Impulse drying: Status of the pilot-scale research program

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ABSTRACT

The Institute of Paper Science and Technology and Beloit Corp. are jointly developing impulse drying for application to board grades. The short-term objectives are to develop the necessary technology and to demonstrate that technology on a pilot paper machine.

Over the past few years, much progress has been made toward solving a sheet delamination problem, which had previously been the major stumbling block to commercializing impulse drying for board grades of paper. These solutions, which have been demonstrated in laboratory experiments, have now been demonstrated during continuous operation on a pilot paper machine.

This paper describes the process modifications that have allowed impulse drying of board grades to become commercially feasible, discusses the methodologies that were used in developing commercial prototypes, and reports the results of pilot paper machine experiments where these prototypes have been utilized. The current status of the commercialization is also discussed.

Application:

This is an emerging technology that is ready for commercial demonstration. The work that is reported demonstrates that a window of operation for linerboard is practical.

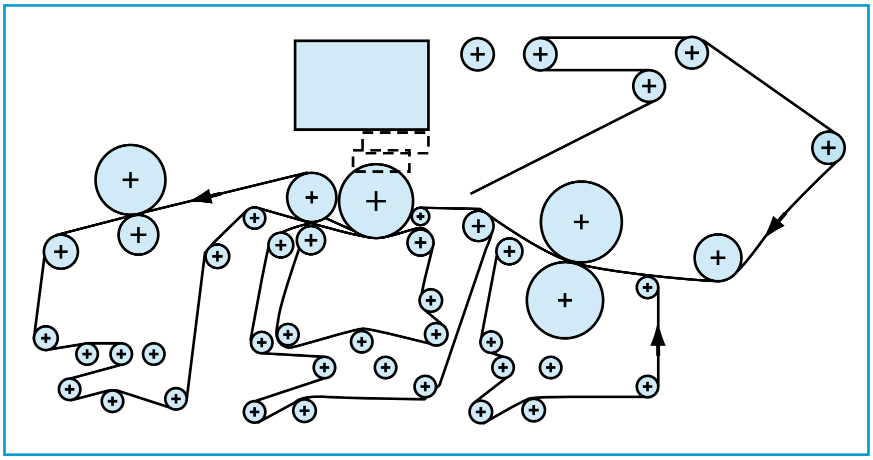
In the watershed paper by Crouse, Woo, and Sprague *(1)*, impulse drying was shown to have the potential of disrupting and delaminating (breaking of fiber bonds) the linerboard sheet. They found that delamination could only be avoided when the sheet-fed pilot press was operated at temperatures below 150°C, conditions that only resulted in sheet strength and press dryness that could as easily be achieved by conventional pressing at elevated ingoing sheet temperatures. Hence, it was concluded that delamination must be fully understood and alleviated for impulse drying to become a commercial technology that is applicable to the manufacture of board grades.

In response to the work of Crouse, Woo, and Sprague, research was undertaken at a number of corporate and academic research centers to overcome the sheet delamination problem. Over the ensuing years, research on preventing delamination has taken two paths. The first consisted of modifications to the press nip, such as reducing the thermal properties of the press roll, drilling the press roll, and changing the conditions of the nip (e.g., impulse, pressure profile, and sheet construction). The second path, which has been much more sparsely reported, approached the problem through modifications to the conditions that the sheet experiences as it leaves the nip. Examples include the use of steam chambers, gas chambers, roll wraps, and secondary nips. Both of these research paths have recently been reviewed by Orloff and Crouse *(2)*.

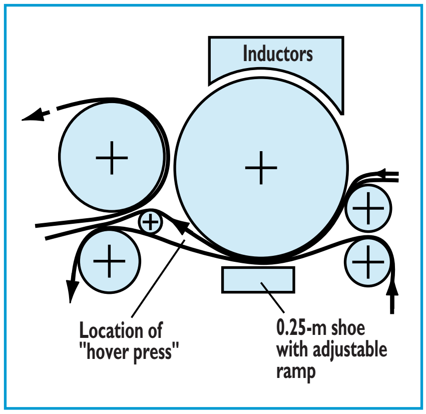
In 1994, Orloff *(3)* proposed modifications to an impulse drying simulator to allow process modifications during and immediately following nip opening. He hypothesized that delamination occurs when subcooled water, at high pressure and temperature in the sheet, flashes to vapor when the nip opens to ambient pressure. To test the significance of the pressure that the sheet is exposed to upon nip opening, the simulator was to be designed so that, at nip opening, the sheet would be exposed to pressures well above 1 atmosphere.

Using the modified simulator, Orloff *(4)* developed and patented a method of impulse drying at elevated ambient nip-opening pressures. The method exposed the web to ambient pressures above atmospheric and provided increasing cooling rates when the press load was released. The patent showed that sheet delamination could be prevented by opening the nip to a sufficiently high "critical" ambient gas pressure. The gas used could be any gas as long as it is at a temperature below 100°C. Based on simulations, "critical" pressures were found to increase with increased temperature of the heated press surface, increased basis weight, increased ingoing sheet moisture content, and increased specific surface of the sheet.

