

Critical pressure control of delamination in impulse drying

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THE CONCEPT OF IMPULSE DRYING is to increase the dewatering of the paper web in the press section using high temperatures and longer residence times. Over a number of years, the impulse drying technique has been developed, but its progress has been delayed by the paper web delamination problem. Many methods have been tried to prevent delamination, and much of this work has been done at the Institute of Paper Science and Technology (IPST) in Atlanta, GA. In this paper, those methods are discussed and a new method is presented. The new method and the phenomena behind it are also discussed.

Delamination occurs during depressurization, or after the press nip. When superheated water flashes to vapor and forces its way out, the web delaminates. The vapor pressure is mainly determined by the roll temperature, the peak pressure, and the residence time. Crouse *et al.* (1) observed five modes of delamination; four of them are caused by excessive vapor pressure: complete delamination, blisters (heated and felt side), and internal deterioration. These authors suggested a long list of parameters that affect the delamination phenomenon, including temperature, basis weight, pulse shape, and pressure. The common belief today is that delamination can be avoided with different methods, as listed in **Table I**.

The aim of this work is to show that the press temperature can be high without causing delamination

of the web, as long as the hydraulic pressure in the paper web is sufficiently low. The concept is that a low hydraulic pressure gives a low temperature profile, and the resulting vapor pressure is thus insufficient to delaminate the paper web. The low hydraulic pressure is obtained through a low peak pressure. The press temperature in our experiments, 300°C, is well above the temperature limits of 149–177°C suggested by Crouse *et al.* (1).

Similar experiments have been made by Orloff (2), who reports that the critical temperature for a steel platen, i.e., the temperature above which delamination occurs, increased with decreasing peak pressure. Decreasing the peak pressure and thereby the hydraulic pressure means that higher press temperatures can be used. In contrast to this work, the lowest peak pressure was 3.1 MPa, and the corresponding critical temperature was about 210°C. However, for a ceramic surface, the critical temperature increased with peak pressure. According to Orloff (2), the behavior between a steel and a ceramic-coated surface differs because (a) the ceramic surface is transferring less energy and (b) the energy transfer is independent of pressure.

EXPERIMENTAL

Equipment

The experiments were performed on a platen press from Material Testing Systems (MTS). The MTS press can provide a maximum load of 40 kN, which corresponds to a peak

ABSTRACT

Different methods of preventing delamination in impulse drying are discussed, and a new method to avoid delamination is presented. The method is based on maintaining a low hydraulic pressure in the paper web. This gives a low temperature in the web, and the corresponding vapor pressure is not sufficient to delaminate the paper web.

Experiments were made on a nip simulator to determine the critical pressure, the peak pressure above which delamination occurs. The critical pressure was determined as the pressure where the Scott bond value suddenly decreases. Experiments were made at 300°C and a dwell time of 40 ms for three basis weights: 54, 84, and 155 g/m². For the 54-g/m² basis weight, no delamination could be determined. For the 84- and 155-g/m² basis weights, the critical pressure was determined as 1.6 and 1.4 MPa respectively. For the 54-g/m² basis weight, an increase of the peak pressure did not affect the moisture ratio change, but for the 84- and 155-g/m² basis weights, the moisture ratio change increased with increasing peak pressure.

