A PAPERMAKER'S APPROACH TO THE ANALYSIS OF PAPER PRINTING CHARACTERISTICS

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Abstract: With constantly changing papermaking and printing processes, the update of old methods and the development of new diagnostic methods to define the print-related paper properties are required by both papermakers and printers. A new, comprehensive approach to the problem has been taken by the Pulp and Paper Research Institute of Canada.

Today's regular newsprint may or may not entirely satisfy the new demands of water-based flexography, especially multicolour printing. For instance, there is presently conflicting evidence as to whether more or less water absorbency is desired in paper for water-based flexography. In the course of a new project, the Institute is developing a bench scale flexographic proof press to investigate paper requirements and ink-paper related problems of water-based flexography.

A two-colour web offset press built at the Institute is used in controlled reproducible print runs to evaluate the fundamental principles of paper linting. The press is also used in a factorial design experiment to differentiate paper properties responsible for linting from press parameters. Some preliminary results indicate the relative importance of dampening and blanket properties as compared to paper furnish.

The results of a fundamental study of ink transfer to paper and ink film splitting have been combined with the results of a fundamental study of the principles of paper roughness air-leak measurement to form the basis of an evaluation of paper printing characteristics. The new test, called the Printing Efficiency Test or PET, contains 3 indices defined as the ratio of print density, print through, and setoff measured at the maximum in the fractional ink transfer curve to the ink weight transferred to the paper at

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this maximum. The indices are then compared to the paper roughness. The PET has been shown to be more sensitive to paper variables than conventional print tests used in the paper industry.

INTRODUCTION

The resulting quality of a print is a function of the qualities of two fundamental components, the paper and the ink, which the printing press, or the non-impact printer merges together during a mere millisecond, or less. With constantly changing papermaking and printing processes, the update of old methods and the development of new diagnostic methods to define print-related properties for new paper grades and new printing processes are required by both papermakers and printers. The Pulp and Paper Research Institute of Canada (P.P.R.I.C.) is addressing such research in three specific areas of the printing field at both the fundamental and the practical levels. The three research projects concern printing newsprint with water-based inks, linting in offset lithography, and ink transfer.

Water-based flexography. As far as papermaking is concerned, the research attitude of the P.P.R.I.C. is greatly influential regarding the assessment of the impact that the development of water-based flexographic printing of newspapers will have on the paper industry.

Two recent publications (A. Schipke, 1985, IFRA, 1984) pointed out that the emphasis in research in water-based flexographic printing of newspapers was on process colour, inks, plates, and anilox rolls. The IFRA report devoted only a paragraph to newsprint. The apparent lack of research in the newsprint field relates to the process changes implemented in the printing field. The changes in water-based flexography for process equipment, plates, and especially the inks, are revolutionary. However, while the newsprint properties for water-based flexography can be predicted, their degree of importance is, as yet, unknown. Moreover, the changes in newsprint for flexography will only be evolutionary. It follows that newsprint is not in a position to either make or break water-based flexography.

Offset linting. In offset lithographic printing of newsprint, the 25-year-old problem of linting has joined the leading problem of newsprint runnability (Ionides, 1984). Yet, no fundamental research has ever been done on defining the physical principles involved in paper surface failure in the offset printing nip. Work so far has been devoted to testing paper for linting propensity (Adams, 1960, Brecht and Globig, 1958, Carlsson and Hultgren, 1968, Charles et al, 1966, Cheatman, 1964, Dunlop and Freundlich, 1968, Elphick, 1976, Heintze et al, 1976, Kuvaja, 1972, Meret and Szanyi, 1981, Pritchard, 1957, Rieche, 1977), describing the accumulation of lint material on the blanket (Daniels, 1974, Hughes, 1966, Lindqvist and Meinander, 1981, Parker and Roe, 1971, Poujade, 1980), and designing in-house procedures to control the linting problem (Barron, 1970, Browning and Parker, 1970, Hughes, 1966, Larocque, 1971, Meret and Szanyi, 1978, Parker and Morton, 1967, Parker, 1970, Sangster, 1974, Snider, 1978). Unfortunately, although quite effective for limited applications, these research attitudes leave the roots of the problem untouched. Today, most North-American offset pressmen have learned to accept some degree of linting.

