THE USE OF RHEOMETRY TO PREDICT OFFSET INK PERFORMANCE ON PRESS

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ABSTRACT

A stress controlled rheometer with cone and plate geometry was used to study the rheological properties of offset inks. Inks were emulsified with different levels of fountain solutions, up to maximum absorption. Correlation between rheological properties, as measured by a Carri-Med rheometer, and observations from press trials was investigated.

INTRODUCTION

An extensive effort has been made by the printing ink industry to use rheological as well as other physical measurements to predict ink performance on the press. The complexity of the lithographic printing process has made it very difficult for a single experiment to accurately foretell ink behavior. A survey of the procedures used today to test inks and prints in the laboratory showed that the majority of testing is still done using unemulsified inks.

The importance of studying ink emulsions in order to predict ink performance is obvious: The lithographic press prints a water-in-ink emulsion, not just ink.

Examples of prior art using emulsified ink to predict performance include the water pick-up test (Surland, 1980), the rate of water pick-up (Bassemir and Shubert, 1985) and others.

The study of ink emulsions using various rheometers has also been investigated (Chou and Fadner, 1986; Chou and Cher, 1990; Durand and Wasilewski, 1993) and others.

The scope of this paper is to see if a correlation can be drawn between the performance of heatset inks in the pressroom and their rheological behavior as studied on a controlled stress rheometer.

PROCEDURE

I. Sample Preparation

Ink samples were prepared for rheological measurements in a jacketed cup using a Cowles blade high-speed Dispermat mixer with controlled rpm. The unemulsified ink was dispersed for 5 minutes at 4000 rpm before testing. The resultant temperature of the ink reached 40 to 45°C with a recirculation bath set at 25°C. If more than one test was run on the same emulsion, an additional 2 minutes of mixing was performed immediately before each test.

In one of our studies, it was found that ink samples taken from various parts of the press contained 15 to 35% fountain solution. Therefore, inks were emulsified by dripping predetermined amounts of fountain solution (0, 20, 40% and maximum) into the vortex of the ink, while observing that uniform mixing was maintained. After the desired amount of fountain solution was added, the mass was then dispersed for 5 more minutes. The maximum amount of fountain solution was reached when bulk flow became discontinuous with addition of more fountain solution and would not resume within a reasonable amount of time.

After mixing was completed, samples were then immediately transferred to the rheometer for measurements.

In this study, "good" ink was defined as an ink/fountain solution combination that ran well on press. "Bad" ink was defined as an offset ink/fountain solution combination that did not run well on a commercial press because of ink/water balance problems.

II. Rheometric Measurements

A Carri-Med controlled stress rheometer model CS500 equipped with a Peltier temperature control system was used in this study. Two modes were then employed:

(1) Shear Stress Sweep (Flow Mode)
A continuous shear stress logarithmic sweep, up to 10,000 $dynes/cm^2$ was applied using a 4 cm., 2 degree cone with a 2-minute ascent time followed by 2-minute descent time.

(2) Torque Sweep (Oscillation Mode)
A torque was applied using a 2 cm. flat plate at 25° C. The frequency was set at 1 Hz, while torque was increased in 50 increments from 5,000 up to 200,000 dyne.cm.

SHEAR STRESS SWEEP (FLOW)

Results

This procedure was used to determine ink emulsion stability. Interpretations were derived from shear rate/shear stress plots. Observed parameters were the change in the hysteresis area, and the rate and direction of viscosity change at different levels of fountain solution. In the plots, the greater the slope, the higher the viscosity, and vice versa.

Inks that did not perform well on commercial press due only to ink/water balance problems were selected for this study. Comparisons were then made with control inks that performed well on the press.

The following examples illustrate our findings.

Example One:

A printer encountered problems with excessive emulsification causing color variation. It was necessary for the printer to push too much fountain solution to prevent scumming. Figure 1A shows the hysteresis loops of the "bad" ink at 0, 20, 40, and 56% (maximum) fountain solution. Viscosity increased with the addition of 20 and 40%, then at 56% viscosity decreased. The 56% fountain solution level shows a much greater breakdown in structure and lack of recovery, as evidenced by the dramatic increase in the hysteresis loop area (area of thixotropy).

In Figure 1B the corresponding "good" ink curves at 0, 20, 40 and 64% (maximum) fountain solution showed smaller change in loop area, even at maximum water uptake. There was only slight increase in viscosity with increasing water content.