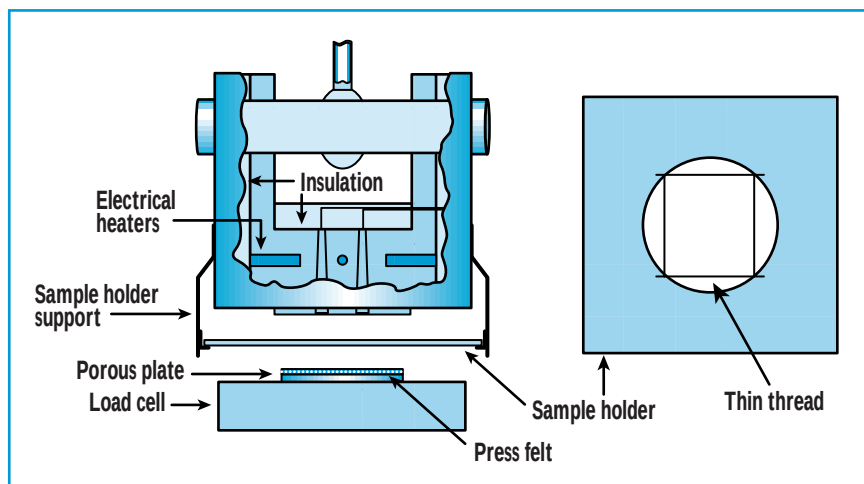
Application:

This paper presents several methods that can be used to prevent delamination in impulse drying.

pressure of 8 MPa. The load is measured by a load cell placed in the bottom of the equipment. The MTS press has a data-acquisition system that records the press load and the pressing head position. The pressing head is made of SS1914 steel and is heated by three heating elements, which are placed symmetrically in the cylinder (see **Fig. 1**). The pressing head was constructed by Krook (3).

Method	Phenomenon
Use low basis weight	Crouse <i>et al.</i> (1) found that linerboard of higher basis weights gave a lower temperature limit for delamination. This was confirmed by Lindsay <i>et al.</i> (9), who hypothesized that “macropores” play an important role in dewatering low-basis-weight papers. In higher-basis-weight papers, the “macropores” are averaged out, and they are less influential.
Increase the permeability	Orloff (10) and Boerner <i>et al.</i> (11) report that the critical temperature increases with decreasing hydraulic specific surface. This gives the vapor larger pores to flow through. Larger pores, and thereby higher permeability, can be achieved through less refining, for example.
Decrease the heat flux	Phelan <i>et al.</i> (12) and Orloff (7) report that delamination occurs when there is excessive energy transferred to the web. Their solution is to decrease the heat flux; this is achieved with a ceramic layer on the press roll. The ceramic layer has a low thermal mass (defined as the thermal conductivity divided by the square root of the thermal diffusivity), which provides a lower energy input to the web. This technique results in a very low heat flux of about 0.6 MW/m ² to the web. This can be compared to Krook <i>et al.</i> (8), who reports a range of 2–8 MW/m ² at 100–300°C for a steel-platen press.
Optimize the pressure profile	If the nip pressure profile is designed to give a slower depressurization, the vapor created will have more time to flow out of the paper web than with a fast depressurization. This means that at the end of the nip, the vapor pressure inside the paper web will not be sufficient to delaminate the web. This is confirmed by experiments conducted by Betz (13). The experiments were made with sheets of 80-g/m ² basis weight, a peak pressure of 8 MPa, and a press temperature of 300°C. If the residence time were set to above 50 ms, no delamination could be determined. This indicated that a slow depressurization or a longer residence time prevents delamination. On the contrary, Orloff <i>et al.</i> (14) indicate that the critical temperature increases when the peak pressure is closer to the end of the nip.

1. Methods for preventing delamination



1. The pressing head and the sample holder

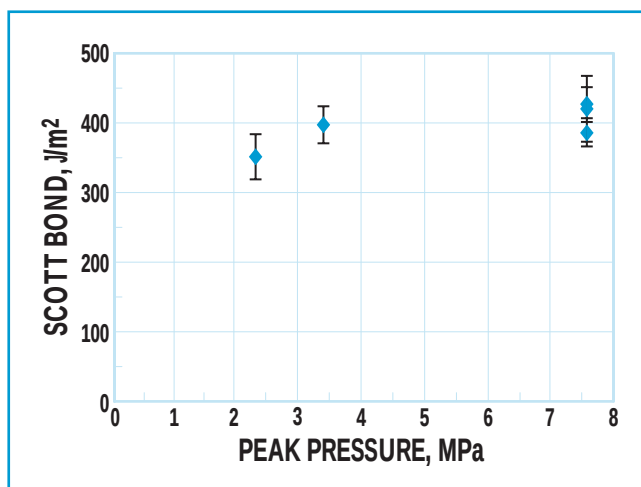
Two fast-responding thermocouples from Nanmac Corp. are installed on the surface. These units consist of thin wires of chromega and constantan separated by thin sheets of mica. A time constant of less than 10 ms is reported by the manufacturer. The thermocouples are connected to a

