THE PRINT QUALITY OF PAPER MADE FROM CO-REFINING BCTMP AND RECYCLED FIBRES

Patrice J. Mangin*, Jacques L. Valade**

ABSTRACT
Co-refining is a process whereby secondary fibres (office waste) and mechanical pulp are refined together in a secondary stage refiner as opposed to refining them separately and subsequently mixing them. Paper samples were manufactured on a pilot scale paper machine from both pulps refined together (bleached chemi-thermomechanical pulp and office waste) and the original pulp mix without co-refining. The pilot paper machine papers, calendered to the same-PPS roughness using conventional, temperature gradient, and soft nip calendering were printed on an sheet-fed offset press using a novel approach called the Normal Contrast Intensity (NCI). In NCI, the inking level is gradually increased to beyond optimum inking conditions. Samples are retrieved and analyzed at each inking level. The average print density, print-trough, variation in print density, and contrast are evaluated for all samples. It is found that increasing the secondary fibre content decreases print-through, increases contrast but also print unevenness. Refining pulps together also increases print-through but improves printing uniformity. It produces the same contrast and graininess as when pulps are refined separately. Calendering has complex effects on the printing characteristics of paper. Temperature gradient calendering improves print-through. Soft-nip calendering is best for print uniformity but worst for print-through and contrast. It is concluded that co-refining has a market potential and that pulp furnish and calendering condi- tions can be tailored to customer's end-use.

INTRODUCTION
Co-refining is a process whereby waste paper is refined with mechanical pulp in a secondary stage refiner [1]. Co-refining may prove to be an economical alternative to produce some paper grades containing recycled fibres when investing in deinking/recycling facilities is not feasible.

* Royal Institute of Technology Stockholm, Sweden
** Université du Québec à Trois-Rivières

The objective of this work is to investigate the printing characteristics of papers made from mechanical and secondary fibre pulps refined together. **Figure 1** shows a schematic drawing of the process. Co-refining may prove to be an economical alternative for some paper grades containing recycled fibres. In this preliminary study, the waste paper, consisting of office waste, was not deinked prior to the co-refining stage.

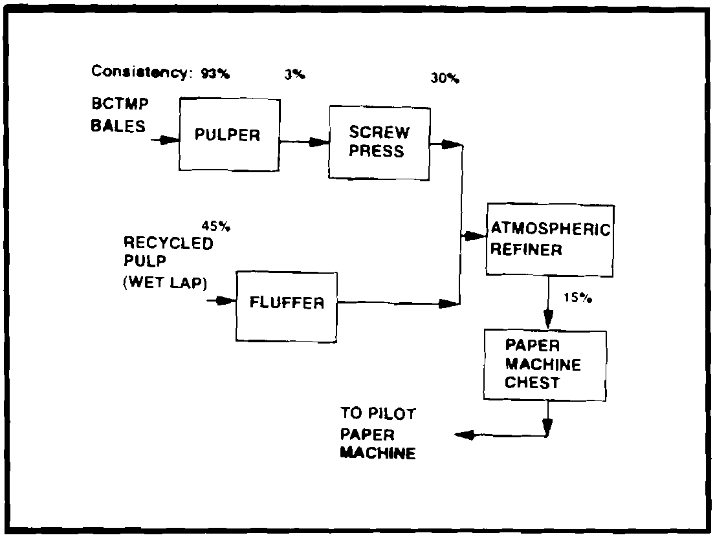


Figure 1. Co-refining of BCTMP and recycled pulp.

In order to evaluate the market potential of papers made with varying amounts of co-refined pulp, a preliminary investigation of the printability of such papers was initiated. The approach was two-fold. First, in order to understand how co-refining affects the final surface structure of the sheets, the surface characteristics of the samples were evaluated. Second, the calendered samples were printed on a sheet-fed offset press to determine their performance in terms of offset print quality. As no previous knowledge exists on which calendering process is best suited for such paper grades, conventional, temperature gradient, and soft-nip calendering were included in the experimental design. As no protocol exists to quantitatively evaluate the printing characteristics of paper on a commercial scale, we also developed an approach to be able to compare the effect of co-refining and recycled pulp content on the printing characteristics of papers. The new approach led to conclude that co-refining is a viable process as far as the printing characteristics of papers made from such pulps are concerned. The new printing approach is also outlined and the variations of the printing indices as a function of print density, co-refining, recycled pulp content, and calendering processes are discussed.

EXPERIMENTAL

Paper Samples

Two pulps were used: a bleached chemi-thermomechanical pulp (BCTMP) of aspen containing 50% office waste and 50% printed ledger which were not deinked. The recycled pulp contains up to 90% hardwood. The recycled pulp was washed but not flotated. From various mixes of these pulps, two types of paper samples were made from either the pulps refined together (co-refined) or from the pulps refined separately (rs): Formette Dynamique samples (DSF, Dynamic Sheet Former) and pilot paper machine samples. A Sunds Defibrator CD-300 was used where the refining energy required ranged from 400 to 550 kWh/(bdmt). All paper samples were made at 60 g/m^2 basis weight. The 60 g/m^2 basis weight was chosen as a compromise between experimental cost because of refiner capacity and the amount of pulp required to run the pilot paper machine. The pilot paper machine, is a slow speed Fourdrinier (120 m/min). To limit the number of paper machine parameters, no retention aids were used in this experiment. Due to variations in the basis weight during manufacturing, the paper rolls were cut in 11"x18" sheets and the weight and the calliper of the sheet were recorded. Sheets of target basis weight were than selected for calendering and printing. **Table Ia** shows the percentages of each type of pulp used to make the pilot paper machine samples and there average roughness PPS roughness. The optical and gloss properties are shown in **Tables Ib**. The DSF sheets were used mainly to measure the surface compressibility of the samples, a surface property recently identified as a key printing characteristic **[2,3]. Table II** shows the paper characteristics of the DSF samples. As an extension of the work on gravure, surface compressibility was measured to verify its importance for offset print quality. The dynamic sheet former was used here to avoid formation and paper machine variability effects on the compressibility evaluation.
1 bone dry metric ton

Calendering

The selected sheets of pilot paper machine samples were calendered to a target Parker Print-Surf (PPS, soft backing, 1 MPa, or S10) value of 5 mm using conventional (CC), temperature gradient (TG) and soft-nip (SN) calendering. The average PPS roughness values of the calendered samples obtained were 5.16 mm and 5.17 mm for the CC and TG samples, and 4.33 mm for the SN samples, higher calendering loads creating blackening. All calendering was performed on laboratory calenders. Conventional calendering was performed at 50°C, and at a speed of 50 m/s with single nip loads varying from 43 to 75 kN/m. Temperature gradient calendering was performed at 210°C, at a speed of 100 m/s with loads ranging from 20 to 37 kN/m. Soft nip calendering was performed at 50°C with the Paprican soft nip calender at 50 m/s with loads ranging from 40 to 70 kN/m. The DSF sheets were not calendered. Only the calendered pilot paper machine samples, as listed in **Table Ia** were offset printed. This corresponds to 7 conventionally, 7 temperature gradient, and 7 soft-nip calendered samples for a grand total of 21 samples.

