Where the Water Really Goes. I. Derivation of a Definitive Model for the Fate of Dampening Water in the Lithographic Printing Process

by

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ABSTRACT

A novel net water flow rate approach was used to evaluate five different keyless lithographic configurations for which world-wide field results seemed to not always reflect laboratory operational successes.

The model predictions did not coincide with published lab and field keyless lithography experience until dampener configuration details were also taken into account.

Minimum water input rate requirements can readily be modeled, as well as relative water flow rates at the critical inking-form-roller/printing plate nips. These results allow predicting which configurations should have the least ink/water interaction problems.

The predictive capability of this approach is not limited to evaluating keyless lithography. It is directly applicable to conventionally inked systems, always with one major precaution. Lithographically efficient dampening must be used. Few, if any, conventional dampeners are efficient. They all supply excess water to the inking portions of the press, water that is lithographically useless. The presence of this free liquid water in the lithographic press system creates the well-known operating problems and negates system predictability. This explains why a definitive basis for understanding water/ink interactions in lithography had historically been so elusive.

BACKGROUND CONSIDERATIONS FOR THE MODEL

In lithography, the most important feature involving water is its activity at the surfaces of inked and uninked press components and of the substrate being printed. It is well known that at least some of that input water is continuously lost from the plate non-image surfaces by evaporation and that some is transferred to the paper substrate. Consequently, keeping the non-image areas of a lithographic plate clean while printing requires continuous dampening water input. Since water is also known to become emulsified into the ink, water likely evaporates from the ink residing on the inking roller surfaces.

In developing any model for the fate of water during lithographic printing, the just above scum operating condition is mandatory. This stipulation avoids redundancies associated with presenting to the plate more water or less water than that just required to print with clean non-image areas. This reproducible condition is lithographically similar for any print run using any set of material and press factors. It therefore enables meaningful comparisons of theoretical model predictions with results from all press tests that were run at the true just above scum condition (1).

During lithographic printing start-up, some of the input water is mulled into the ink films on the inking rollers and into ink films on the plate image areas. Buildup of water in thin ink films that are subjected to the static and shearing pressures due to roller interferences occurs rapidly, certainly within 100 or so copies (2,3). It has been shown that these thin ink films present little or no physical barrier to water migration (4). Accordingly, water also can readily migrate out of and evaporate from press roller ink films. Consequently, the just above scum steady-state operating condition is expected to involve water loss by evaporation from virtually all of the operational press roller surfaces.

No evidence exists that the rate of water loss at any given press roller surface position is dependent upon how much water happens to be present at that position. Accordingly, this model dismisses concern for defining relative water contents in the ink films on the press. It also avoids defining water film thicknesses on the plate. Rather, it begins with the intuitive assumption that only the uppermost surface layers of material on all of the press rollers are available for and active in continual evaporative losses of water. Consequently, the steady-state volumetric amounts of water present at various press locations are of little consequence in developing the model.

RULES FOR THE LITHOGRAPHIC WATER PATH MODEL

The following assumptions or conditions were used to establish relative quantitative water processing rates by any lithographic printing press:

1. The minimal rate of water loss from the press system corresponds to the just acceptable operating condition at which the natural rate of evaporation of water from all of the participating roller surfaces is just achieved. No misting or other gross loss of liquid water from press components is allowed.

2. Water evaporative rates do not vary with roller surface material. Consequently, at just above scum, all roller surfaces subject to the presence of water continuously have the same instantaneous amount of water available per unit area for evaporation. That is to say, at the just above scum condition, the rate of water evaporation from every surface containing water is a constant and at a maximum under given temperature, relative humidity, press speed, etc. conditions.

3. Output of water to the paper corresponds to transfer of water from the blanket surface to the paper at a rate equal to that as if the just above scum rate of water evaporation from the blanket had taken place. This is equivalent to stating that only water able to rapidly diffuse away from any roller surface

within about 50 millisec or less of contact can transfer.

4. The rate of evaporation from the surfaces of large two-page around press cylinders is defined as the quantity e per half-revolution. That for the smaller-surfaced cylinders is defined as e/2 per half revolution. This is an admittedly simplifying assumption to avoid trivial calculations requiring the use of numerous differing roller surface areas.

5. Evaporation from surfaces will not be allowed into near-press regions such as the arch of a newspaper press when the water input source (the dampener) is located in that region. Intuition dictates that these relatively closed regions do not participate in continual evaporative dissipation of water.

6. As with Rule 5, no evaporation is expected into the confined regions between successive inking form rollers in 2- and 3-form roller presses. Consequently, for evaporative water loss purposes, all multiple form roller presses can be approximated by single form roller counterparts.

7. For similar reasons as for Rule 5, water evaporation from the blade side of the metering roller is disallowed for keyless inkers requiring a scraping blade on the metering roller ink input system.

8. A further simplifying assumption is that the water of lithographic interest is only that which actually enters the press. Liquid or vapor water losses from the dampener are of no consequence in the lithographic process.

These rules were used to establish internally consistent models for the fate of dampening water being input to five different keyless printing press configurations run under similar conditions and for which ink and water consumptions had been measured. As will be seen, this lithographic model actually has no dependence on whether inking is being done in the keyless mode.

