IMPULSE TECHNOLOGY ON THE EUROFEX MACHINE

Authors: Mikael Rigdahl, Marie Bäckström, Clas-Göran Hedström, Bo Norman, Malin Kilian *), Risto Talja **)

STFI (Swedish Pulp and Paper Research Institute), Box 5604, SE-114 86 Stockholm Sweden

*) Valmet-Karlstad AB, Box 1014, SE-651 15 Karlstad, Sweden

**) Valmet Corp., Paper and Board Machines, P. O. Box 587, FIN-40101 Jyväskylä, Finland

ABSTRACT

The research paper machine EuroFEX at STFI (Swedish Pulp and Paper Research Institute) was equipped with impulse units during the winter of 1996-97. During 1997 and 1998, several pilot trials were performed to assess runnability aspects and dewatering. Among the parameters varied are roll temperature, line load, machine speed and type of pulp. This paper describes some of the experiences and results from these trials and from the machinery development related to the impulse unit.

APPLICATION

This is an emerging technology that can increase the efficiency and flexibility in the papermaking process. This work describes the initial stage of a major research programme at STFI working with Impulse technology.

INTRODUCTION

During the winter of 1996-97, STFI equipped its research paper machine EuroFEX with two impulse units. The financial support for this investment came from NUTEK (Swedish National Board for Industrial and Technical Development), Knut and Alice Wallenberg Foundation, Elforsk (Swedish Electrical Utilities R&D Company), and from the STFI financing companies. Research work with the units commenced during the beginning of 1997. The research programme encompasses a very wide range of topics, including basic studies of the mechanisms of pressing at high temperatures, the possibilities of generating new paper-based products or products with improved properties, and runnability and design aspects.

Looking back, it is clear that the concept stems from Douglas Wahren's invention and vision of combining pressing and drying into more or less a single operation (Wahren 1978, 1982). The concept was called "impulse drying" and envisaged a very efficient dewatering of the paper web by exposing it to a heated surface. Later, it has been realised that the high temperatures used can also provide a potential to modify or improve the paper surface. To encompass this extended opportunity, the concept of "Impulse technology" was established. Impulse technology means that the wet paper web is subjected to pressure and high temperature in the press section of the paper machine. In the EuroFEX machine, a shoe press constitutes the impulse unit and the roll in this unit can be heated by induction to very high temperatures. The water in the region of the paper web which is closest to the heated roll evaporates quickly, and a steam pressure is built up. It has been hypothesised that the improved dewatering efficiency at high roll temperatures is due to the fact that the steam formed can assist in expelling the water (in liquid form) from the web (Zavaglia and Lindsay 1989, Lindsay 1989). It is also possible that the high temperature induces a thermal softening of the amorphous parts of the fibres closest to the heated roll. If so, this would constitute an important starting point for any attempts to modify the paper properties.

The introduction of impulse technology (or impulse drying) in the paper industry appears to have been hampered by two severe runnability problems, viz.: adhesion of the web to the hot roll and delamination of the web. The latter phenomenon appears to be the more serious. Earlier studies (Crouse et al. 1989, Orloff and Sobsczynski 1993, Orloff et al. 1997, Larsson and Stenström 1998) have shown that delamination can occur if the applied pressure decreases rapidly, i.e. when the web passes out of the nip. The superheated water in the web flashes to vapour as a result of this pressure drop and, if this steam cannot escape from the web structure, delamination may occur if the strength in the z-direction is insufficient.

The problem of delamination has received a great deal of attention, especially within the research performed at IPST. The concept of a critical temperature at which delamination takes place has been established. This critical temperature can depend on the pressure profile applied and it increases with decreasing hydrodynamic specific surface of the sheet. The aim is of course to achieve as high a critical temperature as possible and, in order to obtain that, Orloff and his coworkers developed a press roll with a ceramic surface (Orloff and Sobczynski 1993). This type of "low thermal mass" material increased the critical temperature but, at a given initial temperature of the heated surface, it gave approximately the same extent of water removal as a heated steel surface. The function of the ceramic press-roll surface is then to provide a high heat flux at the beginning of the pressing process, while suppressing it towards the end of the process, cf Orloff (1992). With the ceramic cover, the temperature within the sheet will be reduced towards the end of the press cycle, and this decreases the steam flashing and thus the delamination tendency.

