Correlation between Ink Rheology and Press Performance of Water-based Flexographic Inks

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Abstract

Water-based inks represent an exciting trend in the world of packaging industry and provide a technology for printers to eliminate VOCs (volatile organic compounds) emissions. There has been significant growth in the usage of water-based ink in the flexo packaging market, such as labels, corrugated products, paper products, and some of the polyethylene products. Over the years, ink manufacturers have worked to improve ink properties in order to achieve better print quality.

Rheological properties have major impacts on flow of inks and are fundamental in determining ink transfer in flexo printing. Of special interest are how water-based flexo inks behave and whether the rheological characterization has any power in predicting press performance of inks. In this paper, measurements of rheological properties of six water-based flexographic inks are discussed. A Flexo trial was performed on a three-color ComCo Commander flexographic press. Print performance was analyzed and interpreted, and was correlated to ink rheology data. Comparisons were made between fresh and aged inks of the same color, as well as between different colors.

Water-based flexo inks exhibit viscoelastic behavior under oscillatory and steady shear. The creep test also shows the viscoelastic behavior of these inks. It was found that rheological properties of an ink are more related to varying ink formulation, such as the choice of binder polymers, pigments, and the presence of additives in a system. A difference on the press performance was noted between the fresh and aged inks. Better print fidelity and higher print density was found in less shear-thinning inks, and print qualities are also related to ink viscoelasticity.

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Introduction

Water-based flexographic inks were introduced to reduce the VOCs emissions in flexographic printing. However, the emulsions employed in these water-based ink formulations have extremely low viscosity, and thus they do not possess the same rheological properties as their solvent-based counterparts.

Early water-based flexographic ink formulations employed the use of silica as a rheology modifier [Wallstrom, 1996]. However, these materials have undesired flow properties and produced poor print gloss, and thus they were of limited use. The two most popular groups of rheology modifiers employed in water-based systems are non-associative and associative thickeners. Non-associative thickeners comprise water soluble polymers with a high molecular weight, which dissolve in an aqueous phase and create strong linkage with neighboring water molecules [Kalenda, 2002]. The thickening effect of the non-associative rheological additives is based primarily on hydrodynamic volume exclusion (HDV) mechanism. Associative thickeners are low-molecular polymers, soluble in water, which are modified by hydrophobic groups [Kalenda, 2002]. Such groups include the hydrophobically modified polymers such as HASE and HEUR, which are widely used in water-based coating and printing ink systems. The thickening effect of this group is based on the interaction of the hydrophobic components of the thickener molecules with the hydrophobic components in a coating such as emulsion and pigment particles.

Rheology is defined as the study of the deformation and flow of materials. Materials such as printing inks are normally exposed to a variety of deformation (shear stresses) during their application processes. Rheometers provide a means for evaluating this entire range of viscosity changes as well as material viscoelastic properties.

Rheology of ink plays a central role in ink distribution and transfer in rotary printing processes, such as rotogravure and flexographic printing. Rheological modifiers on the improvement in the rheology of water-based inks have been investigated by Mai et al (2006), also, many studies have been done on paints and coatings; however, more complete viscoelasticity data on water-based flexo inks have been lacking so far. With a main objective of elucidating the rheological properties of water-based flexo inks and how rheology will relate to press performance of an ink, the rheological behavior of six water-based flexo inks was analyzed. The rheological properties are related to the print performance of these inks on flexo trial with print characterization.

Experimental

The experimental data consisted of the rheological characterization, particle size measurement, and print testing of six water-based flexographic inks. The print testing was on a pilot scale.

Rheology Characterization

Rheological measurements were performed using a TA Advanced Rheometer AR 2000 with a standard concentric cylinder system (or cup and bob system). Concentric cylinder systems are generally used for low viscosity samples that cannot be held within the gap of cone and plate or parallel plate systems.

In all of the rheology measurement, the samples were first exposed to a conditioning step which ensured the samples were at the correct temperature and the residual normal force was at an acceptable level, followed by a two-minute equilibrium period. The geometry was maintained at the constant temperature at 25˚C ± 0.1˚C using a circulating water bath. Rheological tests have been carried out in oscillation stress and frequency sweep, steady state flow, and creep recovery.

