New technique for monitoring ink-water balance on an offset press

JOAKIM VOLTAIRE[1], WARREN BATCHELOR[2], ANDREW FOGDEN[3]*, AFRIANA SUDARNO[4], PAUL BANHAM[5]

SUMMARY

An acoustic technique, with microphone placed near the print nip exit on a sheet-fed offset press during trial printing of newsprint, was used to provide information relating to splitting of the ink-fountain solution film. The average acoustic power increased with tack of the ink used and with target optical density. Further, average power decreased during each run, reasonably strongly correlated to increase in fountain solution consumption. This indicates that average power is primarily sensitive to instantaneous tack of the ink-fountain solution film, and can be used to monitor tack and indirectly infer ink-water balance in the nip. Laboratory experiments were also performed using the Hydroscope instrument to simultaneously measure tack and average acoustic power of the splitting of inked rollers during fountain solution titration and evaporation. While these two measured parameters were not directly correlated over all conditions of emulsification, both decreased in tandem over intermediate amounts of fountain solution.

KEYWORDS

Offset printing, ink tack, ink-water balance, fountain solution, newsprint, linting, acoustic emission, lithography

Introduction

Offset lithography relies on the differences in rheology and surface chemistry between ink and fountain solution (mostly water) and their preferential interaction with the lipophilic (ink accepting) image carrying area and hydrophilic (water accepting) non-image area, respectively, on the printing plate. Ink and water are delivered through separate roller trains and meet on the plate at the forme rollers. At normal operating conditions the ink will, by means of turbulent jet and shear action (*1*), partly emulsify the water during nip film splitting, with the remainder left as surface water. From the plate cylinder the image is carried over, i.e. "offset", to the paper via the blanket cylinder, thus transferring both ink and water to the paper. The lithographic printing performance depends primarily on the content of surface water (*2*), which ideally should be eliminated by emulsification or evaporation, so as to not interfere with ink transfer, or otherwise it has to be squeezed away in the nip.

For this reason, ink-water emulsion stability, with focus on both rheological (*3*) and thermodynamic properties (*4*), has been studied extensively using a range of laboratory techniques and supported by theory. Indeed, one such commercial instrument, the Hydroscope (*5*), developed to characterise emulsification behaviour on inked rollers in order to assess ink-fountain solution compatibility in press applications, is used in the current study. By the same token, shear rates, flows and timescales typically encountered in print nips are rarely accessible with laboratory equipment. This necessitates a compromise between, on the one hand, the quality and amount of information obtainable at laboratory scale, and on the other, the reality of that which can be obtained by monitoring on-press. A number of measurement principles to quantify water content can be adapted to on-press applications, based on, e.g. infrared (*6,7*) and radioactive trace element (*8*) detection. However, knowledge of the emulsified state of this water and how it influences splitting force (i.e. tack) during transfer would require support from an on-line tack measuring device. Knowledge of instantaneous tack on press is important in itself, as it controls ink transfer and thus the final print quality. A number of laboratory instruments are available to determine tack and follow its time evolution, e.g. the Hydroscope for ink-fountain solution emulsions between rollers, and the Deltack (*9*) for ink (without water) between rubber blanket and paper. For the reality of all four components (ink and water, paper and blanket) present on a lithographic printing press, such mechanical-electrical measurement principles (*10-12*) are though difficult to implement non-intrusively.

The present study tests a non-conventional method, based on the noise emitted by ink film splitting from the exit of an offset print nip, as a possible means to non-intrusively monitor tack and thus interpret the ink-water balance at the nip. The literature of acoustic emission (AE) applications to printing is sparse compared to the wide use of such techniques in analysis of e.g. cracks and faults (*13*). One exception is the work published by a Japanese research group in the early 1990's, demonstrating that the offset ink film splitting generally gives rise to high frequency broad band noise, centred at 10-20 kHz. Its overall magnitude, or average power, was found to increase for tackier or structured inks, and decrease on fountain solution addition (*14-16*). Further, Iwasaki et al (*17*) showed that the transition from image to non-image on the blanket cylinder on a sheet-fed press gave rise to an acoustic impulse pattern sensitive to tack and printing speed through the nip. More recent studies involving two of the current authors observed an increase of the acoustic average power with optical density when acoustically monitoring an IGT laboratory printer (*18*), a heat-set web offset press (*19*) and a two colour sheet-fed press (*20*), although the fount level was not measured in the latter study.

The phenomenon of print nip splitting noise (*18*) involves at least three sub-disciplines of fluid dynamics, namely acoustics (*21,22*), lubrication and cavitation flow (*23-25*). Lubrication represents the ideal film flow (*26,27*), mostly prevailing about the centre region of the print nip, whereas cavitation results from the

[1]Postgraduate student and communicating author, [3]Research Fellow
YKI, Institute for Surface Chemistry
Stockholm, Sweden
[2]Senior Lecturer, [4]Postgraduate student
Australian Pulp and Paper Institute, Monash University
Melbourne, Australia
[5]Senior Scientist
Norske Skog Research and Development
Boyer, Tasmania, Australia
*Present address: Dept. Applied Mathematics, Australian National University, Canberra, Australia

sub-ambient pressures to which the (incompressible) ink is subjected in the diverging exit of the nip (*28*,*29*). As cavities extend and implode into a filament break, they cause elastic volumetric strain (*22 p.7*) of the enclosed air or vapour, consequently producing a sound pressure wave emanating from the nip exit. While it is clear that no general, simple mathematical relation exists between the tack, i.e. tensile stress in the nip exit, and magnitude of sound pressure produced, they exhibit sufficient similarities in response to ink amount and type and fountain solution amount to suggest that useful empirical relations may hold over the range of fluid properties of relevance to offset printing. To this end, the current paper first analyses emulsions of fountain solution in coldset offset inks on the Hydroscope, simultaneously measuring tack and acoustic emission to determine the experimental correlation between these two parameters. Similar inks and fountain solution are then used in newsprint printing trials on a sheet-fed offset press, again monitored by microphone, and with the response compared to simultaneous monitoring of fountain solution consumption and optical density to provide deeper insight into tack and ink-water balance in the nip.

Fig. 1 Photograph of Hydroscope instrument, showing the two brass rollers, the upper black rubber roller placed in contact with the back brass roller and white tubing through which fountain solution is applied dropwise onto the front roller before entering the nip. The unit on the left controls the temperature of the brass rollers.

