. The differences in predictions and behavior is not much different than the 20% oil case. Figure 4 shows the results for the pure ink case. If the Darcy coefficient of the ink is at a high value, the filtercake model will well under predict the gloss response. If it is set to the value used for the paper, then a good prediction is obtained: this is caused by the ability of the filtercake to slow down the absorption. For the pure ink case, the thickening model underpredicts gloss because the viscosity is predicted to increase rapidly to a high value.

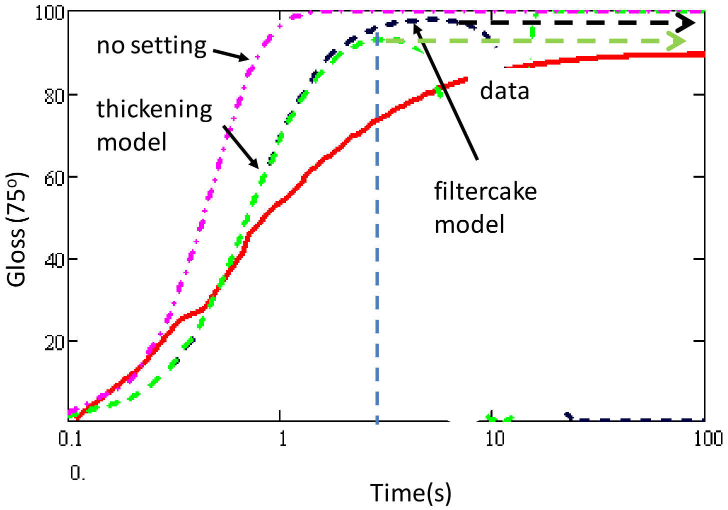

Figure 3. Results and predictions for the 10% oil and 90% ink case.

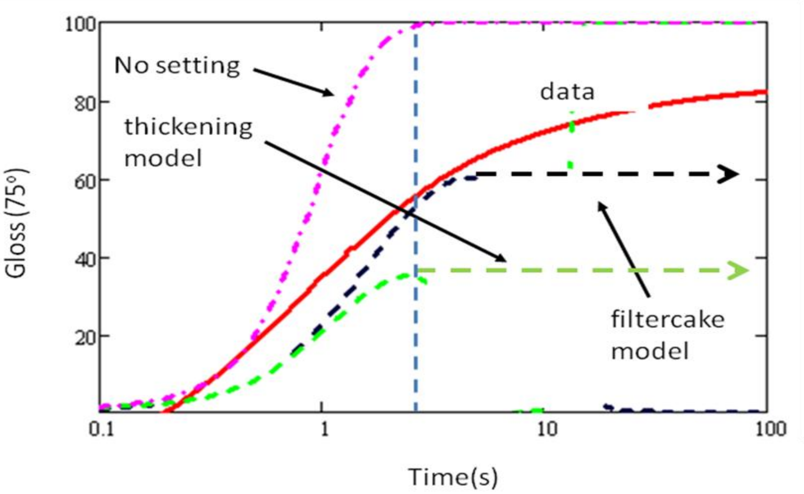

Figure 4. Results and predictions for the pure ink case.

Even though a few of the parameters had to be estimated, the general trends in the predictions and prediction of gloss is reasonable. The gloss results may help lead to a better understanding of the setting mechanism of an ink.

Glatter T., and Bousfield D.W., “Print gloss development on a model substrate”. *TAPPI J.* 80 (7): 125 (1997).

Ma D., R.D. Carter, and D.W. Bousfield, “Prediction of coating structure change during calendering”, Proc. of the Advanced Coating Fundamentals Symposium, TAPPI Press, Atlanta, GA. (2008).

Orchard, S.E.(1962): On surface leveling in viscous liquids and gels. *Appl. Sci. Res.* **A11**, 451-464.