data-acquisition system, which is connected to a computer. The paper samples are placed on thin threads situated in a hole in a metal plate (see Fig. 1). This sample holder is constructed to quickly obtain experimental data. The sample holder is positioned in a support, which is

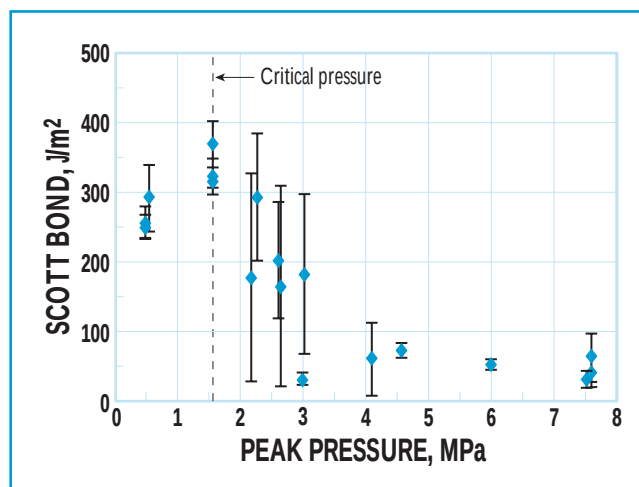
mounted on the pressing head. A press felt and a porous plate are placed under the sample holder to absorb the removed water.

Experimental procedures

Handsheets of 54-, 84-, and 155-g/m² basis weights were made by bleached kraft pulping in a laboratory former. The paper samples removed from the handsheets featured an 81-mm diam. The samples were weighed before and after the experiment. Water content in the samples was calculated as moisture ratio, defined as mass water per mass dry substance (ds). A Lorentzen & Wettre Rapid Dryer was used to finish drying the sample, and the dry sample was used to measure the Scott bond. From every sample, four Scott bond values could be determined. All experiments were performed in a conditioned room of 23°C and 50% RH. **Table II** lists the experimental settings.



2. Scott bond for different peak pressures for the 54-g/m² basis weight



3. Scott bond for different peak pressures for the 84-g/m² basis weight

RESULTS

Scott bond

For a 54-g/m² paper sheet, the Scott bond value increased slightly with peak pressure (see Fig. 2). At this basis weight, no sign of delamination was seen. The bars in this figure indicate the standard deviation for every sample (four Scott bond values per sample). A maximum Scott bond value of 425 J/m² is obtained for a peak pressure of 7.6 MPa. This agrees well with the peak Scott bond value of about 550 J/m² reported by Talja (4) for a 65-g/m² chemical pulp web pressed at 140°C.

In the cases of higher basis weights, a tendency to delaminate was observed for higher peak pressures. The Scott bond increases up to the critical pressure, the peak pressure above which delamination occurs when the Scott bond rapidly decreases to nearly zero. This sudden decrease in Scott bond is caused by delamination. When the standard deviation starts to increase, the samples have been subjected to delamination. This means that a partially delaminated sheet has a high standard deviation, and the nondelaminated and totally delaminated sheets have a low standard deviation.

In Figs. 3 and 4, critical pressures for 84-g/m² and 155-g/m² basis weights were determined to be 1.6 MPa and 1.4 MPa, respectively. At

higher pressures, delamination is either partial or total. In the experiments with the 155-g/m² paper sheets, total delamination was observed for the peak pressures over 2.5 MPa, and therefore the z strength was zero. Peak Scott bond values of 370 and 345 J/m² were found for the 84- and 155-g/m² basis weights, respectively. According to Lindé (5), these values can be compared with the mean value of 330 J/m² for an industrial 200-g/m² white top liner.

