A STUDY OF LITHOGRAPHIC PERFORMANCE MECHANICAL VS. THERMODYNAMIC CONSIDERATIONS

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ABSTRACT: Experimental evidence is presented which confirms the desirability of low interfacial tensions between litho inks and fountain solution. This was proposed in an earlier work as deriving from theoretical consideration.

The roles of press dampening system, paper surface properties and lithoplate surfaces in altering the theoretically desirable surface energy relationships between the various components of the printing system are analyzed, in respect to obtaining the most tolerant litho performance on press.

A parameter has been identified which can be used to evaluate fountain solution efficiency. This parameter is linearly related to optimum fountain solution feed.

I. Introduction

The central problem in analyzing the lithographic printing process, is to determine what factors control the successful operating range of the ink/fountain solution balance. There have been several theoretical and empirical approaches suggested for predicting the press performance of a given ink/fountain solution combination with varying degrees of success.

The empirical approaches essentially consist

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of emulsifying fountain solution into an ink with mechanical devices of varying designs and shear rates. The interpretations are based on shape of the water pickup rate curves, rate constants derived from the curves and rheology of the emulsions [1-4]. Alternately, roller devices and tackmeters have also been used for creating the emulsions. Parameters which are generally used to correlate with lithographic performance include rate of water pickup and release [5-7].

The use of surface energies to explain the lithographic process was first attempted by Padday [8]. Experimental measurements of the surface energies of the various components were first done by Kato et.al. [9].

Prior publications by us [10,11] indicated the thermodynamic considerations involved in the lithographic process. An analysis of the spreading of ink on the image area and of fountain solution on the nonimage area of the litho plate was the starting point for a calculation of a driving force for good lithography. The result indicated that it would be desirable for the surface energy of the ink to be greater than the surface energy of the fountain solution. An extension of the above analysis [11] by separating the surface energy into polar and nonpolar (dispersion) components, revealed that even when total surface energies are not optimum, if the ink has a sufficiently high polarity it leads to a low interfacial tension which was shown to be desirable at equilibrium running conditions of the press.

In this paper experimental evidence for the desirability of stable fountain solution in ink emulsions is given.

In addition, as pointed out by Fadner [14] and others dynamic mechanical forces should also be taken into consideration in understanding the lithographic process.

It is the aim of this paper to analyze how the various mechanical and other parameters (dampening system design, speed, paper absorbency, plates, etc.) alter the required surface energy relationships between ink and fountain solution derived earlier.

II. Effect of Stability (of Fountain Solution in Ink Emulsions) on Lithographic Performance

Prior theoretical work [11] indicated that low interfacial tensions between ink and fountain solutions would optimize equilibrium driving force. Additional confirmation of this has been obtained in both laboratory and field trials of inks. These have indicated that more stable emulsions of the water in oil type do indeed have wide water balance and more tolerant performance on a lithographic press.

A simple laboratory test has been devised to indicate the relative stability of the emulsion formed when an ink and fountain solution interact (see Appendix B). This test involves a controlled high shear mechanical emulsification of a fixed amount of fountain solution into the ink at constant temperature and subsequent microscopic examination of droplet size and distribution of the fountain solution phase.

Figure 1 shows photomicrographs taken at 200X of thin films of the emulsions from several inks which had been run on the press with the same fountain solution used in the laboratory evaluation. It is clear that the droplet size of the emulsified fountain solution is inversely proportional to the efficiency on the press [Table 1]. Since the smaller and more uniform the droplet size, the greater the stability must be, it follows that the more stable systems show better lithographic performance.

TABLE 1

INK	MAX.DROP	SIZE DIST.	WATER FEED*
A	3 um	VERY GOOD	65% - 80%
B	5 um	GOOD	75% - 85%
C	20 um	POOR	85% - 90%

* Water feed range is given as % feed from just above catch up to just below wash marks.