Materials and Methods

Materials

The inks for the laboratory experiments and printing trials were all coldset test newsprint black inks supplied by Toyo. In particular, the Hydroscope experiments used two such inks, labelled Ink C and D, of tack 6 and 9, respectively, while the printing trials used another two samples, Ink A and B, of tack 4 and 13.5, respectively. These tack numbers were obtained from Inkometer measurements performed by the manufacturer. The fountain solution used together with these inks in all experiments and trials was 5% Eurofount H (DS Chemport, Australia). The paper for the printing trials was A3 cut sheets of Norstar (Norske Skog), an improved newsprint of grammage 52 g/m^2 with ISO brightness 74, containing 5-8% filler. This batch of Norstar was produced in a horizontal gap former, with its bottom side (facing downwards) receiving the print in the trials.

Hydroscope instrument

The Hydroscope (*5*) measures the evolution in ink tack from film splitting between motor-driven rotating rollers before, during and after addition of fountain solution. As shown in Figure 1, it consists of two brass rollers, both of diameter 79.5 mm and length 145 mm, with a fixed gap between them. Tack is measured from a smaller rubber roller of diameter 49.7 mm and again 145 mm long, which is placed in contact with one of the brass rollers. The test uses 10 g of ink, equivalent to the very high amount of 105 g/m^2 on the rollers, uniformly distributed through approx. 100 s of rotation at the start of each run, after which fountain solution addition is commenced. The solution is added dropwise at a fixed rate of 1.3 ml/min to the middle of the other brass roller, subsequently entering the nip between them. At the point of time when fountain solution first becomes visible by the operator along the entire length of the nip, its feed is switched off, after which evaporation from this saturated state eventually returns the ink to the initial solution-free state and the experiment is concluded. The temperature and speed of the rollers were kept constant at 25°C and 40 m/min respectively throughout the experiments.

Printing press

The printing trials were performed on the single-unit sheet-fed offset press (Heidelberg GTO-52) shown in Figure 2a.

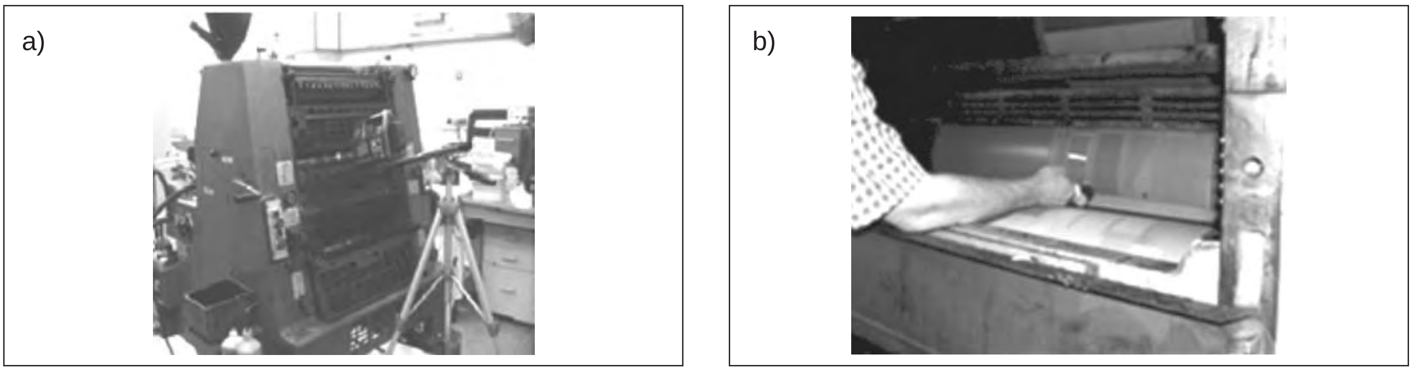

Fig. 2 a) Heidelberg sheet-fed offset press used in the printing trials, also showing the tripod upon which the microphone was mounted, directed into the exit of the blanket-paper nip.
b) Removal of blanket deposits with adhesive tape after a printing run to determine lint weight.

The press was run at a speed of 8000 sheets/hour, corresponding to 2.22 revolutions per second of the blanket cylinder (of circumference 520 mm). The model print layout used comprised two square fields of 50% halftone followed by 100% fulltone, both equally large and together covering the entire A3 sheet aside from a thin unprinted border. A total of 7000 copies were printed per trial run. During each run the fountain solution consumption was monitored by manually reading its level from a graded scale, and recalculated as usage per sheet. The optical density of the 100% field was measured using a Gretag densitometer after every 500 sheets. Further, the lint amount remaining on the blanket in the two fields was measured at the conclusion of each 7000-sheet run. For this measurement the print cylinder was disconnected, to prevent further transfer of ink and fountain solution to the blanket, and the press was then run for 20 additional copies to remove the free ink and fountain solution remaining on the blanket. Following this, the lint particles, as well as the small amount of dried residual ink, were removed using pre-weighed tape (Fig. 2b), with its weight increase then used to calculate the lint amount in g/m^2.

Acoustic monitoring and signal processing

The microphone was clamped in a fixed position close to, and directed towards, the exit of the nip, in particular at an approximate distance of 2 cm for the Hydroscope experiments and 5 cm for the printing trials (Fig. 2a), to detect the local sound pressure as a voltage signal. This microphone comprised a high level 1/4-inch condenser microcapsule of type 40BE (G.R.A.S.), with its preamplifier connected to a battery power supply. Digital sampling was performed by a laptop connected to an analogue-to-digital converter (DT9801). The detectable frequency range was 10 Hz-50 kHz, with the upper limit set by the sampling frequency of 100 kHz, and the sound pressure level (*SPL*) range 40 -168 dB. At regular intervals over the course of the Hydroscope experiments and printing runs a record of signal amplitude versus time was collected, with sampling duration of 2 and 5 s, respectively. Using LabView® and DTLV-Link®, this signal was split into buffers of 0.1 s, then concatenated into larger recordings.

Processing of the sampled raw data to extract the measure(s) of interest was performed afterwards. Signal amplitude was converted from voltage back to pressure, *p*, using the microphone's calibrated sensitivity of 3.92 mV/Pa. The current study used only the simplest averaged measure, termed the average power, defined as (*30 p.6*):

$$P_a = \frac{1}{N}\sum_{k=0}^{N-1} p_k^{\;2} \qquad [1]$$

where p_k denotes the sound pressure contribution from each of the *N* individual samplings in the analysed record. The average power is proportional to the potential energy density of the sound field (*22 p.76*). Spectral analysis was performed via the power spectral density, *PSD*, defined by (*31 p.504*):

$$PSD = \frac{2\left|X_n\right|^2}{N^2\Delta f} \qquad 1 \le n \le \frac{N}{2}-1 \qquad [2]$$

Here X_n is the discrete Fourier transform (DFT) of the sampled p_k array, obtained by the Fast Fourier Transform (FFT) algorithm (*31 pp.504-510*) and $\Delta f = f_s/N$, where f_s is the sampling rate (here 100 kHz). The *DC* ($n = 0$) and Nyquist ($n = N/2$) frequencies are omitted from Equation 2. According to Parseval's theorem (*31 pp.504,551*), the discretised frequency integral of the *PSD* then gives back the average power in Equation 1, or its filtered value on subsequent selection of whatever subinterval of *n* in Equation 2 is deemed appropriate to exclude unwanted frequencies.

