PREDICTION OF STEADY-STATE OPERATION IN KEYLESS LITHOGRAPHY

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Development of lithographic keyless inking systems at Rockwell Graphic Systems over the past several years has included numerous printing tests on web-fed presses during which ink and dampening solution consumption rates were monitored. Ink, dampening solution, press configuration and metering roller construction were the major system variables. The results were reviewed recently in an attempt to uncover basic principles that might apply to keyless lithographic systems across this spectrum of variables. Doing so required reconsideration of the mechanism by which doctor-blade-scraped celled rollers meter viscous oil-based inks into the press system. Accordingly, cell volume was found to not be a controlling parameter in celled-roller metering of paste inks. Cell area at the surface is important. Applying the new mechanism and actual materials-use data from the press trials allowed formulating a simple equation, involving measurable variables, which quite accurately predicts the water-in-ink steady-state condition over a wide range of system variables.

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BACKGROUND

In previous keyless lithography publications (1, 2), we showed that water content of the input ink gradually increases with copy count. This happens because of the practical necessity for reusing water-containing ink that is continuously scraped off the metering roller by the doctor blade. We also pointed out how approach of the water content in the ink input reservoir to a steady-state value can be used to select suitable inks for keyless lithographic printing (2). Ink and dampening solution combinations that cannot reach a steady-state reservoir water content will fail lithographically when used in keyless inking systems.

Variation in printing conditions disallows apriori determination of the number of printed copies required to reach steady-state. In practice this may occur anywhere from 20,000 to 200,000 copies. Printed quality may or may not remain constant during this time, depending largely on how high the steady-state water content value will be. Gradual failure may occur even after visual judgment at low copy count seems to indicate successful running conditions. Determining whether or not the output from every conceivable set of press and materials conditions will reach a steady operating state can obviously be a major task. Consequently, we investigated means for estimating steady-state water content values from relatively short print tests of, for instance, about 20,000 copies.

Over the past 3 or 4 years we have recorded ink and water use rates, optical densities and other print qualities, as well as reservoir water contents for many of our hundreds of keyless inking press tests. To investigate predictability, we needed to develop a reasonable model for celled roller/doctor blade metering of oil-based inks. Then we could readily determine whether the predicted ink and water relationship fits existing experimental data.

METERING OF VISCOUS OIL-BASED INKS WITH CELLED ROLLER/DOCTOR BLADE SYSTEMS

A generic lithographic press configuration having the elements essential to keyless inking when using celled roller/doctor blade metering of ink is shown in Figure 1. All of the indicated rollers run approximately at the same surface velocity.

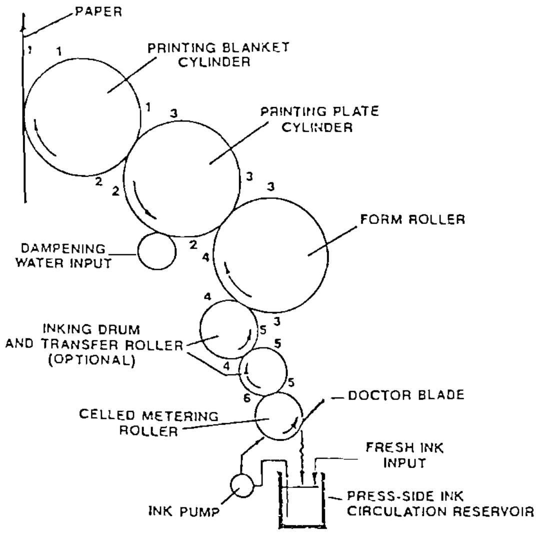

FIGURE 1. GENERIC KEYLESS INKER PRESS CONFIGURATION WITH SINGLE FORM ROLLER SIMPLIFICATION

For this derivation, it is assumed that the metering roller surface is over-filled with input printing fluid every revolution just prior to removing the excess printing fluid with the doctor blade. It will also be assumed that ink is the continuous phase of the printing fluid, despite the presence of water, and that the printing fluid films split equally from all oleophilic and hydrophobic roller surfaces at the exit from their nip junctures. For simplicity, it will be assumed that an overall solid ink film is being printed and that a single form roller is used as shown in Figure 1. None of these simplifying assumptions alter the basic nature of this model.

Under the stated conditions, the relative ink film thicknesses on the press rollers may be appropriately indicated as shown in Figure 1, selecting the printed film thickness as unity (e.g., one micron).

The thickness of the ink film being returned by the transfer roller towards its nip with the metering roller is five times that being printed out to the paper. To maintain mass balance, the rate of input ink by the metering roller must equal the rate of output ink to the paper. Accordingly, the ink film on the transfer roller after that nip must be six times that being printed out, for a net input of one.

As a first approximation the conditions of the scraped metering roller surface and the transfer roller surface of Figure 1 just prior to their mutual nip can be represented by Figure 2, in which the indicated dimensions in microns are typical for celled metering rollers we have found useful in keyless lithography.

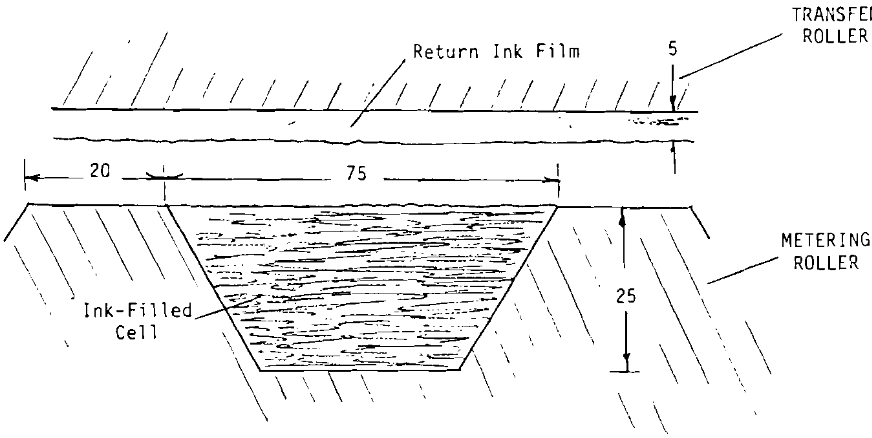

FIGURE 2. FIRST APPROXIMATION INK FILM CONDITIONS JUST BEFORE TRANSFER ROLLER/METERING ROLLER NIP

The cell geometry typically corresponds to a truncated pyramid but this analysis does not depend upon specific cell shapes. It is crucial to this model that both the cell and land surfaces of the metering roller be oleophilic and hydrophobic. Only with this surface chemistry can printing fluid be assuredly carried on all of the inking system rollers when water is present in that printing ink fluid.

At the metering roller/transfer roller nip, ink and roller surface contacts are made similar to that in Figure 3 and retained for a few milliseconds dwell time during which surface boundaries disappear.

