THEORETICAL AND PRACTICAL ASPECTS OF SINGLE FLUID LITHOGRAPHY

Shem M. Chou* and Lawrence Bain*

KEYWORDS: Single Fluid Lithography, Emulsion Ink, Positive-Feed Keyless Offset, Anilox Keyless Offset

ABSTRACT: Single fluid lithography, an offset process that prints emulsion inks without the need for a separate dampening system, has been successfully demonstrated in full-scale laboratory experiments. This process eliminates the dampener and hence any printing problems associated with maintaining ink-water balance using independent inker and dampener controls. It does not require new plate and ink technologies as waterless lithography does, nor does it require special temperature controls. This paper will discuss the press design and emulsion ink stability requirements for single fluid lithography from theoretical and practical considerations. Print quality attributes (solid ink density, background density, mid-tone dot gain, and print contrast) of printed samples are presented to prove the feasibility of single fluid lithography.

BACKGROUND

Ink-water balance is one of the most critical factors determining the fate of a lithographic printing job. Seeking a proper ink-water balance at the start-up accounts for the makeready waste which is higher than any other printing process. It is necessary to monitor and adjust constantly the ink

* Rockwell Graphic Systems
700 Oakmont Lane
Westmont, IL 60559

and water settings throughout the entire press run to maintain proper ink-water balance. A skillful crew of pressmen is therefore essential to all lithographic printing shops. However, lithography is still the most popular printing process because it delivers higher quality image reproduction at relatively low cost in the medium- to long-runs.

In the past decades, some researchers were searching for an ideal dampening system, but others were seeking ways to eliminate the dampener entirely. The obvious goal is to capture the operational simplicity of letterpress printing without losing the economics and quality benefits of lithographic process. A reduction in the makeready waste will also make lithography more competitive in the short run markets.

One of the most enduring efforts in this regard has been driography or better known as waterless lithography, invented first by Curtin (1970) and marketed by 3M in the 70s. It is now commercialized under the Toray name. The image differentiation chemistry of waterless lithography is substantially different from that of conventional lithography. The non-image areas of waterless plates are composed of a silicone rubber and the image areas are either bare aluminum surface or some photopolymers. The surface energy of silicone rubber is so low that the adhesion of waterless inks to the non-image surface is relatively weak. However, image differentiation in the waterless lithography still demands inks of higher viscosity and higher tack than conventional lithographic inks to ensure ink release from the non-image areas through silicone rubber/ink interface (Chou, 1992).

Due to the absence of cooling effect from water evaporation in conjunction with the excessive heat generated by the highly viscous waterless ink, the press temperature rises rapidly. Once the plate temperature exceeds the critical toning temperature, background toning occurs and the process fails. Control of press temperature therefore becomes the most critical factor in waterless lithography. In other words, the control point has shifted from ink-water balance in the conventional process to temperature in the waterless process. We found that controlling the temperature of a high speed waterless press was not so easy as one might think. Our findings in waterless lithography temperature issues will be reported in the future.

Another technology directed toward achieving the same end result as the waterless concepts, namely elimination of the dampener, is what we call **Single Fluid Lithography**. In this approach, fountain solution is preemulsified into the ink in the form of W/O emulsion and the press prints this emulsion ink or single fluid without the aid of dampener. That is, the ink and fountain solution delivery systems are united together and the inker must be able to supply sufficient amounts of ink and fountain solution to the plate to retain proper image differentiation. The important implication of this technology is the retention of the standard lithographic plate and hence the image differentiation chemistry of lithography, oil-based ink and aqueous fountain solution.

Printing a water-in-ink emulsion is not a new concept at all (Bulloff, 1974). It is a known fact that the emulsions are deliberately created all the time in offset presses. The famed Dahlgren dampener, and all the other inked-roller dampener arrangements use emulsification as an operative property. Ink-train dampeners in newspaper presses are the extreme manifestation of these concepts that feed water to the plate through the ink. But all these systems include some kind of on-press water input device.

The Milwaukee Journal made extensive tests of printing emulsion inks on DiLitho presses in the 70s. The emulsion inks contained as much as 40% water. However, they could not eliminate the dampener entirely. An auxiliary water supply system was used to keep the page margins and low image coverage areas clean.

The goal of this study is to demonstrate the feasibility of single fluid lithography. The emulsion ink stability and press design requirements for single fluid lithography will be discussed on the basis of theoretical and practical considerations.

EMULSION STABILITY REQUIREMENTS

Emulsion Stability Window

It is obvious that for a successful single fluid lithography the emulsion ink must remain stable on the distribution roller train of the press. It must also break down to give up sufficient water to the plate to keep ink off the non-image areas as soon as it reaches there.

