Chemical Engineering Science 123 (2015) 579–587

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Modeling absorption and rheological changes as suspensions are applied to porous substrates

Jong Suk Sonn, Douglas W. Bousfield *

Paper Surface Science Program, Department of Chemical and Biological Engineering, University of Maine, Orono, ME 04469, USA

HIGHLIGHTS

- a novel experimental method to characterize rheology changes after contact with a porous surface.
- a quantitative comparison of proposed models of ink setting.
- a new model that describes both the absorption rate and the rheology changes.

ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form
8 October 2014
Accepted 27 October 2014
Available online 4 December 2014

Keywords:
Coating
Suspensions
Absorption
Rheology
Setting
Printing

ABSTRACT

During the application of a suspension to a porous substrate, some components of the suspension can penetrate the substrate and change the properties of the suspension. During offset printing, a pigmented ink contacts porous paper and absorption of the oil from the ink by the paper influences the final product quality and press operations. Although various models have been presented in the literature to describe these processes, a quantitative comparison of models is lacking.

Commercial cyan ink was diluted with mineral oil to generate various pigment and resin concentrations in the oil base. A porous ceramic plate with pores of approximately one micron in the top layer was used to simulate the porous layer of a paper-coating layer. The absorption rate of the ink-oil mixture into the plate was characterized gravimetrically. The viscosity change of the mixture after contact with the ceramic plate was characterized by a controlled stress rheometer. Three different models described in the literature were developed further to predict absorption rates and the rate of increasing viscosity. Next, the predictions of these models were compared to the experiments.

A filtercake based model predicts the absorption rate at various concentrations of oil and ink. The increase in viscosity due to absorption is predicted qualitatively using various models. A modified filtercake model is proposed that predicts the absorption rates and viscosity increases of these systems within expected accuracy.

1. Introduction

Fluids are applied to porous substrates in many situations, including painting, the application of adhesives, the production of textiles, carpet and flooring manufacturing, paper coating, and printing. In many cases, the fluid is a suspension. For example, silicon-carbide coatings and polyurethane coatings are applied to textiles to impart various properties to the fabric (Meng et al., 2009; Park and Kim, 2012). Upon contact, the liquid phase can be forced into the pore space by applying pressure or can be pulled into the pore space due to capillary forces. During the coating processes, these processes can change the amount of material that is transferred to the web and the expected force-coat weight relationship (Devisetti and Bousfield, 2010). For example, during painting, an absorptive surface can alter the rheology of the paint and the film thickness that is obtained when using a specific force. Although some models are available to predict penetration for certain processes (Ding et al., 2013; Ghassemzadeh and Sahimi, 2004), a good understanding of the changing absorption rates and the suspension rheology during application to a porous substrate is lacking in the literature.

Most offset printing inks are composed of a pigment and resin binder that are suspended in some type of oil, such as a mineral oil. The resin is often added as a solid, which dissolves to a small extent, and at 10–20% (by weight) of the ink. Cold set printing inks are solidified on the paper surface through the absorption of the oil phase into the paper pores during application and are made permanent through oxidation during storage. Although the final

---

* Corresponding author.
E-mail address: bousfld@maine.edu (D.W. Bousfield).

http://dx.doi.org/10.1016/j.ces.2014.10.049

drying process occurs through a chemical reaction, the absorption of the fluid phase over a short time frame is regarded as an important factor for achieving the desired print properties (Leach and Pierce, 2004). Rapid initial setting can result in low print gloss results. Slow setting rates can lead to “blocking” or ink transfer to the sheet on top of it. Another feature of inks is their resin component. The resin component is added at a level that allows some fraction to the resin to dissolve into the oil phase, with some resin remaining available as a solid particle. This solid resin phase is expected to be somewhat swollen and may be able to release oil if the conditions change (Leach and Pierce, 2004).

Various models have been introduced to describe ink setting by absorption, as shown in Fig. 1. The “thickening” mechanisms suggest a uniform increase in viscosity as the ink oils absorb into the paper, and the viscosity is a function of oil content (Gane et al., 2003; Gane et al., 2003). Xiang and Bousfield suggested the formation of a pigment filtercake with hard resin particles as oils migrate into the paper. In this case, the filtercake properties control the rate of setting (Xiang and Bousfield 2000; Desjumaux et al., 2000). Donigian proposed a “two phase” mechanism to describe the distribution of oils and resins into various phases within the ink film with different relative concentrations. When the oil is absorbed by the paper, the oil can diffuse out of the resinous phase to replace the oil in the oil rich phase (Donigian, 2006). This mechanism was proposed to account for rapid increases in viscosity that have appeared in some dynamic gloss tests and can explain the long-term changes in some samples.

