LOW SHEAR VISCOSITY OF PUBLICATION GRAVURE INKS AND ITS IMPLICATIONS

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Abstract: Transfer of publication gravure inks takes place in the low shear region of 0.01 - 300.0 sec^{-1}. Comparative studies of inks show that psuedo-plastic flow in this region, without excessive solvent evaporation, can greatly improve transfer which is evident in a more faithful dot reproduction. This is especially true for the mid to light tones. Photo-micrographs and viscosity studies on the Haake RV100/CV100 Viscosimeter show this to be the case.

Publication gravure inks must typically run at high speeds, in the range of 2000 ft/min. (10m./sec), provide extremely fast drying and maintain faithful reproduction of midtones, and even more importantly the light tone areas. Ink viscosities are of the order to 5-7 centipoise and relatively Newtonian at 30°C.

Competing with gravure in the publication printing industry is the web lithographic process. Web lithographic inks are characterized by relatively high viscosity and the ability to print discrete dots in the mid to light tone areas.

A comparison of properties for these different printing techniques is instructive:

Table I

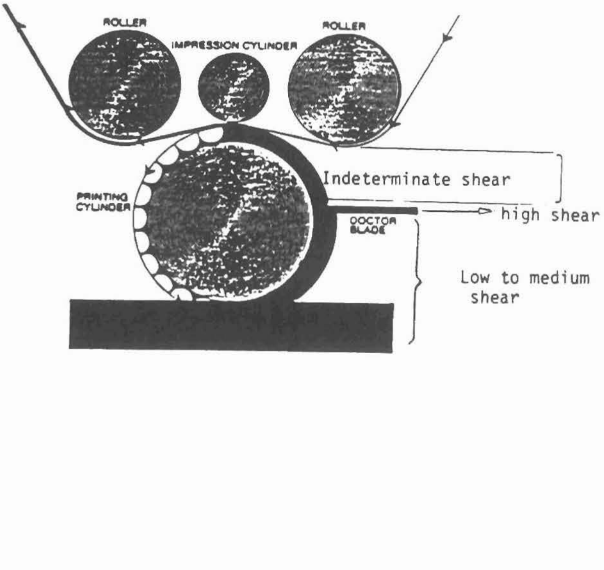
	Web Offset	Gravure
High speed prtg.	Indirect 1000-2000 ft/min.	Direct 2000 ft/min.
Plate	Planographic	Engraved Cylinder
Drying Characteristics	Solv. Evap. final oven temps. 200-300°C	Solv. Evap. warm air 30-35°C. between units

Apparent Viscosity 30°C	psuedo-plastic 5000-10,000 cp	Newtonian 5-7 cp
Yield Stress(1)	1000-2000 dynes/cm^2	virtually none

(1) Yield stress is defined as the stress (force) required to initiate flow when starting at very low rates of shear. The values given in this table are the results of actual laboratory testing.

Gravure printing historically has had distinct advantages in continuous tone reproduction. With the expanded use of mechanically engraved cylinders printability problems are being encountered in the mid to light tone areas. As Table I indicates inks for the gravure process must be of low viscosity and release solvent rapidly through evaporation. Each cell must print sharply after being exposed to shear rates in excess of 100,000 sec.$^{-1}$. If the ink dries too fast, it will tend to plug the cells thereby reducing transfer in that area and will show up in the form of missing dots in the mid to light tones. An example of calculating approximate shear rate in sec^{-1} is as follows:

> A roller passing under a doctor blade at 1000 cm/sec and depositing a film of 100 microns (0.01 cm) will create a shear rate of 1000 cm/sec divided by 0.01 cm = 100,000 sec^{-1}.



The purpose of this paper is to investigate: "What actually takes place just prior to the instant the ink transfers from the cylinder to the paper?" At this point there is no shearing action taking place and therefore the shear rate is essentially "0". We would like to know the rheological profile of the ink at this point. Since this is an area that can't be measured directly, our study covers the range of 0.01-300 $\sec^{-1}$. This range also approximates the shear rates which occur in the bulk fountain ink.