If the emulsion is not stable enough, premature ink-water separation occurs on the distribution roller surface. Free water released from the ink will interfere with subsequent ink transfer, resulting in an image of low density along with a background scum due to a short supply of emulsion ink to the plate. When a large quantity of water is suddenly flushed out to the plate, the image appears washed. So, the print characteristics for an unstable emulsion are simultaneous, sporadic scum and wash marks.

If the emulsion is too stable, it will not release sufficient amount of water to the plate to keep the background clean. The print characteristics for an excessively stable emulsion are poor image differentiation and overall scum on the entire page. In conclusion, there exists a window of emulsion stability within which the emulsion will print successfully. This emulsion stability window is, in fact, equivalent to the ink-water balance latitude in the conventional lithographic process.

Factors Affecting Emulsion Stability

Investigation into the stability of emulsion inks has been a major research project in our laboratory for years. Some of the results were reported previously (Chou and Fadner, 1986; Chou and Cher, 1989). The stability of emulsion inks was found to depend strongly upon the physico-chemical nature of both ink and fountain solution. For a given combination of ink and fountain solution, its stability decreases as the water content increases.

We also observed that the stability of emulsion inks was influenced, in addition to its composition, by the environmental factors such as shear conditions and temperature. In general, the emulsion ink remains stable at low shear rates; emulsion coalescence and reformation proceed simultaneously as shear rate gradually increases; and a gross phase separation between ink and water occurs at high shear rates. A similar transition from a stable state to gross phase separation was found as the temperature gradually decreased.

PRESS DESIGN REQUIREMENTS

Ink and Water Feed Requirement

The ink feed device of conventional lithographic presses consists of a number of ink keys which are used to regulate the amount of ink delivered to the plate. The mass balance condition of ink requires that the amount of ink input to the distribution train be equal to the amount carried away by the paper, which is proportional to the percentage image coverage of the plate. This principle has been practiced for decades without question. Figure 1 illustrates schematically the relationship between ink feed and image coverage of the plate.

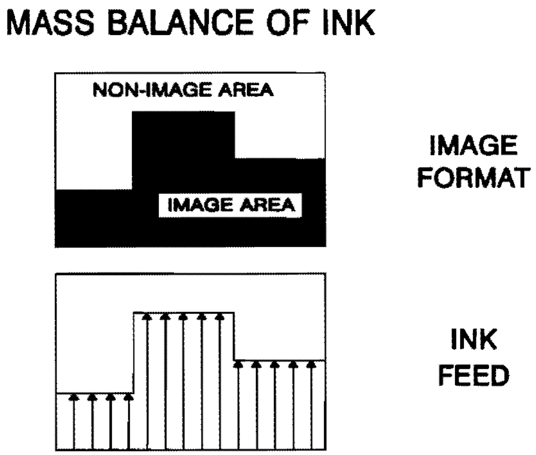

Figure 1. Schematic diagram illustrates the relationship between ink input and image format in a conventional offset press.

The same rationale predicts that the rate of water input should be proportional to the percentage non-image areas of each printing zone, or inversely proportional to the percentage image coverage. In practice, the water feed is more or less uniform across the press (Figure 2). This uniform water input may be due to past practical experience. It may also result from the simplification of process control. Considering that if both ink keys and dampener settings have to be adjusted at each printing zone according to the image coverage, it will be extremely difficult to operate the press.

We believe that because fountain solution is a weak fluid, the water form roller is unable to pull it back from the image surface of the plate once it is forced onto the plate. Fountain solution forms a continuous film on the non-image surface, which acts as a barrier keeping the background free of ink. It will recede into many tiny droplets on the image surface which is generally referred to as surface water. If this surface water is not removed from the image areas, it will interfere with subsequent ink transfer, resulting in snowflakes in the image. This is the reason why lithographic inks are designed with the ability to emulsify fountain solution. So, water feed is practically independent of the image coverage of the plate in the current dampening systems. The important implication is that water is over-fed to the zones of large image areas.