Uncorrelated white noise in the *PSD* was eliminated using the Welch method (*32*), in which the time record is divided into overlapping sub-intervals over which each *PSD* is calculated and summed. The average power was used in both short and long time analyses. For the former, the average was calculated in a time window of 0.001 s and then slid forward in time with 50% overlap, thus tracing the dynamics during e.g. the printing of individual sheets. In long time analyses, specific time intervals were extracted and summed to single averages, used to follow evolution over entire print runs or Hydroscope experiments. For scaling reasons all graphs below are presented in the unit dB *SPL*, using a reference of 20 µPa corresponding to the lowest audible sound pressure:

$$SPL(\mathrm{d}B) = 10\log_{10}\frac{P_a}{4\cdot 10^{-10}} \qquad [3]$$

For the rapidly varying signals from the press, with each period comprising sheet in-feeding followed by printing, time filtration is necessary to isolate the same sub-interval of the printing interval to compare over the course of a printing trial. Since the recording was not externally triggered by press cylinder motion, as was the case in (*19*), the time shift between records was instead determined by cross-correlating the running average power of each, relative to a reference. This method proved to be fast since, compared to the full record, its running average power contained much less, but still sufficient, information. Since no low pass filtering was applied prior to sampling, aliasing errors are expected, in which power is mirrored from frequencies above the Nyquist frequency (50 kHz) into the analysed region below 50 kHz (*31 p.500*). However, since the *PSD* decays before this value, aliasing only gives a minor error, which is unimportant to the analysis. Further, it could be assumed that any extra aliased noise also originates from the ink film splitting of central interest to this study.

Results and Discussion

The following presents the results and interpretations, first from the simpler situation of the Hydroscope laboratory experiments and then from the printing trials, with the role of ink and fountain solution compared in these two cases.

Hydroscope tack and acoustics

For each of the two inks, C and D, a pair of Hydroscope experiments were performed, with the details given in Table 1 and Figure 3. Figure 3a, comparing the tack force evolution (i.e. the standard information obtained from the Hydroscope) of the two inks, shows that Ink D reaches its minimum tack value, and thus maximum capacity (i.e. amount of added fountain solution at emulsion collapse), slower than Ink C. This, together with the observation of the longer time taken for the tack of Ink D to return to its initial value after the addition of fountain solution is halted, indicates a higher affinity to fountain solution for Ink D. The average acoustic power, measured simultaneously with tack, is shown in Figure 3b. This power was high pass post-filtered to remove contributions from frequencies below 2 kHz, as these were dominated by machine and motor noise and remained essentially constant during the experi-

Table 1
Total amounts of ink and added fountain solution at titration stop (FS capacity), and start-stop times of addition of the latter, for the two inks and their pair of replicates in the Hydroscope experiments.

Ink_Replicate	Ink mass on roller (g)	Titration start (s)	Titration stop (s)	FS capacity (ml/g ink)
C_1	10.2	96.4	258	0.34
C_2	11.2	96.4	308	0.41
D_1	10.4	96.0	334	0.50
D_2	10.3	102	310	0.44

ments, in contrast to the sensitive response of the retained high frequencies to the titration and subsequent evaporation of the fountain solution.

It is clear from Figure 3 that the Hydroscope reproducibility, either measured in tack or average acoustic power, is reasonably good, taking into account the slight initial shift in sample D_2 due to its somewhat later start, and the time-dilation of the curve for sample C_2 due to its 10% higher ink amount. Further, it is clear that both measures give roughly similar-shaped curves, in the sense that both tack and average power decrease to a minimum during fountain solution addition, then return to their initial states after fountain solution removal by evaporation. However, some differences in behaviour between these properties are also apparent, warranting closer inspection. In particular, beginning with the tack results, during the first approx. 100 s of ink distribution prior to titration, Ink D displays higher tack than Ink C, in agreement with their Inkometer tack ranking. During the next 100 s, tack drops linearly due to addition of fountain solution, i.e. due to emulsified droplets lowering ink film cohesion, and any non-emulsified surface water that might be present, creating a weak boundary layer. This fall is slower for Ink D, presumably due both to its higher ink tack and its higher affinity for fountain solution, with the latter aiding in reducing both the size of emulsified droplets (helping film cohesion) and increasing the rate of emulsification (more rapidly removing surface water).

The minima in tack are reached around the cessation of titration (which takes longer for the higher ink amount of C_2), at which stage the amount of excess surface water is greatest. Following this the tack of both inks rises relatively fast to overshoot their starting values before rather slowly relaxing back to the initial level, often in a non-monotonic (oscillatory) manner. This overshoot is mainly due to the establishment over these long times of “better” emulsions, i.e. with smaller droplets and less surface water, compared to those hastily forced upon the ink during titration, with these smaller drops contributing positively to both viscosity and elasticity, and hence to tack. The oscillatory behaviour at long times is presumably caused by the interplay of changes in emulsion state and progressively decreasing thickness of the emulsion film.

While the average acoustic power in Figure 3b also initially ranks the two inks in the order of their tack values, it then rises during the first approx. 50 s of titration (as could be heard too), and especially so for Ink C, before exhibiting an extremely rapid fall (for both inks) around t = 200 s. The rise is presumably due to the fact that the sound from the ink itself, owing to its cavitation and subsequent expansion, deformation and collapse of these internal ink-air interfaces in the nip exit, is now complemented by similar contributions from the new sources, i.e. the interfaces between ink and fountain solution droplets. Thus average acoustic power increases, despite the fact that these extra sound sources lower the tack. The lesser rise for Ink D then merely reflects the fact that its higher air-cavitation noise gives proportionally less scope for further increase from the extra ink-water contributions on titration. As emulsification proceeds, the rate of creation of these new internal interfaces slows, at which time the expected effect of tack decrease on reducing the average power then begins to dominate, producing the rapid fall. After this time the slower fall in average power to its minimum and subsequent fast rise after termination of titration (but again slower for C_2) both mirror the corresponding trends in tack. Note though that in the final stage, another distinction becomes evident, namely that average power displays a basically monotonic rise to its original level, without the overshoot and oscillations in tack. This suggests that air cavitation once again largely dictates average power, with the smaller, less deformable fountain solution droplets at this stage contributing little extra, and their effects on fluctuations about already-high tack levels apparently also having little impact on average power.