Solvent evaporation from conventional gravure ink produces increased viscosity and length, which is an undesirable type of rheology for faithful transfer. What is wanted is a formulated rheology comparable to the high yield stress which is present in a modern web lithographic ink. If this is done, solvent evaporation during the inking process is also reduced without affecting the final drying rate. This should definitely enhance the mid to light tone cell reproduction. A prototype ink was developed using this approach and compared to a standard gravure ink.

The instruments used in this study were:

1) Microscope - Bausch and Lomb Stereo zoom with maximum 70 X magnification.

2) Haake RV100/CV100 programmable viscometer with rotational and oscillatory capabilities.

3) Sensor System - Mooney Ewert (ME-30)

   Bob and cup with cone shaped base (Fig. I) utilized for all testing due to its high sensitivity to shear stress.

The standard ink gave acceptable prints visually across the entire tonal range. Close examination under the microscope revealed that the mid to light tone areas were actually missing some dots and the more densely populated areas were smudged furnishing a more nearly solid print. (Photograph 1A and 1B). A similar photo-micrographic examination of the specifically designed prototype ink showed that the missing dots had now printed and the smudged area was printing sharp and clean. (Photograph II A and B) This comparison raised some interesting questions:

1) How much had we slowed down the solvent evaporation,

if at all?

2) Had we, as planned, increased the structure in the low shear region?

3) What did the Rheological profile look like and could the difference from the standard ink be measured?

4) Having modified the ink accordingly, could we make further improvements?

Utilizing the Haake RV100 Viscosimeter the rheological changes were measured at constant and increasing shear rates over the previously referenced ranges. The standard and prototype ink were run at 300 sec. $^{-1}$ at 30°C. for 1 hr. on the ME-30 and the viscosity change measured:

Table II

Constant shear rate - 300 sec^{-1}

	Visc.-cp t=0	 t=1 hr.	% change	#2 shell Cup
standard ink	6.1	7.0	14.75	18 sec.
prototype ink	5.6	5.85	4.5	18 sec.

The slope of the standard ink is steeper as seen in Graph I.. The Mooney-Ewert system is enclosed to minimize evaporation, but under these conditions there was still more evaporation from the standard. This confirms that we have indeed decreased the evaporation rate and can at least partially account for the results thus far seen.

Since at this shear rate there is no apparent difference in the two inks, a test was run in the low shear range from 0-3 sec^{-1} at 30°C. Graphs 2-4 show the difference in the structure of the inks individually and compared to each other. It can readily be seen that the prototype ink was shear thinning below 0.1 sec^{-1}. This change combined with the lower evaporation rate would account for the sharper dots and cleaner mid to light tones. The structure present in the prototype ink should not be confused with true yield stress. Graph 5 shows a plot of shear stress versus shear rate. It is readily apparent that flow is initiated immediately for the prototype ink and therefore does not fulfill the requirements for true yield stress.

Rheologically, it has been shown that for the prototype ink:

1) Evaporation is reduced.
2) Structure was introduced at the low shear end.
3) The differences are measureable and can be seen in the printing properties of the ink as well.

In answer to the last question another experimental ink was made increasing these same properties. Graph 6 shows that at constant shear of 300 sec^{-1} the shear thinning profile is also present. Running at constant shear for 1 hour shows an initial decrease in viscosity to 33 cp. and a further buildup to 34 cp., due to solvent evaporation. This is only a 3% increase which is 30% less than the original prototype ink. The viscosity however, is 600% greater at this shear rate. Graph 7 shows that at 30 sec^{-1} the shear thinning is even greater since the lower end is now magnified 10 times. Viscosity has reached approximately 11000 cp. below 1 sec^{-1}. Graph 8 is a recovery curve. The ink is initially sheared at 300 sec^{-1} for 12 minutes and then the shear rate is reduced to 0.3 sec^{-1}. It is readily apparent that this ink recovers immediately to 4500 cp. from 34 cp. Photo micrographs of this ink show we have still maintained the print quality of the original ink. (Photographs III A and B)

Graphs 9 and 10 are Lissajous figures developed using oscillation imposed on rotation of the ME-30 cup and bob. (Lissajous figures are circle like figures produced by the sine wave affect of the oscillation.) A purely viscous material will always give a circle like figure since the shear rate is in - phase with the shear stress. A visco-elastic material however, will give elliptical figures which shows that the shear rate is out-of-phase with the shear stress.