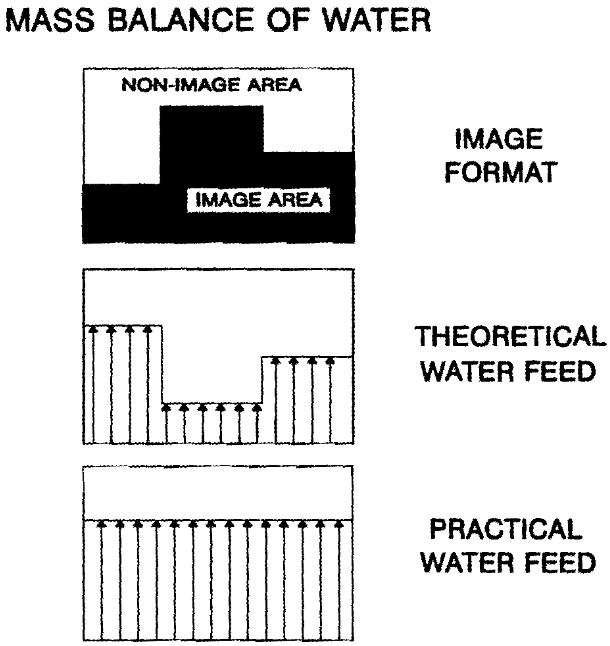

Figure 2. Schematic diagram illustrates the theoretical and practical water input relative to the image format in a conventional offset press.

In the single fluid lithographic printing process, the fountain solution is supplied to the plate solely by the emulsion ink. If the emulsion ink feed is regulated according to the image format as in the conventional presses, a large image area will call for input of a large amount of ink, and therefore a large amount of water, even though the latter is not required. Likewise a small image area will call for input of a small amount of ink, and therefore a small amount of water which is insufficient to keep the non-image areas of the plate free of ink. This is why an auxiliary water supply system was needed in the trials of printing emulsion inks at the

Milwaukee Journal. Figure 3 illustrates schematically the feed rates of ink and fountain solution in the single fluid lithography operation in a conventional, keyed press.

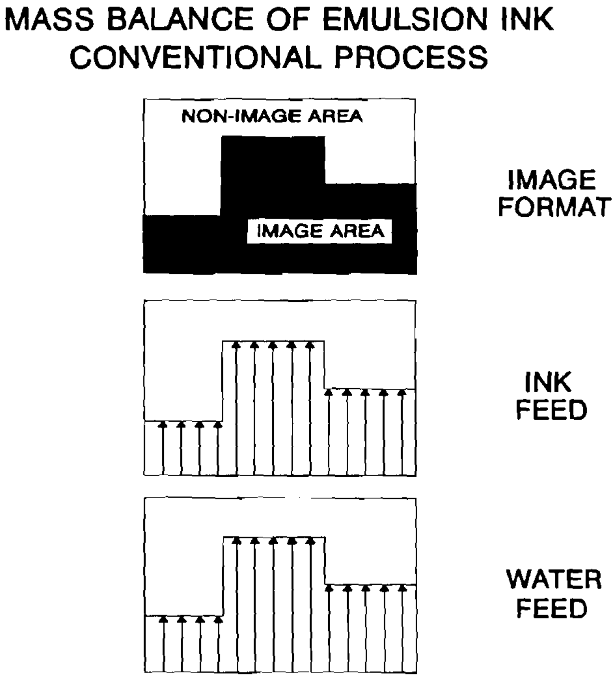

Figure 3. Schematic diagram illustrates the ink and water input of emulsion inks in a conventional, keyed offset press.

The fundamental operating principle of keyless systems is to deliver enough ink to accommodate any demand by the plate, and to subsequently remove from the inking train any ink not required by the plate. Using a keyless system with an emulsion ink then results in a uniform input of both ink and fountain solution, as described schematically in Figure 4. Both are always sufficient to accommodate the plate requirements whatever they are. Any ink and water not taken by the plate are removed from the distribution train, combined with make-up water and ink, and reblended into the proper emulsion.

In the conventional two-fluid system where more water is always forced

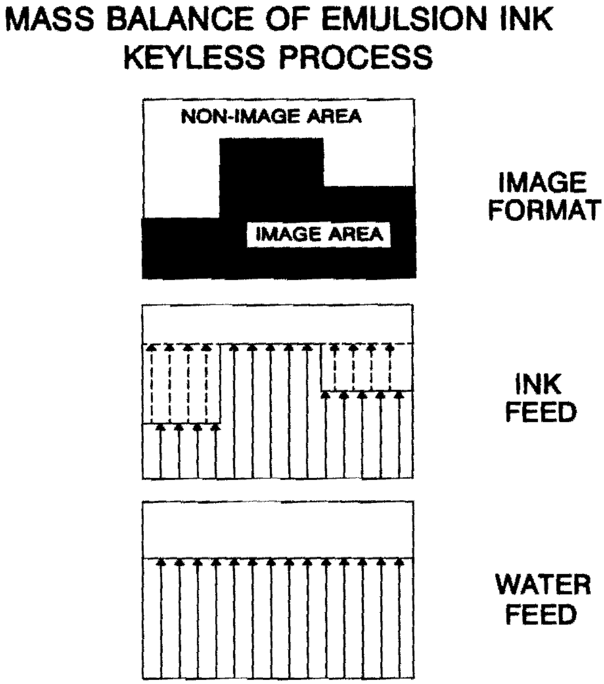

Figure 4. Schematic diagram illustrates the ink and water input of emulsion inks in a keyless offset press.

to the plate, the system must somehow consume the excessive water. In comparison, the plate takes away the amount of water it needs and the remainder is removed from the distribution train in the single fluid process. The system is not forced to consume any excessive water and hence the dampening efficiency in single fluid lithography is predicted to be better than that in the conventional process. So, the first requirement for a single fluid lithographic press is as follows.