Figure 4 combines Figures 3a and b to plot the two measures against one another, i.e. parameterised by time, for these two inks and replicates of each. The curves clearly illustrate that there is not a

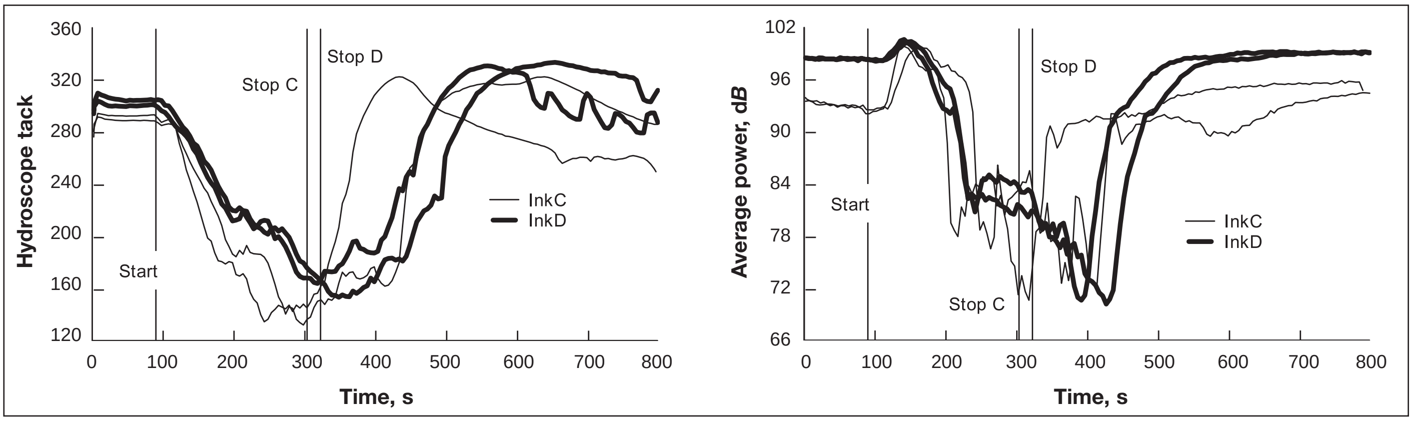

Fig. 3 Hydroscope results for Ink C and D (two replicates of each), with titration start and stop times indicated by the vertical lines, in terms of a) tack and b) average acoustic power.

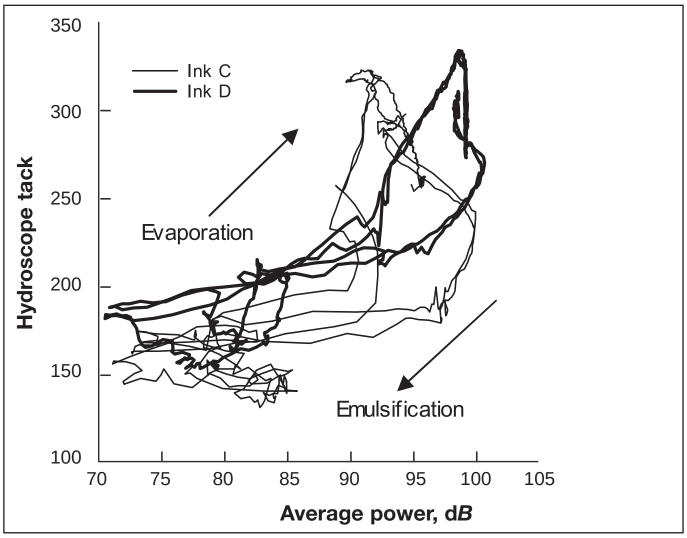

Fig. 4 Combined plot of tack versus average acoustic power from the Hydroscope for Inks C and D, obtained by eliminating time from the graphs in Fig. 3.

single linear correlation between tack and average power, but rather a history-dependent loop driven by emulsification on the way out and evaporation on the way back in. In particular, the deviation from linearity is chiefly due to the initial maximum in average power and final oscillation in tack, as well as the noise and slight delay in average power near the end of titration. However it should be borne in mind that the wealth of linked information in Figure 4 gives a somewhat misleading impression, distracting from the fact that tack and average acoustic power are reasonably well correlated.

Printing trial acoustics

Three printing runs, each of 7000 sheets, were performed, with Run 1 and Run 2 using the low tack (4). Ink A and high tack (13.5) Ink B, respectively, in both cases targeting an optical density of 1.0 in the 100% field, and Run 3 again using Ink B but now targeting a lower optical density of 0.7. Pauses of varying durations were taken between these runs, and temporarily during each, and will be detailed below.

As mentioned above, acoustic monitoring of the press in operation is somewhat more complex than for the Hydroscope, in terms of the need for time filtration to extract the sub-intervals of interest (in our case during ink transfer and splitting) and coupled to frequency filtration to separate this ink contribution from the loud machinery noise obscuring it. For this reason more attention will be given to explaining the various steps in processing the raw signal, leading up to interpretation of the processed results. The processing is illustrated in Figure 5 for a representative record of 2 s duration from Run 1. From the raw signal, the periodic spike clusters (originating from the in-feeding machinery) are partially discernable, but no useful information related to the ink splitting and transfer events occurring between these is apparent. From this the corresponding running average power, calculated from Equation 1 after high-pass filtration at 30 kHz and shown in Figure 5b, much more clearly distinguishes these periodic sub-intervals during which printing of each sheet occurs. The *PSD* determined from Equation 2 from within such a printing sub-interval is displayed in Figure 5c, and compared there to that from the complementary sub-interval between sheet impressions (i.e. containing the in-feeding). The spectra are distinctly different above around 15 kHz, with that from printing possessing an extra contribution. The nature of this contribution, i.e. a broad band without sharp peaks or well-defined frequency combinations, together with the absence of sources of such bands from press machinery during this printing sub-interval, suggests that this indeed arises from the ink film splitting. On the other hand, at frequencies below approx. 15 kHz the spectra from these sub-intervals are more similar, suggesting their dominant source to be machinery sounds from the rotating cylinders and their