Surface compressibility

The paper surface compressibility was measured using the apparatus and the method developed at Paprican **[2]**. Using confocal microscopy, a sample is mounted in the compression apparatus and image uncompressed and re-imaged after five levels of compression. The roughness of the same area can therefore be measured at different pressures. The compressibility is calculated as the slope of the logarithm pressure curve. In order to evaluate the effect of recycled content on compressibility, the DSF sheets were used. Surface compressibility is reported for these samples only **(Table II)**.

Printing experiment

Printing conditions

Sheets of 11″x17″ were printed on a sheet-fed offset press Oliver 58 at slow speed (0.8 m/s or 4200 copies/hour). In printers terms, the printing pressure corresponded to 4 thousands of an inch over-packing of Vulcan 2000 compressible blanket. Blanket hardness was 82° Shore A. The printing plate was an Hoechst Canada Enco N61. The dampening solution used was Varn Total Chrome Free, and the pH adjusted to 4.20. The ink, BASF TEC low-tack 7 was specially designed for the job. Printing temperature was fixed at 21°C.

Printing procedure

A specially designed test form was used for the printing experiment. Its main features are the well-known chess-player picture **[4]**, screened at 133 lines per inch (lpi), for qualitative evaluation of print quality, with a 25%/75% screen on top, also screened at 133 lpi, to measure contrast, and a solid at the bottom to measure print unevenness; 3 series of halftones at 20, 30, 45, 55, 65, 75, and 85% coverage at 100, 120, and 133 lpi; the corresponding GATF midtone dot gain scale, and an EMPA/UGRA plate development scale used here as a resolution scale.

Development of a new testing approach

In 1969, Schirmer and Renzer [5] developed a procedure to find the correct inking level on an offset printing press. From their work, we adapted the idea to progressively increase, then decrease the inking levels to find the best printing conditions for any paper being tested on a sheet-fed offset press. In their initial work, the authors thus evaluated the colour saturation of prints, which is governed by the thickness of the ink film, by measuring colour contrast. The original test was called Normal Colour Intensity or NCI. The printing pro- cedure is here adapted to print with black ink only to evaluate the printing characteristics of papers. It is called the Normal Contrast Intensity to maintain, as others have done [6] in the past, the NCI acronym, as it is an NCI-related test. To guarantee that each paper is printed in optimum conditions, the ink keys are progressively opened to reach a maximum in print density, up to the actual plugging of the halftones, then decreased progressively. For each increase or decrease in inking, the press is stabilized and printed samples are collected. The lack of hysteresis between the increase and the decrease in inking phases is a good test for the stability in the printing experiment. A total of 8 inking levels corresponding to target print densities of 0.4, 0.6, 0.8, 1.0, 1.1, 1.2, 1.3, and 1.4 are chosen. Various printing characteristics are measured for each inking level. Accuracy of the printing experiment is verified from lack of hysteresis between the up and down curves.

Ideally, the printing characteristics should be analyzed as a function of the ink weight transferred to the paper. As this is not feasible on a commercial sheet-fed press, printing curves, representing the variations of any printing characteristic as a function of print density are established. The comparison of paper printing characteristics is effected by comparing the various curves, curve parameters, or maxima, if any. In this experiment, due to some printing problems related mainly to sheet-feeding through the press, the printing characteristics of some samples were evaluated at 5 inking levels only.

The measure of the paper printing characteristics

Print density and print-through

The print density was measured both with a MacBeth densitometer (0/45° configuration) for the analysis of contrast and with an Elrepho (integrating sphere illumination) for the analysis of the solid print density, and for the corresponding print-through. Equations for print density (PD) and print-through (PT) are described in **Appendix.** The reported print density and print-through values are the mean of 15 readings done on 3 sheets at each inking level.

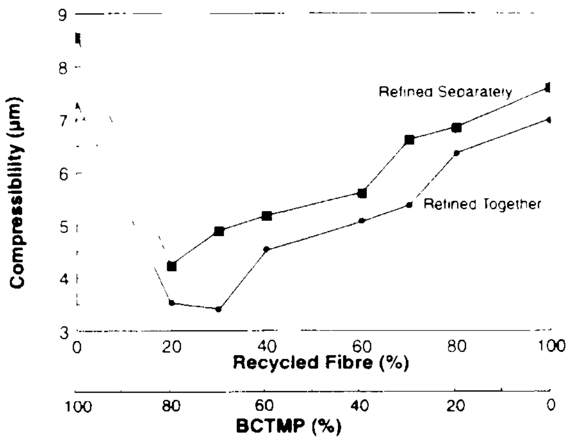
Print uniformity: RMS print density and graininess
Print unevenness is measured by image analysis using the Paprican Microscanner. Here, the only printing characteristics considered are the RMS (root-mean square) print density, and the specific perimeter [**7**]. The RMS print density is the variation in the print density evaluated by the standard deviation of the print density of inked elements from the average print density. On a solid print, the specific perimeter or print graininess is the total length of the median density contour per unit of viewed area. Equation for the print graininess (G) is reported in **Appendix**. RMS, and graininess reported values are the average of 3 evaluations done on 3 sheets (9 values). A high graininess corresponds to a fine grained print structure with many small areas of varying density. A low graininess corresponds to a coarse grained structure with few large areas. The evaluation of print quality is subjective. The best print quality usually translates into a high graininess parameter.