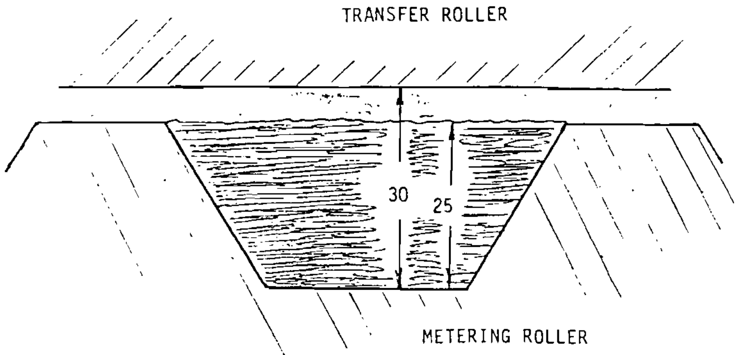

FIGURE 3. FIRST APPROXIMATION INK FILM CONDITION AT METERING ROLLER/TRANSFER ROLLER NIP

There exists no documented basis for predicting how much of a viscous ink contained in a 25 micron deep, 75 micron wide metering roller cell will transfer to an inked roller in contact with the surface layer of the ink in that cell. However, we know that the net amount of ink input at this nip must equal the amount of ink being printed out onto the paper. That is, the equivalent ink film on the exit side of the transfer roller in the Figure 3 nip must be six times that printed out, as called for by the Figure 1 ink film pattern.

Having assumed a 50/50 split of printing fluid at all ink receptive surfaces, the post-nip ink film condition of the roller surfaces shown in Figures 2 and 3 will be similar to that shown in Figure 4.

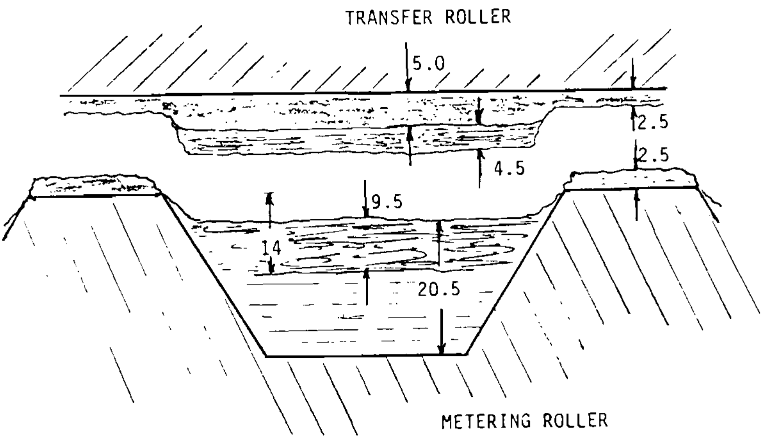

FIGURE 4. FIRST APPROXIMATION INK FILM CONDITIONS AFTER THE METERING ROLLER/TRANSFER ROLLER NIP

As a temporary convenience the relative ink film values shown in Figure 4 involved assuming equivalent surface areas of lands and cell openings. Adding the ink quantities on the transfer roller surface results in the required average film thickness of six [0.5 (5 + 4.5) + 0.5 (2.5)]. In practice, this initially uneven film becomes smoothed out by the subsequent inking roller train.

In flexographic or gravure celled roller metering of fluid inks, substantially all of the ink in the cells participates in delivery of ink to the plate or to the paper. If this was true for lithographic inks, and if we stay with 50/50 film splits, the input of printing fluid transferred to the press at Figure 4 would correspond to an averaged film thickness of about 17.5 [0.5(25+5) + 0.5(5)], instead of 6. The discrepancy with the experimental facts documented here would be even worse if more than half of the ink is removed or drained from the cells at the transfer roller nip.

Obviously, the cell depth, more correctly the cell volume, is not a controlling factor in celled roller viscous ink metering systems, as long as the cell depth is at least twice the required transferred film thickness. In the present case, 14 micron deep cells of the same relative surface area would suffice equally as well as the 25 micron deep cells we and others have been using.

As the metering roller continues rotating, it next encounters application of excess printing fluid from any one of several ink input means, thereby assuring that all partially emptied cells are refilled, as shown in Figure 5. The doctor blade subsequently scrapes off all of the

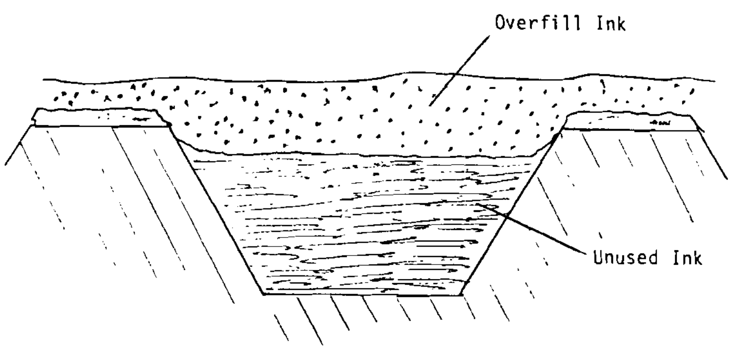

FIGURE 5. METERING ROLLER CONDITION
AFTER PRINTING FLUID INPUT

over-fill or excess ink existing above the nominal plane of the land areas, returning the scraped-off ink and any water contained in that ink for recirculation and reuse as part of the renewal printing fluid. The condition of the metering roller surface after the doctor blade and prior to the transfer roller nip is then depicted as in Figure 6. The relative amount of the return ink on the transfer roller that was scraped off for recirculation is 1.25 times that being printed out (0.5 x 0.5 x 5). This is the only portion of the scraped-off excess ink that carries water to the ink input reservoir. In the present example of 50% land area, the scraped-off fluid volume represents one-fourth of the ink returning on the transfer roller.

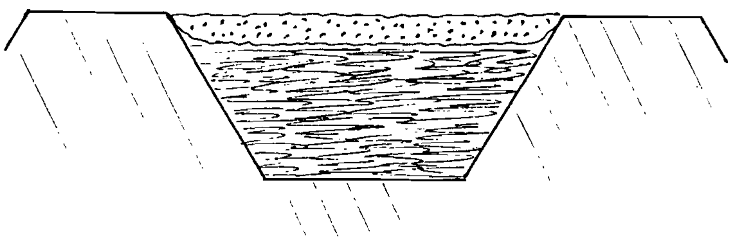

FIGURE 6. ACTUAL METERING ROLLER CONDITION PRIOR TO TRANSFER ROLLER NIP

Figure 6 represents a more accurate representation of the printing fluid make-up near the metering roller surface prior to transfer than that depicted in Figures 2 through 5. Proceeding through another cycle of metering roller rotation provides a corrected view of conditions when using viscous inks in celled metering roller/doctor blade ink metering systems. At the metering roller/transfer roller nip, Figure 7 replaces Figure 3.

And, subsequent to that nip, Figure 8 replaces Figure 4.

It is apparent from Figure 8 that only the uppermost portions of the cells are involved in continuous ink metering, about 4.5 microns at most, corresponding to about 18% of the cell depth depicted here.