Runnability problems associated with web adhesion to the heated surface have been observed in certain temperature regions (Meinecke et al. 1988, Talja 1991) and are attributed to the thermal softening of the wood polymers. At sufficiently high temperatures, it appears that the generation of steam may prevent the web from sticking to the heated roll. The impulse units should preferably operate at temperatures above the adhesion region but at levels lower than the critical temperature for delamination. However, these conditions may in some cases overlap and then no runnability window exists (Orloff and Crouse 1998).

However, if the impulse units are run under conditions at which the problems of adhesion and delamination are suppressed, clear improvements can be obtained with regard to dewatering efficiency and the development of certain paper properties. Such conditions are in general not too hard to find for a given pulp type. Here, initial experiences of running a single impulse unit installed in the EuroFEX research paper machine are described. The focus of the study is on the dewatering behaviour at higher temperatures and on runnability aspects.

EXPERIMENTAL

The Impulse Units

In order to perform studies on impulse technology, the press section of the research paper machine EuroFEX was rebuilt by Valmet (Talja et al. 1998). The press section now consists of one roll press followed by two SymBelt presses. The SymBelt press provides maximum flexibility as the shape of the pressure curve in the nip can be adjusted during the trials. The pilot machine can be used in two different configurations, one with a completely closed sheet transfer and one with short open draws after the shoe presses. The configuration with open draws, shown in **Figure 1**, is used for the impulse technology trials. The rolls in the two shoe presses are inverted in relation to each other; the shoe being in the bottom position in the second press and in the top position in the third press. Both sides of the web can thus be brought into contact with a hot roll, which is essential for the symmetry of the final sheet.

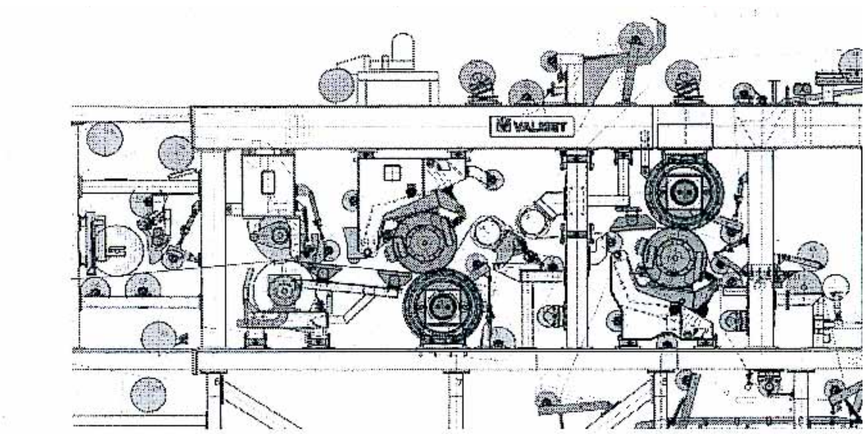

Figure 1. Schematic drawing of the impulse units installed in EuroFEX.

The rolls in the impulse units are made of cast iron and can be coated with different materials. In this trial, the roll was covered with a porous ceramic material. The rolls in the shoe presses can be heated by induction, using externally placed coils, to very high temperatures (300ºC or higher).

Experiments Performed

In the experiments described here, only one of the impulse units was used. This unit was the third press in the machine. Three types of pulp (TMP, bleached and unbleached kraft) have been used in the trials and sheets with grammages in the range of 40-100 g/m^2 were produced. The line load in the impulse unit (shoe press) was varied between 400 and 1000 kN/m and the machine speed was varied between 300 and 900 m/min. The machine speed can be substantially higher, but in this initial stage, this speed interval was considered to be suitable. The temperature of the heated roll was changed from room temperature to 350ºC. The produced paper was dried off-line either on a one-cylinder dryer or using the ten-cylinder EuroFEX-dryer.