Print contrast
The print contrast was measured both in the light and dark tones. The light tones correspond to a 25% screen band, and the dark tones to a 75% screen band. The equations to calculate contrast are presented in **Appendix**. The reported contrast values are the mean of 15 readings, done on 3 sheets at each inking level. Contrast was evaluated with two instruments: the Macbeth densitometer, similarly to printers practice, and with an Elrepho, according to a papermaker's way of evaluating print density.

RESULTS AND DISCUSSION

The surface compressibility of paper made from BCTMP and recycled fibres.

Figure 2A shows the compressibility measured on the Formette Dynamique samples as a function of the percentage of recycled content in the sheet. Both the 100% BCTMP and the recycled pulp show high compressibility. The higher BCTMP compressibility may be related to a more open network structure that provides room for surface flattening. The high compressibility of the 100% recycled sample may also be related to a large proportion (90%) of hardwood in the pulp. We were unable to explain the sharp drop in surface compressibility observed from the 100% BCTMP sample and the samples containing 20% recycled pulp with either density or formation.



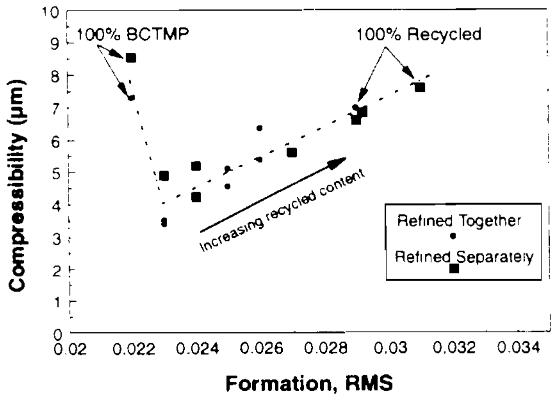


Figure 2. A) The local compressibility of DSF sheets made of pulps refined together or separately as a function of the recycled pulp content. **B)** As a function of formation.

Formation measurements could, however, explain the rise in compressibility from 20% to 100% recycled content, as seen in **Figure 2B,** but other factors may also be important. Besides a high hardwood content, the recycled pulp contains a high percentage of fines. This can be deduced from the CSF and light scattering values in **Table II**. At low levels, we surmised that the fines portion of the recycled pulp contributes to lowering the compressibility by filling-in the open structure network brought about by BCTMP. When the percentage of recycled pulp is increased, a more open and compressible structure network is observed due to the presence of a large proportion of hardwood in the recycled pulp. As a result, the surface compressibility of the sheet increases with increasing amount of recycled pulp.

When the pulp used to make the sheets were co-refined, a smaller surface compressibility was observed. This effect is approximately constant regardless of the composition of the paper sample, which is consistent with the increased bonded area. It seems that, as far as the sheet surface is concerned, refining the pulps together has an approximately constant effect, regardless of the pulp type.

Surface aspect

For all sheets containing recycled pulp, ink particles can be seen on the surface since the waste paper was not deinked prior to pulping. Qualitatively, co-refining the pulps decreases the average size of ink particles on the surface, making the co-refined samples appear better than their non co-refined counterparts.

Print-through properties: the effect of recycled pulp content, co-refining, and calendering.

In the normal printing range, the print-through increases linearly as a function of the print density for all samples with an average coefficient of determination $r^2 = 0.936$. The regression coefficient are listed in **Table III.** The values of the slopes and intercept vary as a function of the recycled content or whether the furnish has been refined together or not. The intercept would corresponds to a print of very low density and thus relates to some paper characteristics. It corresponds to the absorption of the oil vehicle component, as proposed by De Grâce **[8]**, that decreases the paper opacity. The lower the regression intercept, the lower the overall oil vehicle absorp-tion tendency. **Figure 3** shows the results for the conventionally calendered samples. The regression intercept decreases when the recycled pulp content increases. Increasing the recycled pulp content amounts to decreasing the fines content or the sheet overall porosity, and the ink vehicle absorption.

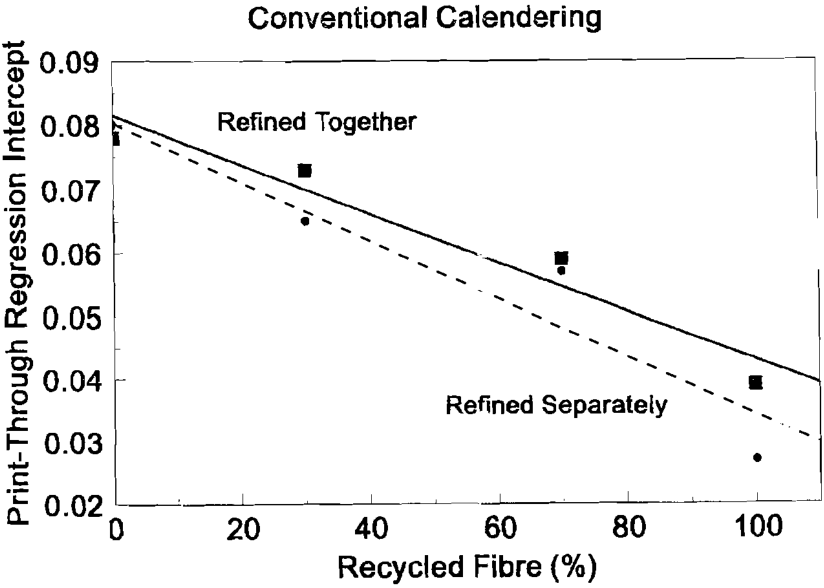


Figure 3. The print-through regression intercept as a function of recycled pulp content for papers refined together and separately. The regression intercept is calculated from the linear variations of print-through as a function of print density. The intercept is interpreted as the overall oil vehicle absorption tendency.

For all pulp furnishes, co-refining shows higher intercept values; i.e. co-refining will tend to produce slightly higher print-through values than when pulps are refined separately. Similar effects due to recycled pulp content and co-refining were found for the regression intercept of all calendering processes used in this study. Although the slopes differences are minor, some marginally significant effects can be outlined. The regression slopes are an indication of how fast the fibrous network saturates with ink: the higher the slope, the faster the ink penetration and the worse the print-through properties. **Figure 4** shows the variation of the regression slopes for the pulps refined together for each of the 3 calendering processes.