- Oscillation stress sweep test
  Constant frequency of 1 Hz was applied and the amplitude of the stress was incremented from 0.001 to 1000 Pa. By performing an amplitude stress sweep, the linear viscoelastic region (LVER) can be determined.
- Oscillation frequency sweep test
  From the amplitude sweep test, a stress or strain was selected from the LVER and incorporated into the oscillation frequency sweep test. During the frequency sweep test, the fixed amplitude of the stress was applied while the frequency was decreased from 100 Hz to 0.01 Hz.
- Creep recovery measurement
  In a creep recovery measurement, a constant low shear stress was first applied to the sample and then removed; the resulting deformation was measured as a function of time and applied stress.
- Steady state flow test
  The material was subjected to a controlled increasing shear rate and the resultant viscosity was measured.

Particle Size Measurement

Particle size measurement was performed using a Particle Sizer Submicron 370 NICOMP analyzer, which is based on dynamic light scattering (DSL). Light from a laser is focused into a glass tube or cuvette containing a diluted suspension of particles. Each of these particles scatters light in all directions. The intensity of the light scattered by a single, isolated particle depends on its molecular weight and overall size and shape, and also differences in the refractive indices of the particle and the surrounding solvent (Sesetyan, 2002; Frimova, 2003).

Press Trial

The ink samples were printed on a three-color ComCo Commander flexographic press. This press is equipped with both UV and conventional hot air dying and has a maximum speed of 750ft/min. It is capable of printing on paper, paperboard, plastic films, metal foils, and laminates.
A banded anilox roller with 600, 700, and 800 lines per inch (lpi) was used in this project. The speed was set at 200ft/min. The substrate used was light weight coated (LWC) paper.

All printed samples were tested for ink performance by measuring their reflective density using an X-Rite 530 SpectroDensitometer. The densitometer measures the difference between light projected onto (through) the sample and the amount of light reflected back (or transmitted by sample). The density is related to reflectance by:

$$\text{Density} \quad D = \log_{10} 1/R \tag{1}$$

Where: reflectance $R = R_1/R_w$, R_1 = Intensity of light reflected from print, R_w = Intensity of light reflected from white paper.

The flexographic printed samples were also tested for print fidelity (dot gain curve) and CIE Lab values. Color difference ΔE were calculated between the fresh and aged ink samples using the following formula:

$$\Delta E_{\mathrm{a,b}} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{2}$$

Where: L_1, a_1, b_1 – CIELAB coordinates of reference color (fresh ink), L_2, a_2, b_2 – CIELAB coordinates of compared color (aged ink), $\Delta L = L_1 - L_2$, $\Delta a = a_1 - a_2$, $\Delta b = b_1 - b_2$.

Results and Discussion

An oscillatory stress sweep reports the storage and loss moduli as functions of the stresses applied at a constant frequency (1Hz) for the six water-based flexo inks. The critical oscillation stress and elastic modulus at the onset point were calculated and are reported in Figure 1. Dynamic tests indicated non-linearity of the viscoelastic response of the inks. The elastic modulus G' of all inks are linear up to an oscillation stress around 7 Pa, which defines the critical stress, then these values have a sudden decrease after the critical stress, indicating a disruption in the ink structures. A higher critical oscillation stress indicates a stronger structure and requires more energy to break up the elastic structure [Aubry and Moan, 1997]. These data are more related to the structure of an ink and its storage stability. The precise role of this viscoelasticity in predicting printing performance of an ink may be difficult to establish. As shown in Figures 4 & 5, it is difficult to predict the trend of print fidelity and reflective density from data obtained from oscillatory sweep stress tests.