WATER LOSSES FROM WATER FIRST, LONG-TRAIN KEYLESS LITHOGRAPHIC PRESS

LOSSES FROM THE INKER PATH - Referring to the Figure 1 inker portion of the Figure 2 press roller schematic, the net flow of water towards the return sides of each inking roller nip a, b, c, d, must be zero. This is based on the physical fact that net water flow can never be towards the water input source. Net water flow is always towards the losses.

Assumption 4 stipulates that water evaporation rates from each side of each of these rollers is either e or e/2. These losses are indicated in Figure 1 and the total continuous evaporation rate from this set of inking rollers is (5 x e/2) + 2e = 4.5e. Therefore the required net water flow toward the inker at f is 4.5e.

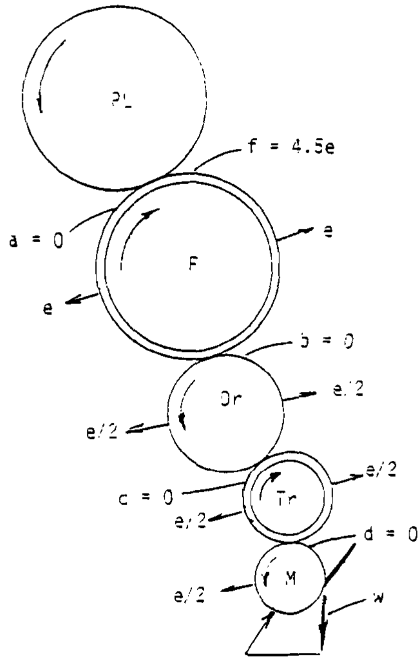


FIGURE 1. MODEL OF WATER PATHS IN INKER PORTION OF FIGURE 2 CONFIGURATION

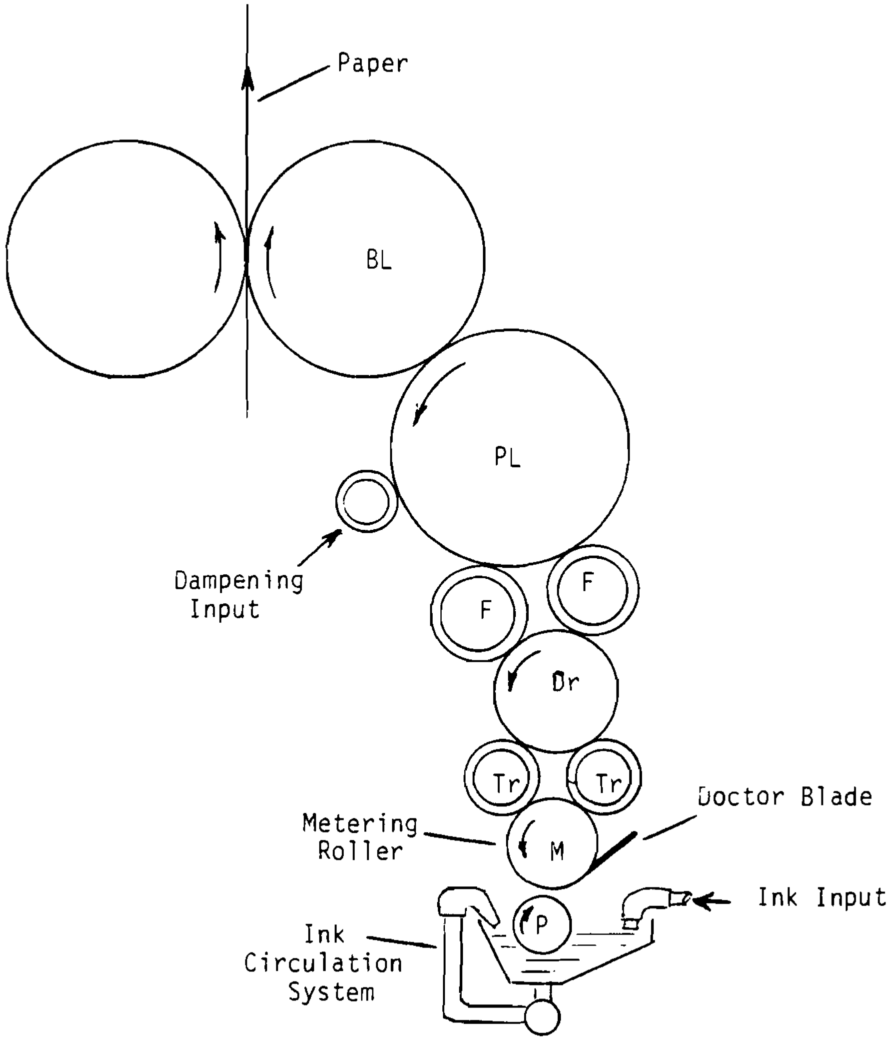


FIGURE 2. TYPICAL LONG-TRAIN, WATER-FIRST KEYLESS LITHOGRAPHIC PRESS CONFIGURATION

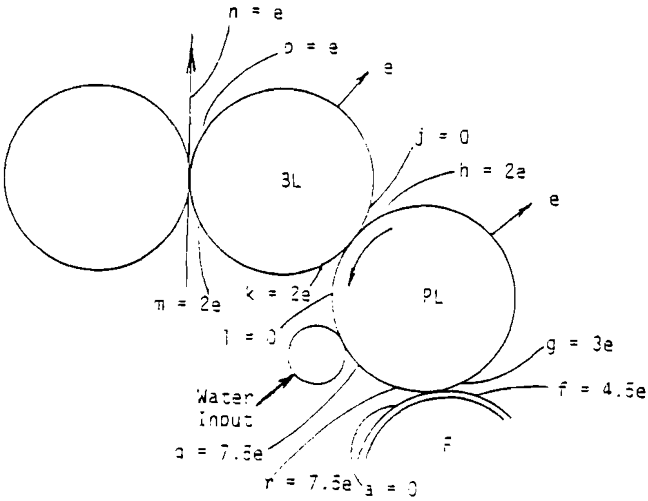


FIGURE 3. MODEL OF WATER PATHS IN PRINTING CYLINDERS AND PAPER PORTIONS OF FIGURE 2 CONFIGURATION

The rate, w, at which water is scraped off along with the return ink film by the doctor blade operating on the metering roller is not counted as a water loss factor because it is in fact not a loss of water. The scraped-off printing fluid (ink plus water) is continuously reused by means of the ink input recirculation system. Consequently, there is no net water loss associated with the scraped-off return ink.* This fact renders this modeling approach applicable to lithography independent of keylessness.

LOSSES FROM THE PAPER/PRINTING CYLINDERS PATH - One of the lithographic press nip locations at which net water flow rate involves two directions,

*In any keyless lithographic system that allows water loss due to ink handling during scraping and recirculation or as a purposeful design feature, the required just-above-scum water input to the plate must necessarily be greater than in the absence of this extra loss. Ink/water balance latitude accordingly narrows. Lithography becomes more difficult.

rather than one, is at the plate-cylinder/form-roller nip exit, f and g of Figure 3. Rule 1 states that the net water flow rates towards each of the loss paths are dictated solely by the cumulative subsequent water loss rates in the two directions.

The maximum rate at which water can be conveyed to the paper substrate at minimum acceptable dampening input according to Rule 3 is the same as evaporation from one-half of a large cylinder. Consequently, on Figure 3, $n = e$.

The rate of water flow, p, to the blanket from the blanket/paper nip also equals e, since that amount of water can evaporate from the return side of the blanket each half revolution of the press. Since there can be no net water flow from the blanket towards the plate, $j = 0$. The nip exit water flow rate values n and p establish the water flow required to the blanket surface prior to the paper nip as $m = 2e$. There is no evaporation of water from the cylinders in the arch of this press, Rule 5. Consequently, the plate/blanket nip exit water path rates are $k = 2e$ and $l = 0$.