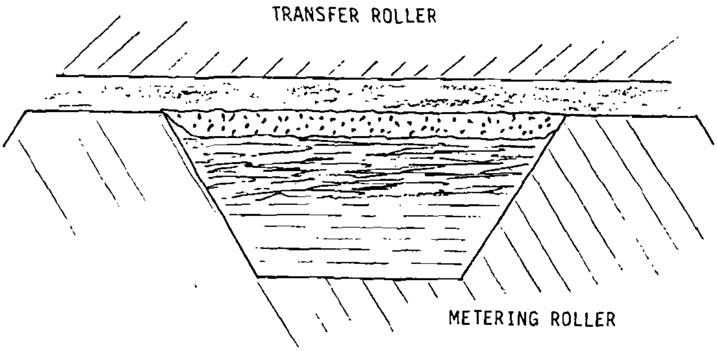

FIGURE 7. CORRECTED INK FILM CONDITION AT THE METERING ROLLER/TRANSFER ROLLER NIP

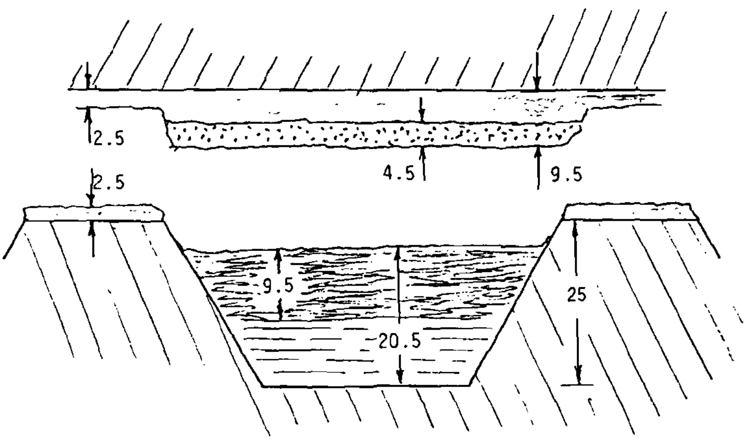

FIGURE 8. CORRECTED INK FILM CONDITIONS AFTER THE METERING ROLLER/TRANSFER ROLLER NIP

A short keyless inking train, common in Europe, is depicted in Figure 9. The active depth fraction of similar metering roller cells will be nearly the same but less of the water-laden ink will be scraped off and returned to the circulation reservoir because of the smaller ink film thicknesses involved, 0.75 (0.5 x 0.5 x 3) instead of 1.25. However, the fraction of the return ink film being scraped off remains the same, one fourth. The actual amounts of water conveyed to the ink reservoir for short and long train inkers will differ based on differences in water evaporation from the differing amounts of inking roller surface present.

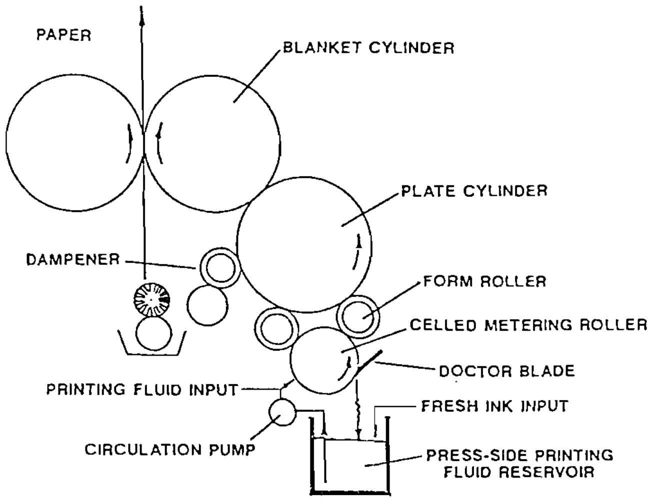

FIGURE 9. TYPICAL SHORT KEYLESS LITHOGRAPHY PRESS SYSTEM

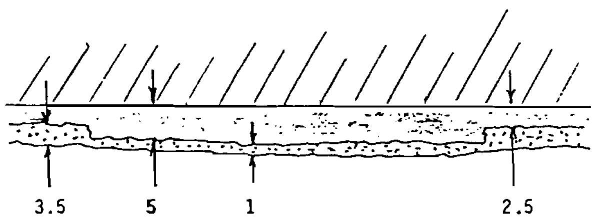

FIGURE 10. SMOOTHED INK FILM ON INKING DRUM OF LONG KEYLESS INK TRAIN

When the renewed transfer roller film is subsequently smoothed out by for instance a second transfer roller, the relative average ink film thickness is of course 6, made up more or less as in Figure 10. Assuming limited mixing of return ink with fresh ink within these relatively immobile ink films, the transfer roller conveys and presents towards the next roller in the inker a nearly uniform fresh printing fluid film of unity, independently of the residual or base return ink film thickness on the roller.

DAMPENING WATER INPUT TO THE INK RESERVOIR

From the preceding discussion, a more general relative printing fluid film thickness on the return side of the transfer roller just prior to the metering roller nip can be written as shown in Equation 1, where x is the area fraction of image on the plate and varies from 0 to 1.0.

$$\text{Return ink film} = (6 - x) \qquad x = 0 \rightarrow 1 \tag{1}$$

The fraction of the return printing fluid on the transfer roller that transfers to the land regions of the metering roller and which is subsequently scraped off is then given by Equation (2).

$$\text{Scraped return film} = \frac{(6 - x)a}{2} \qquad x = 0 \rightarrow 1 \tag{2}$$

where a is the metering roller land area fraction and the modifier 2 represents a 50/50 film split of return printing fluid at the land areas.

We can express the ratio of scraped return film to the fresh ink in the recirculated printing fluid film that is continually replacing the amount being printed out to the paper, x, by Equation 3.

$$\text{Ratio of scraped to printed fluid} = \frac{(6 - x)a}{2x} \qquad x = 0 \rightarrow 1 \tag{3}$$

At start-up, water content in the ink reservoir is nil and we can express the volume rate, v, at which printing fluid is being scraped off into the reservoir by Equation (4), where i is the actual volume rate at which ink is being used up while printing.

$$v = \frac{(6 - x)ai}{2x} \qquad x = 0 \rightarrow 1 \tag{4}$$

The percent water in the reservoir printing fluid can then be calculated using Equation (5).

$$\text{Percent Water} = \frac{100w}{v} = \frac{200xw}{(6-x)ai} \qquad x = 0 \rightarrow 1 \tag{5}$$

where w is the measured rate at which water is conveyed to the ink reservoir.

During hundreds of keyless lithographic printing tests in our laboratories, the just-above-scum dampener setting could easily be established within several hundred revolutions at speed, after which the dampener input setting generally required no further adjustment to remain at the just-above-scum condition. The only major exceptions occur when the ink continues to emulsify more and more water as the run progresses or when the ink can pick up only very small amounts of water compared to that needed by the plate. Both of these exceptions represent materials conditions that cannot reach an operating steady-state relative to the minimum required input rate of dampening solution to just keep the plate clean. These are keyless inking failures. They are lithographic failures.