Single Fluid Lithography Must Be A Keyless Process.

Press Configuration Requirement

There are two types of keyless offset presses in the industry: anilox and return-film removal. The excessive ink is returned directly to the ink chamber in the former, and in the latter removed from the distribution train by a doctor blade and reintroduced to the ink feed system. Keyless press along is insufficient to guarantee a successful operation of single fluid lithography. The combination of the press and the emulsion must also be such that the emulsion breaks only at the plate and not elsewhere, as mentioned previously. For a given emulsion ink, the governing mechanical condition is shear rate. The requirement is that the maximum shear rate imposed on the emulsion should occur at the form roller-to-plate nip.

Shear rate is the velocity gradient of fluid in the interacting zone. It is readily comprehensible by considering a model situation in which a fluid is confined between two parallel plates separating by a distance x. One plate is moving at a speed v and the other is held stationary. Shear rate is then equal to v/x.

The shear condition in the roller nip is much more complicated than the model. One of the rollers is generally hard, and the other is soft and compressible. Though both rollers are running at nominally the same surface speed, the soft surface is actually moving slightly faster. In addition, both surfaces are not flat and the distance between them varies throughout the nip. The shear rate thus varies in the nip and is very difficult to calculate exactly. Nevertheless, the relative shear rate can be estimated qualitatively by the thickness of fluid passing through each nip. The thicker the fluid film in the nip, the lower the shear rate.

Figure 5 shows the geometry of the anilox keyless offset press used to test the concept of single fluid lithography. The number next to each roller nip indicates the ink film thickness in units of micrometers, calculated on the basis of the following assumptions. The image on the plate is 100% solid. The split ratio is 50/50 at all nips. And, the ink film printed onto the paper is 1 micrometer thick. It is noted that the gap between metering roller and reversed-angle doctor blade is virtually zero and hence the emulsion riding on the land of the metering roller is subjected to extremely high shear rates. We found that most emulsions could not sustain the shear rates in the metering process and phase separation occurred in the ink chamber, as indicated by free water circulating out along with ink. Free water present in the chamber interfered with ink transfer, resulting in simultaneous scum and wash.

If the emulsion can survive the metering process, it will not come apart at

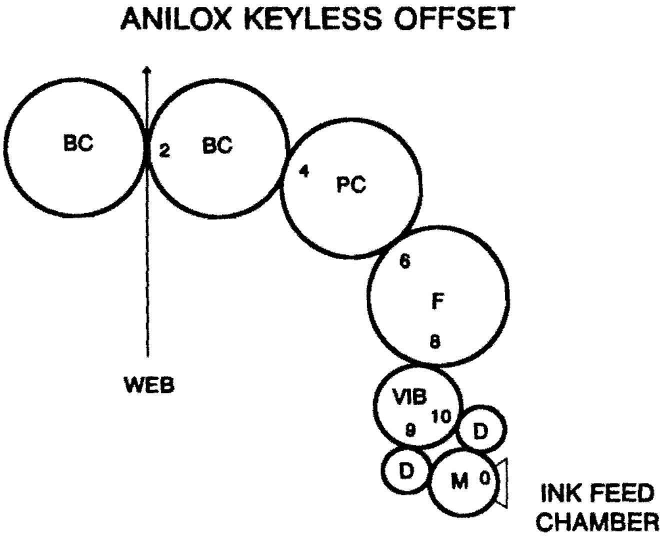

Figure 5. Press configuration of the anilox keyless offset used in the experiment.

the form roller-to-plate nip and provide sufficient water to the plate. The outcome is an overall, heavy scum in the background covering the entire page. The window for emulsion stability is extremely narrow in this type of system. It is extremely difficult to run this press. Moreover, there is no shade control in the anilox keyless offset. This process has to rely on strict quality control of inks. The conclusion is that anilox keyless offset is not suitable for single fluid lithography.