RESULTS AND COMMENTS

Dewatering Efficiency

In all the pilot trials, an increase in the temperature of the heated roll led, as expected, to a more efficient dewatering rate of the paper web, in agreement with the result of other researchers, e.g. (Barlow et al. 1997, Orloff and Crouse 1998 and others). **Figure 2** is an example of the results obtained in one of the first trials. In this case, bleached kraft pulp was used and the machine speed was kept at 600 m/min. Only one impulse unit was used and the line load in that unit was 400, 600 or 800 kN/m. The maximum solids content after the impulse unit was almost 65% and this was obtained at a roll temperature of 350 ºC. The increase in solids content compared to the value obtained without any heating, 44%, is quite drastic.

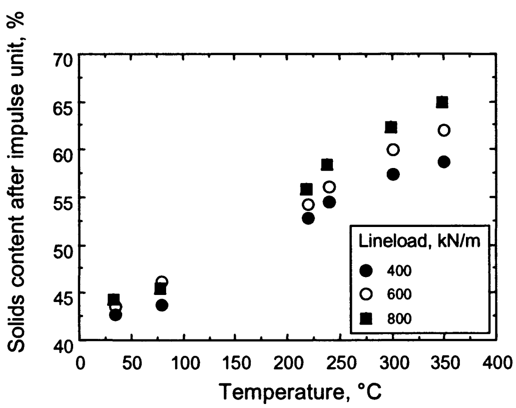

Figure 2. The solids content after the impulse unit as a function of the roll temperature and line load. Bleached kraft pulp was used and the machine speed was kept at 600 m/min. The grammage of the paper was 60 g/m^2. The solids content of the web going into the nip was approximately 40%.

Although the roll temperature was substantially more important than the line load, the line load did have some influence on the final solids content, and its effect increased somewhat with increasing roll temperature as can be seen in the figure. At room temperature (no heating), the difference in solids content resulting from an increase in line load from 400 to 800 kN/m was quite small, but it was about 5% or more at 350ºC.

In this trial, the dewatering improved with increasing temperature indicating that the dewatering mechanism in the temperature interval is the same, i.e. that no change in the mechanism associated with steam-assisted water removal can be inferred from the data. However, from trials performed at a later stage of the project, indications of a change in dewatering mechanism was observed, **Figure 3**. In this case, bleached kraft pulp at two refining levels (SR 30 and 40) was used. For this trial, the increase in solids content due to increased temperature did not seem to be linear, which could indicate a steam-assisted water removal at high temperatures. This nonlinearity is also observed in the moisture rate change versus the temperature of the hot roll. Further work is however required in order to strengthen this hypothesis. Another conclusion from the figure is that the temperature is substantially more important for the solids content than the refining level.

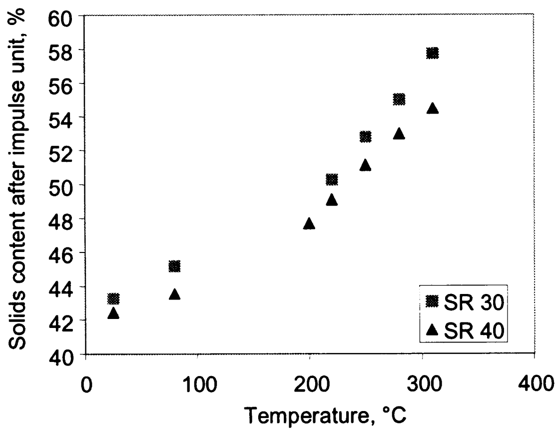

Figure 3. The solids content after the impulse unit as a function of the roll temperature. Bleached kraft pulp refined to 30 and 40 SR was used and the machine speed was kept at 600 m/min. The grammage of the paper was 60 g/m^2 and the line load 600 kN/m. The solids content of the web going into the nip was approximately 40%.