Fundamental studies and test development. Finally, traditional printability tests (Calabro and Fabbri, 1971, Larocque, 1951, SCAN P35:72, 1972, SCAN P36:77, 1976) have been designed as control tools to be used by printers to evaluate paper rolls. On the basis of such tests, lots are rejected and returned to the papermaker. Unfortunately, the papermaker cannot use the test results as a diagnosis tool, and take corrective action. The need for such diagnostic tools became apparent when traditional printability tests failed to differentiate among newsprints of known different surface structure obtained through conventional and novel calendering methods. Therefore, recently acquired knowledge in the fundamentals of ink transfer (Mangin, 1980, Mangin et al, 1982, De Grâce and Mangin, 1983) and paper surface roughness evaluation (Mangin and De Grâce, 1984a), were combined in the development of a test tailored to analyse paper structural properties important in ink transfer (Mangin and De Grâce, 1984b).

THE WATER-BASED FLEXOGRAPHIC PRINTING OF NEWSPRINT

In its search for better, more economical printing processes, the newspaper printing industry is investigating the utilization of the flexographic process as an alternative to conventional letterpress and lithographic offset processes. The use of water-based inks, the simplicity of a keyless inker, and the possibility of sharp, rub proof colour prints make the process quite appealing, more particularly when considering a conversion of old letterpress units or retrofit option to an offset option. In its search for a satisfied customer and, therefore, the market, the papermaking industry is investigating the paper properties required for the new printing process.

In order to predict the paper requirements for water-based flexographic printing of newsprint, the papermaker must first understand how and to what extent printing with water, in a process that is more or less assimilated with conventional letterpress, affects the newsprint paper surface.

The paper requirements of water-based flexography versus shallow-relief polymer plates letterpress.

In a papermaking context, the significant differences between conventional letterpress and water-based flexography would be in the inks, the inking system, the printing pressure, and multicolour printing. Although it is an oversimplification, the printing plates can be considered to be similar.

With about 15% pigment, 50% water, 10% organic co-solvent, 20% latex, and 5% miscellaneous additives, water-based flexographic inks have a waterlike viscosity (10-50 cP), about 1,000 to 10,000 times less than letterpress newsinks. The presence of latex means a minimum rub-off while the absence of oils ensure a reduced show through. Mineral oils are the most common letterpress newsinks vehicle. These oils are well-known for their ability to decrease paper opacity as they spread within the paper.

In conventional letterpress, ink holdout of the oil-based inks is affected only by the physical structure of the paper, namely, paper roughness and pore structure. In water-based flexography, both paper structure and water absorbency of the newsprint influence the ink holdout. In flexography, the only way at present to adjust the ink holdout is by changing the ink viscosity. An alternate solution would be to change the water absorbency of paper. Unfortunately, controlling the water-absorbency of newsprint is not a trivial matter. Paper furnish changes during a production year as the wood supplies change from summer to winter. Moreover, as newsprint self-sizes with age, water absorbency decreases (Aspler et al, 1984, Aspler and Lyne, 1984) thus rendering the task of controlling water absorbency even more difficult. Decreasing water absorbency of newsprint will likely improve the ink holdout, at the expense of setoff and other drying problems. Increasing the water absorbency of newsprint may help to improve the solids uniformity and to solve drying/trapping problems, but may lead to runnability problems such as curl, misregister, and lint. However, the importance of increased or decreased water absorbency is not yet known, and is the subject of on-going research at P.P.R.I.C.

As the keyless flexographic inking system (Figure 1) makes it impossible to adjust the ink holdout locally, the cross-direction uniformity of the newsprint, as far as structure and/or water absorbency is concerned, has to be good.

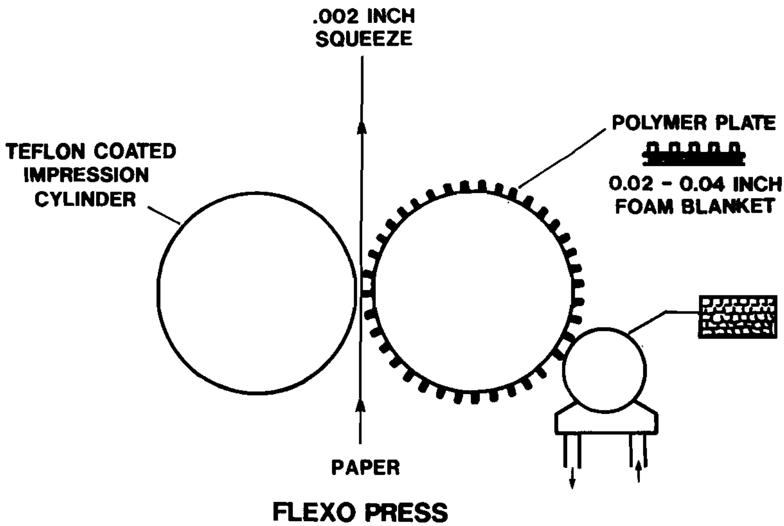

Figure 1. Simplified schematic principle of water-based flexographic printing of newsprint.