An open fountain keyless offset press with the return-film removal mechanism that was tested in our laboratory is illustrated schematically in Figure 6. The thickness of ink film gradually decreases from the fountain roller-to-pickup roller nip to the form roller-to-plate nip and the shear rate increases accordingly. This system provides a desired profile of shear rates. The window for emulsion stability is expected to be wide for this type of system. The optical density of prints can be controlled by varying the fountain roller speed or the gap between fountain roller and blade.

Although several successful tests were made on this press, we had difficulty in setting and maintaining a uniform gap across the press. The gap is also very sensitive to changes in the fountain roller and/or press

OPEN FOUNTAIN KEYLESS OFFSET

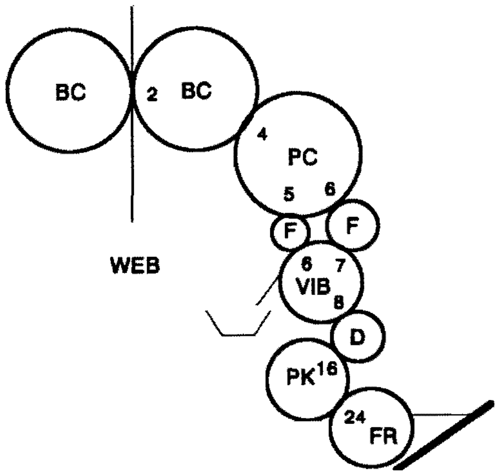

Figure 6. Press configuration of the open fountain keyless offset used in the experiment.

speed due to the blade deflection resulting from the hydrodynamic pressure of fluid flowing through it. Therefore, it was concluded that the open fountain keyless offset is not suitable for single fluid lithography either.

Figure 7 shows the geometry of the positive-feed keyless offset press modified from our Colorliner in the laboratory. This press has a correct profile of shear rate, as evidenced by the gradually decreasing ink film thickness in the nips from pickup roller to plate cylinder. The window for emulsion stability is expected to be wide for this type of system. The optical density of prints can be controlled by varying the pump rate of digital injector. We had so many successful tests on this press that we are confident in the following conclusion.

Positive-Feed Keyless Inker Is Vital To Single Fluid Lithography.

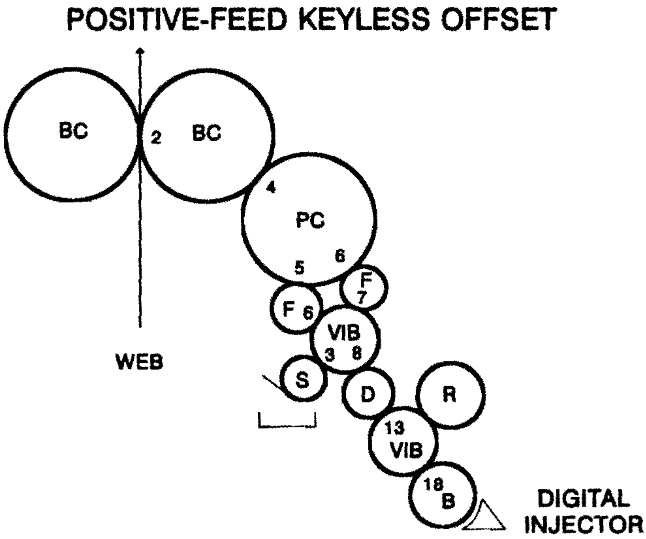

Figure 7. Press configuration of the positive-feed keyless offset used in the experiment.

Emulsion Reconstitution/Recirculation Requirement

It was mentioned previously that the surplus emulsion ink was scraped off the distribution train in the keyless offset. Free water was observed to coexist with the ink in the scraped emulsion, again due to the extremely high shear forces by the doctor blade. To determine the water content of scraped ink, free water was mixed back into the emulsion and then measured with a Mettler DL18 Karl Fischer titrator. It was found that the water content of scraped emulsion was generally 10 to 25 percentage lower than the original emulsion. These results indicate that the plate requires a portion of the input water to protect the non-image areas and takes only what it needs. In comparison, the plate in the conventional lithographic process has to take all the input water. We therefore believe that single fluid lithography will provide the most efficient dampening.

The ideal model in Figure 7 shows that for every one micrometer of ink printed the scraped ink is 1.5 micrometers. In fact, the amount of ink scraped from the distribution train is several factors higher than that carried away by the paper. That large amount of ink cannot be wasted for economic and environmental reasons. It has to be combined with make-up water and ink, reblended into the proper emulsion, and reintroduced into the inker. Hence, the third requirement for single fluid lithography is

An Emulsion Reconstitution and Recirculation System Is Essential To Single Fluid Lithography System.