Moisture ratio change

The change of moisture ratio was measured to show the influence of the peak pressure. For the 54-g/m² basis weight, the moisture ratio change is constant at about 1.7 kg H₂O/kg ds (see Fig. 5). This indicates that the dewatering is flow controlled. The scattering of the moisture ratio change in Figs. 5–7 can be due to rewetting and/or saturation of the press felt or the porous plate.

For the 84-g/m² basis weight, the moisture ratio change increased with higher peak pressure (see Fig. 6). The moisture ratio change increased from 0.9 at 0.5 MPa to about 2 kg H₂O/kg ds at 7.5 MPa. This is the same order of magnitude as reported by Karrila *et al.* (6). They report a moisture ratio change of 2 kg H₂O/kg ds for an 80-g/m² sheet, a dwell time of 40 ms, a peak pressure of 8 MPa, and a press temperature of 300°C.

Parameter	Range
Initial block temp., °C	300
Dwell time, ms	40
Pulp	Bleached kraft
Beating, SR*	21.8
Basis weight, g/m ²	54, 84, 155
Ingoing moisture ratio, kg H ₂ O/kg dry substance (ds)	2.2–3.8

*Schopper-Riegler value

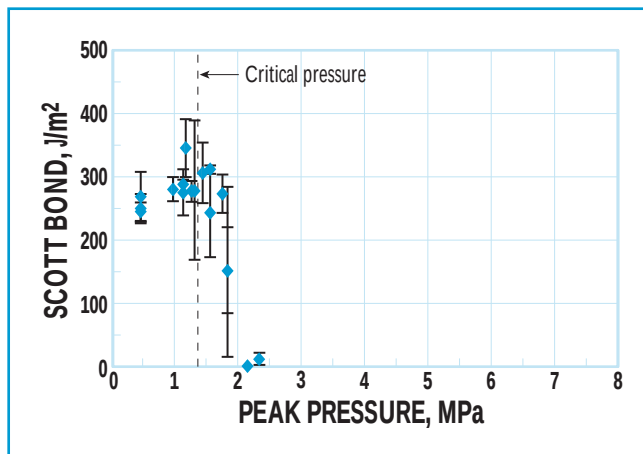
II. Experimental settings

For the 155-g/m² basis weight, the dewatering capacity increased up to a pressure of 2.5 MPa (see Fig. 7). The moisture ratio change increased from 1.0 at 0.4 MPa to about 2.3 kg H₂O/kg ds at 2.5 MPa. Thereafter, the paper sheet totally delaminated, and no measurements could be made. This agrees with the results reported by Orloff (7). For a 205-g/m² linerboard, a moisture ratio change of 1.0 at 3.1 MPa to 1.15 kg H₂O/kg ds at 6.2 MPa was reported for a 20-ms dwell time and a press temperature of 300°C.