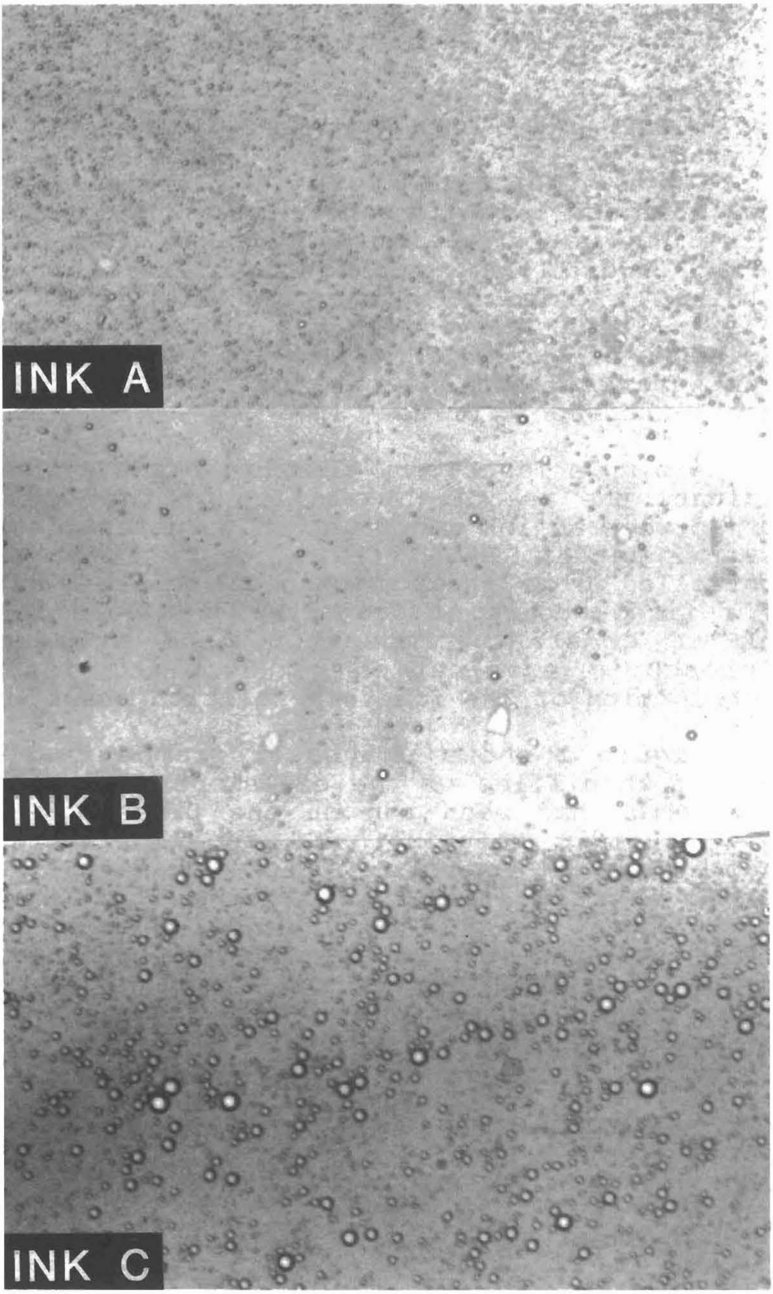


Figure 1. Emulsions of three different inks containing 10% of the same fountain solution.

Emulsion photomicrographs were published by Braun [12] for a given ink and different fountain solutions (with and without isopropanol). The isopropanol containing solution led to smaller droplets. As is well known, the water balance is enhanced by the presence of isopropanol in fountain solution. This result also supports the theoretical prediction of good lithography in systems with lower interfacial tension,which will be more stable.

However, there are several statements in the graphic arts literature which seem to counter the above conclusions concerning stability.

According to Banks [20], failure to find any correlation between emulsifying tendencies and interfacial tension is to be expected "because to disperse one phase in another means increasing the interfacial area, with a consequent increase in free energy for all positive values of surface energy. An emulsion, if formed, is less stable than the undispersed system."

But as pointed out by Ruckenstein and Krishnan [13], that when the droplet sizes are small, as is the case in a good lithographic emulsion of fountain solution in ink films of the order of microns, the decrease in free energy due to the entropic effects can overcome the increase due to interfacial tension, thus giving rise to thermodynamic stability. (This is shown in Appendix A). Of course, in low interfacial tension systems the likelihood of this occurrence is greater. Thus Banks observation is not strictly applicable in the usual lithographic case.

Another study showing a relationship between emulsion stability and scumming of sheetfed offset inks exists in the literature [16]. In this work the scumming observed in inks which were deliberately contaminated with Zinc resinate and which were found to be more shear stable, could be simply due to a tendency for the formation of a stable oil in water emulsion, because the type of emulsifier used is known to promote such inverse emulsions. Stability of the wrong type of emulsion cannot produce good lithography!