Figure 1A

Shear stress sweep of a bad ink

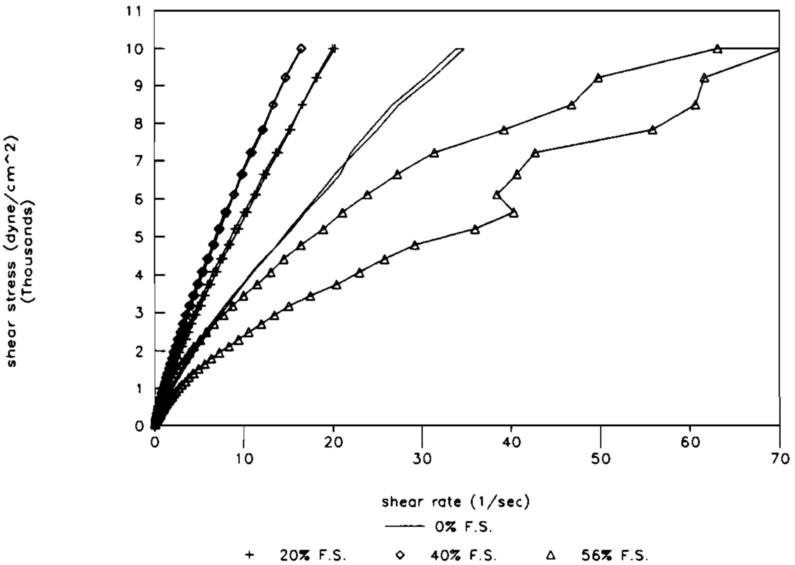
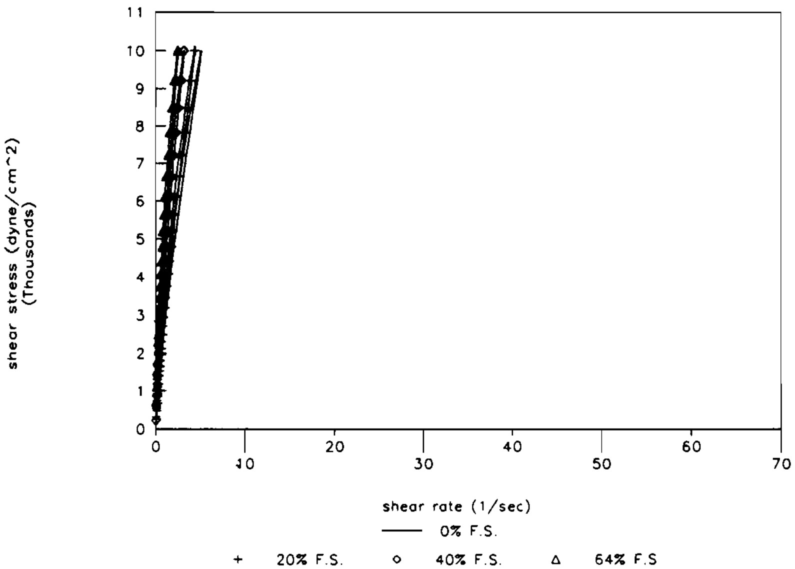


Figure 1B

Shear stress sweep of a good ink



Example Two:

A particular brand of fountain solution was blamed for causing ink piling on the plate and blanket. At two different printers, excessive emulsification was reported. Figure 2A and Figure 2B represent the flow curves of the two "bad" inks.