The printing pressure used in water-based flexography is lower than in conventional letterpress. This often results in poor quality of the printed solids. In this regard, the good formation and high smoothness paper requirements for letterpress may well be the minimum requirements for water-based flexography.

In colour printing, ink trapping, drying, and second impression setoff are of concern to the printer. Applying several layers of water on newsprint are of concern to the papermaker, since the dimensional stability and the surface strength of newsprint may be affected, leading to curl, misregister, fibre puffing, and even lint problems.

Laboratory and commercial testing of newsprint for water-based flexography.

Many laboratory benchtop printing presses such as the GFL letterpress rotary press can be used to measure the effect of various paper properties on ink transfer and on the final print properties in conventional oil-based letterpress printing. However, just as water-based flexographic inks are incompatible with existing pressroom equipment, they are also incompatible with existing laboratory equipment. For this reason, P.P.R.I.C. is currently building a benchtop press (Figure 2). The press will permit the measurement of print density, show through and setoff of water-based flexographic inks at high speed on newsprint samples, in order to evaluate the influence of both physical structure and water absorbency on ink holdout.

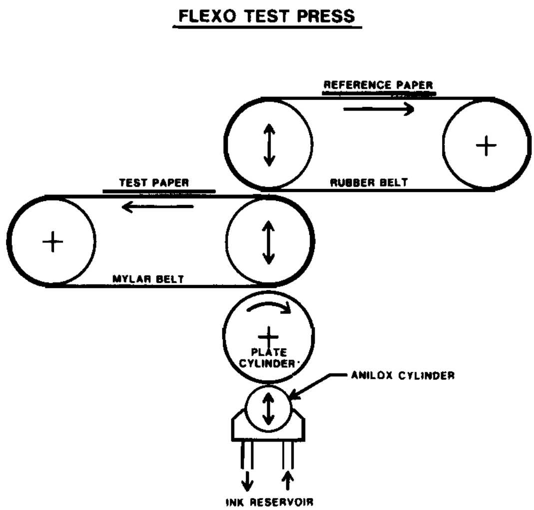

Figure 2. Simplified schematic principle of the Paprican flexographic test press.

Over the last few years, P.P.R.I.C. has carried out several commercial newsprint evaluations in both offset and letterpress, as part of the MultiDimensional Scaling (MDS) programme done in collaboration with the Psychology Department of McGill University (Lyne, 1979, Lyne and Parush, 1983). In these tests, the standard Paprican test photograph is printed on eight different newsprints under steady state press conditions. The only variable is assumed to be the newsprint. Random samples from the commercial run are selected and people are asked to make pairwise preference and difference judgements among the samples. A judge may have a distinct preference for one or the other in a pair. He can also weigh his opinion along a scale between the two extremes. From all the possible pair comparisons, the MDS computer programme calculates the location of each sample in a two or more dimension space. Correlation performed between physical tests results from the unprinted and printed papers, and the position of each sample along each axis indicates which paper physical properties have influenced the subjective judgements of the panel members.

Similarly, commercial water-based flexography trials, beginning in April 1985, will help to determine the influence of paper properties on physically measurable print properties, as well as on the subjective viewpoints of the judges. As an example, the first trial will include newsprint from eastern and western Canada, and from the southern U.S.A.

LITHOGRAPHIC OFFSET LINTING

The linting propensity of paper is a printing problem mostly associated with lithographic offset printing. The importance for both the papermaking and printing industries of such a pressroom related problem can be appreciated when considering that, in 1983, for the first time, more than 50% of the total Canadian newsprint production (ANPA, CPPA, Bruno) was consumed in offset pressrooms. Furthermore, the printing industry considers nowadays that offset linting rivals pressroom runnability in level of importance as a paper printing requirement.

Linting, as opposed to paper dust, picking, or delamination, is defined as the tendency of paper to shed loosely bonded surface fibers, fines, and vessel fragments during the printing operation. Dust, or paper dust, refers commonly to any fiber, fine, or paper particle just sitting on the paper surface and, because it is often trapped in-between two plies of the web, is easily released by a simple unwinding operation. Usually, some straightforward housekeeping at the papermill stage will solve any dusting problem. Picking means that the paper surface is damaged to such an extent that further printing is impossible because particles, pieces of coating or paper are pulled out from the paper surface. Delamination is a more extensive deterioration of the paper surface. It is often associated with coated papers and means that the coating of a paper with a portion of the paper surface is completely taken off during the printing operation. If picking or delamination occur, printing has to stop immediately. Both picking and delamination are related to basic surface strength of the paper and can only be fixed by increasing surface strength and bonding. The linting problem, having no simple obvious solution, remains the most elusive of these surface defects.

