TRANSFER AND SETTING OF WATER-BASED INK, PART I: A new flexographic proof press

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Abstract: A single-sheet proof press for printing paper samples by water-based flexography has been developed. The repeatability of measurements from the press are within accepted limits for other proof presses. Print densities from this press are in good agreement with data from a laboratory web press.

The increase in flexo print density with ink transfer to paper is explained by the same exponential model used for oil-based inks. The increase in print density with increasing halftone dot coverage correlated with the print density of the corresponding solid prints, suggesting that the same paper factors control solid density and halftone density. This may be related to the concentration of fine paper fibres in the sheet surface.

Introduction

Water-based flexography is now an accepted process for printing on newsprint. About 5% of North American newsprint consumption (both newspapers and commercial printing) is printed by flexography. Considerable work has already been done at Paprican (Aspler, 1987; Aspler and Perreault, 1988; Aspler, 1988; Aspler et al., 1989; Aspler and Taylor, 1991; Boluk and Aspler, 1991) on newsprint requirements for water-based flexography. Interest also exists in using water-based flexography to print higher quality grades of paper

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(particularly supercalendered, uncoated paper). In a related area, for environmental reasons, gravure printers may be forced to replace their current solvent-based inks with inks that are similar to water-based flexo inks.

Just as water-based inks are incompatible with existing pressroom equipment designed for oil-based inks, they are also incompatible with proof presses which require only one or two sheets of paper to predict print quality using oil-based inks. The only existing single-sheet flexo proof presses are large units, used to make printers' proofs at slow speed, without the ability to make setoff measurements. A flexo accessory -- also without the option for setoff measurements -- was also recently introduced for one model of the IGT printability tester (Wester, 1988).

The absence of a suitable single sheet flexo press has confined both research and testing to web presses. Since laboratory-prepared handsheets could not be printed, the range of paper properties that could be studied was limited. For this reason, we have developed a proof press that can print single sheets with water-based flexo inks.

In this report, we describe the design and operation of this press. In Part II (Aspler et al., 1992), we describe the influence of pH, paper structure, and water absorbency on ink transfer to uncoated paper.

Experimental

Design of the press

The press is illustrated in Figure 1, and a schematic diagram is shown in Figure 2. The press consists of an engraved anilox inking cylinder, doctor blade assembly, plate cylinder, impression cylinder, and setoff cylinder. The press is microprocessor-controlled, allowing for variable ink distribution times, and variable delays between inking, printing, and setoff.

Inking system

The engraved anilox cylinder carries ink from the ink supply to the plate, without the long train of inking rollers found in conventional offset and letterpress units. Since the only practical way to vary the inking level in a flexo press is to vary the engraving of the anilox cylinder, eight different engravings were prepared, across a wide range of ink levels. The cylinders were fabricated at

TABLE I

Characteristics of anilox cylinders
Increasing ink transfer levels to newsprint

Cylinder engraving, lines/inch	Cell depth µm	Ink capacity, (theoretical), g/m²	Ink transfer g/m²	Print density (PD)	Print through (PT)
300 Q	20	6.98	2.38	0.776	0.043
360 P	20	7.88	1.83	0.708	0.039
400 P	12	4.34	1.66	0.676	0.039
5-banded cylinder					
165 Q	42	14.6	6.52	0.947	0.086
180 Q	36	12.0	4.75	0.909	0.068
200 Q	30	10.5	2.64	0.801	0.049
360 Q	29	9.60	1.99	0.699	0.044
250 P	20	5.11	1.80	0.699	0.044

P: inverted pyramid
Q: inverted, truncated pyramid

Paprican. Engraving and chrome plating were done by Neo Industries, Brampton, Ontario. Characteristics of our anilox cylinders are shown in Table I.

The amount of ink carried by the anilox cylinder to the plate depends on the number of cells per unit area and on the cell shape and depth. The most common cell shapes are the inverted pyramid and the truncated, inverted pyramid. The truncated inverted pyramid is particularly effective, since a flat-bottomed cell empties more completely (IFRA Special Report, 1987). Since the most common screen ruling for newspapers is 360 lines per inch, this ruling was also chosen for routine work on our press.

The ink is held in a pond behind a doctor blade, as shown in Figure 2. As this doctor blade did not provide a sufficient amount of doctoring (resulting in an ink film that was uneven and too thick) a second, reverse angle doctor blade was installed.

<u>Plate and impression cylinders</u>

The impression cylinder (Figure 2) is fixed. Other cylinders (anilox, plate, and setoff) are brought into contact pneumatically. The pneumatic load is applied at both ends of the cylinders to maintain a symmetric nip load. Printing pressure was kept at the minimum pressure required to give uniform printing: about 2.5 MPa between the plate and the paper, as measured by Fuji pressure-sensitive film.