Figure 2A

Shear stress sweep of a bad ink

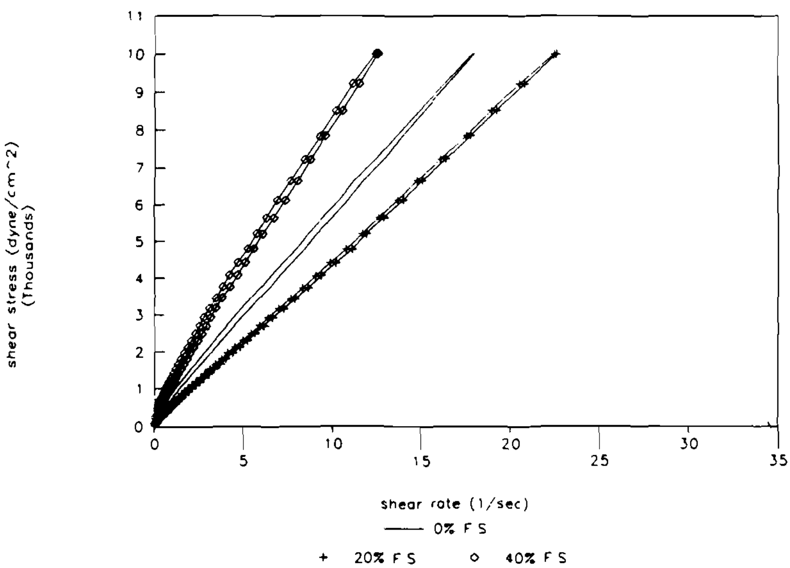
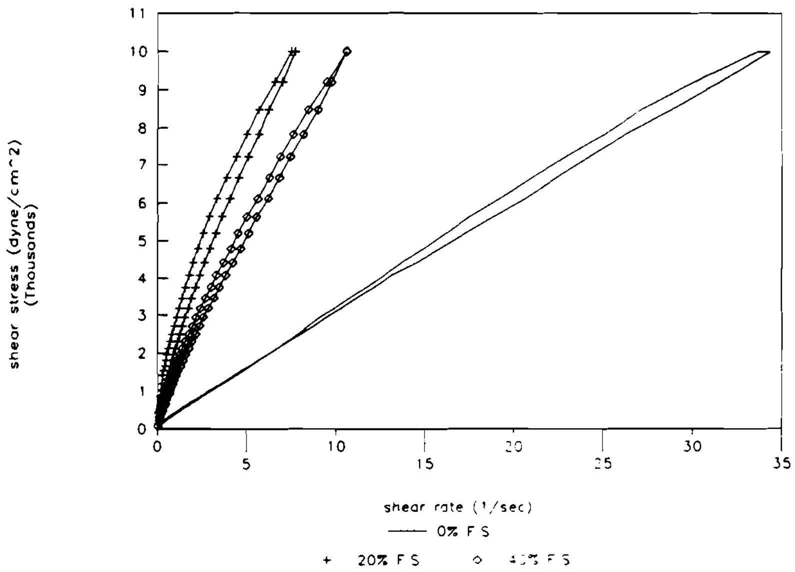


Figure 2B

Shear stress sweep of a bad ink



In Figure 2A, it is evident from the slope of the curves that at 20% fountain solution the ink emulsion has a lower viscosity than at 40%. Figure 2B shows that in addition to viscosity fluctuation, the emulsions have increased appreciably in viscosity compared to the neat ink.

A different fountain solution was then used in combination with the same ink in Figure 2B, and the press showed no emulsification problem. The viscosities of the inks in Figure 2C only increased in small increments in order of increasing fountain solution. In Figure 2D, another "good" ink is shown with a downward, instead of upward, progression in viscosity.

Figure 2C

Shear stress sweep of a good ink

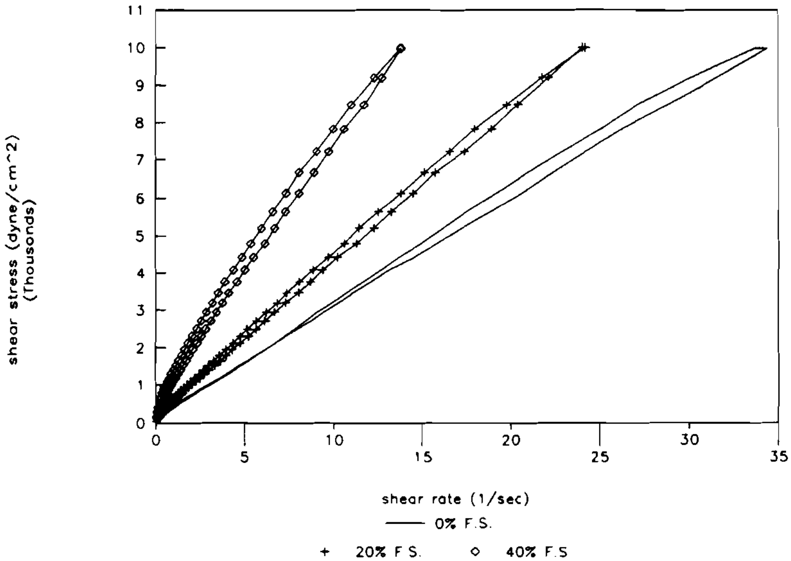
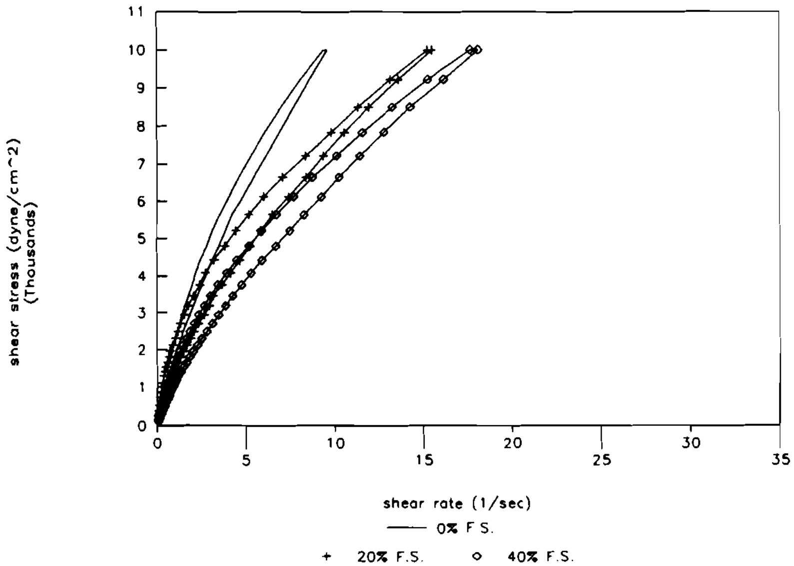