Other studies indicate that steady-state water contents in the ink on the inking rollers are established very early in a press run (3). Consequently, the volume of ink (printing fluid) being printed out is invariant during the run and optical density is invariant despite the fact that some of the input dampening water is being gradually "siphoned off" to the "ink" circulation system reservoir. Of course, the reservoir also reaches a steady-state water content. That steady-state value will be similar to the transfer roller ink film steady-state water content value. For lithographically stable ink/water systems, it appears that there is no change in printing fluid delivery to the plate nor in print quality relatable to the rate or extent of water build up in the ink circulation reservoir.

This simple and demonstrable conclusion is valid only when the metering roller is rigorously and permanently oleophilic and hydrophobic. It also does not apply when the press is operated at severely high or severely low dampening input conditions typical of lithographic failures. Nor does it apply when the press system does not erase format-based water content differences in the return ink, for instance, by continuous removal and homogenization of that return ink film, prior to its reuse by the ink metering system. All lithographic keyless inking systems not meeting all three of these criteria will fail (4).

A corollary of these considerations is that Equation 5 should be correct at any copy count, not just at start-up. It should also apply at the eventual reservoir steady-state. Accordingly, Equation 5 can be rewritten as Equation 6 and used to predict steady-state water contents in a keyless lithographic ink reservoir, SS, in which the factor, a, varies over the range of practical celled

$$SS = \frac{200xw}{(6-x)ai} \qquad x = 0 \rightarrow 1 \tag{6}$$

roller land area fraction of about 0.2 to 0.6.

EVALUATION OF STEADY-STATE PREDICTABILITY

Experimental Approach - Four different keyless inker/dampening press configurations were evaluated as shown in Figures 11 through 14 and Table I.

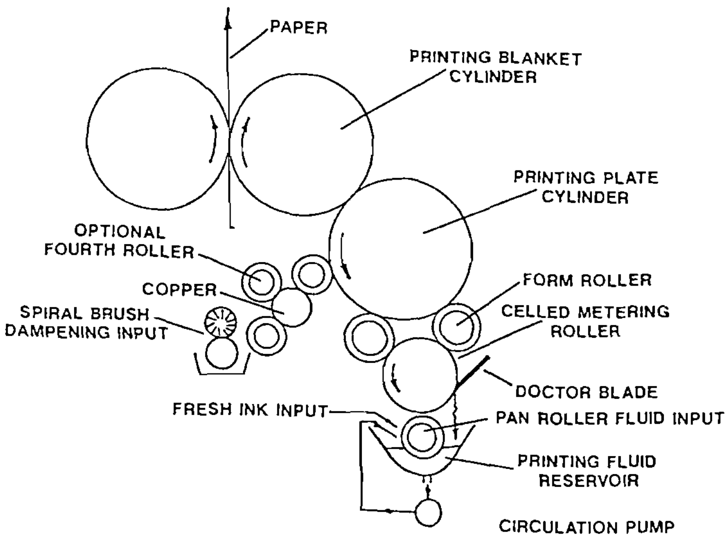

FIGURE 11. WATER-FIRST SHORT-TRAIN KEYLESS INKER WITH PAN ROLLER INK INPUT

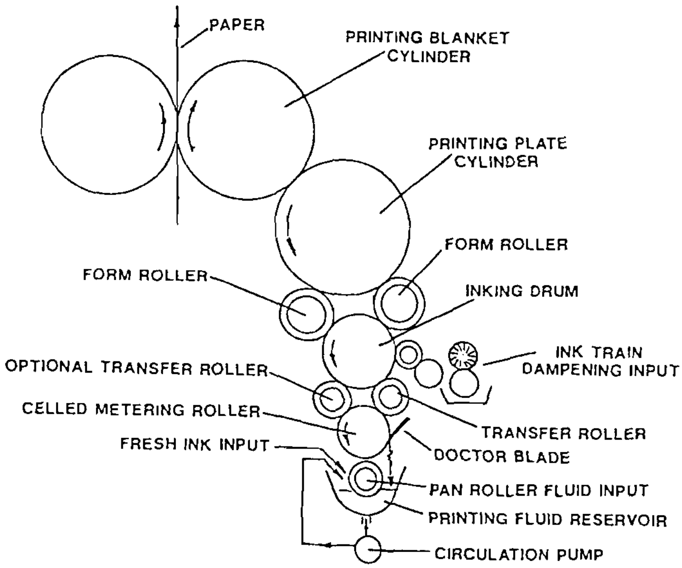

FIGURE 12. INK TRAIN DAMPENING LONG-TRAIN KEYLESS INKER WITH PAN ROLLER INK INPUT

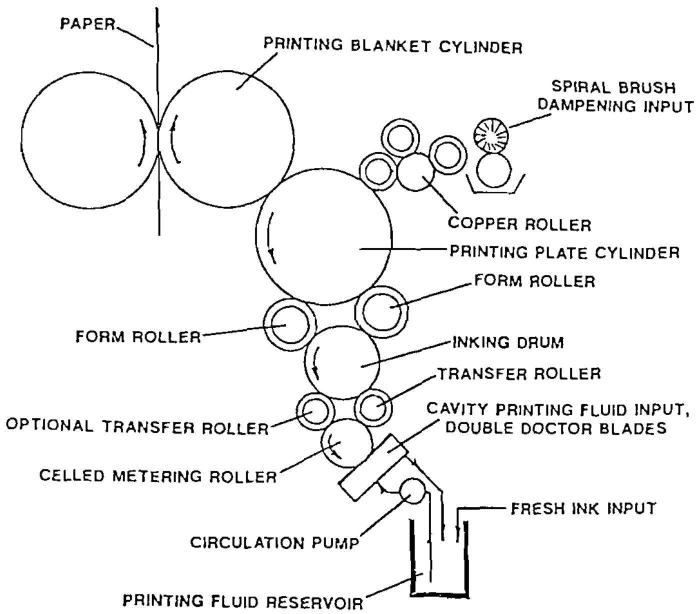

FIGURE 13. WATER-LAST LONG-TRAIN KEYLESS INKER WITH CAVITY INK INPUT

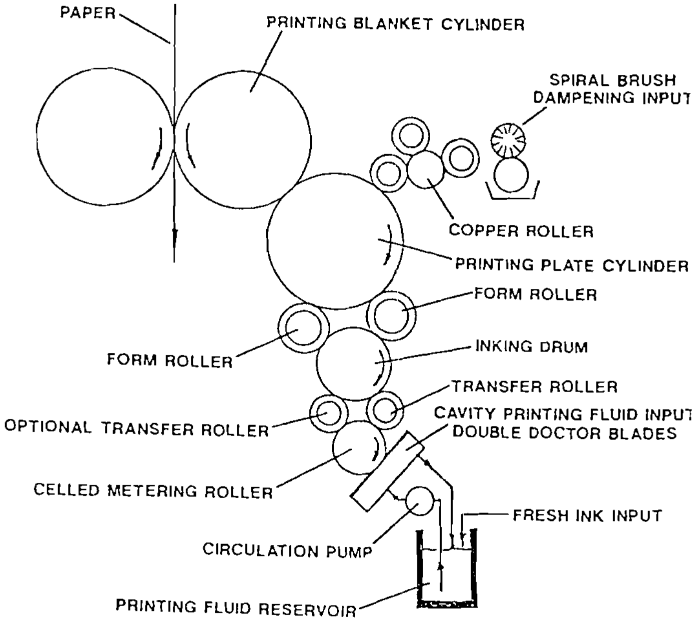

FIGURE 14. WATER-FIRST LONG-TRAIN KEYLESS INKER WITH CAVITY INK INPUT

TABLE I. KEYLESS INKING CONFIGURATIONS USED FOR STEADY STATE PREDICTIONS

Fig.	Ink Input Means	Ink Metering Means	Ink Train Means	Dampening Means
11	Pan	Celled Roller/Blade	Short	Water First
12	Pan	Celled Roller/Blade	Long	Ink Train
13	Cavity	Celled Roller/Blade	Long	Water Last
14	Cavity	Celled Roller/Blade	Long	Water First

The Figures 11 to 14 printing couples are variations of standard one-around, two page wide, newspaper presses such as the Goss Community brand.