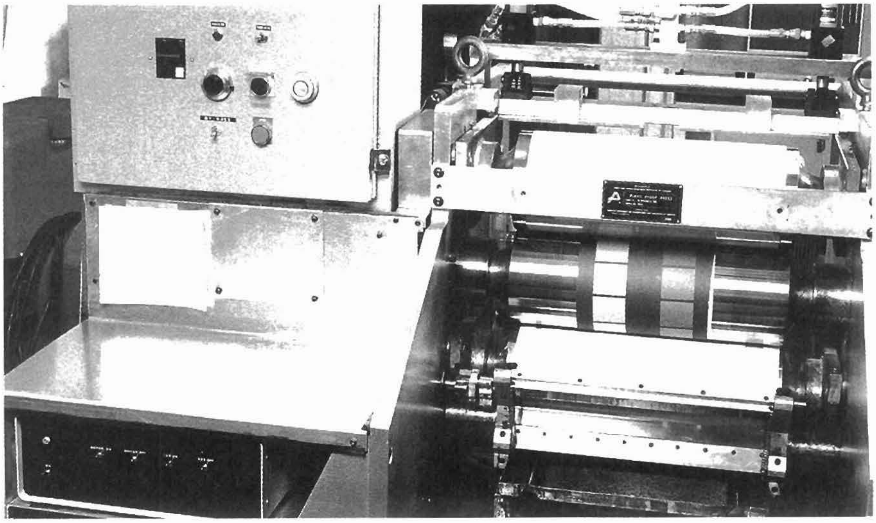

Figure 1 Single sheet flexo proof press.

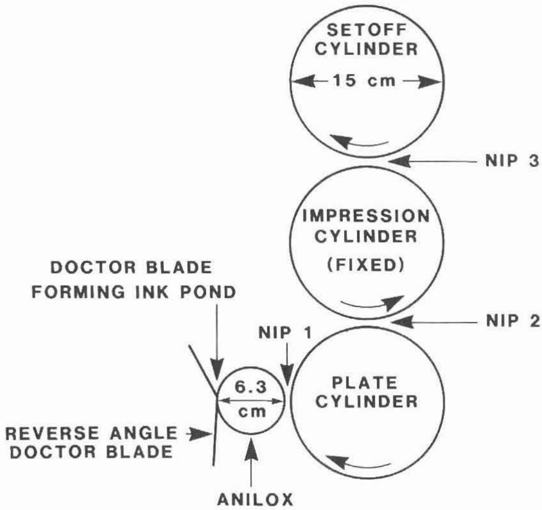

Figure 2 Schematic diagram of single sheet proof press.

<u>Plates and underpadding</u>

A compressible adhesive underpadding from Goodyear Tire & Rubber Company with a thickness of 1 mm (0.040") is attached to the plate cylinder. Photopolymer flexo plates from Hercules Inc. are then attached to the underpadding. The flexible backing of these plates allows them to be glued to the small-diameter (15 cm) plate cylinder -- an arrangement that is not possible with stiffer metal-backed plates. It is particularly important to eliminate air bubbles under the plate and the blanket. In addition to a test plate containing only a solid, a test plate with a range of halftone values from 10% to 80% is also used.

Although the impression cylinder is about 47 cm in circumference, paper samples are kept to a maximum length of 25 cm, or about half the circumference. This is necessary to avoid double-inking the plate and double-printing the sample, as well as to avoid smudging of the ink at the impact and release of the printing nip.

Ink

A black, water-based, flexo newspaper ink from Flint Ink Corp. (formulation KZK075/5 containing 18% carbon black), diluted to a viscosity of 0.015 Pa·s (as measured on a Shell No. 3 cup viscometer) was used. The formulation and viscosity are both typical of current commercial inks. For quantitative ink transfer measurements, a portion of the ink was substituted by a similar ink, labelled with CdS, also supplied by Flint. The blended ink contained 4.88 mg of Cd per gram of ink. The amount of ink transferred to the paper was determined by analysis of the Cd content of the ashed prints, by atomic absorption spectroscopy. The final ink had a pH of about 8.5.

Newsprint samples

For the initial measurements, a single eastern Canadian newsprint (PPS S-10 roughness of 3.13 ± 0.12 μm) was used. This sample had previously been characterized in work with oil-based offset inks (sample 7 in Aspler et al., 1991). Results of ink transfer and repeatability studies are shown in Table II.

The effect of calendering to different levels, as well as that of accelerated aging, was also tested for a single newsprint. These samples had been previously printed in a trial on a web press (Aspler, 1988). The results of the printing experiments are compared in Table III.

Nineteen North American newsprints, representing the range of current production from eastern Canada, western

Canada, and the southern USA, were also printed. These papers have been described in detail previously (Aspler et al., 1991). Key physical properties are shown in Table IV.

Printing procedure

A press speed of 200 rpm (about 1.6 m/s) gives the best print quality. Slower speeds give poor ink distribution and poor print uniformity. Higher speeds cause the spattering, and also give non-uniform ink distribution.