To allow for $l + k = 2e$ at the plate/blanket nip exit, with $j = 0$, mass balance establishes the net water flow to that nip at $h = 2e$.

Water can evaporate from the aisle side of the plate cylinder surface, so the water path flow rate to the printing plate just after the form roller nip is $g = 3e$.

Adding the water losses from the inker and paper paths for the Rule 6 simplified version of the Figure 2 press configuration establishes the required total net water input flow rate to the plate/dampener-form nip as $r = g + f = 3e + 4.5e = 7.5e$. With Rule 5, the dampener input requirement q is also 7.5e.

IMPLICATIONS, HIDDEN AND REQUIRED - This model for this configuration predicts that 50% more water goes towards the inker path than towards the paper path, 4.5e versus 3e. This result may be expected because of more evaporative surface area in the inker. However, it also implies that if the ink did not need to take on water for lithography to be practical, less water would need to be input to the form/plate nips to interfere with ink input. The model predicts that only 13% (100e/7.5e) of the input water finds its way to the paper.

It is of utmost importance that an efficient dampening system be used, defined by the absence of liquid water misting off of press components and by absence of liquid water being input to the inked regions as a separate phase. The misting condition is characteristic of commercial dampeners which attempt to force the water to the plate with as few roller components as possible. This liquid water phase restriction corresponds to absence of free water (water not in the ink) anywhere in the press system except in the plate non-image areas. These implications reflect the statements used in the model assumptions; the water input rate is no greater than that lithographically required to maintain the just-above-scum quantity of free water in the plate non-image areas.

The press must be operated at the minimal water input rate corresponding only to "lithographically-clean" non-image areas. All dampener water input increases that may be required to make up for poor press roller settings or to make up for ink that mists from press components onto the plate, or increased dampener input to make up for toning of ink due to poor choice of ink/damping solution combinations are disallowed in this treatment. All of these correspond to using excess water input as a crutch to obviate less than optimal printing practices and have little to do with the inherent nature of lithographic image differentiation.

WATER LOSSES FROM A WATER-FIRST, SHORT TRAIN KEYLESS LITHOGRAPHIC PRESS

Using similar reasoning as in the previous section, the Figure 4 inker configuration was analyzed. Details are given in Appendix I.

The total water input requirement at q' is 5.5e, which value is only 73% that of its Figure 2 long inking train counterpart.