The fact that the recycled pulp content has no coherent effect on the slopes is related to formation variations as the curves are similar for all 3 calendering processes. The samples refined together show a similar curve, but with inverse minimum (now at 30% recycled) and maximum (at 70% recycled). However, in the scope of this preliminary study, the reasons for such variations were not fully investigated. However, the ink absorption property decreases as a function of the calendering process in the order SN, CC, TG. The ranking is related to the openness of the surface structure (which was evaluated using confocal microscopy): soft-nip calendered samples presenting a more open structure than conventionally calenderedsamples, temperature gradient having a very closed surface. The effect is well illustrated in **Figure 4**, for samples refined together and above 50% recycled pulp content.

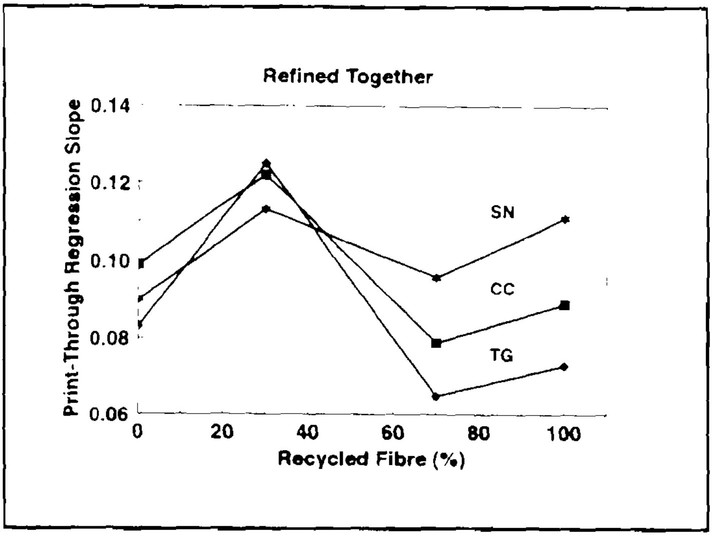


Figure 4. The print-through regression slope as a function of recycled content for 3 calendering processes. The slope is calculated from the linear variations of print-through as a function of print density. The paper originate from co-refining. The slopes are interpreted as the an ink saturation rate; i.e. how fast print-through will increase when more ink is transferred to the paper.

RMS Print density

For all samples, the density variation in the print or RMS print density first increases linearly, then reaches a plateau. As examples, **Figure 5** shows the variation of the RMS print density for the soft-nip calendered papers made from pulps refined separately while **Figure 6** shows the RMS print density variations for the temperature gradient calendered samples made from pulps refined together. In both figures, the RMS print density appears to decrease with increasing recycled content. **Table IV** lists the intercepts and slopes of the linear portions of the RMS print density variations as a function of the print density. **Figure 7A** shows that the regression intercept for the soft-nip calendered samples increases linearly as a function of the recycled content while **Figure 7B** shows that, for the same samples, the regression slope decreases as a function of the recycled content. This trend was found for all calendering processes. In other words, the RMS print density versus percent of recycled pulp forms a family.

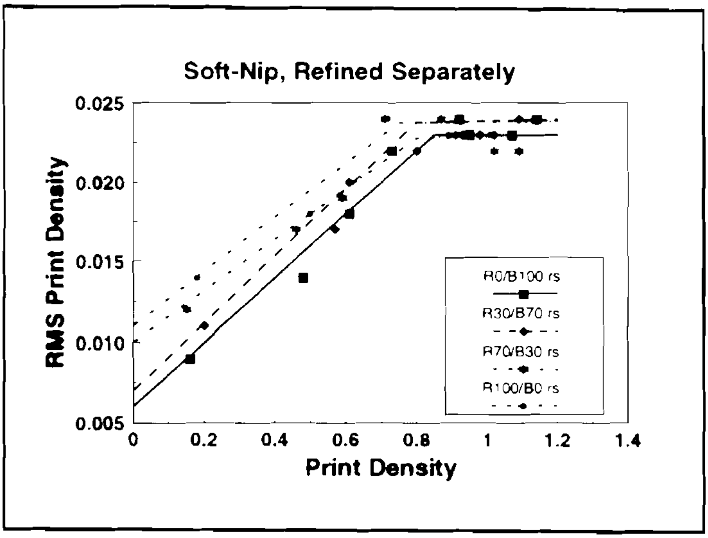


Figure 5. RMS print density as a function of print density for soft-nip calendered papers refined separately.

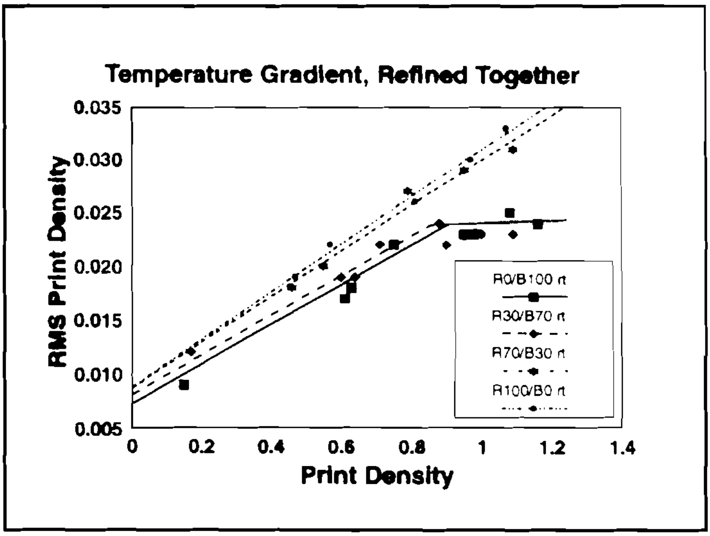


Figure 6. RMS print density as a function of print density for temperature gradient calendered papers refined together.