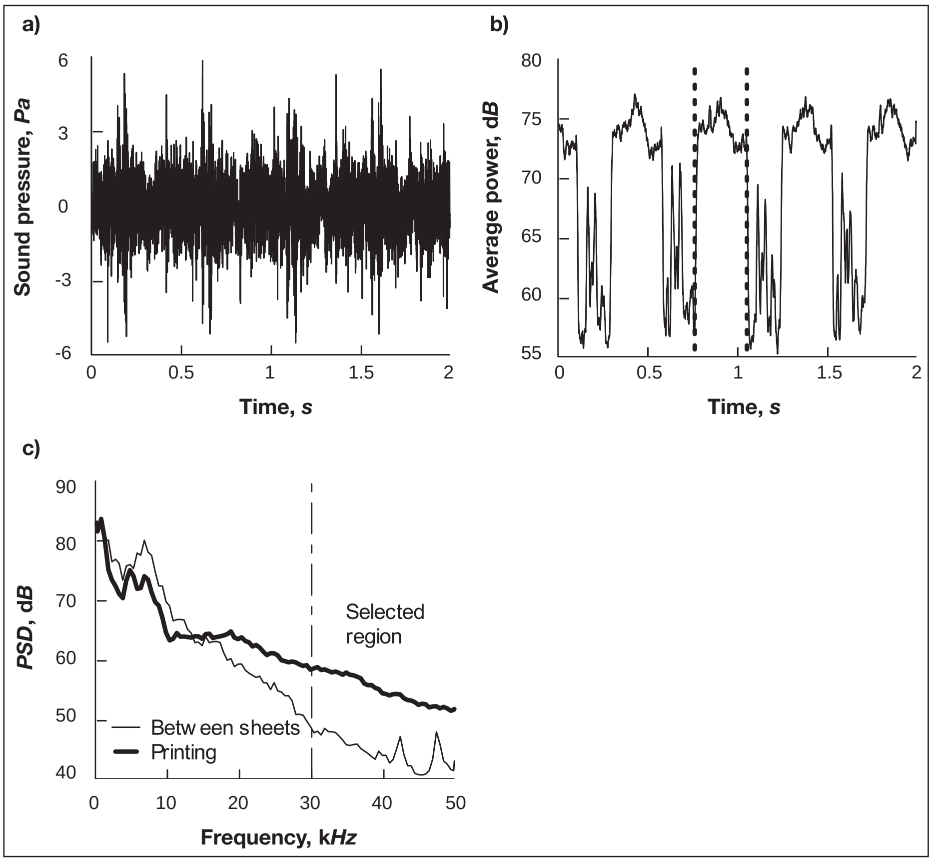

Fig. 5 Illustration of acoustic signal processing, here for Run 1 with Ink A at optical density 1.0, showing a) typical sound pressure raw signal over an interval of 2 s, and b) corresponding average power of this raw signal after high-pass filtration at 30 kHz. The two dotted vertical lines identify one of the periodic sub-intervals during which ink transfer occurs, with c) power spectral density (PSD) of this printing sub-interval compared to that from between impressions.

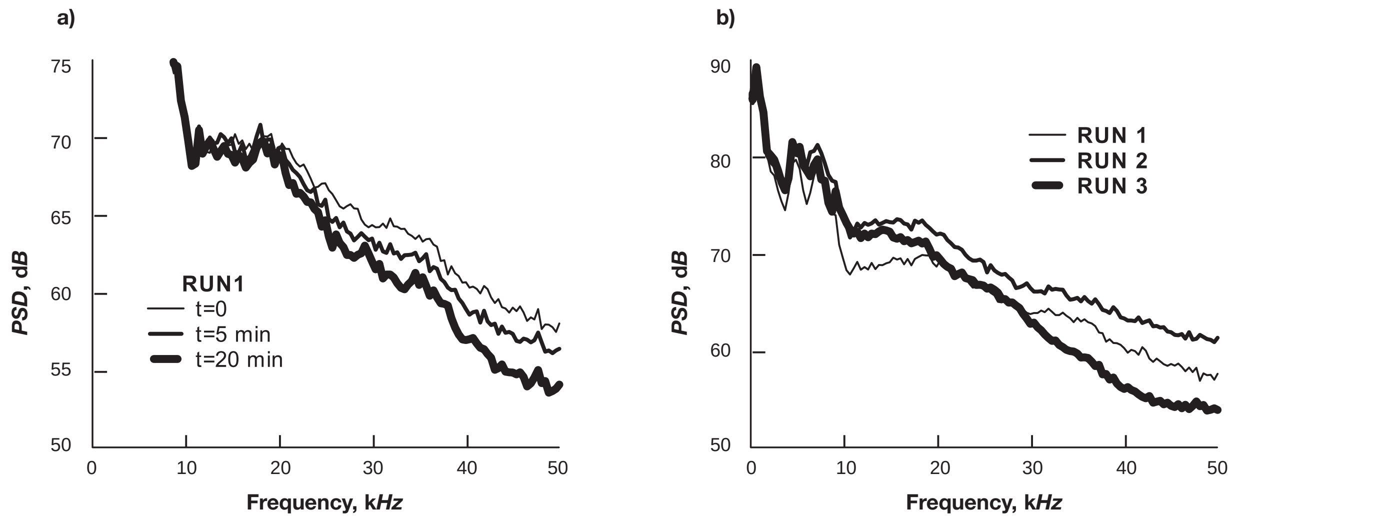

Fig. 6 ***PSD*** **of printing sub-intervals from a) three different times during Run 1, and b) the start of Runs 1, 2 and 3. Ink tack was 4 for Run 1 and 13.5 for Runs 2-3. Target optical density was 1.0 in Runs 1-2 and 0.7 in Run 3.**

motors, with that from the non-printing sub-interval also containing sharper peaks (both at low and high frequencies) arising from sheet in-feeding.

Although these suppositions are consistent with experiences of acoustic emission from other printing trials (*15,16,19*) further evidence of their validity is necessary, and is supplied by the spectra in Figure 6. In particular, Figure 6a shows the *PSD* (although not for low frequencies to allow better resolution of the high frequency contributions in this graph) from printing sub-intervals taken at three different times (0, 5 and 20 min.) during Run 1. This clearly illustrates that again 15 kHz appears to be the crossover point from similar to different responses at these times. The implication is that, while the press machinery itself, which dominates at low frequencies, is relatively stable with time, the ink and fount borne and transferred by it (manifested in the higher frequencies) have not yet equilibrated, with their noise decreasing over the first 20 min. of operation. The spectra from the printing sub-interval obtained from the start of Runs 1, 2 and 3 are given in Figure 6b. They again reveal strong similarities at lower frequencies (below around 10 kHz now) from common machine and motor noise, and clear distinctions at higher frequencies, as would be expected from their differing ink tack and ink film weight, if this contribution derives largely from film splitting.

On the basis of these observations, the *PSD* for the printing sub-intervals of all records was high pass filtered at 30 kHz to only admit the very high (ultrasonic) frequencies as far removed as possible from press machinery contributions (Fig. 5c). Note that the sub-intervals cover both the 50% and 100% fields; further subdivision could be used to isolate the separate contributions from these two, but is not performed here. Figure 7 then presents the evolution in the average power thus calculated over all three printing runs, while Figure 8 provides the corresponding time dependence of fountain solution consumption and optical density for Runs 1 and 2 (the corresponding data for Run 3 were unfortunately not measured).