Table II

Repeatability of Printing Experiments

	Print density	Print through	Setoff	Ink transfer, g/m^2
Day 1	0.708 ± 0.012	0.039 ± 0.001	0.048 ± 0.006	1.86 ± 0.07
Day 2	0.709 ± 0.007	0.042 ± 0.001	0.054 ± 0.007	1.78 ± 0.04
Day 3	0.699 ± 0.009	0.040 ± 0.001	0.048 ± 0.005	1.82 ± 0.05
Day 4	0.711 ± 0.012	0.039 ± 0.001		1.88 ± 0.05

Repeatability (from pooled standard deviations; at the 5% probability level)

Print density:	Print through:	Setoff:	Ink transfer:
0.007	0.001	0.004	0.07

Typically, one mL of ink forms the ink pond between the first doctor blade and the anilox cylinder. Once the ink is poured, the press cycle is initiated. A small timing bias is programmed into the operating sequence to correct for the lag time of the pneumatic system.

Prints without setoff

The paper sample is taped to the impression cylinder, and the ink is allowed to distribute on the anilox cylinder for about four revolutions of this cylinder (about 0.5 s). The pneumatic system then closes both nip 1 between the anilox cylinder and the plate (Figure 2) and nip 2 between the plate and the paper. Therefore, although the plate is continuously inked even as the paper is being printed, the position of the plate and the cycle selection both ensures that no part of the plate is double-inked, and no part of the paper is double-printed. After the print is made, the nips open and the press halts.

TABLE III

Test results from a single newsprint after different treatments*

Sample	Printing opacity, %	Print Surf roughness, S-10, μm	Web Flexo Press (Aspler, 1988)			Single Sheet Press		
			Print density	Print through	Second impression setoff	Print density	Print through	Setoff
A	96.93	5.51	0.736	0.019	0.252	0.715	0.018	0.030
B	96.52	3.40	0.753	0.021	0.236	0.725	0.027	0.030
C	96.68	3.92	0.744	0.021	0.273	0.713	0.020	0.029
D	96.66	4.96	0.727	0.020	0.301	0.715	0.023	0.031
E	97.05	4.56	0.735	0.021	0.314	0.707	0.018	0.030
F	97.15	4.25	0.741	0.022	0.286	0.711	0.019	0.032
G	96.93	4.43	0.743	0.020	0.247	0.707	0.021	0.030
H	97.03	5.05	0.743	0.020	0.206	0.718	0.020	0.028
I	96.82	5.91	0.694	0.019	0.275	0.669	0.018	0.034
J	97.26	5.60	0.710	0.018	0.314	0.673	0.018	0.031
K	96.93	5.72	0.716	0.019	0.272	0.687	0.021	0.031

*Sample treatments:

- A: Uncalendered newsprint
- B-F: Different calendering levels
- G: Accelerated aging (48 hours, 105°C)
- H: Application of water followed by accelerated aging
- I-K: Application of alum solutions followed by accelerated aging. Alum added (by dry weight): 200 ppm, 470 ppm, 780 ppm respectively

Table IV

Properties and test printing results -- 19 North American newsprints (Aspler et al., 1992)

Sample	Printing opacity, %	Roughness Print-Surf S-10, µm	Flexo PD	Flexo PT	Flexo SO	Halftone slope*	Cold extract pH	% Fines 0.1 mm smaller	Water Sorption A_{80}, g/m^2**
1	90.78	4.37	0.756	0.066	0.029	0.00928	6.10	30.88	31.8
2	94.00	3.78	0.749	0.042	0.025	0.00848	6.17	32.04	42.4
3	93.70	3.88	0.734	0.048	0.031	0.00859	6.20	31.75	40.4
4	94.16	4.05	0.752	0.038	0.032	0.00890	5.95	27.99	17.2
5	94.61	3.51	0.751	0.038	0.031	0.00884	5.87	27.01	19.4
6	95.56	2.97	0.732	0.034	0.030	0.00860	6.09	28.59	30.7
7	94.57	2.79	0.742	0.044	0.033	0.00866	6.26	26.90	24.7
8	94.64	3.35	0.714	0.044	0.033	0.00821	6.13	28.44	25.7
9	94.11	3.52	0.749	0.045	0.032	0.00867	6.35	26.66	13.6
10	94.42	3.34	0.758	0.037	0.032	0.00878	6.43	26.49	26.3
11	93.87	3.41	0.746	0.039	0.031	0.00870	6.30	25.98	38.0
12	95.17	3.76	0.732	0.036	0.030	0.00858	6.14	26.86	27.1
13	95.95	3.09	0.719	0.029	0.025	0.00848	5.55	25.36	10.3
14	95.29	4.20	0.742	0.036	0.025	0.00861	5.23	35.21	23.8
15	94.99	3.54	0.748	0.038	0.030	0.00877	4.92	34.11	22.6
16	92.37	3.47	0.759	0.049	0.026	0.00896	4.62	36.29	19.7
17	93.46	3.84	0.732	0.047	0.028	0.00854	4.50	35.93	24.8
18	95.25	4.03	0.731	0.034	0.027	0.00842	5.27	37.24	30.3
19	93.81	3.74	0.761	0.048	0.023	0.00892	5.29	38.91	21.1

* Increase in halftone print density with increasing halftone dot coverage, at constant ink film thickness
** Water absorbency at 80 msec contact time, Paprican-Bristow sorption apparatus

Prints with setoff

Setoff experiments are started in the same way as the previous experiments. However, at 0.5 revolutions (about 0.15 s) after the start of printing (i.e., once the sample has been printed), the plate-paper nip 2 opens and the paper-setoff nip 3 simultaneously closes. The fresh print is run against the reference setoff paper (Kromekote cast-coated paper) for one revolution, after which all nips open and the press stops. The setoff nip pressure approximates that of the printing nip: about 2.5 MPa.