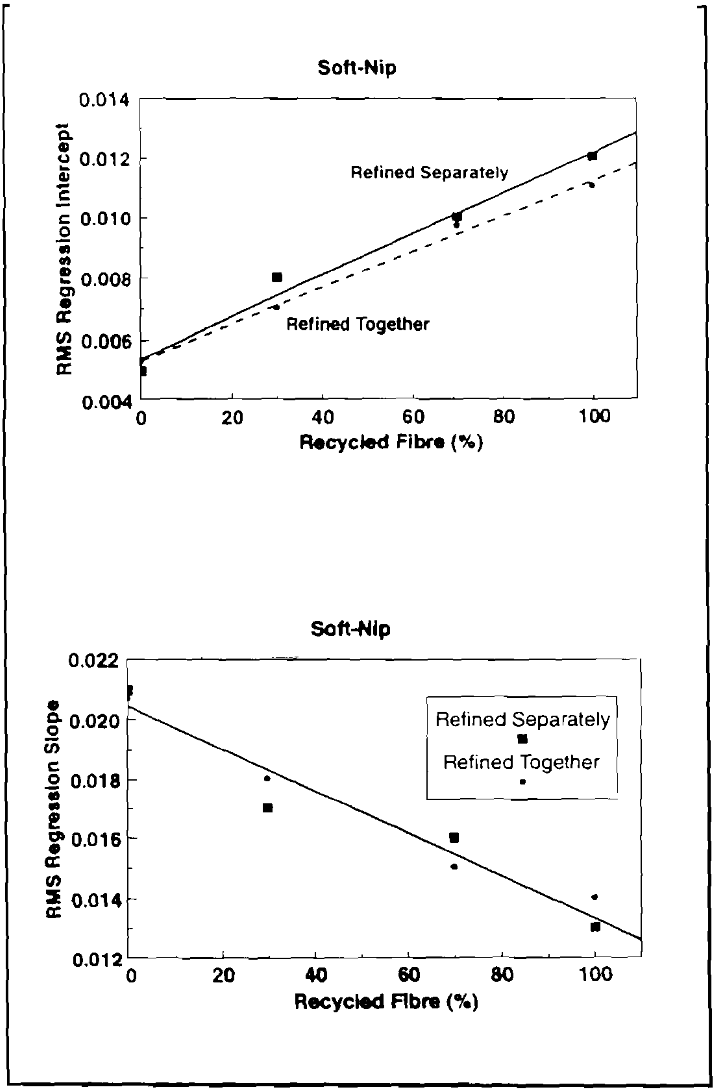


Figure 7. A) The RMS regression intercept as a function of recycled pulp content for soft-nip calendered papers refined together and separately. The intercept is calculated from the linear portion of RMS variations as a function of print density. **B)** The RMS regression slope as a function of recycled pulp content soft-nip calendered papers refined together and separately. The slope is calculated from the linear portion of RMS variations as a function of print density. No physical interpretation of RMS regression slopes and intercept was sought; parameters describe a family of lines.

of straight lines of increasing intercepts and decreasing slopes that do not intersect below 1.0 print density. The RMS variations due to recycled content, co-refining, and calendering are then best analyzed at print densities below 0.8-0.9. As the intercept increases as a function of the recycled content, it is concluded that higher recycled content leads to higher RMS, i.e. poorer print quality as far as print density variations are concerned. However, the regression intercept averaged on all 3 calendering processes shows that co-refining marginally improves the RMS print density.

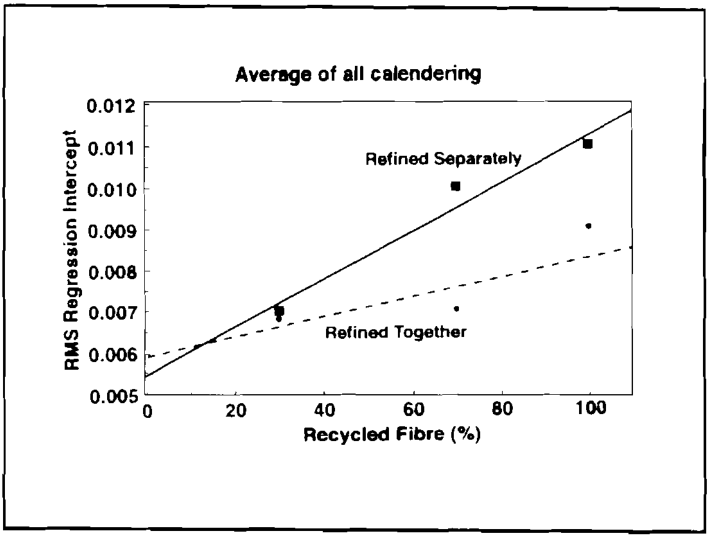


Figure 8. The RMS regression intercept as a function of recycled pulp content for samples refined together and separately, average of all calendering processes.

Figure 8 shows that papers refined together present lower intercept values (the dominant factor in this regression analysis) than the papers refined separately. Calendering does not change the regression intercept but affects the slopes in the order CC>TG>SN. The soft-nip calendered samples present the smallest slope, i.e. the smallest variation as a function of the print density, i.e. it is a better calendering process for these kind of papers. Although statistically significant, the effect of calendering is however of minor industrial significance when compared to the recycled content effect.

Graininess

For all samples, graininess increases linearly from 2.5 to about 3.5 for print densities lower than 0.9-1.0. For print densities above 0.9-1.0, the graininess parameter was ill-defined due to calibration problems: the darker the print, the more difficult it is to evaluate graininess. According to Jordan and Nguyen's original paper [7], graininess increases with print density then reaches a plateau at high density levels. In a first approximation (average r^2 of 0.870), we consider that graininess increases linearly with print density. **Table V** lists the intercept and slopes of the linear approximation. There is no-coherent, significant effect on graininess brought about by calendering (samples were calendered to the same PPS S10), co-refining, or recycled content.

Contrast

No statistical differences were found between the MacBeth (printer's approach) and the Elrepho (papermaker's approach) evaluations of contrast. **Figure 9A** shows the variation of the light tone contrast as a function of print density for the soft-nip papers refined separately and **Figure 9B** shows the dark tone contrast variations for same samples. Contrast varies as a second order polynomial (quadratic) as a function of print density with an average coefficient of determination of 0.944. **Table VI** lists the print density (PD_{max}) corresponding to the maximum values of contrast. A high contrast value translates into a "sharper", i.e. a better print than at low contrast value.