Although these three models are very different, they all explain the same general behavior and seem reasonable. The absorption rate of oil into a porous surface is predicted to decrease with time according to the two-phase and thickening models because of the increased length of the absorption lengthscale. The filtercake model predicts a strong decrease in the absorption rate due to the formation of a filtercake. One important difference between these models is that the filtercake model predicts a gradient in the ink layer properties but the other two models do not. More work is needed to identify the correct mechanisms that control the setting rates of inks.

Much work has been performed regarding the role of coating pore structures on ink setting rates. Desjumaux et al. Desjumaux et al. (2000) and Preston et al. (Preston et al., 2002; Preston et al., 2003) studied the influences of pore size and volume on the rate of ink setting. These authors correlated coating roughness, pore size, and volume with the final ink gloss and found that the leveling of ink filaments on the surface is an important factor for the final print gloss. The structural parameters of the coating were changed by using various combinations of coating materials and by calendering against rough plastic sheets. However, little information has been reported regarding the influences of ink properties on these setting and leveling rates.

Rousu et al. (Rousu et al., 2000a, 2000b, 2001, 2003, 2005) investigated ink absorption and phase separation from ink within the coating structure on an enlarged scale from an infinite liquid source and with a limited absorptive to substrate ratio. The separation of the ink constituents was detected directly from the absorption path using Fourier Transform Infra-Red (FTIR) microscopy. These authors focused on two mechanisms that caused differences in the distribution of the ink constituents in the coating structure during printing. One mechanism is the adsorption-desorption of the pigments due to the coating pigment chemical and morphological variables. The other mechanism is the latex-oil diffusional interaction. Overall, these authors found that print quality parameters, such as print gloss, are affected by adsorption-desorption processes but not latex-oil diffusion.

Ström et al. (Ström et al., 2000, 2003a, 2003b) characterized the different absorption rates of ink oils in the coatings of various substrates after offset printing using gas chromatography and gel permeation chromatography. The hard resin binders and the high molecular mass alkyd resins did not penetrate into the coating. However, the low viscosity ink oils and triglycerides were absorbed by the coating during the ink setting and drying processes. The mineral oil was absorbed the fastest, followed by the vegetable oil and triglycerides. These results suggest that only small amounts of resin penetrate the paper.

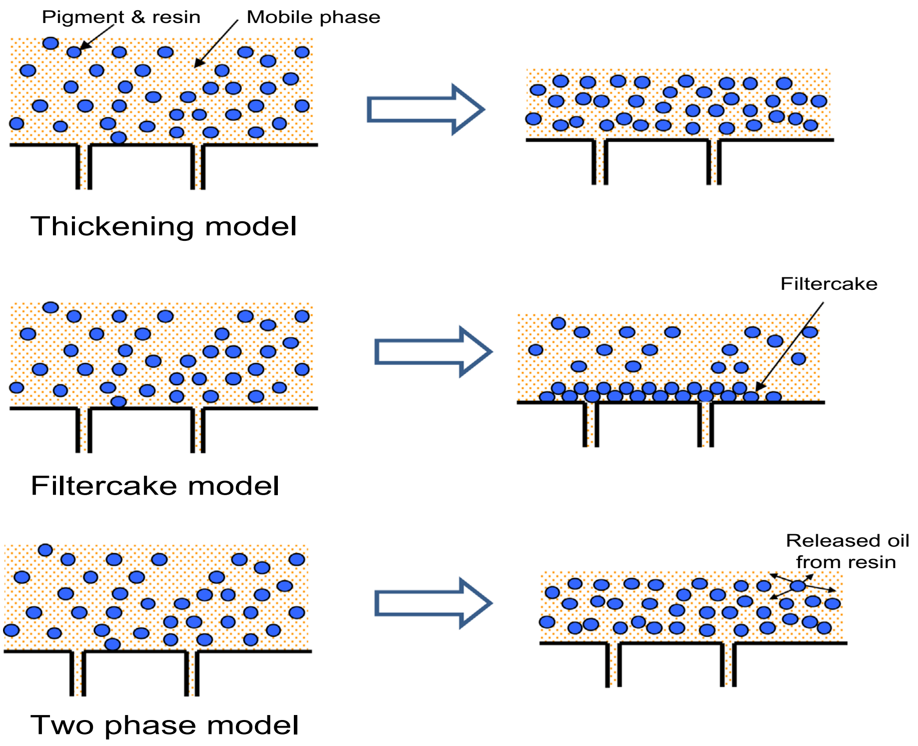

Fig. 1. Three proposed models of ink setting.