An emulsion reconstitution and recirculation system is shown in Figure 8. The scraped ink is delivered to a pre-mixing container into which fresh fountain solution and fresh ink are pumped from separate sources. A level sensor is used to control the ink input and a water sensor for water input. The pre-mixture is then pumped to a high-shear mixer to produce the emulsion of controlled stability. A portion of the emulsion is fed to the ink distribution rail by metering pumps, and the remainder is circulated back to the pre-mixing container.

Emulsion Reconstitution/Recirculation System

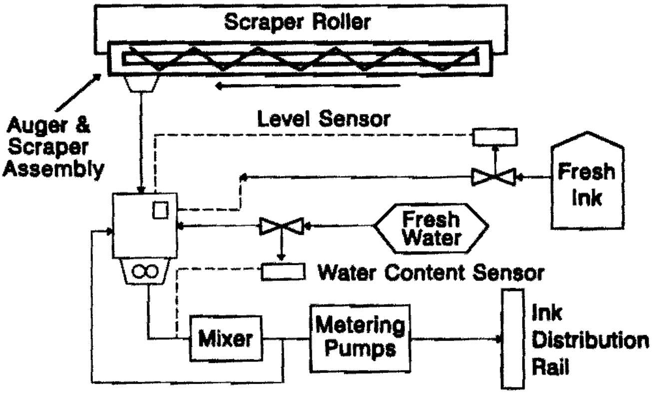

Figure 8. Emulsion reconstitution and recirculation system for single fluid lithography.

PRINT TEST RESULTS

Reported here are experimental results of two print tests. One was designed for studying process stability of single fluid lithography and the other for print quality comparison with the positive-feed keyless process. Both experiments were carried out on a prototype positive-feed keyless Colorliner in our R&D laboratory. The GATF Newspaper Test Form was used as the test image in both experiments. Standard newsprint was used as the substrate. The optical density of printed samples was measured with an X-Rite 428 densitometer. Print quality attributes such as solid ink density, background density, mid-tone dot gain, and print contrast were used to indicate printing capability of single fluid lithography.

Solid ink density was measured to determine if the target density is achievable in single fluid lithographic process because the pigment concentration is significantly reduced in the emulsion inks which generally contain 30% to 55% fountain solution. Background density was measured to determine if the emulsion is able to release sufficient amount of water to keep the non-image surface of the plate free of ink. Mid-tone dot gain and print contrast were used to indicate the sharpness of printed image. The Murray-Davies equation was used to calculate dot gain.

Process Stability Experiment

An emulsion of black news ink A containing 45% of an alkaline fountain solution was used in this experiment. Both ink and fountain solution are commercially available and commonly used in newspaper pressrooms. The printing speed was initially set to 45 KIPH (45,000 impressions per hour), and the printed image appeared slightly light. The speed was then reduced to 40 KIPH and kept constant thereafter for a run length of over 100,000 impressions. Six consecutive copies, i.e. from three plate cylinder revolutions, were sampled periodically. Each copy had two pages of the test image, and three columns were selected from each page for optical density measurements. The results are summarized in Figure 9. Each marker represents the average value of 36 measurements and the error bar indicates the range of data.

Figure 9 shows that the solid ink density is 0.97 ± 0.04 at the printing speed of 40 KIPH, which is lower than the target density of 1.05 ± 0.05 specified by the SNAP committee. The ink curve used to control the rate of ink input was not yet available for this process. An ink curve for the positive-feed keyless process was used instead. This accounts for the low solid ink density produced by the emulsion ink.