Optimal printing is attained when both the light tone and dark tone contrasts are maximized. Maximum contrast occurs around 0.7 print density in the light tones and around 0.5-0.6 print density in the dark tones. As seen in **Table VII** when pulps are refined together the maximum contrast occurs at a higher print density value and is lower than without co-refining. This is true for both the light and dark tone contrasts. Although small, the differences are significant. Similarly, the differences in contrast due to the calendering process are small but significant. Both light and dark tone contrasts decrease in the order conventional calendering, temperature gradient, and soft-nip calendering. Soft-nip calendering showing the lower contrast values. **Figures 10A** and **10B** show that the contrast increases linearly with the recycled pulp content, both in the light tones (Figure 10A, $r^2 = 0.82$) and in the dark tones (Figure 10B, $r^2 = 0.92$).

The increase in contrast can be explained by the change in surface compressibility when recycled content increases. A more compressible structure requires less ink to reach a given print density, which translate in an improved contrast. However, the higher compressibility is due to a more open structure; it is then detrimental

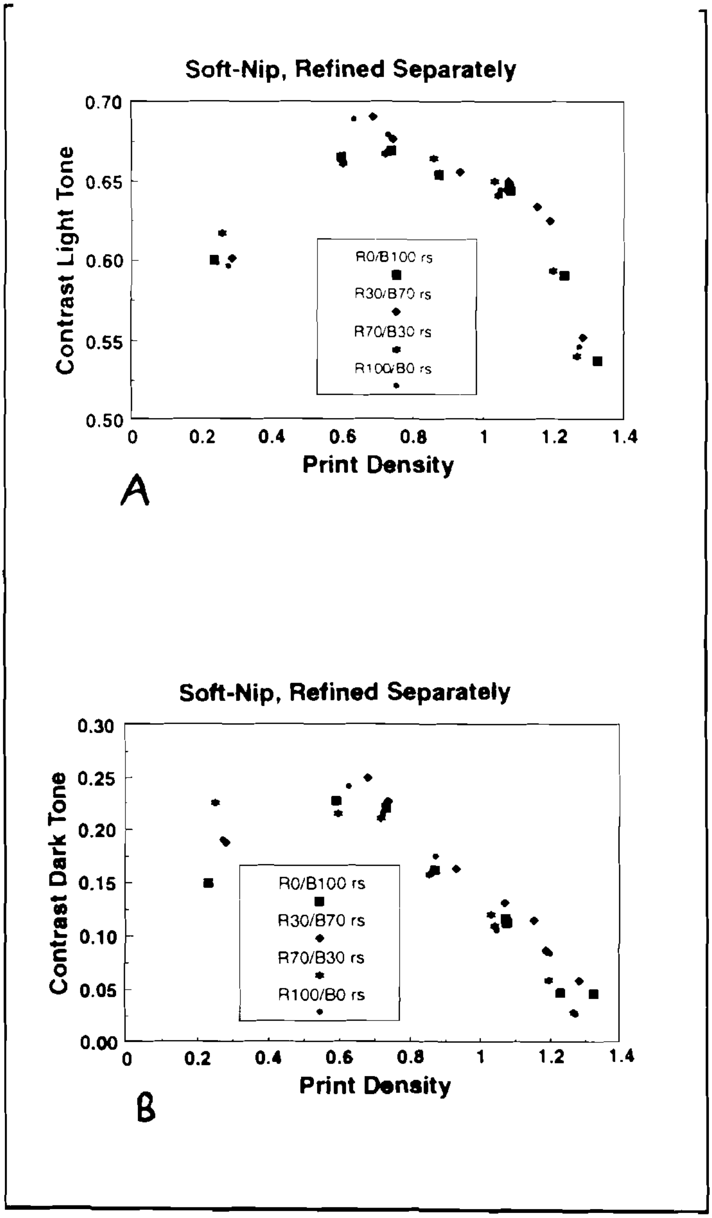


Figure 9. A) Light tone contrast as a function of print density for soft-nip calendered papers refined separately. **B)** Dark tone contrast as a function of print density for soft-nip calendered papers refined separately.

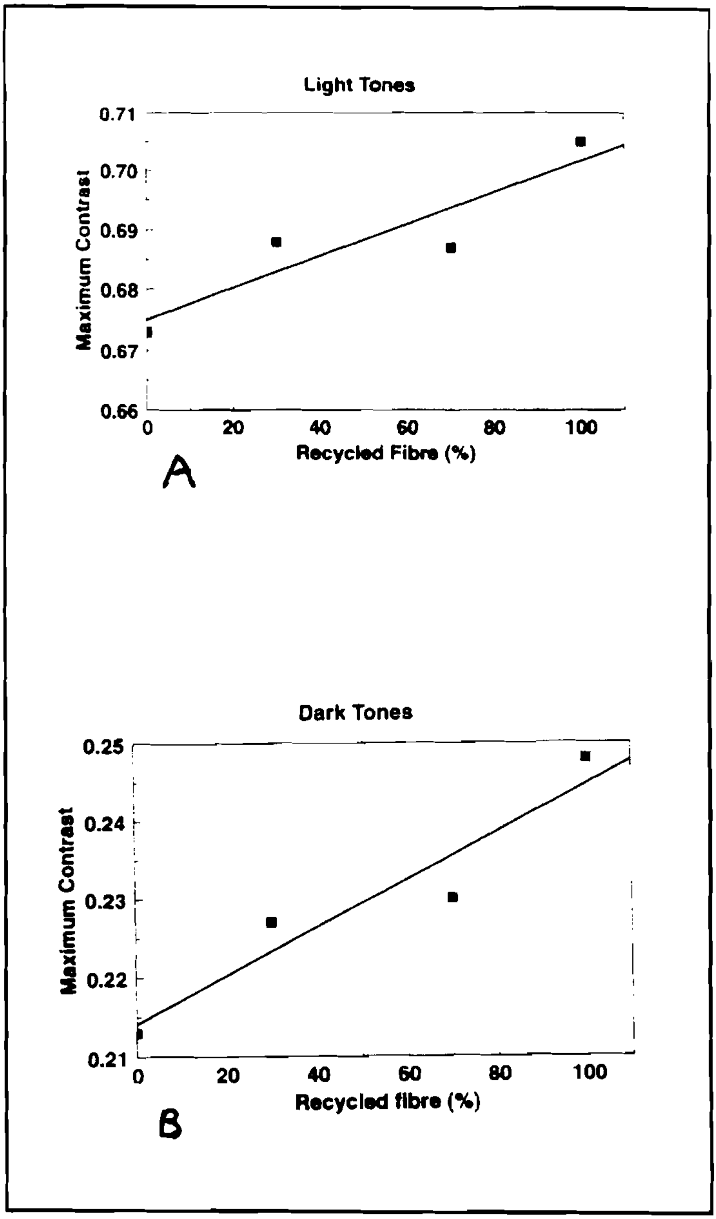


Figure 10. A) Maximum light tone contrast as a function of recycled pulp content, average of all samples. **B)** Maximum dark tone contrast as a function of recycled pulp content, average of all samples.

to print uniformity [2]. As seen previously, RMS print density also increases when the recycled content increases. Co-refining improves contrast but at the detriment of print uniformity.