All of our direct dampening configurations involved a dampener roller train of four oleophilic and hydrophobic rollers to which water was input from a conventional physically-separated spiral brush water spray roller pair. This dampening arrangement is illustrated schematically in Figures 11, 13, and 14. The four dampening rollers become inked during press operation. We found that when water-last dampening is used (5) this represents an essential water input condition enabling easily-controlled, quality print output.

Print test run lengths ranged from 18,000 to 154,000 copies and were carried out over a four year period at press speeds from 20,000 to 35,000 impressions per hour. The average run length was 68,000 copies and the total number of copies reported here is 2.71 million. All tests were run at the just-above-scum lithographic condition.

Inks from four different suppliers were used during the four year period. One of these suppliers was our own laboratory. To enable using inks with controlled properties, we have been formulating newsinks using typical industry materials supplied by Flint Ink Company. Inks for pan roller input (Figures 1 and 2) generally can be more viscous than those for cavity input (Figures 3 and 4). However, the rheology of inks that we formulated was controlled primarily for pumpability in the specific circulation system associated with the configuration being used and of course for favorable print quality properties.

Dampening solutions were from several different suppliers. We tended to stay with one type for significant periods of time. Early on, print tests were biased towards alkaline dampening solutions, more recently towards neutral. We found that dampening solution brand has little to do with details of print test results provided good image differentiation at the plate is possible within reasonable water input rates. Absence of nuisance problems such as plates drying out during stops tended to establish whether or not we stayed with a particular brand.

As previously reported (2), we select ink/dampening solution combinations having a Duke water pickup result approximating a C type curve with a ten minute pickup value between about 40 and 140, as in the shaded area of Figure 15. Any such combination can be successfully run on any of our keyless configurations.

Both presensitized and wipe-on plates from several sources were used. The plate either differentiates image/non-image areas or it does not. There seems to be no "almost" or "partly" useful printing plates in lithography.

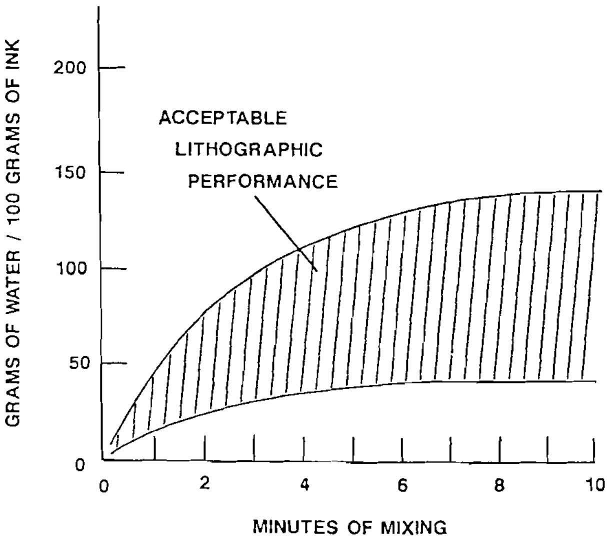

FIGURE 15. DUKE TEST SELECTION OF OPERABLE INK/DAMPENING SOLUTION COMBINATIONS

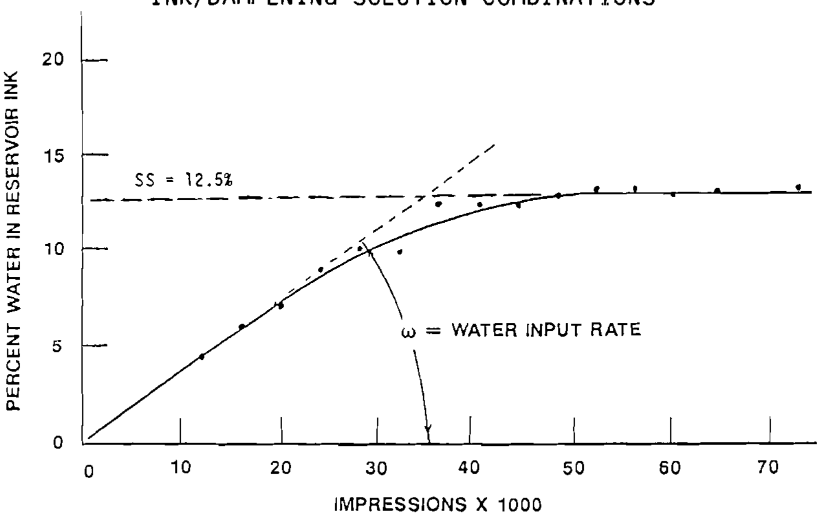

FIGURE 16. WATER INPUT TO INK CIRCULATION RESERVOIR IN KEYLESS LITHOGRAPHY

Ink use was determined by weighing the amount of fresh ink required to maintain the press-side ink circulation reservoir at a constant volume. Rate of use, i, was determined as the total consumption divided by copy count. Dampening solution use rate, W, was determined similarly but by volume. All calculations assume ink specific gravity of one.

No attempts were made to control press temperature, nor ink temperature and none of these print tests required add-on water removal or ink refreshing devices.

The rate of dampening water input to the ink circulation reservoir, w, was determined as the initial slope of reservoir water content curves such as that in Figure 16. Water contents of printing fluid samples taken every 4,000 or 5,000 copies from the ink circulation reservoir were determined using an automatic Mettler Karl Fischer Titrator.

Five different celled metering rollers were used in the tests reported here, representing three different composite technologies that render hydrophobic and oleophilic the roller's inherent wear-resistant surfaces (6). These same metering roller technologies have been successfully used in several extensive field tests.

EXPERIMENTAL AND CALCULATED STEADY-STATE RESULTS

Data corresponding to 56 print tests using the four basic configurations in Figures 11-14 are given in Appendices I through IV. For convenience the averaged results are summarized in Table II.

TABLE II. STEADY-STATE WATER CONTENT VALUES IN KEYLESS LITHOGRAPHY

No.of Tests / Ave.No. Copies	Configuration	% Water at Exp. Steady State	% Water at Calc. Steady State	Ink Use Rate,i gm/imp	Water Rate to Reservoir w,ml/imp	Water In-Put Rate to Press W,ml/imp
7 51K	WF, short pan	27	26	0.10[a]	0.094	0.30
17 63K	ITD, long pan	19	19	0.12	0.075	0.34
10 34K	WL, long cavity	5	3	0.29[a]	0.059	0.26
22 43K	WF, long cavity	12	13	0.17	0.065	0.24

a. Based on relatively few values. Many more tests were made for which either ink or water use rates were not recorded.