Pilot scale evaluation of the linting propensity of paper

The relationship between the surface strength of paper and linting is the subject of controversy. No bench scale test is able to duplicate the complexity of commercial offset printing. The basic ink/fountain interactions and the offset press design preclude a simple laboratory test to evaluate the linting propensity of paper (McPhee, 1979, Karttunen and Lindqvist, 1979). As seen in Figure 3, after impression, the paper leaves the nip with a certain angle (the peel-off angle) which is a function of the dynamic geometry of the printing nip. Therefore, not only ink/water emulsification but the geometry of the printing nip, the physical and chemical properties of the blanket, and the dynamics of the process influence the lint accumulation or lint build-up on the offset blanket (Table 1).

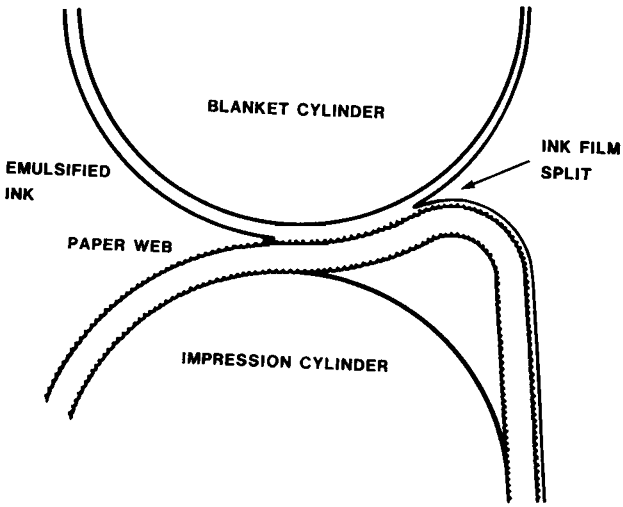

Figure 3. Exaggerated view of the offset printing nip showing the web peel-off angle.

Table I - Printing Parameters Affecting Linting

1. Ink/water balance
2. Ink film thickness
3. Water film thickness
4. Ink and emulsified ink rheological properties
5. Blanket properties
6. Nip geometry
7. Printing speed
8. Printing pressure
9. Printing temperature
10. ....

If a research engineer were to try to build a machine that would satisfy all the conditions of ink/water emulsification, with the flexibility of varying all the printing parameters, he would most probably end up with a true offset press. It is exactly the need for a real, controlled web offset printing press controls that led P.P.R.I.C. to build a research pilot press.

The press (Figure 4) is a single page cut-off, web-to-web press capable of printing under commercial conditions (up to 2000 ft/mn) in either offset or letterpress mode. Starting from a Swedish design, the press was built in P.P.R.I.C.'s machine shops and then extensively modified and upgraded through the addition of all the controls required for research purposes. One major modification includes a pneumatically loaded floating impression cylinder to adjust the printing pressure to a known set value. The web tension is controlled and the inking system temperature is thermostated. The press controls and monitors also include an on-line densitometer which records density variations during each test run, an infrared sensor which records water film thickness variations down to 0.1 μm in the non-image area of the plate, and an infrared sensor which reads the temperature about 9 milliseconds after printing.

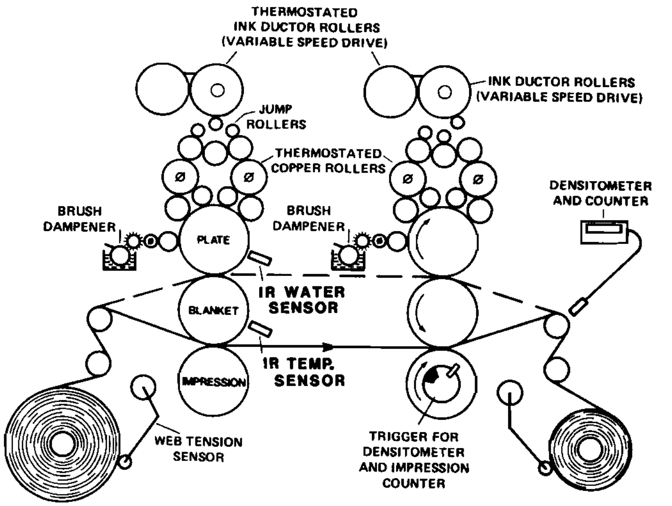

Figure 4. The Paprican multi-purpose research press. The dashed line shows the web path for letterpress printing.