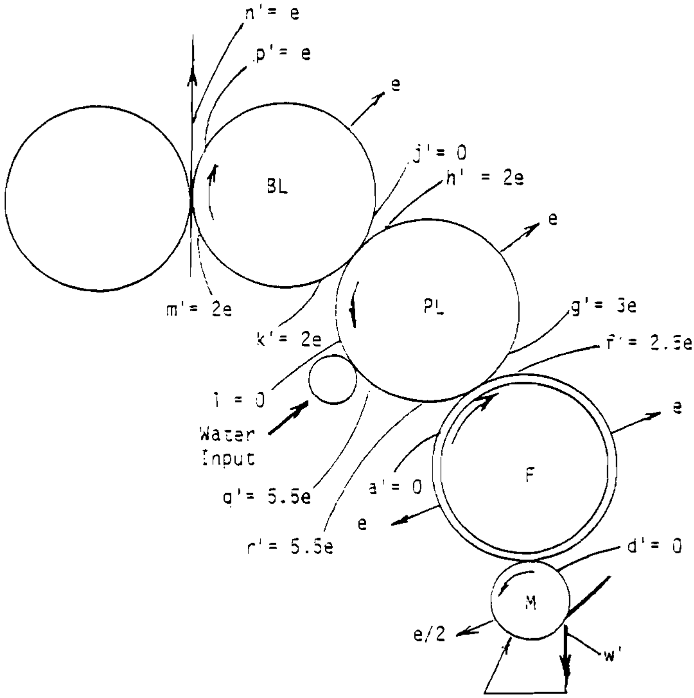


FIGURE 4. MODEL OF WATER PATHS FOR GENERIC SHORT-INK-TRAIN, WATER-FIRST KEYLESS CONFIGURATION

The dampening water flow requirement to the paper path, g' = 3e, is identical to that for the long train counterpart, as it should be, but here net water flow towards the inker, f', is lower than that towards the paper, 2.5e versus 3e. Consequently, this modeling approach predicts that a press with a short inking train will be lithographically less troublesome than a long train inker press in conveying the input water to the plate.

One inference from this result is that less ink/water interaction problems should be encountered when operating a short inking train keyless inker. In practice the opposite has been observed with all of the keyless product candidates from among five world-wide entrants into the field. This dichotomy is considered in a subsequent section.

WATER LOSSES FROM AN INK-TRAIN-DAMPENING KEYLESS LITHOGRAPHIC PRESS

The Figure 5 press configuration corresponds to a modestly successful keyless lithographic press product marketed in Japan. It also corresponds schematically to a conventionally inked lithographic press that has been widely marketed to newspaper publishers by Rockwell Graphic Systems. Analysis is detailed in Appendix II. The total water requirement for this long ink train configuration version is 9.5e, higher than either the Figure 2 or Figure 4 configurations. In this case, water evaporation in the arch area is allowed because the dampener is located on

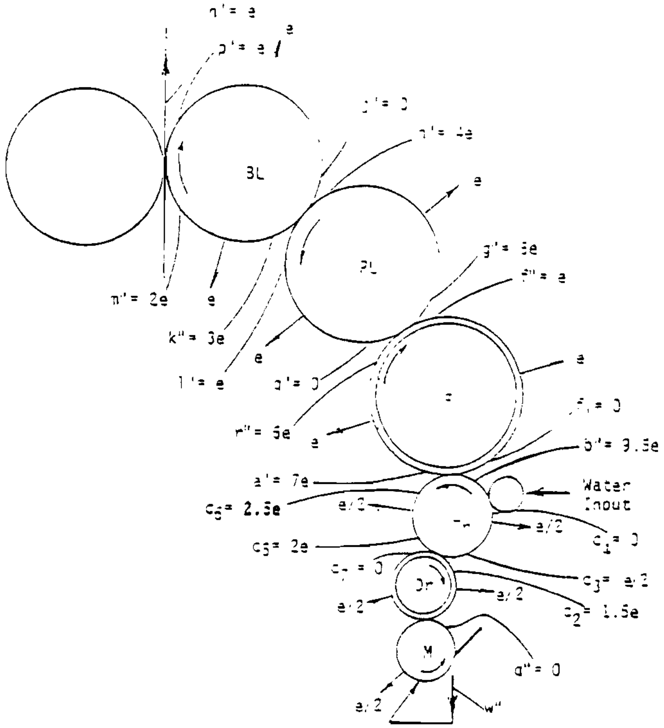


FIGURE 5. MODEL OF WATER PATHS FOR GENERIC INK-TRAIN-DAMPENING KEYLESS CONFIGURATION

the outside, aisle side, of the press. This press feature accounts for the 9.5e value versus the 7.5e value for the Figure 2 water-first configuration. For this reason, water interference with ink transfer is predictably more of a problem with configuration. Field experience with conventional (keyed) inking systems that use conventional dampeners tend to bear out this prediction. However, it must be noted that this configuration either as a keyed or keyless press has been a successful product.