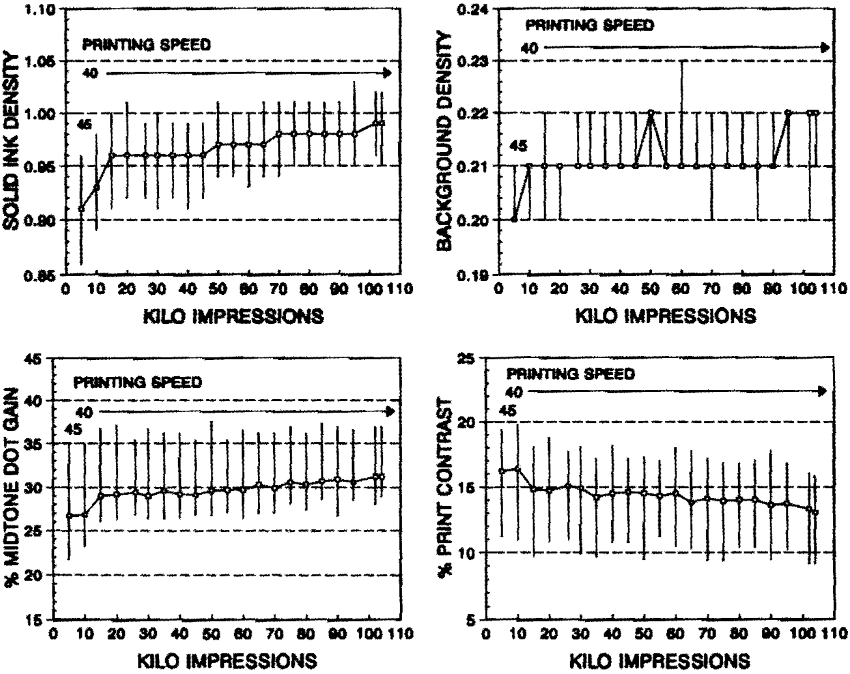

Figure 9. Print quality attributes of single fluid lithography obtained from the process stability experiment.

The background density of 0.21 ± 0.01 (Figure 9) is equivalent to the optical density of virgin newsprint, indicating that this emulsion is able to release sufficient amount of water to protect the non-image areas of the plate. The background density is slightly lower at 45 KIPH than at 40 KIPH. This phenomenon can be attributed to the increasing shear rate in the form roller-to-plate nip. As the press speed increases, more water is forced out of the emulsion.

Close examination of Figure 9 shows a slightly increasing solid ink density with time and correspondingly an increasing mid-tone dot gain and a decreasing print contrast. This trend of print quality attributes is probably related to press temperature. It was noted that the plate temperature rose by about two degrees centigrade at the end of test. In general, an increase in temperature reduces the viscosity of ink, which improves ink transfer and accordingly increases the solid ink density. Dot gain increases and print contrast decreases as the viscosity of ink decreases. This hypothesis will be verified in the future. Nevertheless, this experiment indicates that single fluid lithography is capable of producing prints of consistent quality.

Print Quality Comparison Experiment

A standard news ink was used in the positive-feed keyless process and two experimental inks B and C in the single fluid process. All inks were black. Both emulsion inks contained 50% of an alkaline fountain solution. These tests were carried out on the same press using the same ink curve. The printing speed was fixed at 35 KIPH in the keyless process but varied from 35 to 65 KIPH in the single fluid process. Printed samples were taken at least 2,000 impressions after each change of printing speed to ensure the steady state condition. The emulsion of Ink C was purposely run in two consecutive days to determine if its performance would deteriorate after overnight storage.

Figure 10 compares print quality attributes of the two processes. The solid and dotted horizontal lines represent respectively the average value of print quality attributes of the keyless process and the average value +/- two standard deviations. The standard deviations of samples from the keyless process were calculated from 108 measurements. If the measured data of single fluid process fall within the range enclosed by the dotted lines, we will have a 95% confidence level to conclude that print quality of single fluid process is as good as that of keyless process. The results in Figure 10 show that print quality produced by the emulsion inks is indeed comparable to that by the keyless process, and overnight storage appears not affecting the performance of emulsions.

The background of prints produced by emulsion ink C is cleaner than that by emulsion ink B of the same water content. The solid ink density of both emulsions is higher than the SNAP's target density. These and Figure 9 results indicate that the performance of an emulsion ink differs significantly from others and hence each emulsion needs its own ink curve. It also holds true even for the conventional lithographic process.

BENEFITS OF SINGLE FLUID LITHOGRAPHY

Single fluid lithography is a keyless and dampenerless printing process. There is no more on-press ink-water balance adjustment. Any printing

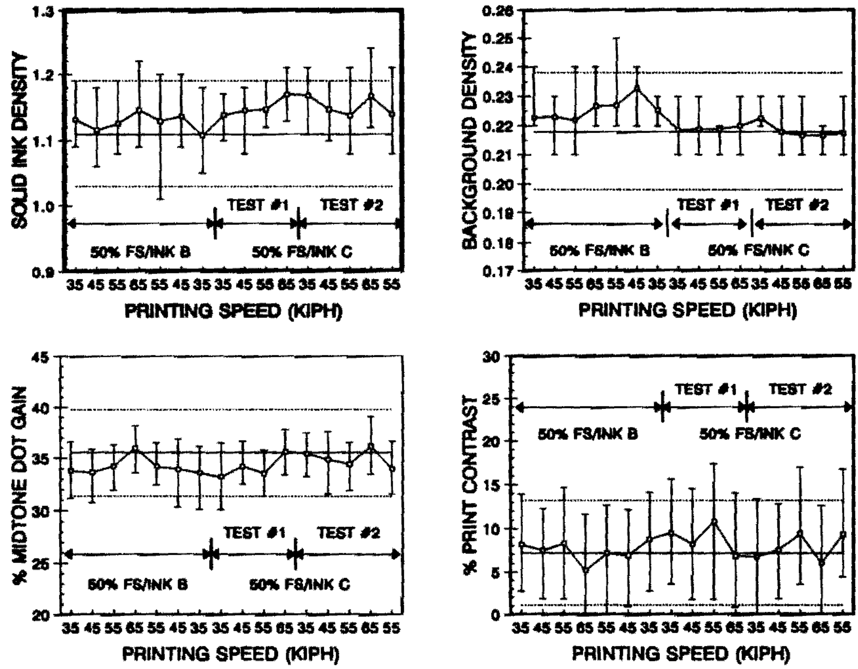

Figure 10. Print quality attribute comparison between single fluid and positive-feed keyless processes.