Figure 2D

Shear Stress Sweep of a Good Ink



Example Three:

Another example is demonstrated in Figures 3A and 3B. In this case, the "good" ink, Figure 3A, shows minimal viscosity and hysteresis area change, while the "bad" ink exhibited instability when tested with 40% fountain solution. The latter ink was taken off the press due to slip roller build-up on an integrated dampening system.

Figure 3A

Shear stress sweep of a good ink

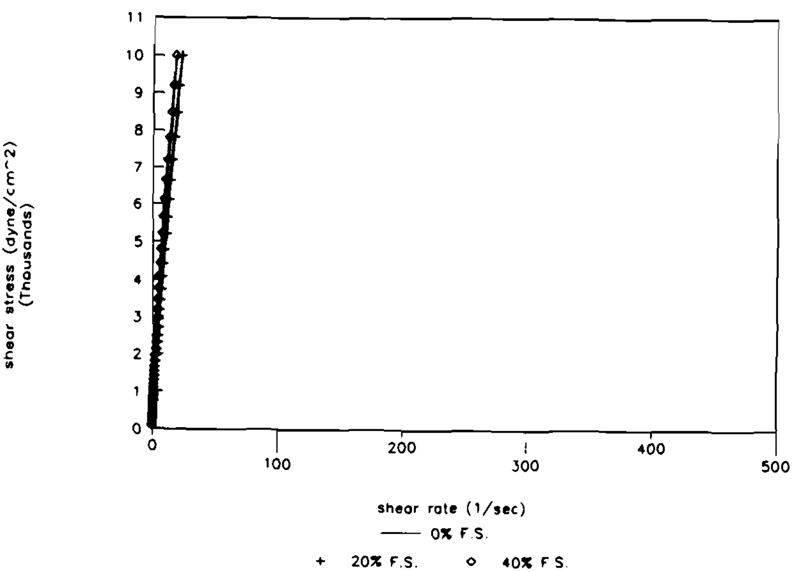
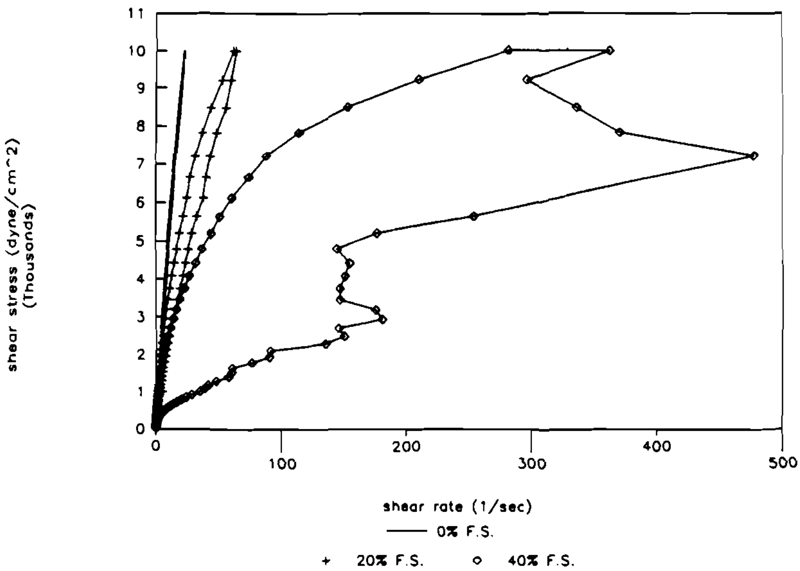