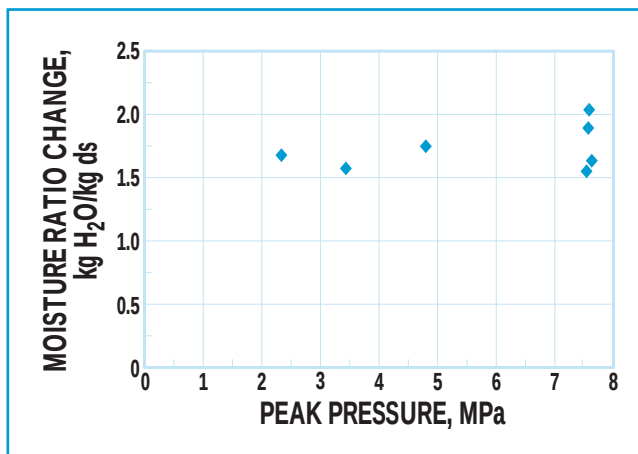
DISCUSSION

Critical pressure

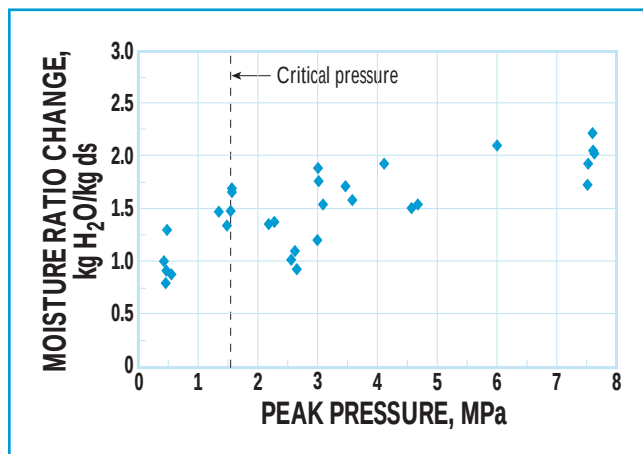
The critical pressure is the peak pressure where the created vapor pressure is low enough to not destroy the paper sheet. The vapor pressure corresponds to the satura-



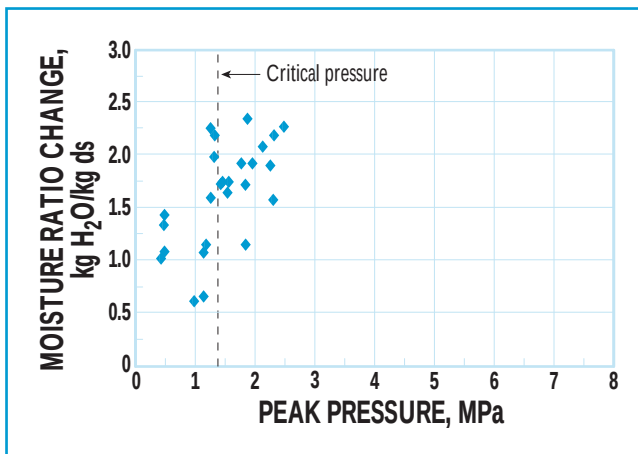
4. Scott bond for different peak pressures for the 155-g/m² basis weight



5. Decrease of moisture ratio for different peak pressures for the 54-g/m² basis weight and an ingoing moisture ratio of 2.2 kg H₂O/kg ds



6. Decrease of moisture ratio for different peak pressures for the 84-g/m² basis weight and an ingoing moisture ratio of 2.8 kg H₂O/kg ds



7. Decrease of moisture ratio for different peak pressures for the 155-g/m² basis weight and an ingoing moisture ratio of 3.8 kg H₂O/kg ds

tion temperature of the water in the sheet. Note that the temperature profile in the sheet is mainly determined by the press temperature, the residence time, the peak pressure, and the hydraulic pressure. The hydraulic pressure, the pressure carried by the water, increases with peak pressure.

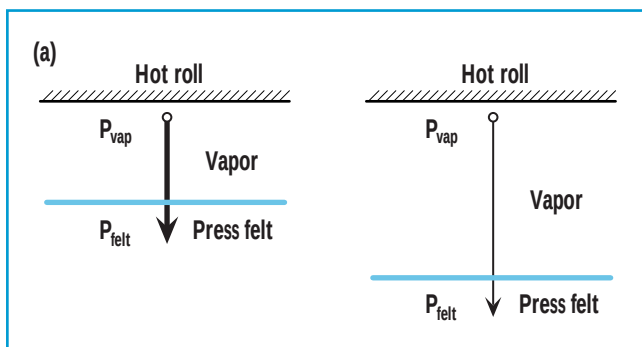
If the press temperature is higher than the corresponding saturation temperature of the hydraulic pressure, the maximum water temperature will be the saturation temperature. This means that if the press temperature is higher than the corresponding saturation temperature, a steam layer will be formed. An increase of the press temperature would therefore not increase the maximum temperature in the sheet, since the heat transferred to the sheet would evaporate the water. If, on the other hand, the press temperature is lower than the corresponding saturation temperature, the maxi-

mum temperature in the sheet would be the press temperature. In this case, the temperature profile is determined by the heat transfer to and inside the sheet.