problems associated with maintaining ink-water balance using independent inker and dampener controls no longer exist. Press startup is fast and makeready is short. Press operation can be fully automatic and its dependence on pressmen's skill is substantially reduced.

As mentioned previously, water is a weak fluid so that it will stay, after splitting at the roller nips, on any surface regardless of the hydrophilic or oleophilic nature of the surface. When the dampened plate is passing through the ink form roller, water droplets on the image surface of the plate is emulsified into the ink and a portion of the water film on the non-image surface is transferred to the ink form roller in the form of surface water. The latter is subsequently emulsified into ink as it passes through the ink form roller-to-inking drum nip. This emulsification process continues until a steady state is reached. Consequently, the pressmen have to constantly monitor the printing process in order to maintain a consistent output.

In the single fluid lithographic process, emulsion inks are fed to the inker. Any ink and water not taken away by the paper are removed from the inker which is always replenished with the same emulsion. That is, the steady state condition is already achieved at the startup. Consistent print quality can be obtained throughout the entire press run. Waste due to inconsistent quality is significantly reduced.

In summary, single fluid lithography renders many advantages over the conventional process. Significant savings in manpower, press time, and waste will make this process even more attractive than other processes and also more competitive in the short-run jobs.

CONCLUDING REMARKS

Theory for single fluid lithography is presented in this paper. Emulsion stability and press design requirements are discussed. Benefits of single fluid lithography are mentioned. Print test results are also presented to prove the feasibility of this printing process. Elimination of the dampener from the conventional lithographic presses is no longer a dream but a reality.

We recognize that a number of tasks remain to be worked out, however. Progress in the following developments will be reported in the future. The emulsion reconstitution system must be able to produce consistent emulsion inks of controlled stability. Lab equipment for producing a small quantity of emulsion inks of controlled stability is desired for subsequent stability tests to screen out any incompatible ink and fountain combinations. Techniques for determining emulsion stability are presented in a separate paper (Durand, et. al., 1995). It is time-consuming and costly to experiment with various emulsion inks on the press.

Ink development is also essential. We had successfully printed a set of process color emulsions which were made with tap water only (Durand, et. al., 1995). This approach takes another variable away from the equation and further simplifies the process control.

Means of inducing and enhancing emulsion breakdown at the plate to widen the emulsion stability window is desirable. These methods include circulating a cooling water through the plate cylinder or a rider roller on the ink form or using an air curtain to lower the plate cylinder temperature. An electrical field, either AC or DC, can be applied near the form roller-to-plate nip to induce emulsion coalescence.

ACKNOWLEDGEMENT

The authors are grateful to Mr. Don Graves and Mrs. Faith Peloso of Rockwell for their assistance in operating the press and performing optical density measurements and data reduction. We would also like to express our thanks to Dr. Richard Durand and Mr. Christian Lee of Sun Chemicals for providing experimental inks and participating in the tests.

LITERATURE CITED

Bulloff, Jack J.
1974 "Emulsion in Printing and Graphic Arts", in *Emulsions and Emulsion Technology* (Marcel Dekker, N.Y.), edited by K. J. Lissant, Vol. 2, pp. 559-637.

Chou, Shem M. and Fadner, Thomas A.
1986 "Shear Stability of Fountain Solution Emulsified in Lithographic Inks", TAGA Proceedings, pp. 37-62.

Chou, Shem M. and Cher, Mark
1989 "Rheological Studies of Emulsion Ink Stability", TAGA Proceedings, pp. 257-280.

Chou, Shem M.
1992 "Perspective of Waterless Lithography", Proceedings of the Mid-America Chinese Professional Annual Convention, pp. 255-269.

Curtin, J. L.
1970 "Printing Plate and Method", U. S. Patent 3,511,178 (May 12, 1970).

Durand, Richard R., Jr., Wasilewski, O., and Chou, Shem M.
1995 "Emulsion Inks For Single Fluid Lithography", presented at TAGA Annual Technical Conference, Orlando, Florida.