Of the 56 print tests, complete materials data were available to calculate steady-state reservoir water contents in 42 cases. Partial data were available for the balance of tests. All calculated steady-state values are within 5 percentage points of the observed or graphically determined steady-state value and generally within 2% as the Table II averages infer. The graphical steady-state determination method foot-noted in these Appendices is shown in Appendix V.

These data illustrate that Equation 6 is quite accurate despite rather wide variation in test conditions, inferring that the basis for its derivation is reasonably accurate.

COMPARISON OF KEYLESS CONFIGURATIONS

The following comparison of the four configurations can be made based on ranking them for highest ink input and for least water input required to operate just-above-scumming. Taken together, these ranks should correlate with least steady-state water content and intuitively should indicate expectation of least ink/water difficulties or problems.

TABLE III. RELATIVE RANK OF KEYLESS CONFIGURATIONS

	Water Input Rank[a]	Ink Input Rank[b]	Steady State Rank[c]	Expected Ink/Water Difficulties
WL, Long, Cavity	1	1	1	Least
WF, Long, Cavity	2	2	2	↓
ITD, Long, Pan	3	3	3	↓
WF, Short, Pan	4	4	4	Most

a. Based on #1 is lowest rate, best value.
b. Based on #1 is highest rate, best value.
c. Based on #1 is lowest and best value.

These rank results are internally consistent. When more ink is delivered to the paper by the system and when less water is required to just maintain differentiation at the plate, the steady-state water content retained in the inking system is least. The best system for least water in the inking system has water last dampening and a long inking train. The worst combination is water-first dampening with a short inking train.

Another interesting comparison is that of relative apparent ink delivery to the different configurations by the metering system at steady-state.

TABLE IV. RELATIVE WATER AND INK INPUTS BY METERING ROLLER FOR VARIOUS KEYLESS CONFIGURATIONS AT STEADY-STATE

	Water Content of Input Printing Fluid at Steady State	Ink Content of Input Printing Fluid at Steady State
WL, long, cavity	3	97
WF, long, cavity	13	87
ITD, long, pan	19	81
WF, short, pan	26	74

The top to bottom listing infers decreasing capability of the configuration to deliver ink into the press. Actually this inference is incorrect.

For most of these tests water content in the input ink was nil at start-up and increased during the test towards the Table II values. During this time, optical density

FIGURE 17. BLACK INK OPTICAL DENSITY DURING KEYLESS LITHOGRAPHIC PRINT TEST

changed very little, usually not at all within experimental uncertainty, Figure 17 (7). It is apparent from these findings that the reservoir steady-state water content value bears no relationship to the output of ink by the printing plate and blanket to the paper.

There are a number of ways to explain this apparent anomoly. Lithography is controlled when water and ink differentiation at the printing plate is controlled. Lithography is not controlled by the relative amounts of water in the ink at various other locations on the press. Water contents in ink samples taken by various investigators at or near the printing plate are reported to be at least as high as the highest reservoir water content seen here, 26%. Obviously, the ink at the plate is already successfully being printed at high water contents, independent of what is going on at the ink input source. Of course, trouble is expected when water content of the ink input sufficiently exceeds the nominal water content of the ink at the plate that is consistent with good lithographic operation.

A more compelling argument is that the ink circulation reservoir merely represents an extension of the transfer inking roller. Within a few hundred impressions, according to VTT of Finland, steady-state has been achieved on the inking rollers (3), because less than about 10 grams of ink are present on the whole train of inking rollers. The reservoir in keyless lithography contains for instance 5 gallons, or about 90,000 grams. It is not surprising that achieving steady-state water content in the reservoir requires tens of thousands of copies.

Yet another view is that at the metering roller/transfer roller nip only one equivalent of printing fluid is input to a transfer roller return film of ink that already contains one of the Table II water contents. The largest possible low-copy-count change in water content of the post-nip resultant input film on the transfer roller is when fresh dry ink is input. Since only one-fourth of the return film is scraped off, Figure 8, the water content at the exit of the nip under these conditions will be reduced only by that fraction. Thus, a 26% return film water content becomes 19.5% in the input film. Later in the run, when the ink in the circulation system has water in it, the water content change is correspondingly smaller. At steady-state the difference disappears. Whenever fractional land area of the metering roller is less than

0.50, this start-up versus steady-state difference is smaller. By the time this fractional change is distributed among the balance of the inking rollers, no effect at the printing plate will be seen. Obviously, then, the printing rollers remain essentially at steady-state throughout the run despite gradually increasing water content in the reservoir.

INSIGHTS FROM THE STEADY-STATE MODEL

Equation 6, repeated below, reveals some interesting facts about keyless lithography, most of which are applicable to conventional lithography.

$$SS = \frac{200xw}{(6-x)ia} \qquad (6)$$

$$x = 0 \rightarrow 1$$

1. The steady-state water content value for a given press configuration and constant ink and water inputs decreases with increasing image content of the format being printed by the factor x/(6-x) for a long-train inker and by x/(4-x) for a short-train inker, as the area fraction of image at the plate varies from 0 to 1.0.

   This reflects the fact that in lithography inks are formulated to be able to pick up and retain some of the dampening water. Obviously, with increasing image content on the plate, more ink is printed out and more of the water that is being applied over the whole plate by the dampener is carried out by that ink to the paper.

2. In practice, dampening solution input to the press rollers at just-above-scum is constant when percent image is varied. This may apply for all but very low image contents, as pointed out by Bassemir (8), MacPhee (9) and Fadner (5). The factor w in Equation 6 is the water input rate to the ink as measured by rate of water build-up in a conveniently large ink reservoir. It is not the overall rate of dampening solution input to the press system. For the uniform continuous forced-input dampening system used here, w is proportional to the rate at which the ink residing on the inking form rollers picks up water and is related to the water paths on the press by Equation 7:

$$W = w + w_e + w_p \qquad (7)$$

where w_e is the overall rate of water evaporation and misting from the press rollers, and

w_p is the rate at which water is printed out to the substrate.

The factors W, w, and w_p, can be measured experimentally, the first two by means described in this paper, the latter by means of beta gauge, or microwave devices commonly used in the paper industry to measure web moisture content.

In any case, for keyless systems where ink presented to the plate surface by the form rollers is uniform in time and area, and where dampening water is also presented uniformly in time and area, it appears that w also represents the net continuous overall rate of water pickup by the ink in the press system being used, not merely the rate at which water shows up in the reservoir.

3. Steady-state water content should be lower as ink input rate i increases at constant image content, x. This is intuitively obvious from the fact that more of the input water will be printed out as part of the ink. Also, as previously noted, higher ink input rate does not necessarily require higher water input rate for the lithographic process to remain at just-above-scum or any other repeatable condition.