Similarly an increased tendency to lint in some newspaper printing, found with some stable systems [15], while certainly an undesirable problem from the printers point of view, does not preclude the coexistence of good lithography. Effective differentiation of image and nonimage by ink and fountain solution may still be established.

In the following sections an attempt is made to clarify how various mechanical and other parameters can alter the basic frame work of surface energy relationships.

III - Efficiency of Fountain Solution Transfer

Thermodynamic considerations [10] showed that the surface tension of fountain solution should be lower than that of ink for quick startup performance. It was also shown that dynamic rather than static surface tension correlated with water balance, although in a non-linear fashion.

It is clear from fluid mechanics, that rheological properties of the fountain solution will also affect its efficiency of transfer from the water pan to the form rollers and the plate.

Work in our laboratory has now revealed a linear relationship (see figure 2) between water feed at just above the scumming point and a parameter which we call Fountain Solution Efficiency (F.S.E.). We seek to define the efficiency of a fountain solution as compared to a reference solution (distilled water), and include both bulk and surface properties, thus:

Let $F.S.E.=Y(water)/n(water)-Y(F.S.)/n(F.S.)$ (1)

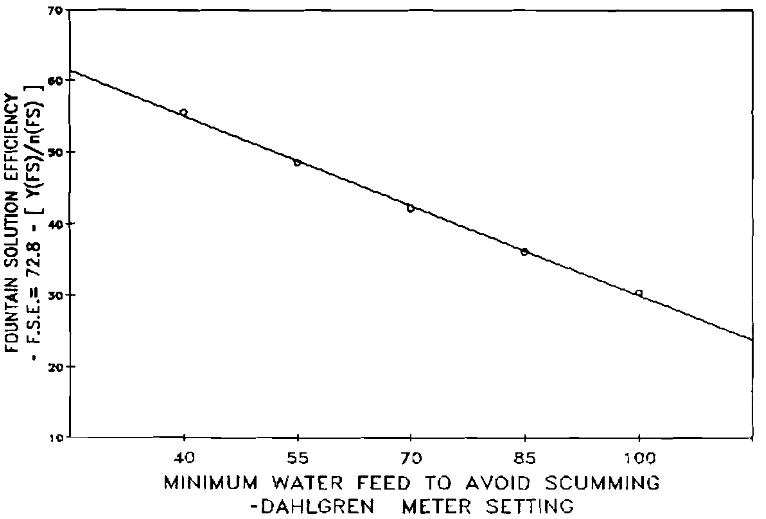
Where Dynamic Surface Tension (Y) is in dynes/cm and viscosity (n) is in cps.

Thus @ $20^{o}C$ for distilled water as a reference fluid:

$FSE = 72.8 - Y(F.S.)/n(F.S.)$ (2)

From the linear relation shown in figure 2,

FIG. 2 - FOUNTAIN SOLUTION EFFICIENCY
VS
MINIMUM WATER FEED ON PRESS



5 FOUNT.SOL'NS. - STANDARD H.S.INK

it is evident that the viscous forces are equally important to those of surface tensional forces. It is also interesting to note that the F.S.E. has the units of velocity (m/s).

One significance of this F.S.E. parameter is as follows: It is well known that in flow of thin liquid films, in order to maintain laminar flow, the Reynold's number should not exceed 20 to 30 (see Levich [17]). This implies that for a fountain solution of viscosity 1 cps and a film thickness of 1 micron, the film velocity should not exceed 20 to 30 m/s. Above this value a so called "wave regime" appears. This can lead to inefficient and non uniform dampening of the plate non image area.

Hence in order to obtain truly efficient dampening the (F.S.E.) parameter should be larger than 40. In the present example (Fig. 2) we see that no water control could be obtained at an F.S.E. of 31 using Dahlgren dampening.

From a model on the dynamics of the nip separation region [21], a dimensionless parameter N_1, defined as

$$N_1 = Y/nU \quad (H_o/R)^{1/2} \tag{3}$$

has been found to control coating transfer efficiency. Here U is the film velocity, H_o is the nip separation and R the radius of the rollers.

It is clear from Eq. (3) that with fountain solutions having high (Y/n) (low FSE values), N_1 can only be maintained constant by decreasing H_o and/or increasing R.

In practice this implies transfer efficiency of fountain solutions can be improved by mechanical alterations such as using softer and larger diameter dampening form rollers and increasing pressure.