Figure 3B

Shear stress sweep of a bad ink



Discussion

It is well known that the hysteresis loop area is a measurement of the ability of the ink structure to recover when the shear rate decreases during the down curve measurement. The larger the area, the slower the rate of structure recovery, and vice versa.

At higher levels of fountain solution and as the rate of shear increased, the dispersed fountain solution eventually coalesces into water droplets. The coalescence process proceeds until the rheometer cone spins out of control, lubricated by a thin water layer. Chou and Fadner (1986) referred to the stress at this point as "critical-shear-stress-value". Inks which approach the "critical-shear-stress value" at relatively lower levels of fountain solution appear to be more susceptible to ink/water balance problems on the press. Our studies show that "good" inks exhibited very little fluctuation in viscosity (Figure 1B and Figure 3A). In other cases, "good" inks showed larger variations in viscosity in one direction, either increasing (Figure 2C) or decreasing (Figure 2D).

"Bad" inks, on the other hand, showed large viscosity fluctuations with no apparent progression (Figure 2A and Figure 2B) with fountain solution increase.

"Bad" inks also exhibited large hysteresis loop areas, especially at higher levels of fountain solution (Figure 1A and Figure 3B). This is an indication of loss of structure recovery.

TORQUE SWEEP (OSCILLATION)

Results

Offset inks are viscoelastic dispersions. They possess both elastic (solid like) and viscous (fluid-like) characteristics.

Oscillation is the technique used to characterize the viscoelastic character of materials. Using this method, a sinusoidal stress wave is applied to a given sample and the phase angle (δ) between the strain wave produced and the stress wave input is measured. Theoretically, if a material is purely elastic, the stress and strain waves are in-phase (0° phase angle). If the sample is purely viscous, the stress and strain waves are out of phase (90° phase angle). By definition, viscoelastic materials have phase shifts somewhere between 0° and 90°. The following dynamic properties are derived from the phase angle δ:

1. Elastic modulus G': Also called the storage modulus. It represents the amount of energy stored with each cycle. It is derived from

$$G' = \frac{\sigma^{\circ}}{\gamma^{\circ}} \cos\delta$$

   where σ° and γ° are the stress and strain amplitudes, respectively.

2. Viscous modulus G'': Also known as the loss modulus. It is a measure of the amount of energy lost with each cycle.

   G'' is derived from:

$$G'' = \frac{\sigma^{\circ}}{\gamma^{\circ}} \sin\delta$$

3. Tan δ: Is the ratio of the viscous to the elastic component.

$$Tan\delta = \frac{G''}{G'}$$

If Tan δ is less than one, the material is more elastic than viscous.

If Tan δ is greater than one, the material is more viscous than elastic.

4. Complex viscosity (η*) is obtained from

$$\eta * = \frac{\sqrt{(G')^2 + (G'')^2}}{\omega}$$

where ω is the angular frequency in radians/sec.

The rheometer used in this study is capable of performing non-destructive oscillation tests, either in frequency or in torque sweep modes. In the frequency sweep mode, a small amplitude sinusoidal stress wave is applied at a frequency range of 0.001 Hz to 10 Hz. In the torque sweep mode, the torque is increased at a selected frequency, and the resultant strain (amplitude) is measured.

The non-destructive tests were first performed on a variety of "good" and "bad" inks. No apparent correlation between ink performance and rheological characteristics was observed in the linear visco-elastic region. When the torque sweep was used in a destructive mode outside the linear range, distinguishable rheological patterns were observed for "good" and "bad" inks.