4. According to Equation 6, the steady-state water content decreases as land area increases. Yet in the inking model, it is the land area that accounts for conveyance of water-laden ink into the ink circulation reservoir.

   Actually, the land area factor, a, cannot increase without a corresponding decrease in the cell surface area, c. Decrease in cell surface area corresponds to a concomitant decrease in ink input, i. Less ink will be input to the system and at constant water input, w, the steady-state water content increases. To reflect this, Equation 6 can be changed to Equation 8:

$$SS = \frac{200xw}{(6-x)(1-c)i} \qquad (8)$$

$$x = 0 \rightarrow 1$$

Of course, as c increases towards 1, the land area fraction approaches zero and the equation derived from this model no longer applies.

CONCLUSIONS

Keyless lithography can be successfully and routinely practiced by adhering to the rather simple system and materials criteria discussed in this paper. Keyless lithography cannot be properly controlled if any one of these criteria are not met. With these precautions, the following factors appear characteristic of keyless lithographic systems.

1. Water build-up in the ink input circulation system is an artifact of lithography. The input reservoir can be considered as an extension of the ink roller train. It merely takes longer for the large quantity of ink in the reservoir to reach a steady-state water content that is reached very rapidly in the thin ink films of the press rollers.

2. Water build-up in keyless lithographic inking system rollers is expected to be no different on average than that for the equivalent conventional keyed system using the same materials. Keyless systems have merely been measured more extensively and more accurately.

3. Successful keyless lithography does not depend strongly on using a specific type of press configuration nor on specific ink and dampening input configurations. All materials and systems for which the lithographic portion of the process is controllable are controllable as keyless systems. However, the severity of ink/water problems will vary depending on specifics of the press configuration.

4. Steady-state water contents in the inking train can be accurately predicted for operable keyless inking system such as those discussed here, using values of ink and water input rates that are easily measured or monitored on keyless lithographic presses.

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APPENDIX I. STEADY-STATE CALCULATIONS FOR SHORT TRAIN INKER WITH WATER FIRST DAMPENER AND PAN INK INPUT[a]

Test Run No.	Ink Type	Ink Supplier	Run Length	Image Fraction, x	Ave OD	Ink Use Rate, i	Initial Water Rate, w	Average Water Input, W	Steady-State Values Observed	Steady-State Values Calculated	Observations
86T116	Black 1	3	74,000	0.30	1.01	0.10	0.11	0.36	40	43	
86T112	Black 1	3	57,000	0.25	1.03	0.10e*	0.078	0.32	35	32e*	*Ink rate value assumed same as 86T116 value.
86T86	Black 2	3	56,000	0.30	0.97	0.10	0.10	0.33	29	29	
86N07	Black 3	2	48,000	0.25	1.02	0.10e*	0.10	0.27	22	24e*	*Ink rate value assumed same as 86T116 value.
86T63	Black 4	1	45,000	0.25	0.91	0.10e*	0.12	0.27	25-26	29e*	*Ink rate value assumed same as 86T116 value. Had 16.5% water at start.
86T62	Black 4	1	20,000	0.35	1.01	0.10e*	0.042	0.30	16	14e*	*Ink rate value assumed same as 86T116 value. Had 10% water at start.
5686	Black 5	2	54,000	0.25	0.94	0.10e*	0.11	0.23	25	27e*	*Ink rate value assumed same as 86T116.
		Averages	51,000	0.29	0.98	0.10	0.094	0.30	27	26	

a. Al_2O_3/Cu metering roller, a = 0.36.

APPENDIX II. STEADY-STATE CALCULATIONS FOR LONG TRAIN INKER WITH INK TRAIN DAMPENER AND INK PAN INPUT[a]

Test Run No.	Ink Type	Ink Supplier	Run Length	Image Fraction, x	Ave OD	Ink Use Rate, i	Initial Water Rate, w	Average Water Input, W	Steady-State Values Observed	Steady-State Values Calculated	Observations
87T36	Magenta 1	1	72,000	0.30	0.89	NA	0.089	0.36	31 (G)	NA	Optical density increased towards failure.
87T35	Cyan 1	1	75,000	0.30	0.90	0.22	0.091	0.36	15	12	
87T38	Black 4	1	72,000	0.30	1.00	0.16	0.068	0.35	13	12	
87T42	Black 6	1	36,000	0.35	1.04	0.11	0.064	0.32	NA*	20	*Steady-state not reached.
87T43	Black 4	1	74,000	0.35	1.00	0.10	0.064	0.40	20	22	Continuation of 87T42.
87T44	Magenta 2	1	74,000	0.35	0.80	0.15	0.12	0.38	22	27	
87T45	Yellow 1	1	72,000	0.35	1.00	0.19	0.12	0.35	18 (G)	22	
87T46	Black 4	1	56,000	0.35	0.90	0.086*	0.046	0.31	20	18	*Rate adjusted to dry basis. Ink had 8% water.
87T48	Yellow 1	1	75,000	0.35	0.93	0.11*	0.058	0.35	28	18	*Rate adjusted to dry basis. Ink had 8% water.OD declining towards failure.
87T49	Black 4	1	72,000	0.30	0.93	0.099*	0.082	0.29	20	22	*Rate adjusted to dry basis. Ink had 10% water.
87T58	Magenta 3	3	37,000	0.30	0.84	0.17	0.076	0.26	11	13	
87T61	Magenta 4	2	70,000	0.35	0.85	0.11	0.081	0.36	25 (G)	27	
87T63	Yellow 2	2	74,000	0.35	1.10	NA	0.054	0.38	NA	NA	OD declining towards failure.
87T65	Black 7	2	73,000	0.30	1.05	0.11	0.066	0.29	NA*	18	*Indeterminate. Not run long enough.
87T71	Magenta 5	2	72,000	0.30	0.8	0.099	0.084	0.32	22 (G)	25	OD declining.
88T22	Black 7	2	85,000	0.30	0.90	0.15e	0.069	0.34	12	13	Ink rate estimated from test 88T46.
88T46	Black 4	1	60,000	0.30	1.05	0.15	0.079	0.34	14G	15	
			63,000	0.33	0.94	0.12	0.075	0.34	19	19	

a. Al_2O_3/Cu metering roller, a = 0.36 except last two for which CuEN metering roller used, a = 0.36.
(G) Refers to use of graphical steady-state determination, Appendix V.