Optical measurements

Reflectances are measured on an Elrepho 2000 photometer using the FMY/C filter. Print density, print through, and setoff are calculated according to the SCAN standard (SCAN P36:77, 1976).

RESULTS AND DISCUSSION

Repeatability of printing experiments on newsprint

The repeatability of print density, print through, setoff, and ink transfer was calculated from measurements done on one newsprint, over a period of four days (Table II). The printing was done with the 360P anilox cylinder.

For print density and print through, the test results in Table II are defined as the mean of 30 reflectance measurements made on 10 prints for days 1 and 2, and as the mean of 15 readings made on 5 prints for days 3 and 4.

After the optical measurements were done, the same prints were analyzed for the amount of ink transferred. The mean is calculated from the results of 10 analyses for days 1 and 2, and from 5 analyses for days 3 and 4.

For setoff, the mean is calculated over 30 readings made on 10 prints. The test was repeated on three different days, for a total of 90 readings. Table II shows the mean and standard deviation for each testing day. The variation within a sheet is not presented.

For each day, print density, print through, setoff, and ink transfer results were subjected to one-way analysis of variance. This test demonstrated that the variance between sheets printed on any given day was no greater than the variance within a single print -- that is, there is no significant sheet-to-sheet variation on any given day.

Analysis of variance was also used to determine if the day-to-day variation is significant. At the 5% probability level, the day-to-day variance <u>is</u> significant. The print density data in Table II show that averages from three of the four days were close together, and the average value from the remaining day is lower.

We used the pooled standard deviations from all measurements to calculate the least significant difference among samples at the 5% probability level. This value is equivalent to the repeatability of the measurements as defined in the Tappi standards (Tappi T1206 rp-86, 1986).

For print density, the repeatability is 0.007. The repeatability of the print through is 0.001. The repeatability of the setoff measurements is 0.004, and the repeatability in the ink transfer measurements is 0.07 g/m^2.

Although the day-to-day variation is statistically significant, the differences are of no practical importance. A difference of 0.007 in print density is below what the average reader can resolve (Larsson, 1989), and is within the limits in density measurements for the standard that we normally use with oil-based inks (SCAN P35:72, 1972).

<u>Variation in setoff measurements</u>

The percent variation is greatest for the setoff measurements (approximately 10%). Since flexo ink sets much faster than common oil-based newsinks, setoff values for the water-based inks are much lower. This is in spite of the fact that the time (0.15 s) between printing and setoff at 200 rpm in our press is only half the time specified in the SCAN standard (Scan P36:77, 1976) for oil-based inks.

A single newsprint after different treatments: comparison with a web proof press

As described by Aspler (1988) and in Table III, a single newsprint was calendered to different smoothness levels, and was also treated to give different levels of water repellency. Figure 3 shows a good correlation (R^2 = 0.85) between the print densities of these samples obtained in the earlier laboratory web press study (Aspler, 1988) and the print densities obtained on the same newsprints on the single-sheet press. The systematically higher print density on prints from the web press was probably due to the different anilox cylinders. As with the prints made with these newsprints on the web press, the correlation between print density (single-sheet press) and Print-Surf roughness for these newsprints is good (R^2 = 0.81; Table III).

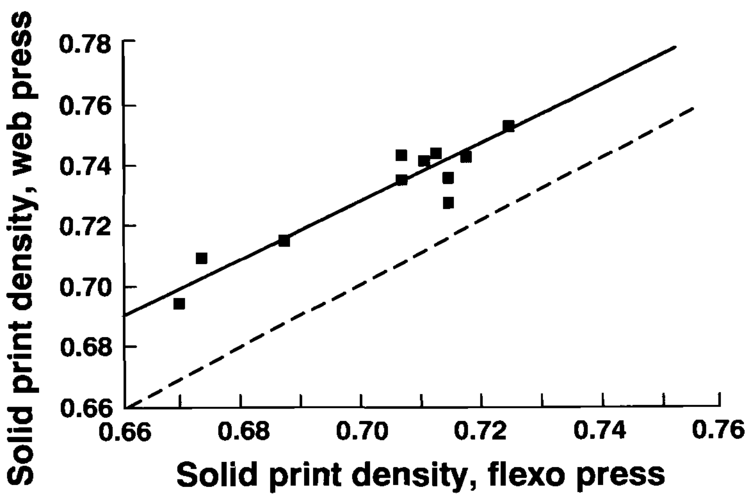

Figure 3 Print densities from Flint Ink web flexo press vs. print densities of the same newsprints printed on the single sheet press. Solid line: least squares fit. Dotted line: (45° line).