WATER LOSSES FROM WATER-LAST, LONG-TRAIN KEYLESS LITHOGRAPHIC PRESS

This not-often-practiced Figure 6 configuration requires the same water input rate as the

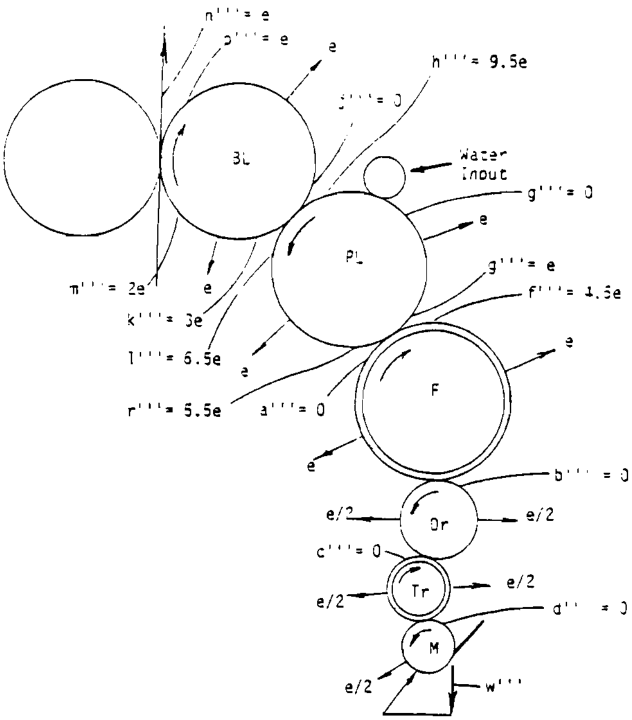


FIGURE 6. MODEL OF WATER PATHS FOR GENERIC LONG-INK-TRAIN, WATER-LAST KEYLESS CONFIGURATION

ink-train dampening configuration of Figure 5, 9.5e (Appendix III). However, water flow to the plate/form-roller nip is less, 5.5e versus 6e for ink-train-dampening, less than the 7.5e value for long-ink-train water-first dampening, and equal to that for the Figure 4 short-train inker. The inference from these water input rate predictions is that water-last dampening should perform better than or equal to these other three more configurations. This performance result has previously been reported (5). However, when using conventional dampeners, water-last dampening is a well-known failure mode. This apparent anomoly will be addressed in part in a subsequent section and resolved in the second paper of this set.

WATER LOSSES FROM A WATER-LAST, SHORT-TRAIN KEYLESS LITHOGRAPHIC PRESS

Based on the preceding analyses, the press configuration requiring least net water flow to the plate/inking-form nip should be water-last with a short inking train. The corresponding Figure 7 configuration, analyzed in Appendix IV, requires water input of 7.5e, the same as for the long train configurations of Figure 2 and Figure 6 but the water rate going to the critical plate/form nip is only 3.5e, which is the smallest value of the five configurations. The least amount of adverse water/ink interaction at that lithographic differentiation nip is expected for this configuration.

During development of materials for celled metering roller keyless lithographic presses (6), hundreds of press tests using this configuration were run over a period of about seven years (1). Its smooth operation and good printed results could be used as the high quality printing standard.

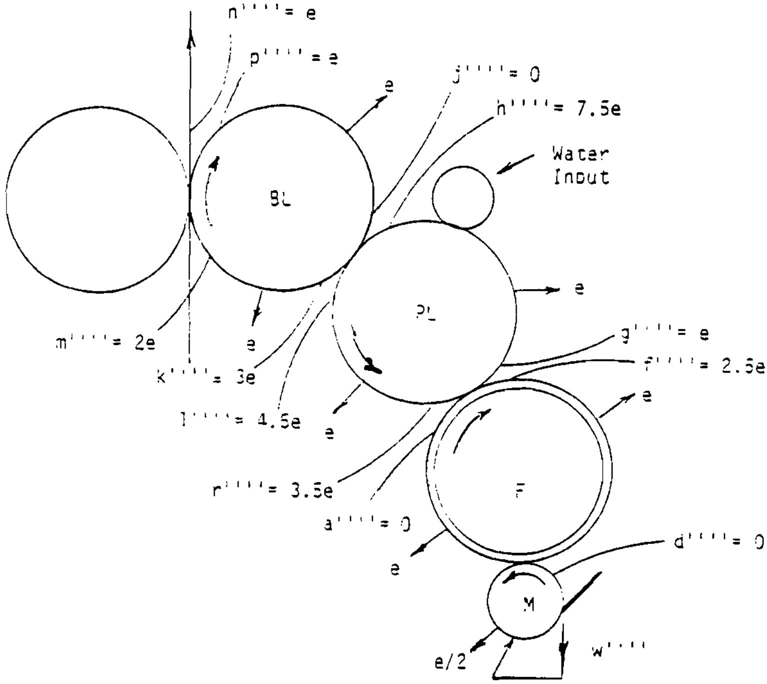


FIGURE 7. MODEL OF WATER PATHS FOR GENERIC SHORT-INK-TRAIN, WATER-LAST KEYLESS CONFIGURATION

COMPARISON OF PRINTING EXPERIENCE WITH MODEL PREDICTIONS

Table I summarizes the predictive modeling results for the five different press configurations considered here. The corresponding predicted relative extents of water interference are ranked for three generic press locations in Columns 5, 7 and 9 of Table I. These ranks involve the minimum required water input rates to the press, the required continuous water input rates to the lithographically important plate/form roller nip, and the required continuous water output rates toward the paper at the plate/blanket nip.