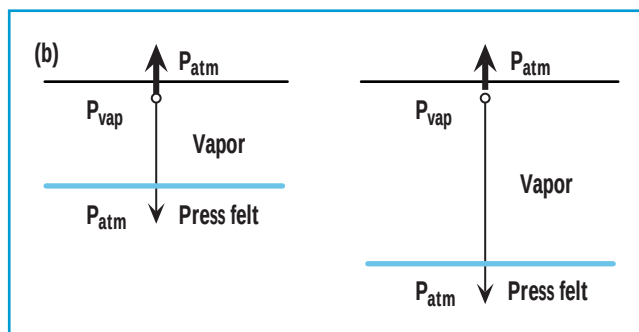
Experiments made by Krook *et al.* (8) verify that the hydraulic pressure and/or the press temperature controls the maximum temperature in the sheet. Temperature measurements were made during a 50-ms press nip in the thickness direction of the sheet. The temperature was measured in three positions: (a) for a 60-g/m² sheet at 20, 40, and 60 g/m² and (b) for a 150-g/m² sheet at 50, 100, and 150 g/m². For a 60-g/m²

KEYWORDS

Bonding, critical pressure, delamination, hydraulic pressure, moisture control, nip, paper webs, shock drying, simulation.



8. Case A: Vapor flows during depressurization for low (left) and high (right) basis weights



9. Case B: Vapor flows after the press nip for low (left) and high (right) basis weights

sheet pressed at 0.5 MPa, the maximum temperature at 20 g/m² was between 100°C and 110°C for press temperatures between 150°C and 300°C. For a 150-g/m² sheet pressed at the same condition, the maximum temperature at 50 g/m² was also between 100°C and 110°C. The constant maximum temperatures, independent of press temperature and basis weight, indicate that the sheet temperature is controlled by the hydraulic pressure, and the maximum temperature in the sheet is the corresponding saturation temperature. The temperatures correspond to the hydraulic pressures between 0.1 and 0.14 MPa.

At higher peak pressures, the hydraulic pressure is higher and allows higher temperatures in the sheet. For a peak pressure of 8 MPa, the temperature in a 60-g/m² sheet increases with press temperature. At 20 g/m², the temperature reaches 100°C for a 150°C press temperature and 170°C for a 300°C press temperature. Therefore, for a peak pressure of 8 MPa, the sheet temperature is controlled by the press temperature and not by the hydraulic pressure. Similar results are seen for a 150-g/m² sheet.

The results by Krook *et al.* (8) verify the theory of maintaining a low hydraulic pressure to avoid delamination. The highest possible hydraulic pressure is determined by the critical pressure. At the critical pressure, the created vapor pressure corresponding to the sheet tempera-

ture is insufficient to destroy the paper sheet.

Basis weight

The basis weight has a strong influence on delamination. For a 54-g/m² basis weight, no delamination could be determined, but for both 84- and 155-g/m² basis weights, delamination occurred. Experiments by Krook *et al.* (8) show that the energy transferred (for a certain peak pressure) does not change between different basis weights. Neither does the temperature profile in the sheets differ significantly between different basis weights. This indicates that the amount of flashed water will be the same independent of basis weight. The only property that differs is the thickness of the sheet—a higher basis weight is thicker than a lower basis weight.

If delamination occurs after the press nip, the vapor pressure inside the sheet must differ between a low and a high basis weight. The vapor pressure decrease is achieved by a vapor flow in the *z* direction, and two cases are possible:

- Case A: Vapor flow during the depressurization
- Case B: Vapor flow after the press nip.