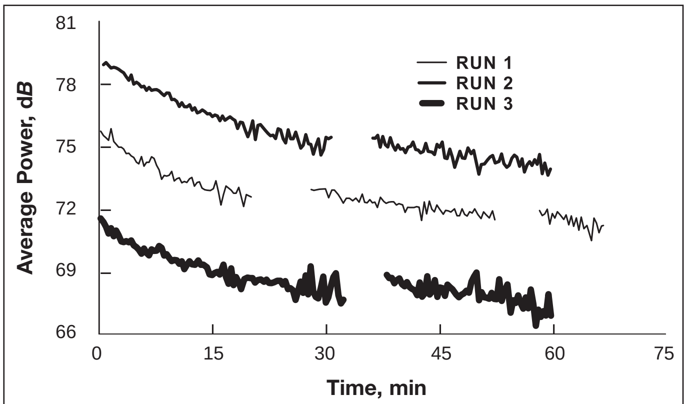

Fig. 7 Evolution of average acoustic power from printing sub-intervals, high pass filtered at 30 kHz, during all three runs of 7000 sheets each.

The error bars in Figure 8b show the standard deviation ($\pm\sigma$, i.e. with 68% confidence interval) from ten measurements across the width of the sheet, and as such, reflect the difficulty of attaining the target density uniformly across the width of the machine in this case. Note that a 120 min. break occurred between Run 1 and 2, during which press cleaning and change from Ink A to B was performed, with a shorter break of 30 min. between Run 2 and 3. However, all runs are plotted in Figures 7-8 as starting from common time t = 0 for convenience of presentation. Observe also from Figure 7 that short pauses also occurred during runs (with two such for Run 1), as the hopper containing the sheets to be printed was refilled.

From Figure 7 it is apparent that the average acoustic power contribution from ink film splitting displays systematic differences between the three runs, and also decreases significantly during the course of each, with these overall changes being much larger than the fluctuations from sheet to sheet. In particular, average power increases from Run 1 to 2, i.e. from Ink A (of tack 4) to B (of tack 13.5) at common target optical density of 1.0. Increasing ink tack serves to stabilise the air cavities nucleated in the nip exit by hindering their coalescence, enabling their extension in elongational flow and thus increasing the pressure pulse amplitude up to and at collapse and accordingly the average power. This replicates the

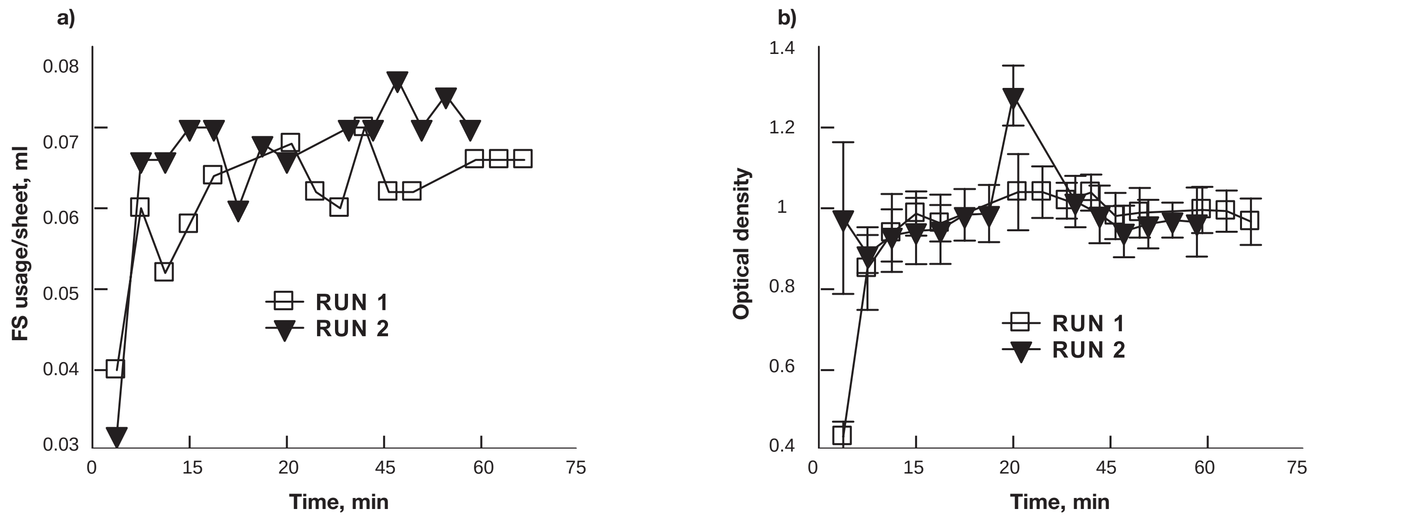

Fig. 8 Evolution of a) fountain solution (FS) consumption and b) optical density, for Runs 1 and 2, i.e. both with target optical density of 1.0.

trend discussed above at the beginning of the Hydroscope experiments in Figure 3. For this higher tack ink B, the subsequent decrease in targeted optical density to 0.7 in Run 3 causes a strong decrease in average power, to substantially below that in Run 2. The decreased thickness of the ink film reduces its ability to seal the nip exit and thus promote cavity growth and deformation, with air now having alternative routes to escape and equilibrate pressure through incomplete film coverage and defects. This decrease is presumably stronger on newsprint compared to, e.g. coated grades, due to the higher air permeability and roughness of the newsprint. Note that these trends in ink tack and amount are generally consistent with those obtained in previous studies, e.g. in heat-set web offset (HSWO) trials on LWC paper (*19*).

As mentioned above, the change in average acoustic power (for these high frequencies) during a run does not arise from press machinery and motor noise, which remains constant, but reflects systematic variations in ink splitting and transfer. Thus it is expected that the changes in Figure 7 bear some relation to the evolution in fount consumption and optical density in Figure 8. Despite the high scatter in the former data, due to limitations in the accuracy of the measurements, it is clear that fountain solution consumption increases over the runs to slowly approach a plateau, in much the same way as average power decreases. Thus the plot of fountain consumption versus average power in Figure 9 displays a reasonable negative correlation, given these measurement limitations. In the above-mentioned HSWO trials (*19*), average power also decreased with increasing water feed, at constant optical density, thus supporting this explanation. Such a correlation also applies on average for the Hydroscope as shown in Figures 3-4 but with a clear exception at early and late times of titration. Presumably these differences between laboratory and press results are due to the much wider range of fount concentrations used for the Hydroscope. That means the Hydroscope results are consistent with the data in Figure 9 provided a restricted fountain solution range is used. The much thicker and less mechanically impacted ink film on the Hydroscope, as compared to the press, might also increase the emulsion stability to initially increase the sound power up to a certain fount concentration. To determine whether this reversed effect could also be manifested on a press would require a more accurate control of the fount feed than achieved here.