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APPENDIX III. STEADY-STATE CALCULATIONS FOR LONG TRAIN CAVITY INKER, WATER-LAST DAMPENER[a]

Test Run No.	Ink Type	Ink Supplier	Run Length	Image Fraction, x	Ave OD	Ink Use Rate, i	Initial Water Rate, w	Average Water Input, W	Steady-State Values Observed	Steady-State Values Calculated	Observations
89T15	Black 8	1	76,000	0.50	0.95	NA	0.007	0.29	1.5	NA	
89T22	Black 9	4	47,000	0.30	1.05	0.32	0.021	0.21	4.0	2.5	
89T23A	Black 10	4	20,000	0.30	1.00	NA	0.00	0.22	0.0	0.0	
89T23B	Black 10	4	20,000	0.30	0.95	NA	0.082	0.26	5.0	NA	Higher dampener setting than 89T23A.
89T26A	Cyan 2	4	20,000	0.50	0.90	NA	0.038	0.28	1.0	NA	
89T26B	Cyan 2	4	40,000	0.30	0.91	NA	0.045	0.28	8.0	NA	Continuation of 89T26A.
89T30A	Yellow 3	4	20,000	0.50	0.85	NA	0.057	0.29	4	NA	
89T30B	Yellow 3	4	38,000	0.30	0.98	NA	0.049	0.29	15	NA	Continuation of 89T30A.
89T31A	Magenta 5	4	21,000	0.50	0.82	0.43	NA	NA	3	NA	
89T31B	Magenta 5	4	38,000	0.30	0.92	0.26	0.030	0.21	6	4	Continuation of 89T31A.
			34,000	0.37	0.93	0.29	0.059	0.26	5	3	

a. Al_2O_3/Cu metering roller with a = 0.28.

APPENDIX IV. STEADY-STATE CALCULATIONS FOR LONG TRAIN CAVITY INKER, WATER-FIRST DAMPENING[a]

Test Run No.	Ink Type	Ink Supplier	Run Length	Image Fraction, x	Ave OD	Ink Use Rate, i	Initial Water Rate, w	Average Water Input, W	Steady-State Values Observed	Steady-State Values Calculated	Observations
88T85	Black 11	4	74,000	0.30	0.85	NA	0.11	0.27	15	NA	
89T86A	Black 12	4	8,000	0.50	0.71	NA	0.13	0.26	None	NA	
89T86B	Black 12	4	48,000	0.30	0.80	NA	0.04	0.26	None	NA	Continuation of 88T86A.
89T01	Black 13	4	94,000	0.30	1.00	NA	0.063	0.25	13	NA	
89T42A	Black 10	4	18,000	0.50	0.91	NA	0.054	0.24	4	NA	
89T42B	Black 10	4	55,000	0.30	0.85	NA	0.081	0.24	19 (G)	NA	Continuation of 89T42A.
89T43A	Black 14	4	18,000	0.50	0.75	0.20	0.054	0.29	NA	11	
89T43B	Black 14	4	39,000	0.30	0.78	0.12	0.079	0.29	30 (G)	25	Continuation of 89T43A.
89T44A	Magenta 6	4	20,000	0.50	0.77	0.18	0.020	0.27	5	7	
89T44B	Magenta 6	4	75,000	0.30	0.80	0.11	0.047	0.27	14	16	Continuation of 89T44A.
89T55A	Black 14	4	20,000	0.50	0.85	0.15	NA	0.20	7	NA	
89T55B	Black 14	4	42,000	0.30	0.90	0.092	0.042	0.20	19 (G)	17	Continuation of 89T55A.
89T56A	Black 15	4	18,000	0.50	0.83	0.18	NA	0.23	4	NA	
89T56B	Black 15	4	42,000	0.30	0.89	0.11	0.034	0.23	9	12	Continuation of 89T56A.
89T58A	Cyan 3	4	18,000	0.50	0.75	0.25	NA	0.23	5	NA	
89T58B	Cyan 3	4	36,000	0.30	0.80	0.15	0.052	0.23	16	13	Continuation of 89T58A.
89T60A	Cyan 4	4	18,000	0.50	0.82	0.17	NA	0.20	5	NA	
89T60B	Cyan 4	4	58,000	0.30	0.85	0.10	0.033	0.20	14	12	Continuation of 89T60A.
89T61A	Yellow 4	4	20,000	0.50	0.99	0.28	0.029	0.16	8	5	
89T61B	Yellow 4	4	20,000	0.30	0.96	0.17	0.058	0.16	20	9	Continuation of 89T61A.
89T70	Black 16	4	154,000	0.30	0.94	0.91	0.15	0.29	12	15	
90T17	Black 17	4	44,000	0.30	1.05	0.24	0.066	0.35*	9	11	*Poor printing plate, higher dampener setting required.
			43,000	0.31	0.87	0.17	0.065	0.24	12	13	

a. Cu/Al_2O_3 metering roller with a = 0.28, except 89T61-89T70 for which CuEN roller used with a = 0.40.

(G) Refers to use of graphical steady-state determination, Appendix V.

APPENDIX V

GRAPHICAL METHOD FOR PREDICTING STEADY-STATE TEMPERATURE

A simple graphical construction method, originally developed for Space Shuttle applications, predicts the equilibrium temperature of a system that is being heated or cooled. The method assumes that the temperature relaxes exponentially toward an equilibrium value. The results can be obtained in minutes without a computer or complex calculations.

A plot of the early temperature-versus-time history of the system must first be determined by measurement for a given set of constant thermal conditions. From this plot, the ultimate steady-state temperature that the system will attain can be constructed. The construction method for a system being heated is as follows:

- A tangent is drawn to the temperature-versus-time curve at the point at which heating or cooling starts (line 1 in the figure).
- A second tangent is drawn to the curve at any point O_2, T_2 (line 2 in the figure). Line 2 must have a slope different from that of line 1.
- Line 3 is drawn parallel to line 2 through temperature T_2 on the vertical axis. The temperature T_s at the intersection of lines 1 and 3 is the steady-state temperature.

The procedure for a system being cooled is identical except that the slopes are negative.

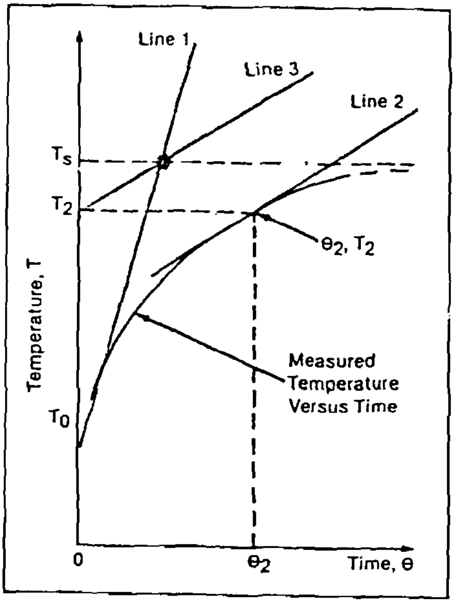
The time θ_s for the system to progress through 99 percent of the temperature difference between the initial and steady-state values is computed from the equation

$$\theta_s = [(T_s - T_0)/(\text{slope of line 1})] \times \ln(100)$$

where T_0 is the temperature of the system at time zero. The 99-percent point is used as a convenient approximation, since theoretically it would take an infinitely long time to reach the final temperature.

The method is applicable to a variety of problems. Examples include the temperatures of buildings, powerplant or refinery components, or chemical reactors; voltages on charging or discharging capacitors; and concentrations of reactants in some chemical processes.

This work was done by Robert L. Case, Jr., of Rockwell International Corp. for Johnson Space Center and is reproduced here from Reference 10.



The Intersection of Two Lines in a graphical construction gives the asymptotic temperature of a system. Developed for analyzing thermal anomalies during flights of the Space Shuttle, the graphical method is also applicable to everyday heating and cooling problems.