The temperature region where adhesion of the paper web to the heated roll occurred was approximately 140-180ºC in this case. At temperatures higher than this region, no runnability problems of this nature were encountered, and a general conclusion was that sticking problems tended to disappear if the temperature was sufficiently high. Roll temperature appears to be an important factor affecting the adhesion, but machine speed and the solids content of the web entering the heated nip are also significant factors (Meinecke et al. 1988).

Figure 4 provides another example on how an increase in roll temperature increases the dewatering rate. In this case, bleached kraft pulp as well as unbleached kraft pulp and TMP were used as raw materials. The amount of water removed in the shoe press was here expressed as the change in the moisture ratio, i.e. the difference in moisture ratio of the web after and before the shoe press. Although there is some scatter in the experimental results, it is again clear that the roll temperature has a strong effect on the dewatering process in the impulse unit. No great differences among the three pulps with regard to their dewatering behaviour could be distinguished in this case.

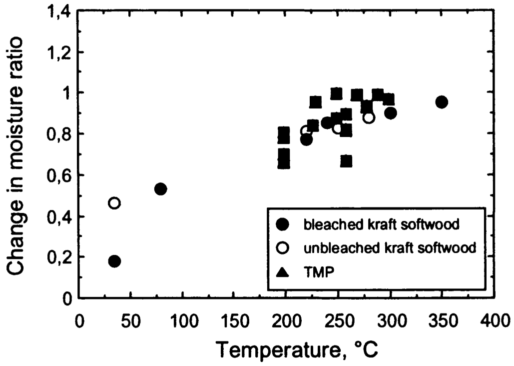

Figure 4. Change in moisture ratio over the heated shoe press vs. the temperature of the heated roll. The machine speed was 600 m/min and the grammage of the produced paper was 60 g/m^2. Three pulps were used; bleached and unbleached kraft and also TMP. The machine speed was 600 m/min and the line load applied in the heated shoe press was 400 kN/m.

Figure 5 shows how the dewatering, expressed as the change in moisture ratio in the impulse nip, increases with increasing roll temperature for webs of different (dry) grammages, 60, 80 and 100 g/m^2. The decrease in moisture ratio in the nip was here more or less independent of the grammage. The moisture ratio of the web going into the nip was however higher at higher grammages (1.74 at 60 g/m^2 and 1.9 at 100 g/m^2). The corresponding values of the solids contents were 37 and 34%, respectively.

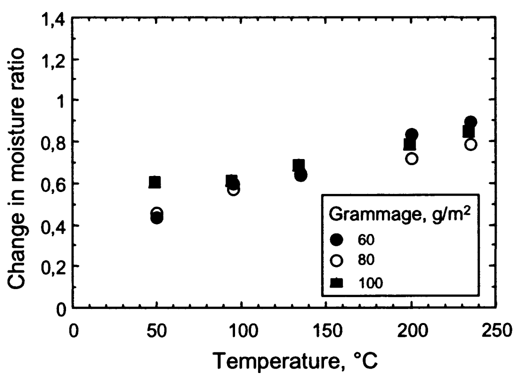

Figure 5. Change in moisture ratio in the heated shoe press as a function of the roll temperature for webs of different grammages. The machine speed was 600 m/min, the line load 800 kN/m and bleached kraft pulp was used.

Delamination Associated with Impulse Technology

Although there may be an appreciable temperature region within which impulse technology can be used, the upper limit is determined by the delamination phenomenon. Delamination is often said to occur because the formed steam cannot penetrate out of the paper structure sufficiently rapidly, so that the steam pressure may then exceed the z-directional strength of the web. Larsson and Stenström (1998) listed a number of methods that could possibly increase the critical temperature for delamination: a) decrease the grammage, b) increase the permeability, c) limit the heat flux to the web (using e.g. a roll with a ceramic cover) and d) optimize the pressure profile.