Although often neglected in the linting evaluation literature, the importance of printing temperature in any linting test evaluation with basically short printing runs can be appreciated in Figure 5 where the printing temperature can be seen to increase during the run and could differ from about 3°C from one run to another. Such temperature differences produce sufficient ink tack and viscosity differences to invalidate the test result (Lyne, 1980, Meret and Szanyi, 1981, Aspler et al, 1984). After 5,000 copies, the web is artificially broken and the nip opened to stop the accumulation of lint onto the blanket. The sudden, further increase in blanket temperature is due to the fact that the paper web removes the heat (generated in the compression-decompression cycles of form rollers) from the press. These results also stress the importance of roll conditioning before any lint test.

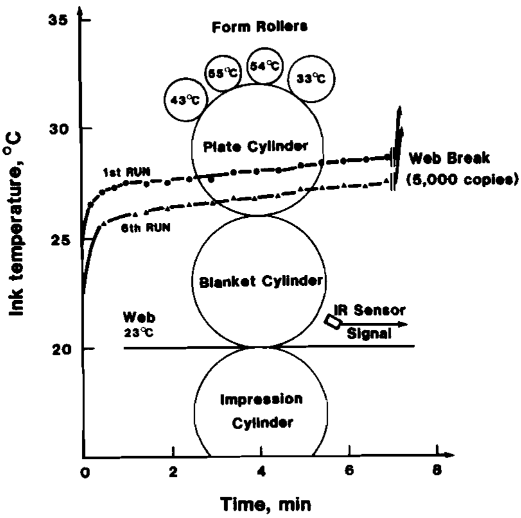

Figure 5. Temperature increase during 5,000 copy runs due to frequent press stops during testing.

The ink/water emulsification is controlled by sampling ink from the top ink fountain cylinder immediately at the end of the print run. The sample is then oven dried to constant weight with a non-emulsified sample as a control. A typical ink/water emulsification curve, average of more than 100 runs can be seen in Figure 6.

Based on previous studies by Lindqvist and Meinander (1981), the run length is limited to 5,000 copies. The test conditions can be seen in Table II. At the end of the run, all the material collected on the blanket is brushed from a 0.02633 m^2 area into a pan. The washing fluid is a solution of 15% isopropanol in water which does not affect the blanket properties and which prevents the blanket from swelling. The collected lint is then sequentially filtered through 8 μm micropore filters and soaked in petroleum ether in order to remove oil and pigment from the fibers. More than 100 tests showed that this procedure removes between 90 and 99% of the pigment and 100% of the oil vehicle. The lint is then weighed and/or dispersed onto a glass slide for image analysis or for qualitative microscopic evaluation. As scanning electromicrograph pictures have shown that carbon black pigment particles can be trapped in the lumen of the fibers, an optical calibration curve, obtained with known amounts of carbon black pigment is used to evaluate the weight of the pigment still associated with the fibers after the cleaning procedure.

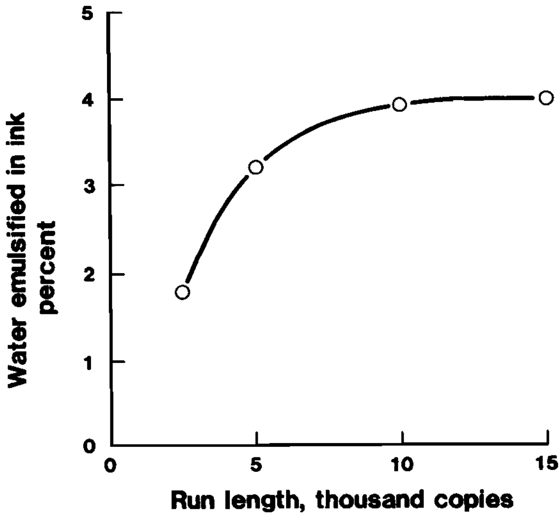

Figure 6. Water-in-ink emulsification curve. Sampling on the top ink fountain roller. The curve is averaged on more than 100 runs.

Table II - Paprican Standard Lint Test

Run length:	5,000 copies
Printing speed:	45,000 copies/hour (7.8 m/s)
Printing pressure:	2 MPa
Plate:	Al, 85 lines/inch, 50% dot area
Dampening solution pH:	4.25 ± 0.05
Dampening solution film thickness:	0.8 µm ± 0.1 µm
Halftone print density:	0.90 ± 0.05

Preliminary results

The effect of the furnish content of the paper is shown in Figure 7 for 4 newsprints sampled on the same position from the same fourdrinier paper machine. The newsprints have been ranked as a function of their thermomechanical pulp (TMP) content. The linting propensity of paper increased regularly with the TMP content of the furnish. For the study, 10% of the groundwood, and 10% of the low yield sulphite have been gradually replaced with TMP. The rather high level of the 80% TMP newsprint is associated to a poor combination of groundwood and TMP. Of course, a complete analysis would have to consider the interactions between the negative effect of removing the low yield sulphite pulp (with bonding capability) and the positive effect of removing the groundwood part of the furnish.