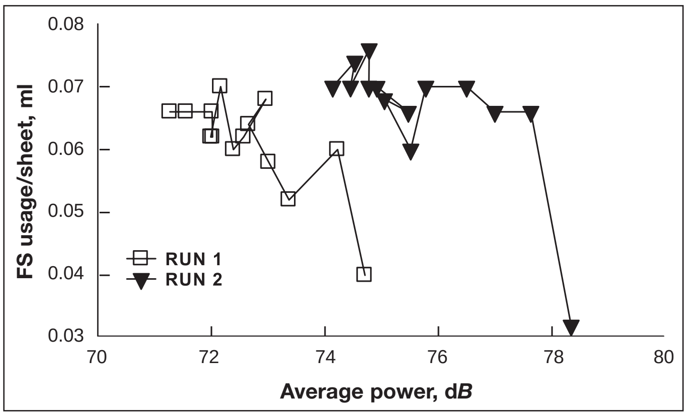

Fig. 9 Correlation between average power and fountain solution consumption for Runs 1 and 2, obtained by combining Figures 7 and 8a.

Fountain solution effects are also apparent at the start or recommencement of print runs in Figure 7. In particular, the lower average power at the start of Run 3 is assumedly partly due to the presence of emulsified fount remaining from Run 2 in the thicker film regions of the ink roller train. The opposite effect is seen between all pauses during runs, with the average power recommencing at a slightly higher level, presumably due to water evaporation from the thin ink films on cylinder and blanket.

Note from Figure 8 that, although optical density does not vary greatly over the runs, relative to the magnitude of the error bars, its average value does appear to exhibit clear trends in evolution. Further, given the sensitivity of average power to target optical density (set to 1 and 0.7 for runs 2 and 3 respectively) exhibited on comparing Runs 2 and 3 in Figure 7, the effect of these slight changes during Runs 1 and 2 should be factored into the above fountain solution-based explanation. In particular, at shorter times, up to the first pause within Runs 1 and 2, optical density rises towards its target plateau. Thus the water-induced decrease in average power over these times is actually stronger than expected on the basis of water consumption alone, in order to cancel and reverse the tendency to increase due to rising density. After each pause, optical density on resumption is higher, and subsequently decreases (rather than increases) towards its equilibrium value. This is in accord with the above-mentioned observation that average power on resumption is higher, due both to reduced fountain solution and consequently higher ink transfer, both serving to increase tack.

Another factor potentially complicating the interpretation of trends is linting, and in particular its occurrence to differing degrees depending on run length, ink tack, and fountain solution. However, the quantification of lint amount on the blanket at the conclusion of Runs 1 and 2 (see Table 2) revealed that the increase in linting for the higher tack Ink B was only relatively small, compared to the estimated error of ±0.3 g/m^2 in determining a single lint value. Thus in this study it can be concluded that linting was not responsible for the trends obtained in Figures 7-9, nor does it need to be taken into consideration in their interpretation.

Conversely though, the results of the acoustic method could be used to develop a more quantitative relation linking nominal ink tack to "true" tack during printing and to linting. Previous trials on both the Heidelberg GTO-52 press tested here, as well as a multi-colour commercial press, found no discernible effect on accumulated lint when printing with inks having tack (measured by Inkometer) in the range of 4-9, and only a small increase in lint when the tack was increased to 13.5 (*33, 34*) a finding that is quite consistent with the results presented in Table 2. The anomaly that must be explained with these results is why such a large change in ink tack produces such a small change in lint, when it would be expected that tackier inks would impose higher forces on the surface of the paper and thus produce more lint.

Table 2
Results of evaluation of lint on the blanket, corresponding to both the 100% and 50% fields, at the end of the 7000-sheet printing Runs 1 and 2.

Ink tack	Lint (g/m^2) 100%	50%
4	1.4	2.4
13.5	1.9	2.8

A possible explanation begins with an appreciation of the differences between ink tack and printing tack. The Inkometer registers the torque required to rotate three rollers covered in a fixed weight of ink, with the measurements performed at a constant speed of 800 rpm. The large differences in values obtained, e.g. between 4 and 13.5, tend to be diminished on press by a number of effects, such as reduction in viscosity due to shear thinning at the high shear rates in the nip, presence of fountain solution (also coupling in the ink's emulsification capacity), lower film weights and accordingly more limited ink-paper contact area. The average acoustic power reflects this reality, though not necessarily linearly correlated to the printing tack. Thus, while the measurements in Figure 7 for Run 1 and 2 return the result that average power, on a linear scale, increases by a factor of approx. 2 from Ink A to B (holding true over the entire runs), this must be calibrated in terms of printing tack for a quantitative connection to lint amount to be made. Given that such a calibration, i.e. the printing press equivalent of Figure 4 for the Hydroscope, is still missing, other alternative, more amenable approaches could be taken. One such alternative would be to acoustically monitor tape peeling on newsprint (at peeling speeds similar to press speed), using a series of tapes of differing (unknown) tack. In this way average acoustic power from peeling could be correlated to (gravimetrically determined) lint amount adhering to the tape, thus providing the calibration required to predict linting on press without the need to transform these measures to printing tack. Such an approach is obviously somewhat too simplistic, e.g. in ignoring the effect of fountain solution on weakening the paper and the cumulative effect of run length, but should provide an improvement on ink tack values currently used to indicate linting tendency.

Conclusions

This study has focused on the potential for using acoustic emission from printing nips to non-intrusively extract valuable information related to (coldset) offset ink film splitting and transfer, with a special focus on the role of the fountain solution in printing. The primary finding was that the average acoustic power, as obtained after appropriate signal processing of the film splitting component, decreased remarkably during a one hour print run while at the same time the consumption of fountain solution increased. For the ink-tack measuring Hydroscope, a corresponding decrease in both average power and ink tack was observed over a wider range of fountain solution concentrations. In addition, the average power increased with the standard Inkometer tack value and the target optical density. This suggests that acoustic sensors have potential to be used as semi-quantitative on-line tack meters or as qualitative indicators of other tack-related factors such as optical density, ink-water balance or linting propensity. When accurately calibrated against any of these factors or even directly to itself, the acoustic signal would provide a way to relatively easy follow the dynamics at different press stations in real time, which could be used as a monitoring tool to predict and control the offset printing process.