During the EuroFEX-trials, delamination of the paper web was also detected at high roll temperatures. The critical temperature for delamination depends upon the type of pulp chosen and also on other processing conditions. In some cases, the web can be successfully run at roll temperatures well above 250ºC without any signs of delamination. Temperature levels of this kind provide significant advantages with regard to the dewatering efficiency, as already shown.

Before the delamination becomes obvious to the eye, it can be detected as a decrease in the Scott Bond value of the produced sheet. In our experience, most paper properties deteriorate as soon as significant delamination of the structure sets in. This applies to tensile strength, tensile stiffness, elongation at rupture, tear strength, tensile energy absorption, bursting strength, and Scott Bond. As the roll temperature increases, the density of the (dry) sheet also increases as long as no delamination takes place. When delaminating, the density decreases quite sharply due to the "opening" of the structure. At the same temperature, the air permeability increases rather abruptly. An example of this is shown in **Figure 6**. The increase in permeability is related to the fact that delamination leads to a more open structure in the z-direction.

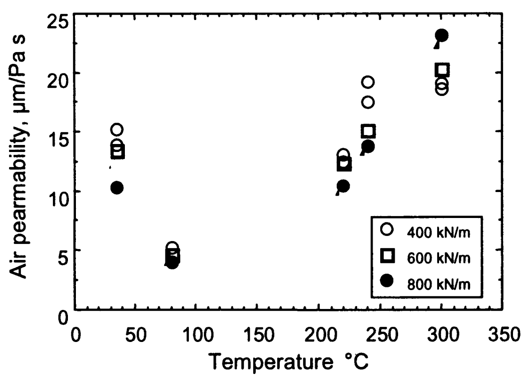

Figure 6. The air permeability of the (dry) paper as a function of the roll temperature in the impulse nip. Different line loads in the third nip were used.

At very high temperatures during the trials, complete delamination of the paper web sometimes occurred, i.e. the web separated into two distinct layers. An example of this is shown by the micrographs in **Figure 7**. The left-hand micrograph shows paper produced by pressing at room temperature, whereas the right-hand micrograph reveals the completely delaminated structure at a position about one-third into the thickness direction from the heated side of the paper.

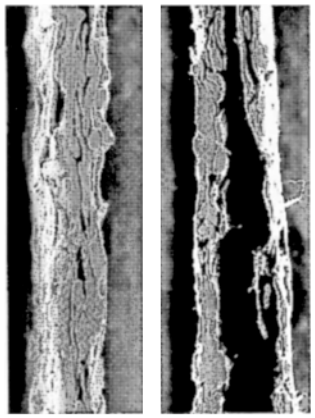

Figure 7. Cross-sections through-paper produced from bleached kraft pulp at room temperature (left) and paper produced with the impulse unit at a roll temperature of 350ºC (right). The grammage of the sheets was 60 g/m^2.

Comments on the Properties of the Papers Produced by Impulse Technology

As the temperature of the roll in the impulse unit increased, the density of the final dry sheet also increased as long as delamination did not occur. This densification in itself produces an improvement in physical properties such as tensile stiffness, tensile strength, etc. This may of course be regarded as a positive achievement. However, the general pattern obtained so far is that, regardless of the temperature of the roll, most bulk properties follow a given relation to the sheet density. In other words, the bulk properties are more or less uniquely related to the density of the material regardless of how this density has been achieved (as long as no local delamination takes place).

Thermal softening of the wood polymers and the application of pressure can promote the development of surface smoothness in impulse technology. This is also supported by the trials performed with EuroFEX. **Figure 8** shows that the side which had been in contact with the heated roll exhibited a lower surface roughness (given as PPS-10) with increasing roll temperature. The decrease is quite substantial, amounting to about 4 µm at a roll temperature of 280ºC. The improvement in surface smoothness is clearly one-sided, the surface of the paper in contact with the felt having an unchanged or perhaps even a somewhat higher surface roughness (only one impulse unit was used in these trials). The one-sided effect presumably results from the development of rather steep thermal gradients in the thickness. High temperatures and sufficient thermal softening of the wood polymers is then probably restricted to a narrow surface region close to the heated roll. This also explains to some extent why the effect of high temperatures on the bulk properties is limited. Significant structural rearrangements may only occur in a rather thin surface layer of the structure. It should be mentioned that Pikulik et al. (1995) and Orloff and Crouse (1998) have also reported a smoother surface of the paper side in contact with the heated roll.