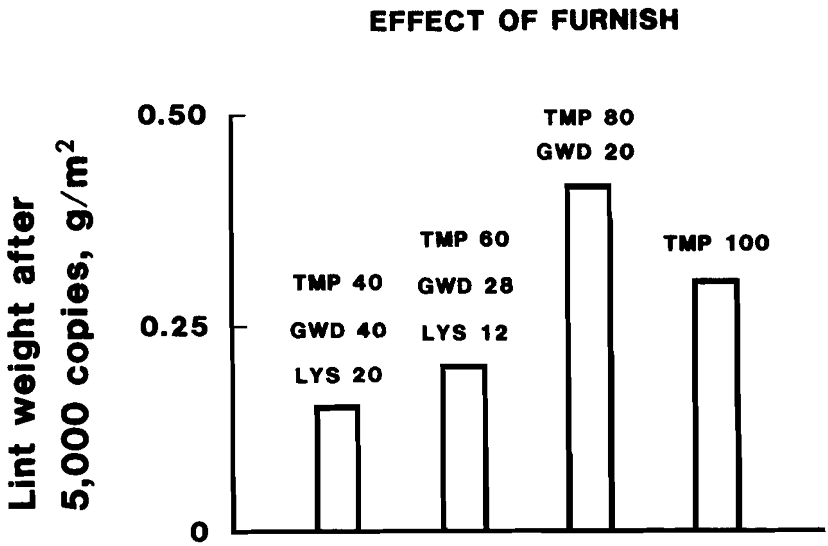

Figure 7. The effect of paper furnish on the linting propensity of paper.

However, press parameters may also influence the final lint accumulation onto the offset blanket, often to a greater extent than paper properties themselves.

This can be appreciated in Figure 8 which represents the lint weights accumulated in the image and non-image areas of the offset blanket for 10 different newsprints evaluated in two consecutive series of print runs, one using a conventional blanket, the second using a compressible blanket from the same manufacturer. Not only were the lint results obtained with the conventional blanket about 4 times less than with the compressible blanket but some inversions occured when comparing the linting propensity values obtained with one blanket compared to the other (newsprints B and C, or F and H, for instance). Another study confirmed that the accumulation of lint material in the image area of the offset blanket could change by 180 percent for a 10 percent change in the fountain solution film thickness as measured in the non-image area of the plate, a fact well known to most pressmen.

It has been concluded from this preliminary work that fundamental studies designed to explain the mechanisms of fiber material removal from the paper surface in a printing nip are required if the papermaker wants to control the paper linting propensity at all papermaking stages. Such knowledge is still lacking and is the object of on-going research at P.P.R.I.C.

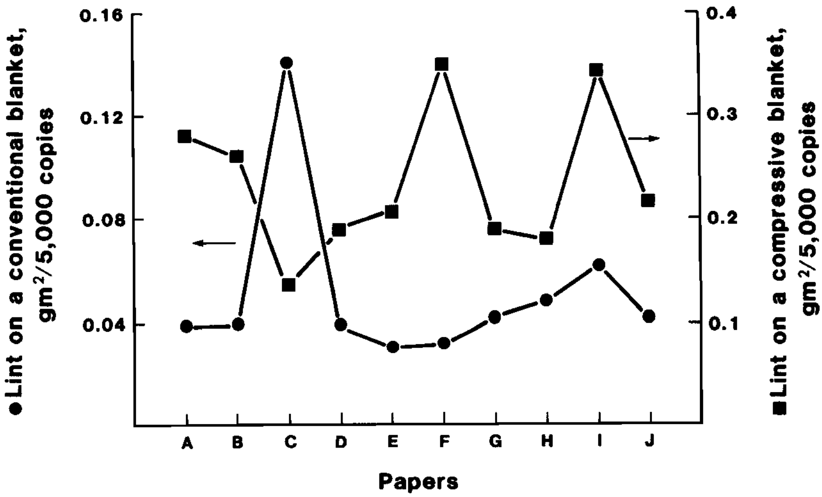

Figure 8. The effect of blanket on the measured linting propensity of paper.

INK TRANSFER AND TEST DEVELOPMENT

In the pulp and paper industry, the two most widely used printing tests for evaluating the printing characteristics of newsprint suffer from a number of deficiencies. The reproducibility of the Larocque test (1951) has been shown to be very poor (De Grâce and Page, 1980, De Grâce et al, 1982). Furthermore, it makes use of a very slow hand-driven proof press and measures a single parameter. The Scandinavian methods, SCAN P35:72 and SCAN P36:77, the only existing standards, evaluate the ink requirement, the print through, and setoff properties of a paper at a given print density. The method utilizes a rotary printing press that simulates commercial letterpress conditions and is also quite repeatable. Nevertheless, it is not always sufficiently sensitive to differentiate among the printing characteristics of different papers (Mangin and De Grâce, 1984a).