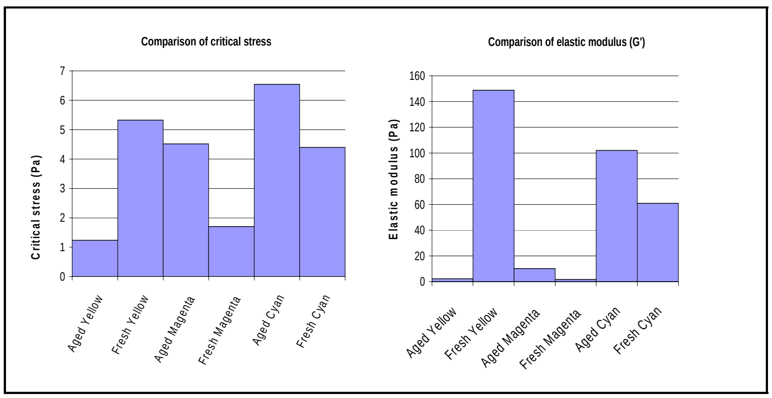

Figure 1. Critical oscillation stress and elastic modulus for water-based flexo inks

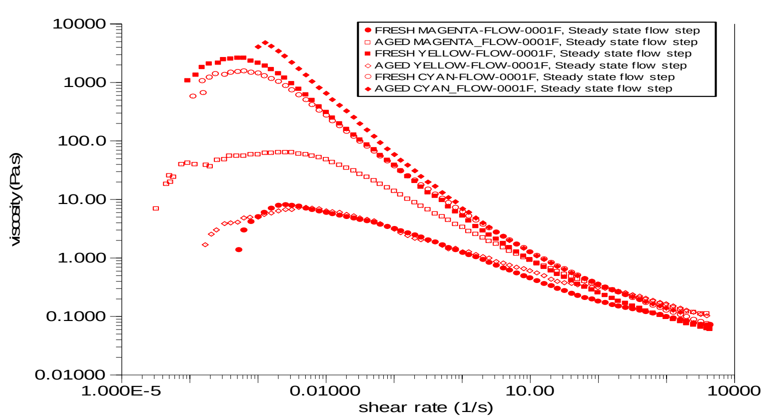

Figure 2. Viscosities as functions of shear rate for water-based flexo inks

In the steady state flow test mode, the material is subjected to a controlled increasing shear rate and the resultant viscosities are measured. This mode can be used for predicting ease of ink application where thin films are printed. The flexographic printing process is a rotary printing process consisting of three rollers, including the metering roller, the anilox roller and the plate cylinder, The ink applied is under shear and the shear rate associated with this application is 10^3 to10^6 s^{-1} depends on the speed and ink film thickness [Whittingstall, 2007]. For easy application, ink should be shear thinning, that is it shows a decrease in viscosity with increasing shear rate.

As shown in Figure 2, although the shear-thinning is different, all six inks are shear-thinning to yield a viscosity less than 1Pa seconds and are suitable for flexo application. When comparison was made between fresh and aged inks, there is evidence showing that the higher shear-thinning rate results in lower reflective density (Figure 5) but higher dot gain (Figure 4). The possible explanation is that the less shear-thinning indicates more Newtonian flow behavior which benefits press performance. According to basic rheological understanding [Oittinen, 1976], shear thinning at low speeds is associated with internal pigment or binder-gel structures [Oittinen, 1992]. Ink components tend to aggregate with time and potentially cause thixotropic behavior of inks. The particle size of aged inks is bigger than that of fresh inks (Table 1).