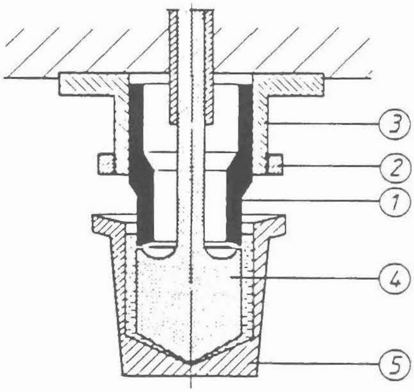
Graph 9 shows that the standard and the original prototype ink superimpose on one another. These inks are still essentially viscous fluids. Graph 10 shows the experimental ink and how it breaks down from it's original visco-elastic structure to a more viscous material. This is also a portion of the large structure breakdown at increasing shear.

This paper has shown that the formulation of a structured gravure ink has improved the print qualities, especially in the mid to light tone areas.

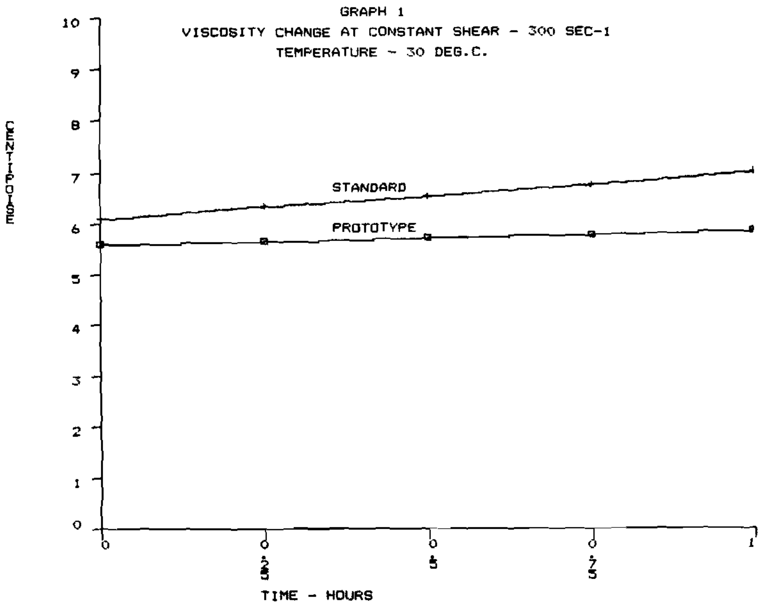
Figure 1

Mooney-Ewert

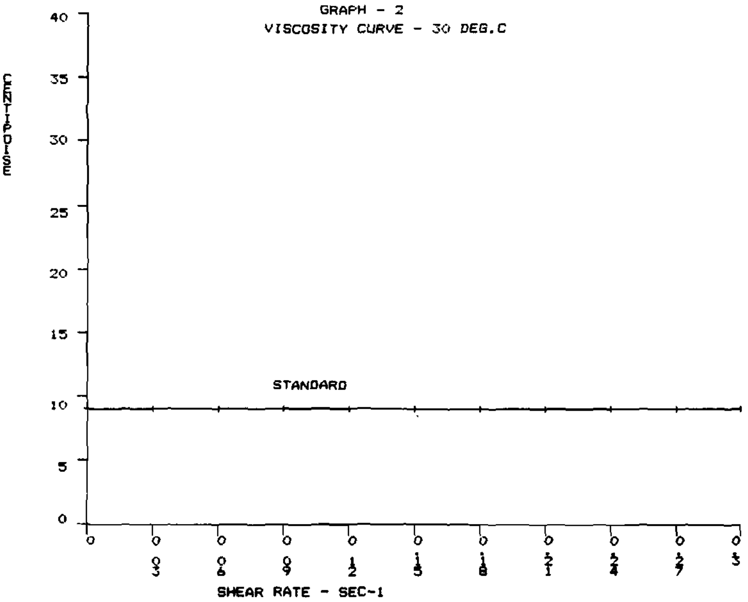
Sensor



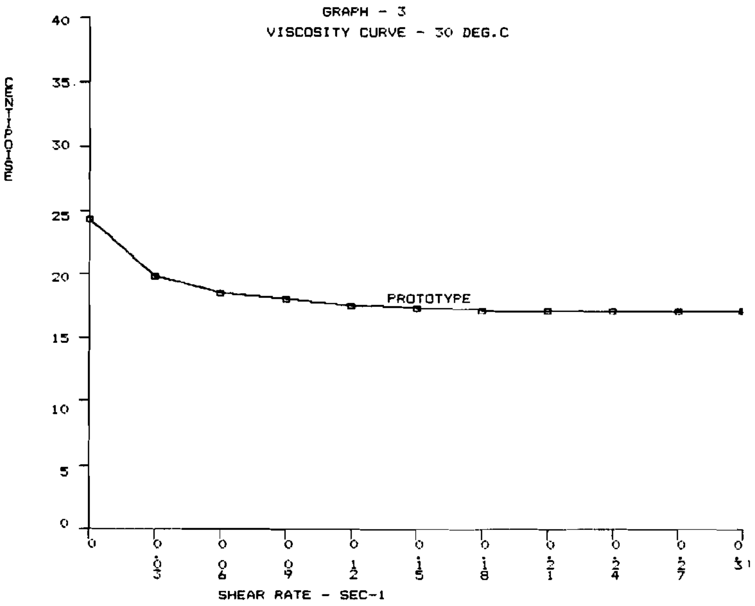
(1) Guardring
(2) Clamping ring
(3) Guardring housing
(4) Inner cylinder or cone
(5) Beaker or plate

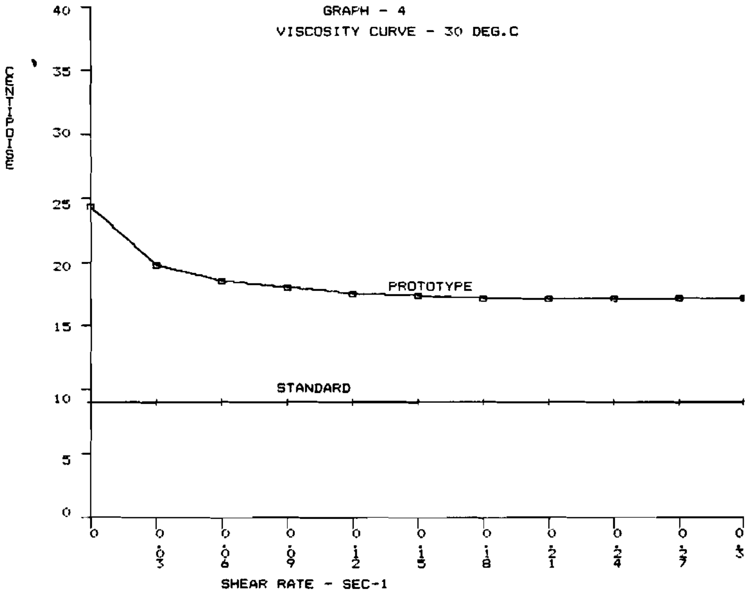


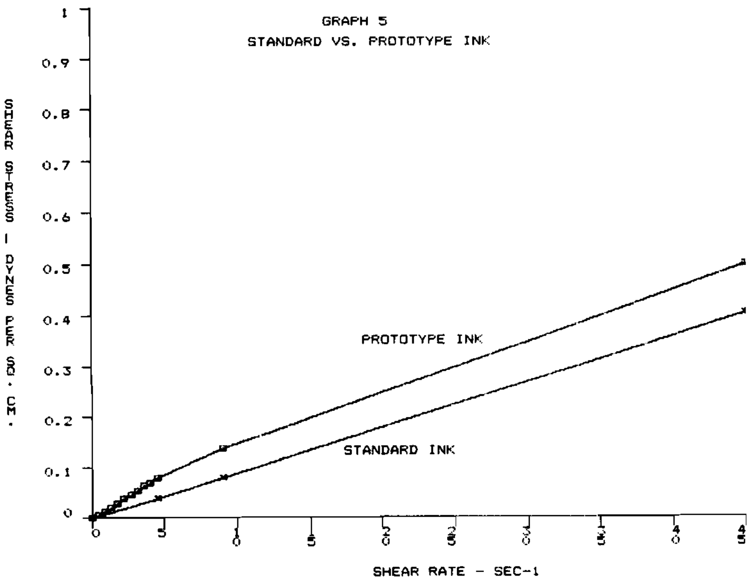
GRAPH 1
VISCOSITY CHANGE AT CONSTANT SHEAR - 300 SEC-1
TEMPERATURE - 30 DEG.C.