TABLE I. WATER PATH MODEL PREDICTIONS OF LITHOGRAPHIC PERFORMANCE

Configuration Diagram Figure	Inker Type	Dampener Location	Calculated Required Water Input		Calculated Water Input Rate to Plate/Form Nip		Calculated Water Input Rate to Plate/Blanket Nip		Sum Rank of Least Overall Water Interference*
			Value	Rank	Value	Rank	Value	Rank	
1,2,3	Long	WF	7.5e	2	7.5e	4	2e	1	3
4	Short	WF	5.5e	1	5.5e	2	2e	1	1
5	Long	ITD	9.5e	3	6.0e	3	4e	2	4
6	Long	WL	9.5e	3	5.5e	2	9.5e	4	5
7	Short	WL	7.5e	2	3.5e	1	7.5e	3	2

Rank of sums of Columns 5,7 and 9. Smallest value is least interference.

In Column 10 of Table I are listed the sum ranks of the Columns 5, 7 and 9 ranks. These rank results infer that the least water interference problems with the printing process will be achieved using short-train inkers, ranking first and second of the five alternatives. Fewer rollers should provide less surface area for continuous evaporative loss of water. Accordingly, less water needs to be input to make up for these losses. Lower water input rate means fewer and less severe water-interference printing problems.

The Table I values do not provide clear distinction among water-last (WL), water-first (WF) and "ink-train dampening" (ITD) modes. One of the water-last configurations ranked second best, the other ranked last.

The sum ranks of the predicted extents of relative water interference problems for the five configurations of Table I are listed in Table II together with the previously reported printing process acceptability of the corresponding practical configurations (1). Despite the inherent appeal of this simple but rigorous evaporative path model for the fate of dampening water, the predicted values seem to have no correspondence with the results from exhaustive controlled printing tests using these configurations (1, 5).

One obvious conclusion is that the model is incomplete or wrong, although subsequent analysis by the author has precluded this alternative. Since comparisons with lithographic models have been relatively unsuccessful in the past (8,9,10), perhaps previous researchers accepted no-correspondence conclusions prematurely. The lack of proven correlation between a theoretical model and actual process experience for over one hundred years is the primary reason that we do not yet have a unifying ink/water materials interaction lithographic model to utilize for optimizing process control.

TABLE II. INITIAL COMPARISON OF PREDICTED WITH ACTUAL PRINTING PERFORMANCE

Configuration Figures	Inker Type	Dampener Location	Sum Rank of Least Overall Water Interference[a]	Observed Printing Acceptability[b] Location	Value
1,2,3	Long	WF	3	Lab	G-E
				Field[c]	G-E
				Field[d]	P-F
4	Short	WF	1	Lab	G
				Field[e]	P/Failure
5	Long	ITD	4	Lab	F
				Field[f]	F-G
6	Long	WL	5	Lab	G-E
				Field[g]	E
7	Short	WL	2	Lab[h]	G-E
				Lab[h]	Failure

a. From Table I.
b. From References 1,3,5 and trade reports.
c,d. Same inker type, different candidates.
e. Several competitive test sites.
f. Several sites.
g. Recently introduced Rockwell product.
h. Same inker type, differing candidates.

IMPORTANCE OF DAMPENER LOCATION IN LITHOGRAPHIC PREDICTABILITY

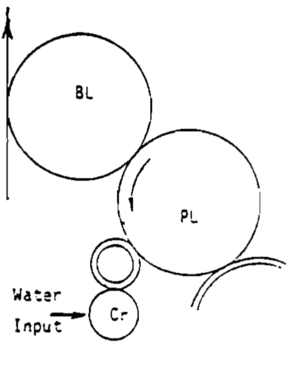
Figure 8 illustrates appropriate location details of the water-first, water-last and "ink train" dampeners for the configurations tested in the laboratory and the field (1,3,5). In Figure 8, all rollers not indicated as copper (Cu) or chrome (Cr) are rubber covered and therefore oleophilic and hydrophobic. The Figure 8 dampener location factors are compared with the qualitative press test results in Table III.

TABLE III. EFFECT OF DAMPENER LOCATION ON KEYLESS LITHOGRAPHIC PRINTING ACCEPTABILITY

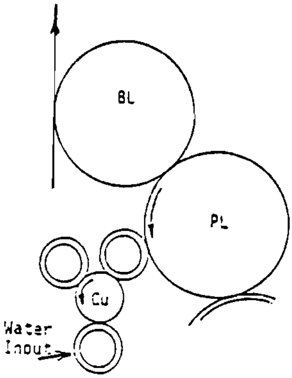
Inker Configuration	Test Location[a]	Dampener Figure No. and Location	Test Result[b]
Figure 1	Lab	8B; WF,Inked[h]	G-E
Figure 1	Field[c]	8B; WF,Inked[h]	G-E
Figure 1	Field[d]	8A; WF,Conventional	P-F
Figure 4	Lab	8B; WF,Inked[h]	G
Figure 4	Field[e]	8A; WF,Conventional	P
Figure 5	Lab	8E; ITD	F
Figure 5	Field[f]	8E; ITD	F-G
Figure 6	Lab	8D; WL,Inked[h]	G-E
Figure 6	Field[g]	8D; WL,Inked[h]	E
Figure 7	Lab	8D; WL,Inked[h]	G-E
Figure 7	Lab	8C; WL,Conventional	Failure

a. Superscripts b through f refer to Table II footnotes.
g. E = Excellent, G = Good, F = Fair, P = Poor
h. Refers to conveying water to the press with multiple rubber rollers capable of carrying ink.