In Table III, there is no correlation between print through measured on the web press and on the single-sheet press. The opacity values are virtually identical. Since flexo print through depends only on sheet opacity, no correlation would be expected, as discussed in Part II.

In Table III, setoff values for the web-printed samples are much greater than for the single-sheet press. There is no correlation between the two. Setoff from the web samples were accumulated from 50 consecutive prints. While this method might be preferable, it is by definition not possible to do so on the single sheet press. Furthermore, in the single-sheet press, the setoff image is transferred at high pressure, while in the web press, the setoff image is transferred at much lower pressure.

Development of print density

Ink transfer data (Table I) were fitted to Equation 1 (Tollenaar and Ernst, 1961).:

$$PD = PD_{\infty}(1 - e^{-ky}) \quad (1)$$

In Equation 1, PD is print density; PD_∞ is the limiting PD at high ink level; y is the ink weight on the paper; and k is a constant related to the rate of coverage of the sheet by the ink. Table I and Figure 4 show print density as a function of the ink level on newsprint.

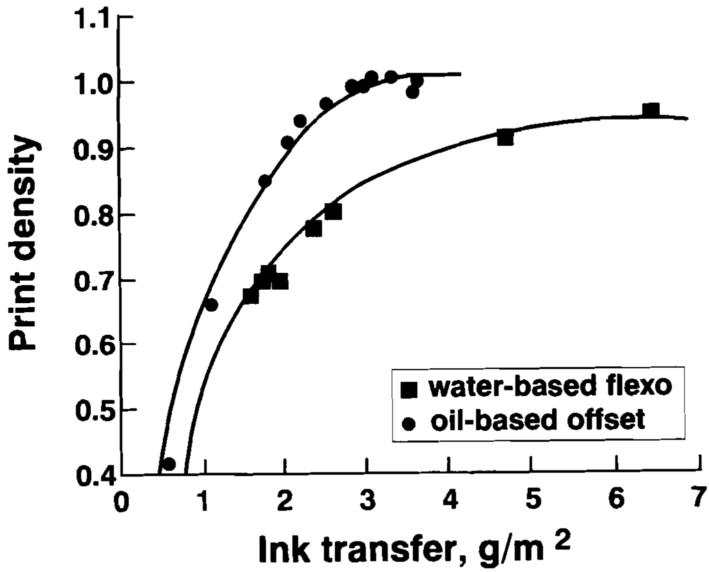

Figure 4 Newsprint PD as a function of ink transferred to the paper. Flexo ink: (■); Oil-based offset ink (●).

For the water-based ink, k = 0.736 and PD_∞ = 0.945. For an oil-based offset ink of much higher viscosity, but the same pigment content, k = 0.935 and PD_∞ = 1.03. That is, the high viscosity ink reached a higher density value, with less ink (Figure 4).

There have been attempts, (e.g. Schaeffer et al., 1963; Blom and Conner, 1990), to relate k and the limiting print density, PD_∞, to paper and ink properties, but they have not been completely successful, due to a lack of data across a wide range of inks and papers. Considering the much lower viscosity of the flexo ink, the lower PD_∞ may have resulted from greater penetration. However, as shown by the small difference between PD_∞ values, and as shown in Part II, penetration differences are not significant in the region of commercial ink film thicknesses (2 - 3 g/m^2).