IV. Effect of Dampening System Configuration

Our previous treatment of the surface energetics of lithography dealt with intensive properties like dynamic surface and interfacial tension. However as was shown by Wilkinson et.al [18] extensive properties such as volume of ink and volume of fountain solution (or the thickness of the film of fountain solution) affect the ink/fountain solution/plate contact angles.

The thickness of the film of fountain solution applied to the plate is strongly dependent on the design and geometry of the dampening system, as well as press adjustments. For example, most brush dampening systems apply a thicker film of fountain solution than a Duotrol or Dahlgren type of system. In systems like the brush type, it is possible to run fountain solutions having dynamic surface tensions higher than the optimum and even much higher than the ink. In this case, any unfavorable surface energetics are overcome by sheer volume effects. A disadvantage of this might be reduction of print quality due to the resulting heavier water film.

In systems where relatively thin uniform films of fountain solution are carefully metered onto the plate surface (e.g. Dahlgren) the surface energetics need to be optimized. For this reason isopropanol, which provides a low dynamic surface tension while simultaneously raising the viscosity of the dampening solution, gives rise to a desirable high value for F.S.E. For example,a typical fountain solution with 20% isopropanol added,turns out to have an F.S.E. of about 58.

Other dampening systems may be intermediate in their fountain solution efficiency requirement due to their mechanical design and geometry. Examples of these are the Duotrol, Alcolor, Bakertrol, etc.

While it is possible to run somewhat lower F.S.E. value fountain solutions in the latter systems, reduction of the amount of water feed necessary to avoid scumming will be achieved by more efficient fountain solutions. This in turn will lead to improved print quality.

V. The Role of Paper

The larger film thicknesses of the fountain solution may not always lead to poor print quality, if a means of removing this excess water exists. Paper of sufficient absorptivity can provide such a means. A mass balance for the fountain solution (FS) shows:

Feed rate (FS) = Emulsification rate(FS in ink) +
absorption rate(FS in stock non-image area) +
evaporation rate (FS) (4)

For a given press configuration and speed, at constant temperature and humidity the evaporation rate would be relatively constant. The paper ultimately absorbs both the fountain solution on the non-image area, as well as the emulsified fountain solution in the ink on the image area.

Fountain solutions having high surface energy (lower F.S.E. values) require the use of larger feed rates as seen from figure 2. In this case, either an ink with large capacity for emulsification (without causing poor stability or rheology) or a highly absorbent stock could eliminate excessive accumulation of water and the resulting print quality defects.

In other cases, where one might intentionally wish to run a higher film of water (even though the print quality might not be optimum), to eliminate linting [19], the higher surface energy of a lower F.S.E.fountain solution may be desireable.

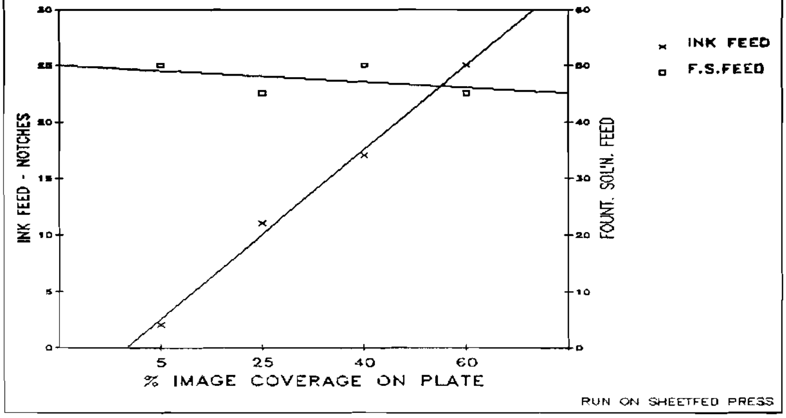
VI. The Role of Image Coverage

One might suspect from Equation (4), that the % ink coverage would alter the fountain solution feed rate. To test this premise, several lithographic plates were designed with varying % of image area and printing tests were carried out on a sheetfed press. The fountain solution feed rate to avoid scumming and ink feed to obtain equal density is plotted in Fig. 3 vs. % ink coverage on plate. It is apparent that while the ink feed is a linear function of the % coverage, the fountain solution feed rate to avoid scumming is practically constant. This is in agreement with MacPhee (22). The explanation for the latter result is as follows: There is a minimum thickness of fountain solution in the non-image area to avoid scumming for a given fountain solution and plate. Since no lateral water control is available, one must feed the same volume of fountain solution (plate area X thickness),regardless of coverage. Of course the water balance range (scumming to wash marks) is still dependent on the % coverage.