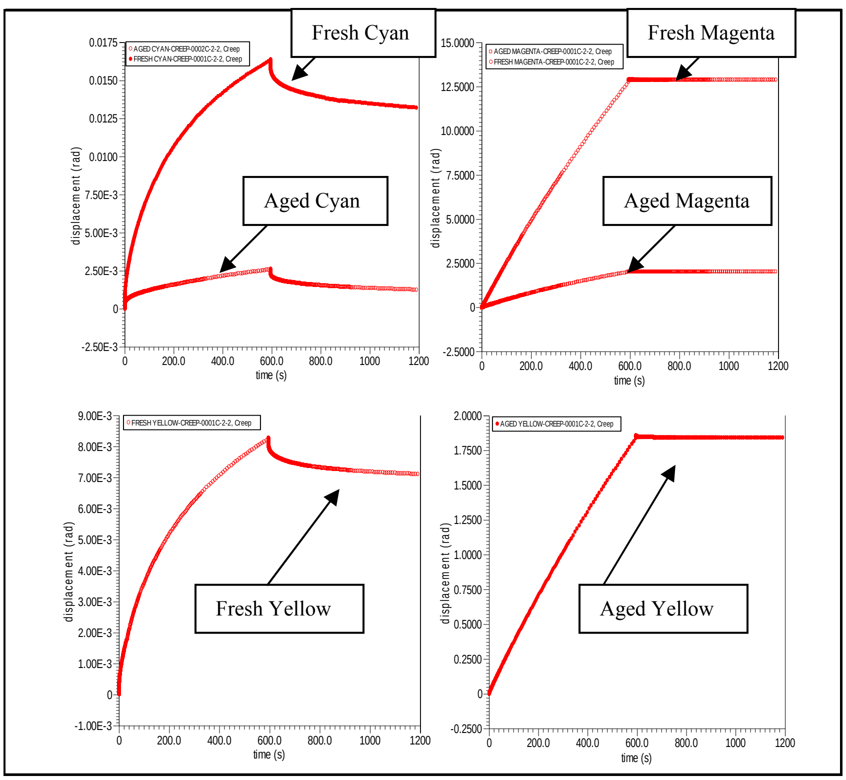

Figure 3. Creep recovery curves for water-based flexo inks

Creep recovery measurements investigate the properties of settling and leveling after applications on surfaces. Creep-recovery curves report how materials respond to stress. The compliance depends on the material tested: the stiffer the material, the lower the compliance. Viscoelastic materials show retarded deformation and recovery, or in some case, a sample can show retarded deformation and continuous flow. Figure 3 shows the creep recovery curves for water-based flexo inks. It is important, that a printing ink demonstrates the correct degree of elasticity. If an ink is too elastic, it will fail to enter the nip, and if elasticity is insufficiency, it will give poor dot definition (lower print density). Appropriate amount of elasticity also prevents excessive surface wetting (better print fidelity). The test result is consistent with the data (Figures 4 & 5) obtained from the flexo trial.

Table 1. Particle size of water-based flexo inks

Ink samples	Mean diameter(nm)	Standard deviation(nm)
Fresh Cyan	236.0	136.1
Aged Cyan	294.0	150.8
Fresh Magenta	220.8	102.5
Aged Magenta	229.8	104.2
Fresh Yellow	196.8	89.7
Aged Yellow	214.3	106.1