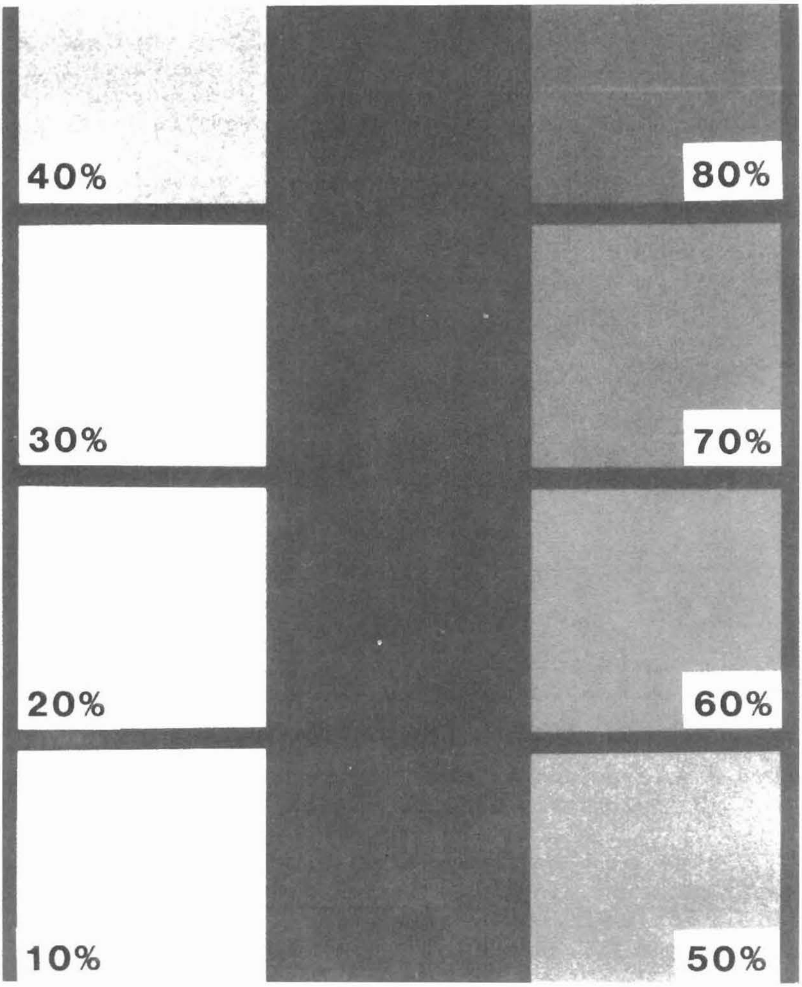

Figure 5 Halftone print. Nominal dot coverage of each area is shown.

Halftone measurements

Figure 5 shows a halftone print. Halftone density is expected to increase with the dot area. This is usually fitted to the Yule-Nielsen model (Viggiano, 1985):

$$D = -n \log[1 - A(1 - 10^{-\frac{K}{n}})] \qquad (2)$$

D is the print density of the halftone areas; A is the fraction of the surface covered by dots; K is the print density of the corresponding solid print, and n is a constant. A best fit value of n = 3.65 was obtained (R^2 = 0.96)*. In Figure 6, the calculated halftone densities are compared to the experimental values. This demonstrates that the press is printing halftones in a predictable fashion. Systematic deviations from the calculated line likely result from the fact that fractional coverage is estimated from dot size on the original plate, not from the prints themselves.

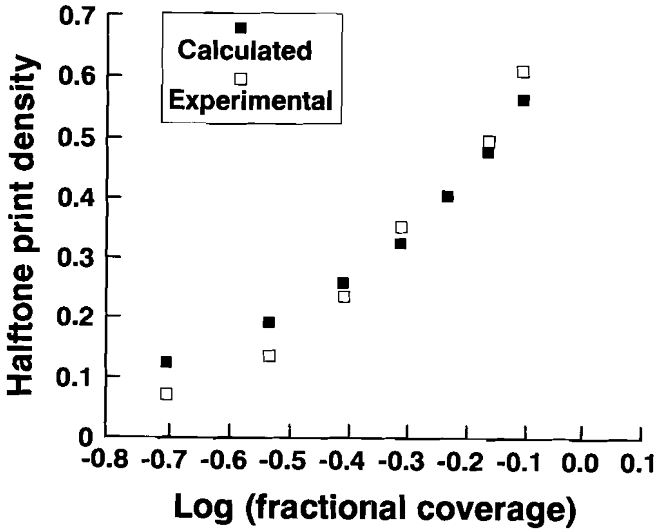

Figure 6 Experimental halftone print densities vs. print density values calculated from Equation 2.

If we plot halftone print density vs. the nominal area, a straight line is obtained. This is illustrated in Figure 7 for a single newsprint sample. Similar graphs are also obtained for each of the other 18 newsprints.

Equivalent results are obtained if, instead of nominal halftone areas, halftone areas calculated from the Murray-Davies equation (Huntsman, 1991) are used.

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* A value of about n = 1.7 is normally assumed (Viggiano, 1985). While our best fit value is much higher, the calculated print densities are quite insensitive to the value of n.

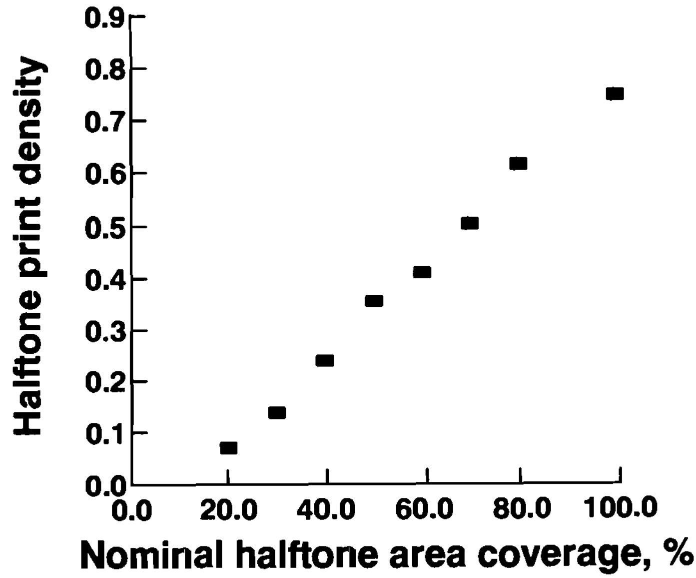

Figure 7 Increase in halftone print density with nominal halftone area coverage.