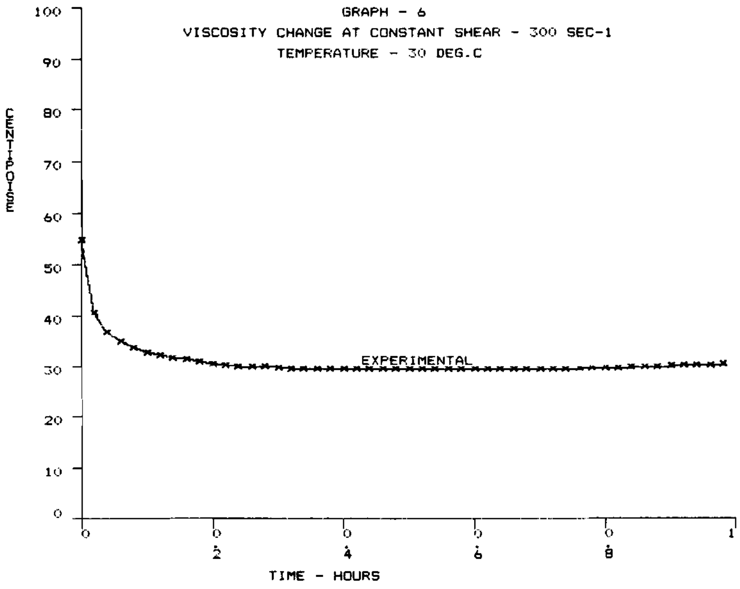


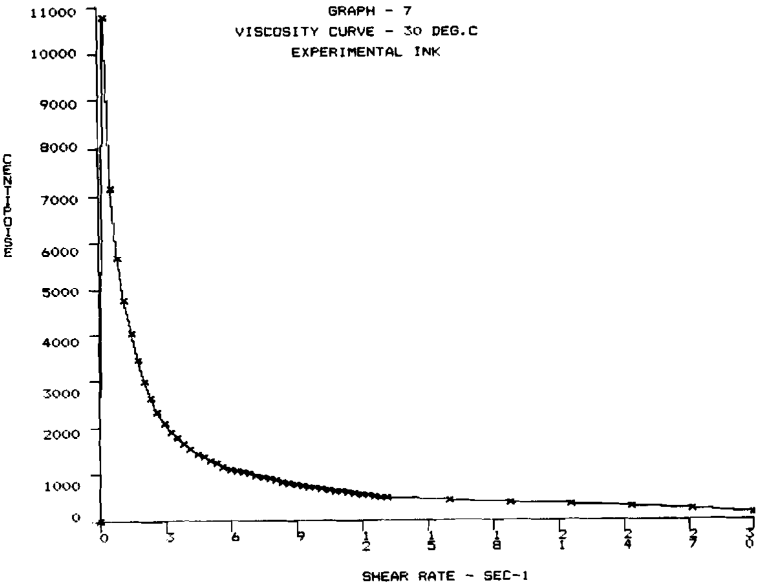
GRAPH - 2
VISCOSITY CURVE - 30 DEG.C


GRAPH - 3
VISCOSITY CURVE - 30 DEG.C
CENTIPOISE
40
35
30
25
20
15
10
5
0
PROTOTYPE
0
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27
0.3
SHEAR RATE - SEC-1