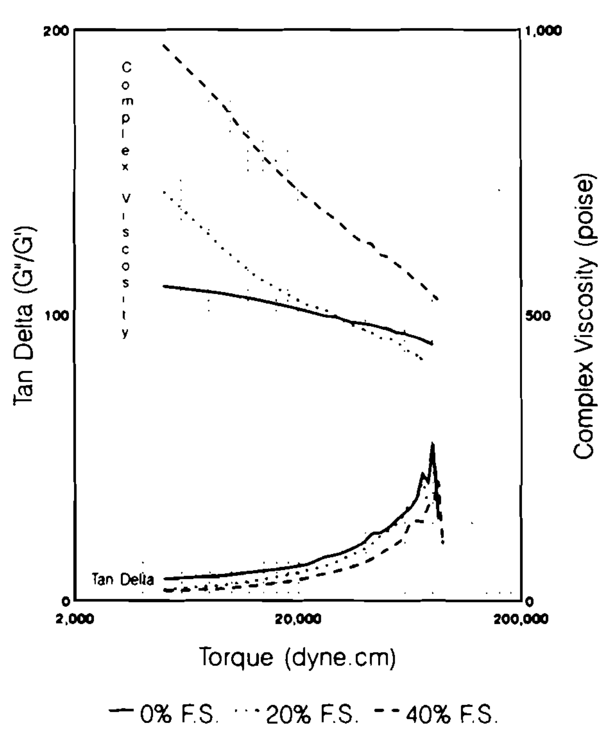
The following examples represent destructive torque sweep results where torque was applied until the strain wave was completely out of phase (90° phase angle). At this point, the elastic modulus equals zero, and the sample exhibits purely viscous characteristics. This point will be referred to as the "critical structure break point". In all cases, complex viscosity decreased, while tan delta increased with increasing torque.

Example Four:

Figure 4A shows the complex viscosity and tan delta versus torque of a "good" ink. The graph shows that all three ink samples, at 0, 20, and 40% fountain solution reach the critical structure break point at about the same torque value. This point occurred around 80,000 dyne.cm. At this point, tan δ is at its maximum ($G' = 0$), and complex viscosity is at a minimum in all cases.

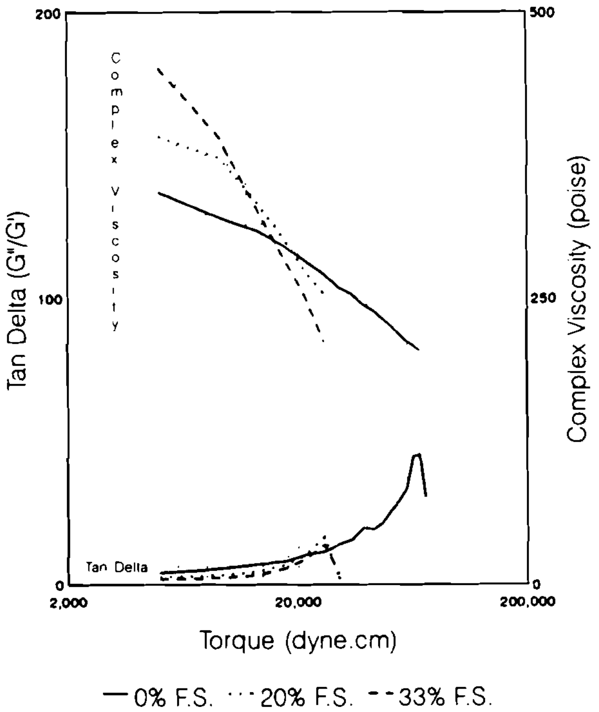
Figure 4A

Torque Sweep of a Good Ink



Another "good" ink is shown in Figure 4B. In this case, the structure break point for the 20% and the 40% fountain solution occurred at the same torque, although lower than that for the unemulsified ink.

Figure 4B
Torque Sweep of a Good Ink



Example Five:

Figures 5A and 5B show one ink tested with two fountain solutions. The ink exhibited excessive emulsification and slip-roller build-up on two different commercial presses. The same ink ran trouble-free when a third fountain solution was used, Figure 5C. Unlike the inks described in Example 4, the "bad" inks shown in Figure 5A and Figure 5B demonstrated different responses to increasing torque when the fountain solution amounts increased from 0 to 40%. The critical structure break point continued to shift to a lower torque value as the fountain solution was increased. The "good" ink in Figure 5C demonstrates very small torque difference between 20 and 40%.