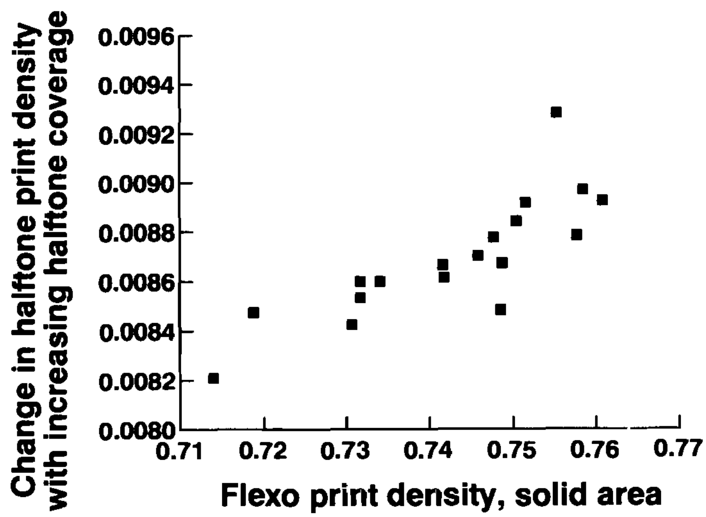

Figure 8 Rate in increase of halftone print density with increasing dot size, as a function of the solid print density, on 19 different newsprints.

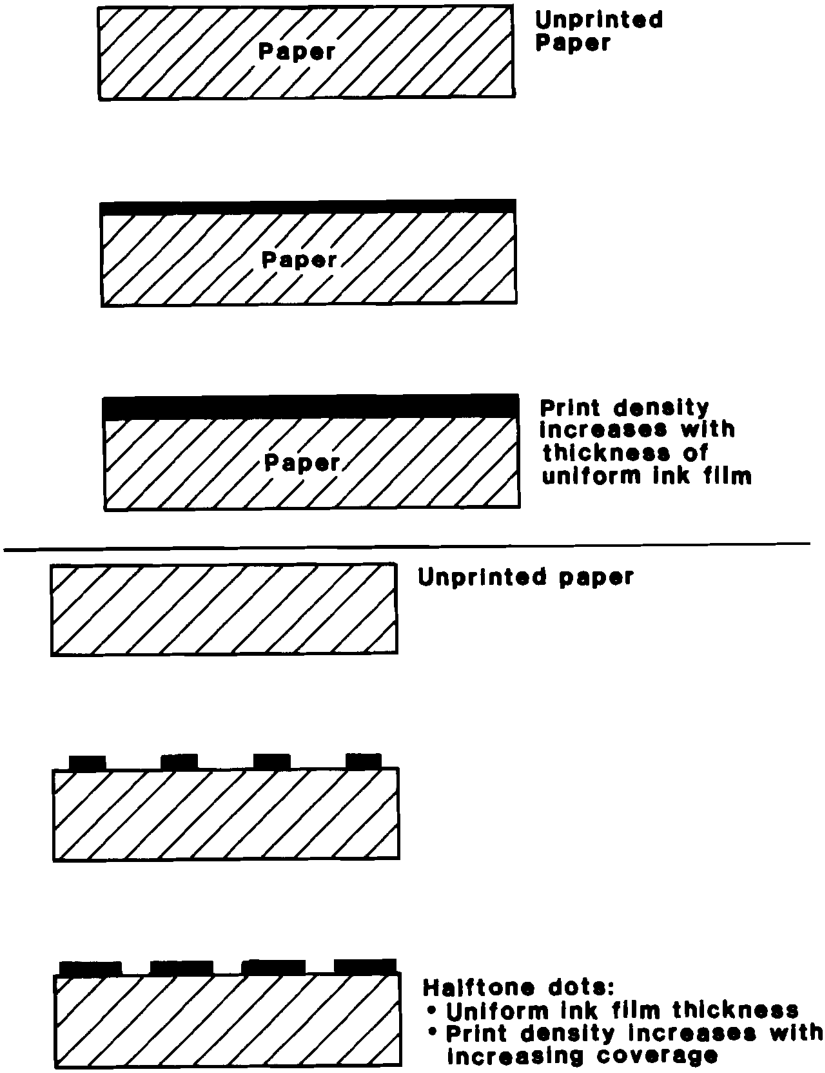

Figure 9 Print density increase influenced by the paper surface. TOP: Solid PD increases with ink film thickness. BOTTOM: Halftone PD increases with coverage, at constant ink film thickness.

Each of the calculated 19 slopes (one slope for each newsprint) is shown in Table IV. In Figure 8, the 19 slopes are plotted vs. the density of the respective solid prints. A good correlation is obtained ($R^2 = 0.67$). That is, for a given paper, a greater rate of increase in halftone print density correlates with a greater solid print density.