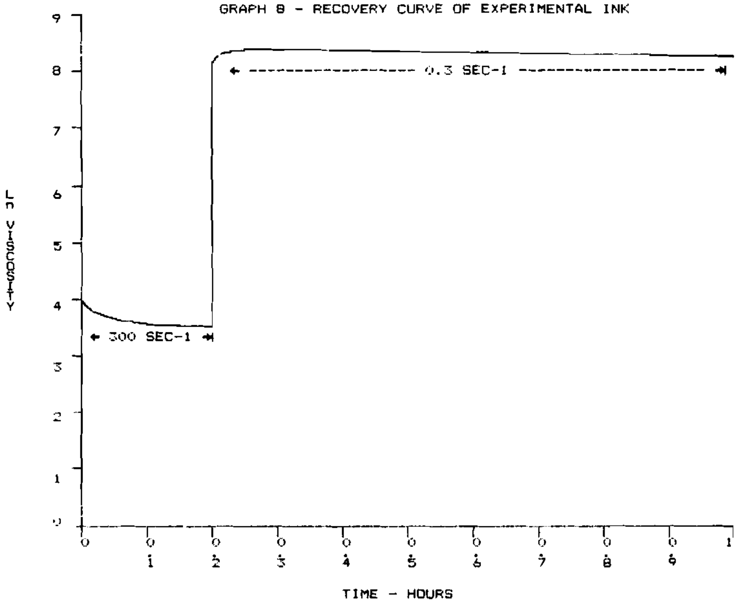

GRAPH - 4
VISCOSITY CURVE - 30 DEG.C
CENTIPOISE
40
35
30
25
20
15
10
5
0
PROTOTYPE
STANDARD
0
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27
0.3
SHEAR RATE - SEC-1


GRAPH 5
STANDARD VS. PROTOTYPE INK
SHEAR STRESS - DYNES PER SQ. CM.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PROTOTYPE INK
STANDARD INK
0
5
10
15
20
25
30
35
40
45
SHEAR RATE - SEC-1


GRAPH - 6
VISCOSITY CHANGE AT CONSTANT SHEAR - 300 SEC-1
TEMPERATURE - 30 DEG.C
CENTIPOISE
0
10
20
30
40
50
60
70
80
90
100
EXPERIMENTAL
0
0.2
0.4
0.6
0.8
1
TIME - HOURS

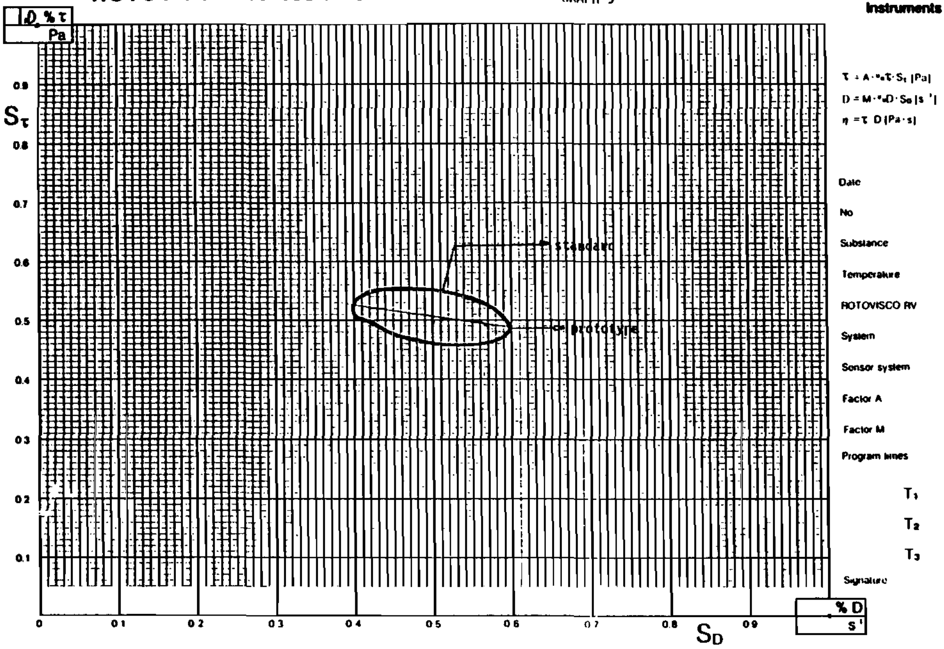


GRAPH - 7
VISCOSITY CURVE - 30 DEG.C
EXPERIMENTAL INK



GRAPH 8 - RECOVERY CURVE OF EXPERIMENTAL INK

ROTOVISCO RV-100 FLOW CURVE GRAPH 9 **HAAKEBUCHLER Instruments Inc.**



ROTOVISCO RV-100 FLOW CURVE GRAPH 10 **HAAKEBUCHLER Instruments Inc.**