VII. The Role of Plates:

In a previous paper [11] a plate efficiency constant was derived, which was based on the surface energetics of the image and the non-image areas of the plate. In addition, the graining and anodizing of the plate influences the thickness of the fountain solution film required to keep the non image area clean.

FIG. 3 - INK & FOUNTAIN SOLUTION FEED vs PERCENT IMAGE COVERAGE ON PLATE



Plates which require higher water feeds may run better with somewhat higher surface energy (lower F.S.E.) fountain solutions. When such fountain solutions are used with these plates, the print quality may not show severe deficiencies,despite the large water feed. In this case, the extra cushion of water can act as a lubricant.

If a higher F.S.E. fountain solution is used, the water feed can be reduced. With plates having a high water demand,this can cause a lack of lubrication. Any plate wear or scratch marks occurring on the plate may then begin to appear on the print, because the thinner water layer cannot desensitize such defects as easily as a thicker layer.

VIII. Conclusions

It is shown that, while the surface energy considerations presented previously can lead to efficient lithographic performance, other variables, notably the relative volumes of ink and water and mechanical and other factors such as paper absorptivity, plate graining and dampening system configurations can modify the basic surface and interfacial energy relationships between ink and fountain solution required for trouble free press operations.

The definition of a fountain solution efficiency parameter should allow a more objective comparative evaluation of dampening solutions in respect to their press performance with different dampening systems.

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APPENDIX A

The free energy change of a system such as an emulsion may be expressed in equation form as:

Delta G = Delta H - (T Delta S)

Delta H is an expression of the increase of the interfacial energy due to the large increase in surface area when the internal phase of the emulsion is dispersed in fine droplets.

The term (T Delta S) will have a value which increases with the number of droplets dispersed, since this represents greater disorder of the system which means an increase in entropy (S). Since the temperature (T) is constant it is possible for T Delta S to be larger than Delta H, thus producing a negative value for free energy (Delta G). Such a negative value would indicate a thermodynamically favorable process.

APPENDIX B

EMULSION STABILITY TEST

1. Purpose

The purpose of this method is to assess the capacity of an ink to form a stable emulsion with a given fountain solution. It estimates the size and distribution of the water (fountain solution) droplets emulsified into the ink. The smaller the size and the more homogeneously distributed the droplets are in the ink matrix, the more stable the emulsion and the better the lithographic properties of that ink/fountain solution system should be.

2. Equipment

a. Constant Temperature Water Bath

b. Electric Mixer
500 RPM, Ratio 5:1

c. DC Motor Speed Control

d. Mixing Blade: Black and Decker Paint Mixer Blades 1 7/8 inches Diameter

e. 8 oz. Glass Jar

f. Microscope and Polaroid Camera

3. Procedure

a. Keep the bath at 25°C

b. Weigh 45g of ink into an 8 oz. glass jar and weigh 5g of fountain solution into a disposable paper cup.

c. Clamp the jar to the stand and immerse the jar in the water bath at 25°C, make sure that the jar is immersed until the level of the water in the bath is above the level of the ink in the jar.

d. Start the mixer (500 RPM). As soon as the mixer is making a good vortex in the ink, add slowly (between 30 sec. and 1 minute) the preweighed fountain solution to the ink. After addition is completed, mix for fifteen minutes.

e. After finishing the mixing (and not more than 10 mins. later), use the dissecting needle to apply a very small amount of emulsion on the microscope glass slide and then cover it with the glass cover slide. Spread the film of ink by applying vertical force only. Continue this until you have a very thin film of ink.

f. Place the slide on the microscope stage and using transmitted light and with the magnification set at about two hundred (200 X) focus and take photos (with the micrometer attachment) as needed. The droplets of water emulsified in the ink appear as spheres or, if very fine, as black specks.

4. Assessment and Interpretation of Results

The photos show comparatively the size of the droplets. The smaller the droplets, the more stable the ink/fountain solution emulsion. In general, if the size of the droplets is less than 3 to 5 micrometers in diameter, the emulsion is considered relatively stable. The test is most useful when comparing two inks for relative performance.