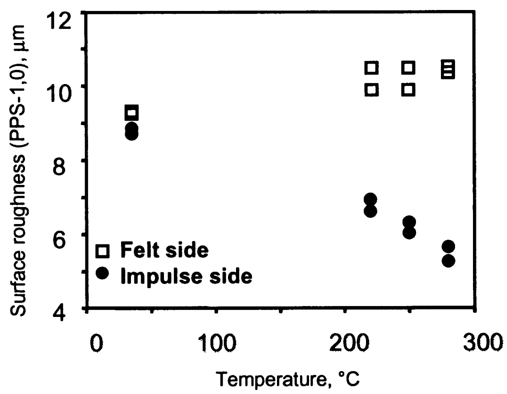

Figure 8. The surface roughness (PPS-10) of the two sides of a paper as a function of the roll temperature. The grammage was 60 g/m^2 and the machine speed 300 m/min. The papers were produced from unbleached kraft pulp (21 SR).

The smoother surface produced with impulse technology was retained after the calendering. **Figure 9** shows as an example the surface roughness (PPS-10) values after laboratory calendering for a fine paper produced at three temperatures at EuroFEX. The calendering was performed at ambient temperature and the paper passed through the calendering nip twice. The surface roughness was measured on the side of the paper that had been in contact with the press roll. The paper produced at the highest roll temperature (280ºC) was smoother than the other two (25 and 200ºC) at a given line load. In order to reach a certain surface roughness, the line load during the calendering operation can thus be decreased if the paper has been exposed to a high temperature in the impulse unit.

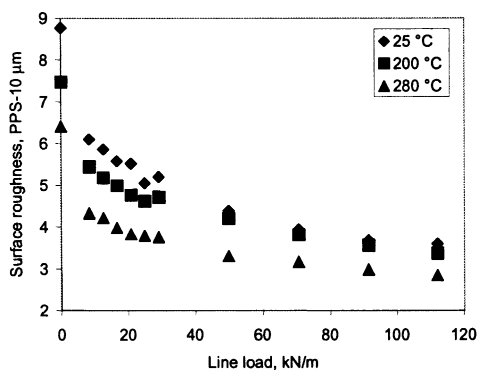

Figure 9. The surface roughness (PPS-10) vs. line load in the laboratory calender for fine paper produced at different roll temperatures. The grammage was 80 gm^2 and the filler content 15%.

Calendered papers with approximately at the same surface roughness values were printed in Prüfbau-equipment in order to get an indication of how papers produced by impulse technology respond to printing. The same type of fine papers that were used in the above described calendering trials where printed on the side of the paper that had been in contact with the hot press roll. In **Table 1**, the amount of ink required to achieve print densities of 1.0 and 1.2, respectively, is shown for papers produced at press roll temperatures of 25, 200, and 280 ºC in the impulse unit. At a given print density, the amount of ink required was lower for the paper impulse-treated at 280ºC, indicating that the paper surface has in this sense become more dense. Further printing trials are required to clarify the potential of impulse technology with regard to printability and print quality.

Press temperature, ºC	Print density	Amount of ink, g/m^2
25	1.0	1.8
	1.2	2.5
200	1.0	1.7
	1.2	2.4
280	1.0	1.5
	1.2	2.2

Table 1. The amount of ink needed to obtain a print density of 1.0 and 1.2 (Prüfbau printing). The grammage was 80 g/m^2 and the filler content 15%.

FINAL REMARKS

The trials performed at STFI with EuroFEX clearly shows that paper can be produced under impulse conditions on a full scale research paper machine and that the dewatering rate is significantly enhanced.