Non-printing tests, such as air leak roughness testers, are not only not sensitive enough but may be quite misleading. This can be seen in Figures 9 and 10 where papers calendered with different techniques cannot be differentiated using bulk and surface roughness measurements but still print very differently. The ink transferred to each sample at the maximum fractional transfer differs according to the calendering techniques for samples with the same 'measured roughness'.

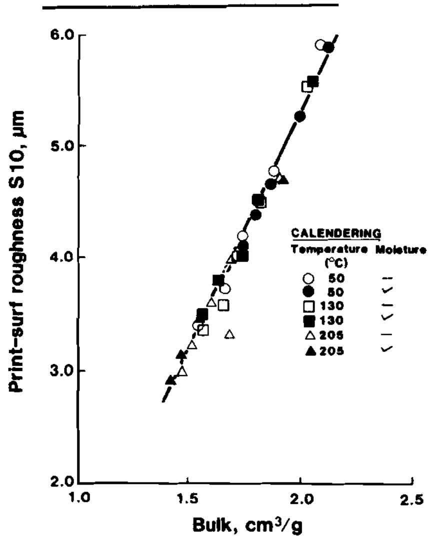

Figure 9. Paper bulk as a function of the Parker Print-Surf roughness for a newsprint calendered to 5 levels with 6 different calendering procedures.

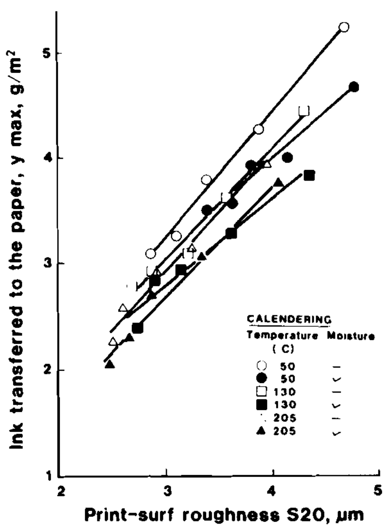

Figure 10. Ink transferred to the paper at the maximum in the ink transfer curve for a newsprint calendered to 5 levels with 6 different calendering procedures.

Clearly, a method that took all these points into account was needed. The new method had to be not only a useful routine control tool but also an investigative tool for possible corrective action when required during the papermaking process.

Development of the method

Recent work on ink transfer (Mangin et al, 1982, De Grâce and Mangin, 1983) has related the maximum, $F.T._{max}$, in the fractional ink transfer curve to the surface roughness and porosity of paper, and to the printing speed and pressure. As far as the paper structure is concerned, it was concluded that the printing characteristics of a paper could be best described by measuring the optical properties of the print at $F.T._{max}$ rather than at some arbitrary density value (0.85, 1.00, or 1.30). Furthermore, the Parker Print-Surf (PPS) roughness tester, an air leak instrument, failed to differentiate between the ink transfer characteristics of newsprints calendered using different techniques. This was explained when the Parker Print-Surf value for newsprint was found to come from a combination of both paper roughness and porosity (Mangin and De Grâce, 1984a). The combination would vary according to the calendering technique.

The Printing Efficiency Test or PET

In the newly developed method, called the Printing Efficiency Test or PET, the printing properties of paper are described by considering the optical properties of the print, and of the setoff print, measured at $F.T._{max}$ as a function of the PPS roughness/porosity value of the paper. As a further refinement of the method, the print density, PD_{max}, print through, PT_{max}, and setoff, SO_{max}, values at $F.T._{max}$, are normalized for the amount of ink transferred to the paper, and defined as follows:

Print Density Index: $$PDI = \frac{PD_{max}}{y_{max}} \quad (1)$$

Print Through Index: $$PTI = \frac{PT_{max}}{y_{max}\, c} \quad (2)$$

Setoff Index : $$SOI = \frac{SO_{max}}{y_{max}} \quad (3)$$

where y_{max} is the ink transferred at the maximum fractional transfer, and c is the sheet thickness, used to account for the differences in paper opacity when sheet thickness varies.

The PDI can be thought of as a description of the ink holdout of the paper. The PTI gives an indication of the proportion of the ink that penetrates the bulk of the paper and contributes to show through problems. The SOI relates to the proportion of the ink that remains on the paper surface as a free ink film and, therefore, to the overall resistance of the paper structure to the forced hydraulic impression in the printing nip.