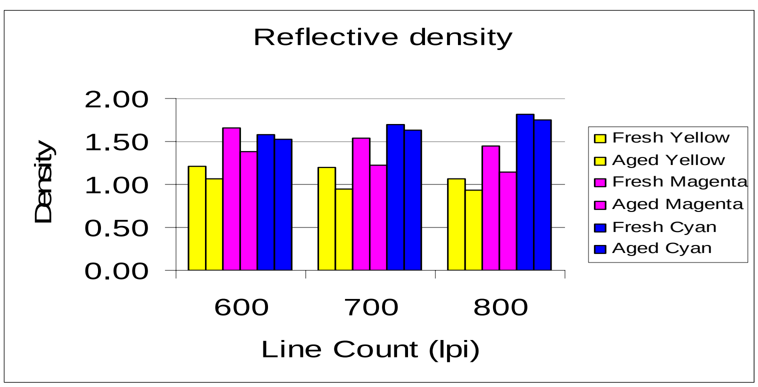

Figure 4. Reflective density of water-based flexo inks

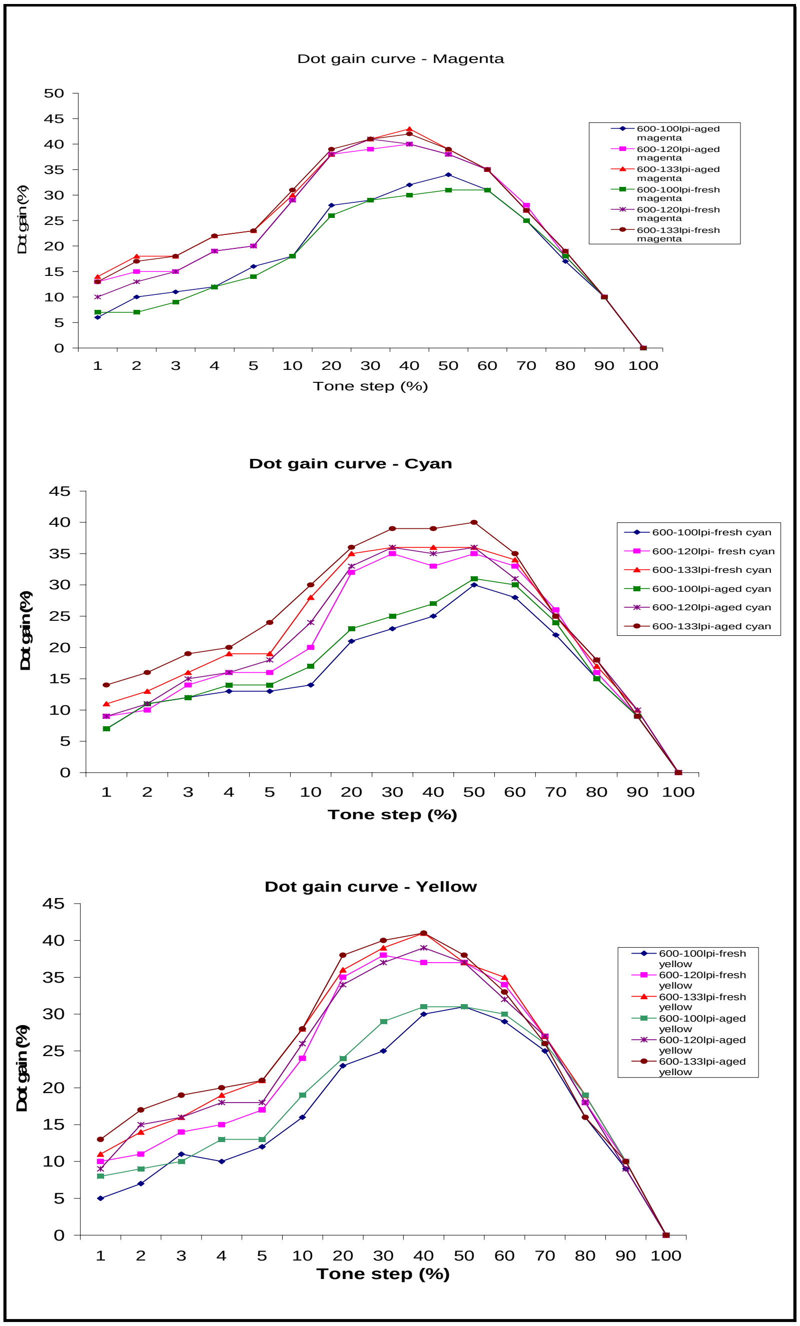

Figure 5. Dot gain curves for water-based flexo inks

Color differences, ΔE, were calculated from CIELAB values. Comparisons were made between aged and fresh ink of the same color. A weak trend, with the exception of cyan inks, indicates that color difference between aged and fresh ink increases as anilox line count increases (shown in Table 2). These differences may be caused by the change in print density and dot gain rooted from difference in ink rheology and particle size.

Table 2. Color difference between fresh and aged ink samples

ΔE / Colors	Line Count (lpi)		
	600	**700**	**800**
Fresh – aged yellow	7.17	9.51	10.96
Fresh – aged magenta	6.66	7.65	9.92
Fresh – aged cyan	7.32	9.07	1.82

Conclusion

The main objective of this work was to investigate the rheological properties of water-based flexo inks and to relate their effects to ink performance on press. It was noticed that water-based flexo inks are viscoelastic materials, and their elasticity has great effects on ink flow properties that lead to different press performance. It was found that rheological properties of an ink are more related to varying ink formulation, such as the choice of binder polymers, pigments, and the presence of additives in a system. A difference on the press performance was noted between the fresh and aged inks. Better print fidelity and higher print density was found in less shear-thinning inks, which have suitable elasticity.

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