Figure 5A
Torque Sweep of a Bad Ink

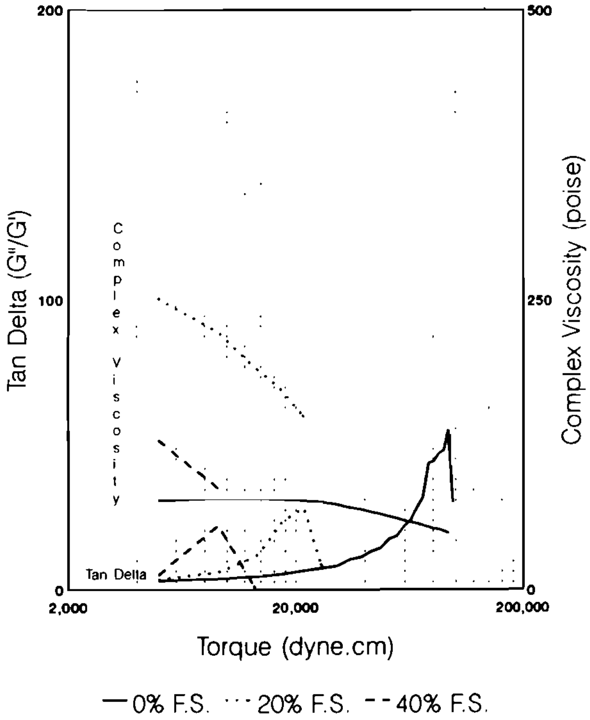


Figure 5B
Torque Sweep of a Bad Ink

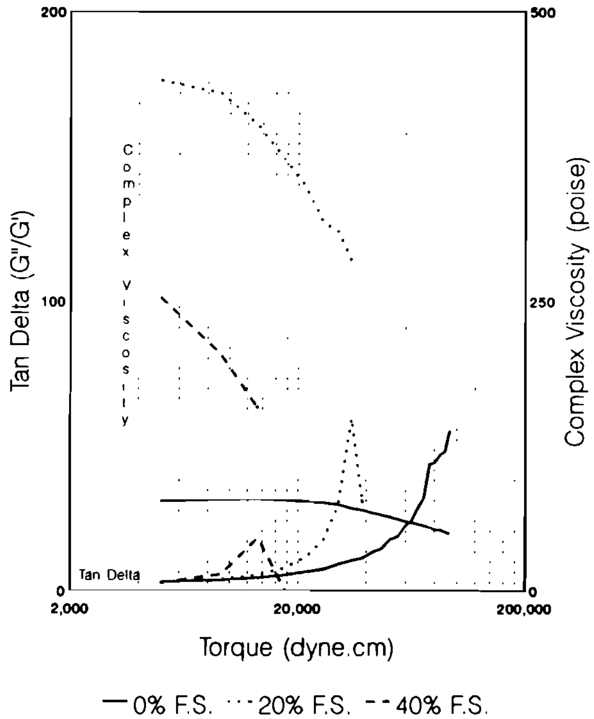
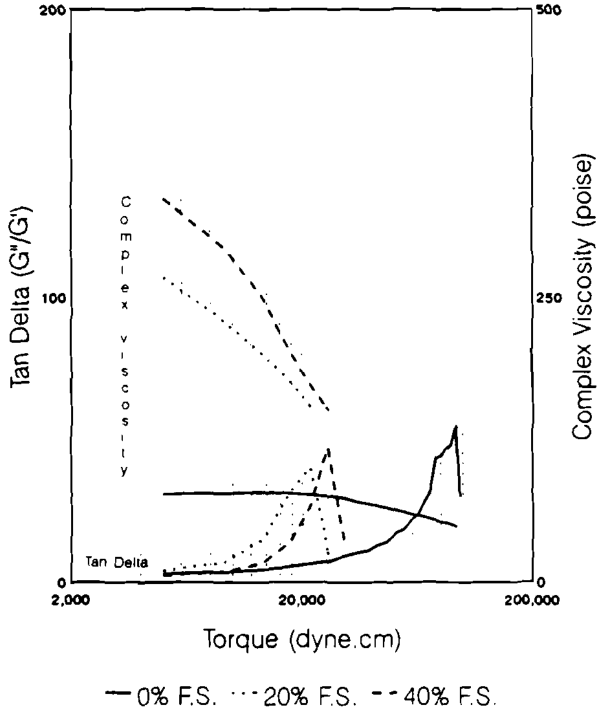


Figure 5C
Torque Sweep of a Good Ink



Example Six:

Figure 6A shows a continuous change in the critical structure break point with increasing fountain solution. This "bad" ink demonstrated excessive emulsification and slip roller build-up on a commercial press. The "good" ink in Figure 6B replaced the "bad" ink on the same press, and the problems were eliminated. The tan delta maximums and the complex viscosity minimums of this "good" ink, as did the "good" ink in Examples 4, occurred in a narrow range of torque at 0, 20, and 40% fountain solution.