So far the work performed has been concentrated to papers within a rather limited grammage range (40-100 g/m^2) and this may be one reason for the somewhat limited effect of grammage on the dewatering behaviour observed at higher temperatures. It could be remarked that in some cases the dewatering improvement appeared to be non-linearly related to the temperature. One interpretation of this would be that the dewatering mechanism changed within the investigated temperature interval, i.e. that there might be a mechanism involving steam-assisted water removal. However, to substantiate this point more detailed investigations regarding the basic mechanisms for dewatering at very high temperatures are required. Impulse technology is certainly a process that imposes new requirements on the equipment, in the first hand the design of the rolls and the construction of the felts, due to the high temperatures involved. STFI and Valmet have together developed a completely new roll concept, which was installed by Valmet in the second shoe press during the fall 1998. The purpose of the new concept is to increase the flexibility of the trials. The new roll concept is able to handle rapid heating to temperatures in excess of 300ºC, it also requires less energy as compared to conventional press rolls, since the energy losses have been reduced. The concept will also be installed in the first shoe press during the late 1999, making it possible to apply impulse technology in two consecutive nips.

The work performed so far indicates that properties like tensile stiffness, tensile strength, etc. are uniquely related to the density development during pressing, regardless of the roll temperature used. More work is required to substantiate this point. The change in surface smoothness is quite significant. It may be that it is in applications where the surface characteristics are of primary importance that impulse technology should first be implemented.

ACKNOWLEDGEMENTS

The authors thank the personnel at the research paper machine EuroFEX for all their help in conjunction with these trials. Thanks are also extended to Dr. J. A. Bristow for the linguistic revision of the manuscript.

REFERENCES

1. Barlow, S. K., Crouse, J. W. and Moriarty, M. G., *Tappi J.*, **80**(7):109(1997).
2. Boerner, J., Orloff, D. I., *Tappi Engineering Conference Proceedings,* TAPPI PRESS, Atlanta, p. 1031(1993).
3. Crouse, J. W., Woo, Y. D. and Sprague, C. H., *Tappi J.*, **72**(10):211(1989).
4. Larsson, H., Stenström, S., *Tappi J.*, **81**(7):117(1998).
5. Lindsay, J. D., *Trans of the Ninth Fundam. Res. Symposium,* C. F. Baker and V. W. Punton, eds., Mech. Eng. Publ. Ltd., London, p. 679(1989).
6. Meinecke, A., Chau Huu T., Loser, H., *Das Papier*, **42**, V159(1988).
7. Orloff, D. I., *Tappi J.*, **75**(5):172(1992).
8. Orloff, D. I., Sobczynski, S. F., *Paper Technol.*, **34**(10):24(1993).
9. Orloff, D. I., Patterson, T., Phelan, P. and Rudman, I. *Tappi Engineering Conference Proceedings,* TAPPI PRESS, Atlanta, p. 1489(1997).
10. Orloff, D. I., Crouse, J. W., *Tappi Engineering Conference Proceedings*, TAPPI PRESS, Atlanta, p. 879(1998).
11. Pikulik, I. I., Sparkes, D. G., Poirier, N. A. and Grotogino, R. H., *81st Annual Mtg. Technical Section Proceedings*, CPPA, Montreal, p. A123(1995).
12. Talja, R., *Pulp & Paper Drying Helsinki Symposium Proceedings*, Helsinki, Finland (1991).
13. Talja, R., Bäckström, M. and Kilian, M., *2^{nd} EcoPaperTech Proceedings,* Helsinki, Finland, p. 289(1998).
14. Wahren, D., Swedish patent application, 7803672-0 (1978).
15. Wahren, D., US Patent 4, 324, 613 (1982).
16. Zavaglia, J. C., Lindsay, J. D., *Tappi J.*, **72**(9):79(1989).

Received for Review: August 26, 1999
Revised: December 21, 1999
Accepted: January 2, 2000

This paper was accepted for abstracting and publication in the August issue of TAPPI Journal.