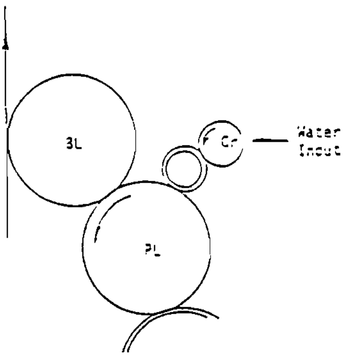
All dampening systems in our industry consist of two major elements, 1) an initial water input means such as spray bar, sock, or its equivalent, misting device or spiral brush, and 2) a set of rollers that receives the water input and conveys it to the printing plate. The only necessary function of the initial water input system is placement of a uniform water volume on the first or second roller of the conveyance system.



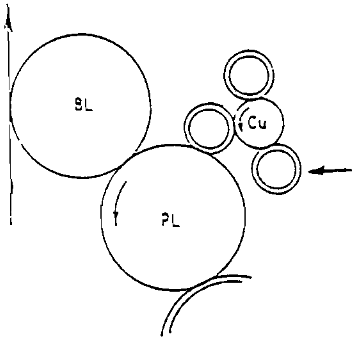
8A. Conventional, Water-First



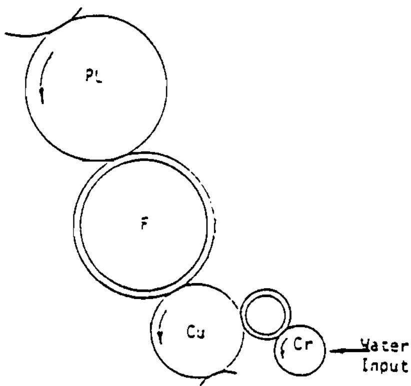
8B. Inked, Water-First



8C. Conventional, Water-Last



8D. Inked, Water-Last



8E. Ink-Train Dampening

FIGURE 8. DAMPENING ROLLER CONVEYANCE SYSTEMS FOR KEYLESS PRINTING TESTS

Doing so does not and cannot assure efficient lithographic dampening, as verified by comparing print test results for Figure 8D versus Figure 8C, and Figures 8A versus 8B configurations in Table III. It is apparent then that each of the dampener locations utilized, WF, WL or ITD, can result in acceptable to excellent printing performance but not necessarily. Thus, dampener location cannot be considered an overwhelming factor in lithographic printing performance.

CONFIGURATIONAL IMPORTANCE OF DAMPENER IN LITHOGRAPHIC PREDICTABILITY

The configurational differences of the dampeners' water conveyance roller portions in Figure 8 are compared in Table IV with the overall qualitative press performance acceptability of Tables II and III. Included are the water-path model predictive ranks. The only significant difference allowing good press performance is the number of oleophilic rollers between the printing plate and a chrome roller or a gap in the dampener's water conveyance roller set. Whenever at least three oleophilic rollers were used in this manner, keyless configurational acceptance was high. None of

TABLE IV. EFFECT OF OLEOPHILIC DAMPENER ROLLERS ON KEYLESS PRINTING PERFORMANCE

Press Configuration Figure	Dampener Configuration	No. of Oleophilic Rollers for Water Transfer to Plate	Printing Test Results	Water Flow Model Rank[a]
1,4	8B, WF, Inked	3+	G-E	1,3
1,4	8A, WF, Conventional	1	P-F	<5
5	8E, ITD	3+	G	4
6,7	8D, WL, Inked	3+	G-E	2,5
7	8C, WL, Conventional	1	Failure	<<5

a. *From Table I, Column 10 and field tests.*

the conventional two-or three-roller dampeners containing a chrome roller are acceptable regardless where placed (WR or WL) either in the author's experience or in several press companys' field experience with keyless press product candidates. Reasons for this result were speculated upon previously (5,7) and will be considered more fully in the second paper of this series.

Most notable relative to the water-path model is that none of the conventionally-dampened configurations could be modeled. These types could not be controllably run. Materials use could not be meaningfully measured. Consequently, there is a strong correlation between the efficient input of dampening water by means of oleophilic rollers (1,5) and the potential for modeling lithographic systems.

On the negative side, there remains a disturbing lack of correlation between the printing performance ranks and the model ranks for configurations that could be run, Column 3 versus Column 5 of Table IV. Further examination by the author has shown that excellent correlation does exist. These quantitative factors are presented and expanded in the second paper of this series.

CONCLUSIONS

Lithographic systems can be analyzed relative to the degree of expected water-related problems by means of simple water flow-rate modeling provided that dampener configurational specifics are taken into account. Correlation of the capability to predict relative required water use rates and the attendant problems for differing configurations with experimentally derived printing values is possible only when 1) the press is run at the just-above-scum dampening condition, and 2) an efficient dampening system is used that introduces no free water into the press system.