To obtain Figure 4, the ink film thickness of a solid print was increased. On the other hand, in Figures 7 and 8, the ink film thickness is constant, while the area covered is increased. In either case, the paper structure must influence the way in which print density builds up, whether for increasing film thickness on a solid print or for increasing area covered on a halftone print. A simple schematic diagram of this concept is shown in Figure 9.

The amount of fines (newsprint fibres less than 0.1 mm long) may also be important. Figure 10 shows the 40% dot diameter vs. surface fines content. The correlation is significant ($R^2 = 0.38$). If the two outlying points are omitted, the correlation is excellent ($R^2 = 0.80$). That is, with more fine material on the newsprint surface, the water-based ink will spread more. We have no basis for omitting these 2 points, except that these newsprints also behaved anomalously with oil-based inks (Aspler et al., 1991).

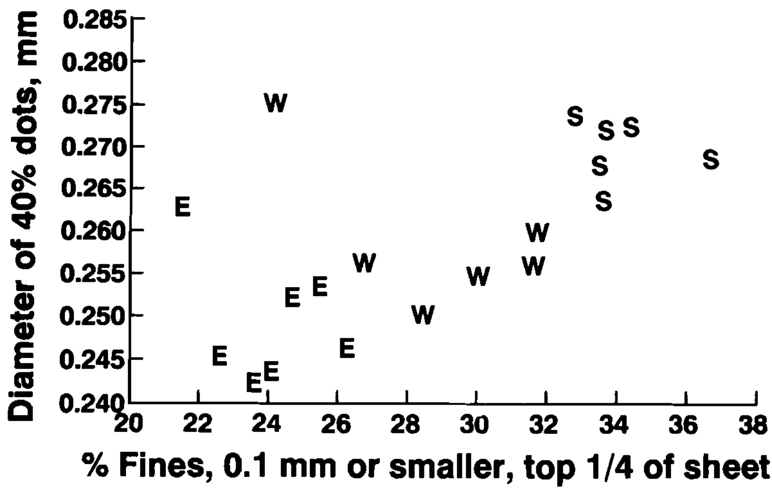

Figure 10 Dot size as a function of surface fines level for the 19 North American newsprints. See text for details.

In Figure 11, the area of the 40% dots is plotted as a function of solid print density. This provides another hint of the influence of fines and surface structure on print quality.

Figure 10 has shown the likely relation between dot size and surface fines. We have elsewhere shown that there is a relation between solid print density and fines (Aspler et al, 1992).

More fines -- filling in what would otherwise be surface voids -- improve ink holdout and so improve solid print density. More fines also apparently provide more area for spreading of halftone dots.

The subject of paper surface contributions to print quality is still open for investigation. More work in this area may help to optimize paper structures in the future.

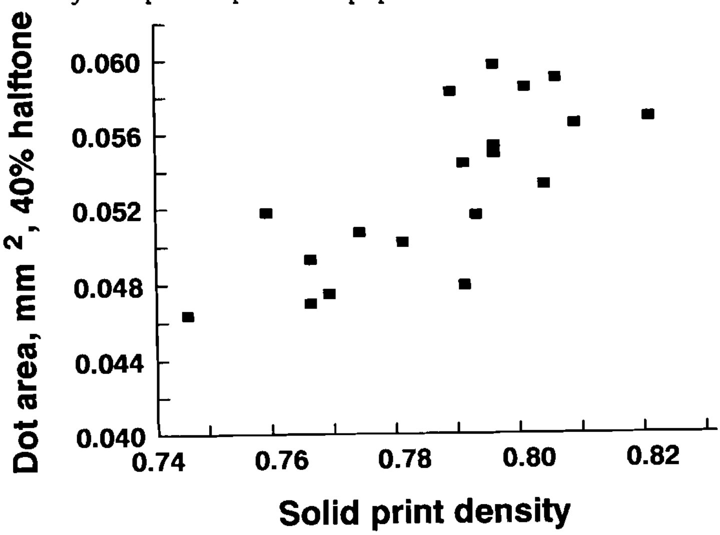

Figure 11 Area of 40% halftone dots for the 19 North American newsprints, as a function of solid print density.

SUMMARY AND CONCLUSIONS

A single-sheet proof press for printing paper samples by water-based flexography has been developed. The repeatability of print density, print through, setoff, and ink transfer measurements are all very good. Print densities of prints from this press are in good agreement with data obtained with a laboratory web press.

The same exponential model developed to explain the increase in print density of oil-based inks with ink level also applies to the increase in flexo print density with ink transfer to paper. Since the increase in print density with increasing halftone dot coverage correlated with the print density of the corresponding solid prints, it is likely that similar paper factors control solid density and halftone density. This may be related to the concentration of fine paper fibres in the sheet surface.

ACKNOWLEDGEMENTS

The authors would like to thank Derrick Pounds, Geoffrey Crofts and Jean-Claude Andrian for their work in the design, construction, and modification of the press. The electronics were designed and built by Terry Murray and Oliver Vadas. Many of the evaluations were done by Sylvie Sauriol, Johanne Lacoursière, and Laurent Piquard. We also thank Emil Koller for reviewing the statistical analysis.

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