CONCLUSIONS

From this preliminary study on the effect of co-refining on the printing properties of paper we conclude, as expected from the structural analysis of the paper surfaces, that co-refining mechanical and secondary fibre pulps produces paper of printing characteristics comparable to grades made from pulps refined separately.

A method, adapted from the normal inking method, has been developed to compare the printing characteristics of papers. In the new method, called Normal Contrast Intensity, print density, print-through, RMS print density, print graininess, and light and dark tones print contrast are evaluated at various inking levels.

Main findings are summarized: below:

1. Variations of printing indices
- print-through increases linearly as a function of PD
- RMS print density increase linearly as a function of PD then reaches a plateau
- graininess or specific perimeter increases linearly with PD
- both light and dark tone contrast increase up to a maximum then decrease with PD; maximum contrast occurs around 0.7 in light tones and around 05-0.6 in dark tones

2. Main effects of co-refining, recycled pulp content, and calendering processes for papers calendered to the same smoothness.
- for all calendering processes, print-through decreases as a function of the recycled pulp content
- for all calendering processes, higher recycled content leads to higher RMS print density
- co-refining, recycled pulp content, and calendering processes have no significant effect on the graininess parameter
- co-refining does not affect contrast
- contrast increases linearly with recycled pulp content

3. Secondary (marginal but significant) effects related to co-refining
- co-refining is slightly detrimental to print-through
- co-refining improves RMS print density

4. Secondary (marginal but significant) effects related to the calendering process
- TG produces less print-through than CC which produces less print-through than SN

- SN produces less RMS print density than TG which produces less RMS print density than CC
- CC shows a higher contrast than TG which shows higher contrast than SN

Most of the above effects could be explained but not directly related to surface structure.

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APPENDIX

Mathematical expressions used to calculated paper printing Characteristics

Print density

The print density is expressed as:

$$PD = \log \frac{R_\infty}{R_p}$$

with R_∞ the reflectance of the unprinted paper and R_p the reflectance of the printed paper.

Print-through

The print-through is calculated as:

$$PD = \log \frac{R_{\infty,\ opp}}{R_{p,\ opp}}$$

with R_{∞}, opp and R_{p},opp measured from the opposite side of the print.

Print graininess

The specific perimeter or graininess parameter G is expressed as:

$$G = \frac{\sum_{i=1}^{i=n} l_i}{L_x \cdot L_y}$$

with l_i the perimeter of any element of density corresponding to the median density of the print, and L_x, L_y the dimensions of the viewed area (30 mm x 40 mm in the Paprican Microscanner). The specific perimeter is expressed in mm^{-1}.

Print contrast

The light tone contrast, K_{LT}, is calculated as:

$$K_{LT} = \frac{OD_{solid} - OD_{25\%}}{OD_{solid}}$$

with OD_{solid}, $OD_{25\%}$ optical densities measured in the solid, and in the 25% screen, respectively.

Similarly, the contrast in the dark tones is calculated as:

$$K_{DT} = \frac{OD_{solid} - OD_{75\%}}{OD_{solid}}$$

with OD_{solid}, $OD_{25\%}$ optical densities measured in the solid, and in the 25% screen, respectively.

Table Ia. Calendered pilot paper machine samples, roughness S_{10} (in μm)

Sample	Composition Recycled/BCTMP % / %	Conventional	Temperature Gradient	Soft-nip
R0/B100rs*	0/100	4.90	5.20	4.40
R30/B70rs	30/70	5.50	5.40	4.25
R70/B30rs	70/30	4.95	5.35	4.00
R100/B0rs	100/0	5.25	4.90	4.30
R30/B70rt	30/70	4.85	5.40	4.50
R70/B30rt	70/30	5.10	5.30	4.55
R100/B0rt	100/0	5.45	4.65	4.35

* R0/B100rs and R0/B100rt are the same sample

Table Ib. Optical properties of the pilot paper machine samples (uncalendered)

Sample	Brightness ISO %	Reflectance R_{inf} %	TAPPI Opacity %	Printing Opacity %	Light Coefficient cm2/g		CIE Colour Coordinates		
					k	s	L^*	a^*	b^*
R0/B100rs	83.50	90.75	74.9	72.7	0.95	198.9	96.14	-1.10	6.06
R30/B70rs	78.85	84.59	73.1	75.4	2.65	187.1	93.58	-0.20	4.78
R70/B30rs	73.97	79.53	79.1	8.2	5.65	214.9	91.32	0.30	4.51
R100/B0rs	75.97	79.56	79.0	83.2	6.09	227.4	91.36	0.50	2.88
R30/B70rt	72.57	80.21	72.6	75.9	4.14	168.8	91.58	0.00	6.60
R70/B30rt	70.56	76.54	73.1	79.0	6.22	171.7	89.96	0.20	5.26
R100/B0rt	73.12	76.35	76.3	81.9	7.14	192.5	89.95	0.30	2.65
Pooled SD	0.09	0.07	0.4	0.4	0.11	3.5	0.03	<0.01	0.05

k light absorption coefficient, and **s** light scattering coefficient

Note: These properties do not vary significantly upon calendering, independently of the calendering method used.