The vapor flows for the two cases are shown in **Figs. 8 and 9**. The driving force for the vapor flow is the pressure drop per length between the vapor zone and the surroundings.

In case A, the vapor flows toward the press felt, and since the distance to the press felt differs between basis weights, the vapor flow must be higher for a thinner sheet. On the other hand, in case B, the main flow is toward the top of the sheet because of the short distance to the surface. However, the main flow does not differ between basis weights; the distance to the top is the same.

The conclusion drawn is that at the end of the nip, the vapor pressure in a thicker sheet will be higher than for a thinner sheet because of a lower vapor flow during the depressurization. The vapor pressure after the press nip will therefore delaminate the thicker sheet and not the thinner. This hypothesis is based on the assumption that the paper properties do not differ between the basis weights.

CONCLUSIONS

In a nip simulator, experiments were conducted to examine if a low hydraulic pressure can prevent delamination. A low hydraulic pressure controls the temperature in the sheet and thereby the corresponding vapor pressure. At the critical pressure, the vapor pressure created during depressurization does not exceed the network strength. If a peak pressure below the critical pressure is used, delamination is avoided.

For the 54-g/m² basis weight, no delamination could be determined independent of peak pressure. This can be explained because the vapor

has a short distance through which to flow, and thus the vapor pressure at the end of the press nip is not sufficient to delaminate the sheet. For the 84- and 155-g/m² basis weights, the experiments showed a critical pressure of 1.6 and 1.4 MPa, respectively. Below these pressures, the temperature and thus the vapor pressure are low enough not to cause delamination. No delamination was observed below this pressure range, either visibly or in Scott bond measurements.

For the 54-g/m² basis weight, the moisture ratio change was constant independent of peak pressure. This means that the dewatering is flow controlled. For the higher basis weights, the dewatering increased with peak pressure.

FUTURE WORK

During the spring of 1997, the FEX machine at STFI in Stockholm was extended with two new induction-heated shoe presses. Impulse drying experiments, which started in the spring of 1997, offer excellent possi-

bilities to test different hypotheses in impulse drying, including that regarding the critical pressure. TJ

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LITERATURE CITED

1. Crouse, J. W., Woo, Y. D., and Sprague, C. H., *Tappi J.* 72(10): 211(1989).
2. Orloff, D. I., *Proceedings of 14th National Conference on Industrial Energy Technology*, Texas A&M University, Houston, 1992, p. 110.
3. Krook, R., Lund University lic. thesis, LUTKDH/(TKKA-1002)/1-30/(1996).
4. Talja, R., *Proceedings of the Helsinki Symposium on Alternate Methods of Pulp and Paper Drying*, Helsinki, 1991, p. 129.
5. Lindé, A., personal communication, STFI, Stockholm, 1997.
6. Kärtilä S., Paulapuro, H., Salmi, J., et al., *Proceedings of the Helsinki Symposium on Alternate Methods of Pulp and Paper Drying*, Helsinki, 1991, p. 79.
7. Orloff, D. I., *Proceedings of the 77th Annual Meeting of the Technical Section of the Canadian Pulp and Paper Association*, CPPA, Montreal, 1991, p. B9.
8. Krook, R. and Stenström, S., *Exp. Heat Trans.*, in press.
9. Lindsay, J. D. and Brady, P. H., *Tappi J.* 76(11): 167(1993).
10. Orloff, D. I., *Tappi J.* 77(2): 169(1994).
11. Boerner, J. R. and Orloff, D. I., *Tappi J.* 77(2): 163(1994).
12. Phelan, P. M., Orloff, D. I., and Kerschner, C. M., *Tappi J.* 79(11): 131(1996).
13. Betz, A., Lund University Report LUTKDH/(TKKA-5008)/1-51/(1996).
14. Orloff, D. I. and Phelan, P. M., *Heat and Mass Transfer in Pulp and Paper Processing*, Vol. 238, ASME, New York, 1993, p. 17.