Acknowledgements

The authors wish to gratefully acknowledge the financial support of the Smartprint CRC, the Bo Rydin Foundation for Scientific Research as well as that of the Australian Research Council and Norske Skog through the SPIRT grant scheme and the Monash Research Graduate Scheme. The work was performed as a part of the Swedish PrintTech Research (T2F) Program. The authors would also like to acknowledge the assistance of Grant Brennan with the Heidelberg printing trials and of Chamundi Gujjari with the Hydroscope measurements.

References

(*1*) Bullof, J.J., - Emulsions in printing and the graphic arts, in Lissant, K.J., (ed.) **Emulsions and emulsion technology,** part II, vol. 6, *Surfactant science series*, p. 573, (1974).

(*2*) Lie, C. and Kihl, L., - Control of ink/water balance with help of an on-line densitometer, *TAGA Proc.*, p 443 (1992).

(*3*) Chou, S.M. and Fadner, T.A., - Shear stability of fountain solution emulsified in lithographic inks, *TAGA Proc.*, p 37 (1986).

(*4*) Bassemir, R.W. and Krishnan, R., - Optimizing lithographic performance-a physical-chemical approach, *TAGA Proc.*, p 560 (1987).

(*5*) Testprint BV., - **Hydroscope manual**, Netherlands (2002).

(*6*) Rosenberg, A., - What part play surface water and emulsified water in the lithographic process, TAGA Proc., p (1985).

(*7*) Thormählen, I., - Testing the lithographic behaviour of printing inks in printing presses and in the laboratory, *TAGA Proc.*, Pira, p 220

(1988).

(*8*) Säynevirta, T. and Karttunen, S., - New fountain solution for offset newspapers, *Graphic Arts in Finland,* 2(2):1 (1973).

(*9*) Smith, D.A., Desjumaux, D., Kessler, H.H., Nicholas, N.R., Sharman, S., and Wright, A., - Operational principles and sensitivity of an instrument designed to measure and explore offset ink tack dynamics, substrate failure and ink transfer mechanisms, *IPGAC Proc.,* p 103 (2004).

(*10*) Devisetti, S., Johnson, M., Xiang, Y., and Bousfield, D.W., - Rapid ink tack measurements in rolling nip systems, *IPGAC Proc.,* TAPPI, Section V (2000).

(*11*) Lim, C.H., Bohan, M.F.J., Claypol, T.C., and Getin, D.T., - A Finite element investigation into a soft rolling contact supplied by a non-newtonian ink, *J. Phys. D: Appl. Phys.,* **29**:1894 (1996).

(*12*) Zang, Y.H., Aspler, J.S., Boluk, M.Y., and De Grace, J.H., - Direct measurement of tensile stress ("tack") in thin ink films, *J. Rheol.,* **35**(3):345 (1991).

(*13*) Holroyd, T.J., - Acoustic emission- an NDT technique evolving into a versatile industrial monitoring method, *Measurement & Control,* **30**(5):141 (1997).

(*14*) Amari, T., Xiamfu, W., Hayashi, T., and Morita, K., - Dynamics and rheology of inks including various types of gelling agents, *TAGA Proc.,* p 354 (1994).

(*15*) Hayashi, T. and Amari, T., - Dynamics of transfer and splitting of emulsified ink, *IPGAC Proc.,* p 75 (1992).

(*16*) Hayashi, T., Morita, K., and Amari, T., - Rheological properties and printabilities of polybutadiene/carbon black ink, J. *Jpn. Soc. Colour Mater. (SHIKIZAI),* **66**(11):644 (1993).

(*17*) Iwasaki, Y., Takahashi, Y., Yukawa, H., and Kada, H., - Study on paper releasing phenomena in offset printing by an acoustic approach, *TAGA Proc.,* p 238 (1993).

(*18*) Voltaire, J., Fogden, A., Craig, V., Jansson, D., and Jacobsson, N., - Acoustic investigation of cavitation noise from offset ink film splitting, *Nord. Pulp Pap. Res. J.* **21**(3):314 (2006).

(*19*) Voltaire, J., Mattila, U., Fogden, A., Nieminen, S., and Reinius, H., - Acoustic characterisation of film splitting in a HSWO printing nip, *IPGAC Proc.,* p 21 (2004).

(*20*) Voltaire, J., Fogden, A. and Hoc, M., - Use of an on-press acoustic sensor to monitor coldset offset printing of newspaper, *Nord. Pulp Pap. Res.* **21**(3):323 (2006).

(*21*) Crocker, M.J., - **Handbook of acoustics,** Wiley cop., New York (1998).

(*22*) Fahy, F., - **Foundations of engineering acoustics,** 2 ed, Acad. Pr.(2003).

(*23*) Hamrock, B.J., - **Fundamentals of fluid film lubrication,** McGraw-Hill Inc., New York (1994).

(*24*) Young, F.R., - **Cavitation,** Imperial College Pr.(1999).

(*25*) Brennen, C.E., - **Fundamentals of multiphase flows,** Cambridge Univ. Pr.(2005).

(*26*) Reynolds, O., - On the theory of lubrication and its application to mr. Beauchamps tower's experiments, including an experimental determination of the viscosity of olive oil, *Phil.Trans. Roy. Soc.,* **A177**:157 (1886).

(*27*) Smith, M.K., - Asymptotic methods for the mathematical analysis of coating flows, *Liquid film coating*, Kistler, S.F. and Schweizer, P.M., (eds.), Chapman & Hall, p. 263, (1997).

(*28*) Myers, R.R., Miller, J.C., and Zettlemoyer, A.C., - The splitting of thin liquid films. Kinematics, *J. Colloid Sci.,* **14**:287 (1958).

(*29*) Sjodahl, L.H., - Ink flow on rotating rollers, *Am. Ink Maker,* **3**:31 (1951).

(*30*) Oppenheim, A.V. and Willsky, A.S., - **Signals and systems,** 2 ed, Prentice Hall Int. Inc.(1997).

(*31*) Press, W.H., Flannery, B.P., Teukolsky, S.A., and Vetterling, W.T., - in **Numerical recipes in C,** Cambridge Univ. Pr.(1992).

(*32*) Welch, P.D., - The use of fast-fourier transform for estimation of power spectra: A method based on time averaging over short, modified periodograms, *Audio Electroacoustics,* **15**:70 (1967).

(*33*) Sudarno, A., Batchelor, W., Banham, P., and Gujjari, C., - Investigation of the effect of press and paper variables on linting during the offset printing of newsprint, *Proc. 60th Ann. Appita Conf.,* Melbourne, p 25 (2006).

(*34*) Sudarno, A., Gujjari, C., Rand, S.F., Janko, P., Batchelor, W., and Banham, P., - Comparison of size distributions of lint particles from different printing operations, *Appita J.* **59**:5 385-390 (2006)

Original manuscript received 22 February 2006, revision accepted 2 August 2006