As printing tests are time consuming and expensive, a papermaker may have to define PDI, PTI, and SOI curves for each paper machine and furnish composition, then use the PPS roughness as a guide for routine control. In an out-of-control situation (outside pre-defined 2 sigma limits) print tests have to resume and the full power of the PET has to be used to analyse the problem.

As a research tool, the printing characteristics of the paper can be analysed considering the 3-coordinate PET vector defined as:

$$(PET) = (PDI, PTI, SOI) \quad (4)$$

Such an example is given in Figures 11 and 12 where the vector projections on the (PDI,PTI) and (PDI,SOI) planes have been represented for different calendering conditions. The print through characteristics of a high temperature calendered newsprint (Line B, Figure 11) are significantly better than that of the same newsprint conventionally calendered (Line A, Figure 11). However, the improved ink holdout has resulted in an increase in the setoff characteristics, as can be seen from the relative positions of the lines representing the conventionally calendered (Line A) and the high temperature calendered (Line B) newsprints in Figure 12.

CONCLUSIONS

Over the past few years, the pulp and paper industry has been concerned with the demands that new developments in printing technology will put on the paper. As a consequence, the Pulp and Paper Research Institute of Canada was given a mandate to analyse the main areas of ink-paper interactions in order to determine customer problems the pulp and paper industry is now facing or will face in the future. In conclusion, three areas of research were defined and their respective objectives can be summarized as:

1) Establishing the paper requirements and the tolerances levels in the paper properties for water-based flexographic printing of newsprint.

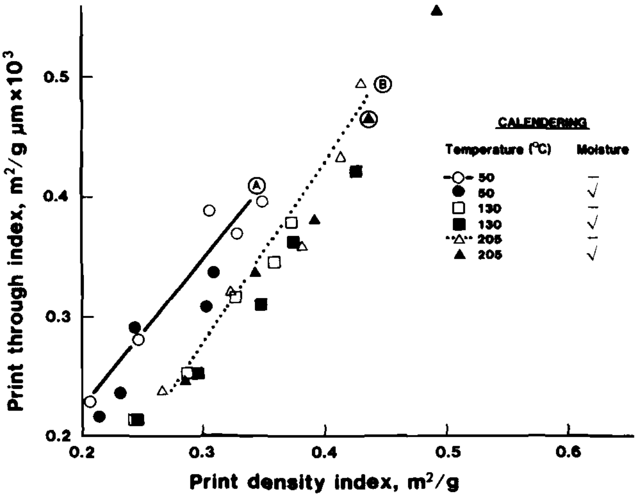

Figure 11. Print through index (PTI) versus print density index (PDI) of a newsprint calendered conventionally (Line A) and at high temperature (Line B). Other calendering conditions show the same linearity of PTI versus PDI.

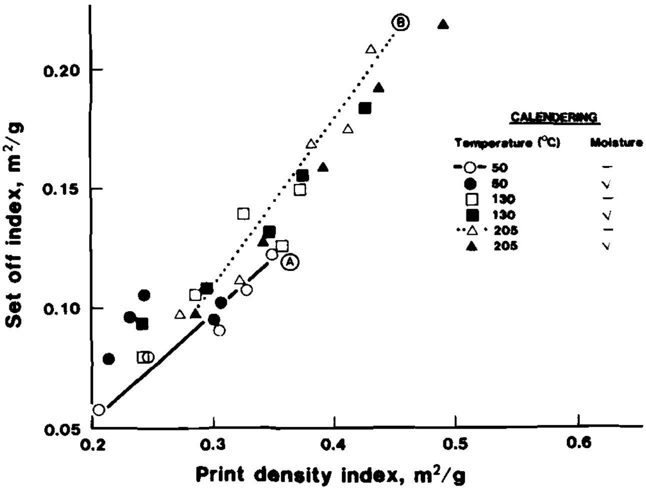

Figure 12. Setoff index (SOI) versus print density index (PDI) of a newsprint calendered conventionally (Line A) and at high temperature (Line B). Other calendering conditions show the same linearity of SOI versus PDI.

2) Establishing the relative importance of the various printing and papermaking factors which influence the linting propensity of paper in the offset printing nip in order to find methods applicable in the paper mill to reduce the linting propensity of paper.

3) Defining the paper properties affecting the fundamentals of ink transfer in the offset and letterpress printing nips in order to relate the final print quality to fundamental paper properties.

Finally, the authors would like to thank TAGA for the opportunity to present an outline of the printing research programme at the Pulp and Paper Research Institute of Canada. We are confident that this is a significant step in increasing cooperation between the various sectors of the printing world: the printers, the printing press manufacturers and their allied industries, the ink manufacturers, and the papermakers and their allied industries.

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