Table II - Dynamic Sheet Former (DSF) samples

Sample Code	Recycled % weight	BCTMP % weight	CSF** mL	Tensile Index Nm/g	Light Scat. Coeff. m^2/kg	Formation	Compressibility µm
1rs*	0	100	280	81.5	38	0.022	8.54
2rs	20	80	325	71.7	40	0.024	4.22
3rs	30	70	310	58.9	41	0.023	4.89
4rs	40	60	315	66.5	42	0.024	5.80
5rs	60	40	360	55.6	43	0.027	5.60
6rs	70	30	350	53.0	44	0.029	6.60
7rs	80	20	360	51.1	46	0.029	6.83
8rs	100	0	390	45.9	48	0.031	5.79
1rt*	0	100	440	86.6	35	0.022	7.28
2rt	20	80	345	93.8	35	0.023	3.52
3rt	30	70	316	84.1	34	0.023	3.40
4rt	40	60	265	81.5	34	0.025	4.53
5rt	60	40	250	92.0	37	0.025	5.08
6rt	70	30	120	70.8	37	0.026	5.37
7rt	80	20	190	94.0	35	0.026	6.34
8rt	100	0	130	80.6	36	0.029	6.97

* rs = refined separately, rt = refined together

** co-refined pulps have been screened (Somerville)

Table III - Print-through as a function of print density						
Sample	Intercept			Slope		
	CC	TG	SN	CC	TG	SN
R0/B100rs	0.078	0.073	0.076	0.099	0.083	0.090
R30/B70rs	0.065	0.057	0.065	0.070	0.077	0.087
R70/B30rs	0.059	0.042	0.049	0.086	0.103	0.102
R100/B0rs	0.027	0.033	0.037	0.072	0.061	0.087
R30/B70rt	0.073	0.060	0.063	0.122	0.125	0.113
R70/B30rt	0.059	0.066	0.052	0.079	0.065	0.096
R100/B0rt	0.039	0.041	0.039	0.089	0.073	0.111

Refined separately: mean intercept = 0.0551, slope = 0.0848
Refined together: mean intercept = 0.0599, slope = 0.0954
Average coefficient of determination, 21 samples is:
r^2= 0.936, SD = 0.059

Table IV - Root Mean Square Print Density (RMS-PD) as a function of print density						
	Intercept			Slope		
Samples	CC	TG	SN	CC	TG	SN
R0/B100rs	0.006	0.006	0.005	0.020	0.020	0.021
R30/B70rs	0.007	0.005	0.008	0.021	0.025	0.017
R70/B30rs	0.010	0.010	0.010	0.017	0.015	0.016
R100/B0rs	0.007	0.014	0.012	0.025	0.013	0.013
R30/B70rt	0.006	0.009	0.007	0.021	0.017	0.018
R70/B30rt	0.003	0.007	0.010	0.029	0.024	0.015
R100/B0rt	0.006	0.009	0.011	0.024	0.021	0.014
Average, rs	0.008	0.009	0.009	0.021	0.018	0.017
Average, rt	0.005	0.008	0.008	0.024	0.021	0.017

Average coefficient of determination for linear portion, 21 samples, r^2 = 0.959, SD = 0.034; pooled SD on intercept < 0.001, pooled SD on slope = 0.002.

Table V. - Graininess parameter as a function of print density

Sample	Intercept			Slope		
	CC	TG	SN	CC	TG	SN
R0/B100rs	2.760	2.604	2.638	2.570	0.854	0.818
R30/B70rs	2.633	2.618	2.562	1.030	1.059	0.820
R70/B30rs	2.493	2.505	2.562	0.855	1.020	1.025
R100/B0rs	2.681	2.560	2.387	0.907	1.088	1.101
R30/B70rt	2.508	2.355	2.371	0.719	1.111	1.293
R70/B30rt	2.727	2.779	2.435	0.806	0.657	0.882
R100/B0rt	2.916	2.743	2.433	0.395	0.631	0.803
Average, rs	2.642	2.572	2.537	1.341	1.005	0.941
Average, rt	2.738	2.620	2.469	1.123	0.813	0.949

Average coefficient of determination, 21 samples r^2=0.870, SD = 0.100

Table VII. Effects of co-refining and calendering on contrast, mean values

Mean Value	Light tones		Dark tones	
	PD_{max}	K_{max}	PD_{max}	K_{max}
Refined separately	0.6943	0.6958	0.4893	0.2440
Refined together	0.7025	0.6808	0.5640	0.2145
Conventional	0.6875	0.6975	0.4657	0.2514
Temperature gradient	0.6913	0.6925	0.5650	0.2238
Soft-nip	0.7163	0.6750	0.5200	0.2188

Table VI - Contrast as a function of print density

Sample	Light tones							
	CC		TG		SN		Mean	
	PD_{max}	K_{max}	PD_{max}	K_{max}	PD_{max}	K_{max}	PD_{max}	K_{max}
R0/B100rs	0.77	0.68	0.80	0.67	0.72	0.67	0.728	0.708
R30/B70rs	0.60	0.73	0.62	0.72	0.75	0.68	0.684	0.700
R70/B30rs	0.72	0.68	0.65	0.69	0.69	0.68	0.686	0.678
R100/B0rs	0.64	0.74	0.65	0.73	0.72	0.68	0.696	0.704
R30/B70rt	0.70	0.66	0.71	0.67	0.71	0.67	0.690	0.684
R70/B30rt	0.65	0.70	0.58	0.70	0.68	0.67	0.662	0.666
R100/B0rt	0.65	0.71	0.72	0.69	0.74	0.68	0.702	0.708
	Dark tones							
R0/B100rs	0.53	0.22	0.64	0.21	0.59	0.21	0.438	0.374
R30/B70rs	0.53	0.28	0.46	0.24	0.59	0.23	0.420	0.360
R70/B30rs	0.41	0.24	0.49	0.20	0.36	0.23	0.340	0.304
R100/B0rs	0.16	0.38	0.57	0.27	0.54	0.22	0.384	0.396
R30/B70rt	0.42	0.21	0.66	0.20	0.55	0.20	0.408	0.364
R70/B30rt	0.68	0.21	0.34	0.27	0.40	0.23	0.380	0.290
R100/B0rt	-	-	0.72	0.19	0.54	0.22	0.483	0.317

Determination coefficient for quadratic regression:
light tones, $r2= 0.937$, $SD = 0.038$
dark tones, $r^2= 0.950$, $SD = 0.028$
grand mean, $r^2 = 0.944$, $SD = 0.034$