Virtually all conventional dampening systems are grossly unable to convey minimum lithographically quantities of water to the plate in useful form. A set of at least three or four oleophilic dampening water conveyance rollers is required between the plate and the water input system or between the plate and the last hydrophilic roller. Not only can meaningful comparisons then be made but optimal lithographic printing performance is then possible.

Congruence of the qualitative results presented here with the previous reports by the author on ink/water interactions is excellent (2,4,5,7). Mulling of the dampening water into the ink is a necessity for highest lithographic efficiency. These collective findings explain why the graphic arts industry has to date been confounded in its attempts to establish definitive and unifying explanations of ink/water interactions during lithographic printing.

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APPENDIX I. WATER PATH FLOW RATE VALUE ANALYSIS FOR SHORT-INKING-TRAIN, WATER-FIRST KEYLESS CONFIGURATION OF FIGURE 4.

a' = 0	There is no net water input from form to plate.
d' = 0	There is no net water input from the metering roller to the form roller.
f' = 2.5e	This is the sum of evaporation from the inker rollers, 2e + e/2.
n' = p' = e	Minimal net rates to paper and blanket at their nip exit are e.
j' = 0	There is no net water input from blanket to plate.
m' = 2e	Required to obtain n' + p' = 2e.
k' = 2e	No net evaporation from blanket in the arch.
l' = 0	No net water input from plate to dampener form roller.
h' = 2e	Required to meet k' = 2e.
g' = 3e	Required to meet evaporation of e and h' = 2e.
r' = 5.5e	Required to supply g' + f' = 3e + 2.5e.
q' = 5.5e	Dampener input requirement.

APPENDIX II. WATER PATH FLOW RATE VALUE ANALYSIS FOR INK-TRAIN-DAMPENING KEYLESS LITHOGRAPHIC PRESS OF FIGURE 5.

c" = 0	No net water input from inking drum to transfer roller.
d" = 0	No net water input from metering roller to inking drum.
C_2 = 1.5e	Rate requirement at C_2 to allow evaporation from inker rollers is 3 x e/2.
C_3 = e/2	Required to meet subsequent evaporation from transfer roller.
C_7 = C_4 = 0	No net return of water towards dampener form.
C_5 = 2e	Required rate to meet C_2 + C_3 = 1.5e + e/2.
C_6 = 2.5e	Required to meet evaporation of e/2 plus C_5 = 2e.
n" = p" = e	Minimal evaporative requirement at just-above-scum steady-state.

j" = 0	No net return of water from blanket to plate.
m" = 2e	To meet n" + p" = 2e criterion.
h" = 4e	To meet l" + k" = 3e + e.
l" = e	To accommodate evaporation from plate roller in the press arch.
q" = 0	No net input of water from plate to form.
g" = 5e	Required to meet plate evaporation e plus h" = 4e.
f" = e	To account for evaporative loss from the form roller return side.
f_1 = 0	There is no net water input from inking form roller towards the inking drum and dampener.
r" = 6e	To meet the g" + f" criterion = 5e + e.
a" = 7e	To allow evaporation of e plus meet r" = 6e criteria.
b" = 9.5e	Dampener input requirement to meet water input requirements for the two paths a" and C_6 (7e plus 2.5e).

APPENDIX III. WATER PATH FLOW RATE VALUE ANALYSIS FOR LONG-INKING-TRAIN, WATER-LAST KEYLESS CONFIGURATION OF FIGURE 6.

a''' = 0)	
b''' = 0)	There is no net water input from inker rollers towards the plate.
c''' = 0)	
d''' = 0)	
f''' = 4.5e	The total water evaporation from the inker roller surfaces is (2 x e) + (5 x e/2).
g_1''' = 0	There can be no net water input from the plate to the dampener form roller.
g''' = e	To account for subsequent evaporation e from the plate roller surface.
r''' = 5.5e	To provide 4.5e plus e to the evaporative paths g''' and f'''.
l''' = 6.5e	To account for evaporation + r''' = 5.5e.
j''' = 0	No net water input from blanket to plate.
p''' = e	To account for subsequent evaporation from blanket.
n''' = e	To account for water transfer to paper.
m''' = 2e	Accounts for p''' + n''' = 2e.
k''' = 3e	Evaporation of e from blanket + m''' = 2e.
h''' = 9.5e	Total required dampener input rate is l''' + k''' = 6.5e + 3e.

APPENDIX IV. WATER PATH FLOW RATE VALUE ANALYSIS FOR SHORT-INKING-TRAIN, WATER-LAST KEYLESS CONFIGURATION OF FIGURE 7.

d'''' = 0)	There is no net water input from inker rollers to the plate.
a'''' = 0)	
h'''' = 3.5e	This is the sum of evaporation rates from the form and metering rollers.
f'''' = 2.5e	To account for inker evaporation of 2 x e + e/2.
g'''' = e	To allow evaporation of e from plate and there can be no net water flow from the inker towards the dampener .
r'''' = 3.5e	Mass balance at plate/form nip.
l'''' = 4.5e	Plate roller evaporation plus the r'''' requirement, e + 3.5e.
k'''' = 3e	Same as for all these systems.
j'''' = 0	There can be no net flow of water input from blanket to plate.
h'''' = 7.5e	Required dampener input is the sum of k'''' + l'''' = 3e + 4.5e.