Figure 6A
Torque Sweep of a Bad Ink

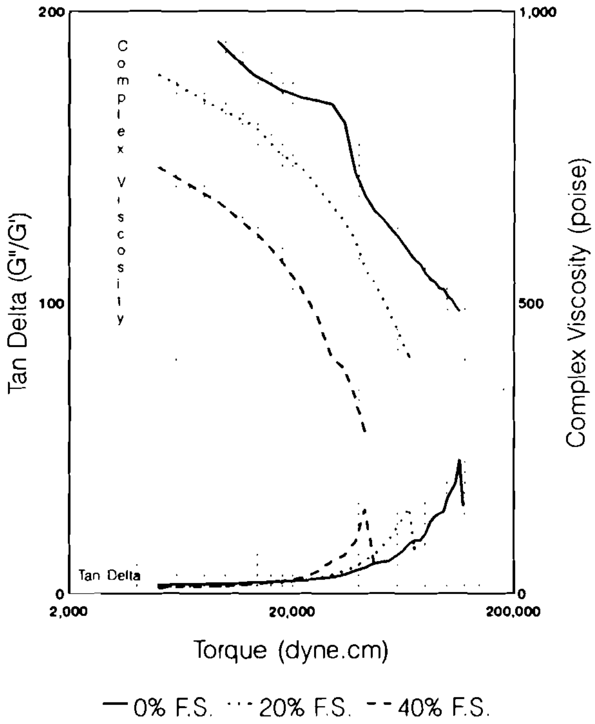
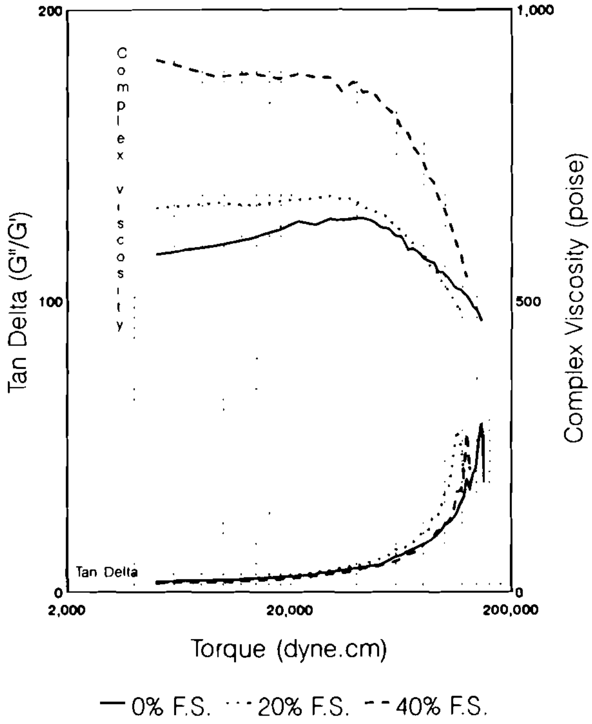


Figure 6B
Torque Sweep of a Good Ink



Discussion

It has been demonstrated, in other published work and in the shear stress sweep section in this study, that ink emulsion stability is critical to successful ink/water balance on the press. By employing the torque sweep technique beyond the linear viscoelastic region, some meaningful results were obtained.

In all the examples cited, the torque was increased until the elastic modulus was reduced to zero. We called this point "critical structure break point". It appears on the graphs at maximum tan delta and minimum complex viscosity. With the addition of 20 and 40% fountain solution, the break point of most "good" inks occurred within a narrow range of the applied torque.

"Bad" inks, on the other hand, behaved differently in that, due to the lack of emulsion stability, the critical structure break point shifted to a much lower torque value with each additional level of fountain solution.

It is noteworthy to observe the relationship between the complex viscosity and the amount of fountain solution at torque values under 10,000 dyne.cm. In the case of the "bad" inks (Figure 5A and Figure 5B), complex viscosity fluctuated with each addition of fountain solution. Figure 6A, however, demonstrated a downward viscosity progression. In contrast, "good" inks exhibited an upward progression in viscosity (Figures 4A, 4B, 5C, and 6B).

CONCLUSION

A qualitative method was developed whereby a stress controlled rheometer was used, in a shear stress sweep and in an oscillation torque sweep mode, to differentiate between inks which performed well or poorly on the press.

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