Thermocouples imbedded in sheets have been used to record internal temperature profiles during nip-opening experiments. Thermodynamic reasoning *(5–7)* was used to show under what conditions those temperatures could be used to infer local internal pressures. In this manner, it was found that opening the nip to higher ambient gas pressures actually reduced the pressure difference between the inside and outside



1. Beloit X2 pilot paper machine



2. Closeup of the winter 1998 configuration of the impulse dryer on the X2 pilot paper machine

PM section	Operating condition	Summer 1997	Winter 1998
Forming	No. 1 wire	145 × 104	152 × 68/34
	No. 2 wire	182 × 145	161 × 110
	Pressure, kPa	36	32
	Flow rate, L/min	3226	2271
	Thick stock, L/min	560	530
	Temperature, °C	47	43
	pH	7.7	NA*
	Solids in, %	32	25
Pressing	Press shoe	0.15 m with ramp extension	0.25 m with adjustable ramp
	Hover press	None	Installed, variable-pressure
	Felt	AI 289250 CSX	AI 289249 CSX
	Wrap roll	Inside link	Outside link
	Blanket	Grooved	Op. side: blind-drilled Dr. side: grooved

*Not available

I. Comparison of operating conditions in summer 1997 and winter 1998

of the sheet during the nip-opening process. Thus the sheet is held together while the internal pressure decays. While it is possible to hold the sheet together with an external gas pressure, a simpler way would be to provide an external mechanical force. Based on this reasoning, IPST filed a U.S. patent *(8)* to cover the application of elevated pressures by techniques such as ramp decompression and a post-nip "hover press." To demonstrate that this concept is not just a laboratory curiosity, the concept was recently evaluated on Beloit's No. 2 pilot paper machine.

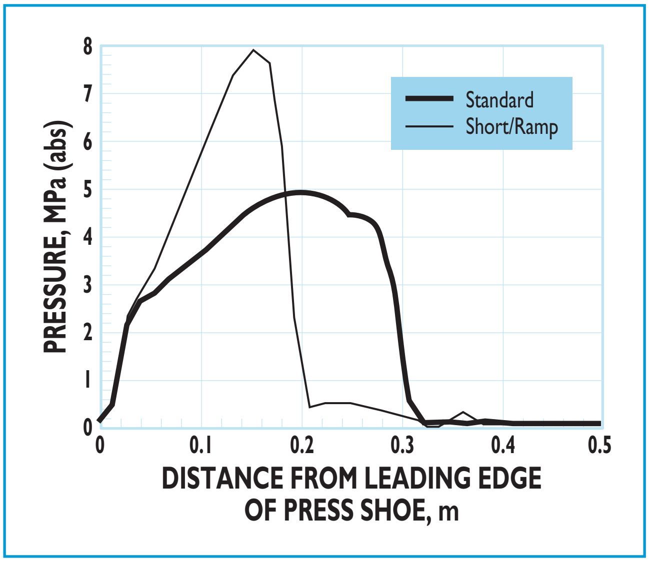
PILOT PAPER MACHINE EXPERIMENTS

The summer of 1997

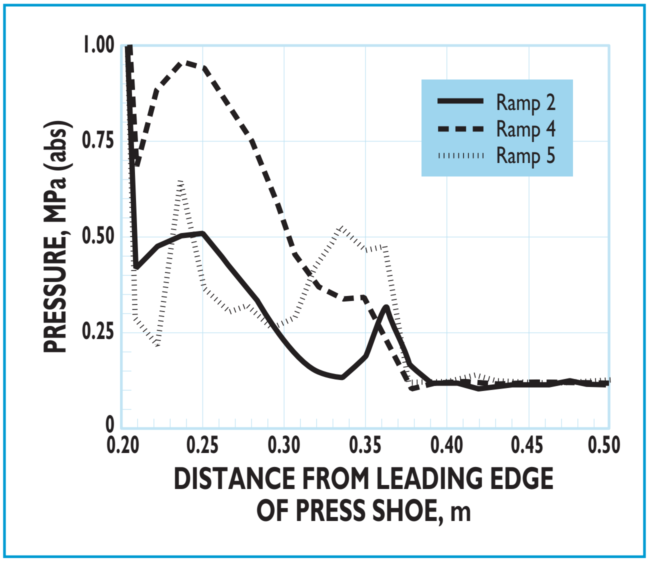
The purpose of the experiments performed during the summer of 1997 was to verify the usefulness of the ramp decompression and hover press concepts in extending the temperature operating limits during high-speed continuous operation. The verification also consisted of showing that proper choice of press roll surface and/or special doctoring technology could eliminate sheet/roll surface picking.

While the X2 pilot paper machine has certain limitations with regard to basis weight, ingoing solids, and width, it has the advantages of having an induction-heated, open-extended-nip press. The open-extended-nip press was desirable as it did not significantly limit press shoe length and geometry. An overall diagram of the X2 machine is shown in **Fig. 1,** and a closeup showing the location of the adjustable ramp shoe and the hover press used in the winter 1998 experiments is shown in **Fig. 2.**

Because the shape of the pressure profile generated by the press shoe and the hover press was a major variable in the experiments, the measurement of this profile was important. To this end, a TechScan pressure measurement system was used to measure pressure profiles. Typical profiles at a press load of 1050 kN/m used during the summer experiments are shown in **Fig. 3.** The standard profile corresponds to the pressure distribution resulting from a commercial 0.25 m shoe. The short/ramp profile corresponds to the profile obtained from a 0.18 m shoe followed by a 0.18 m adjustable ramp. The specific ramp profiles investigated during the summer experiments are shown in **Fig. 4.** Note that the ramps each followed the short shoe, as indicated in Fig. 3.



3. Measured pressure profiles of the standard 0.25 m long and "short" shoe used in the summer 1997 experiments on the X2 pilot paper machine



4. Measured pressure profiles of various ramp decompression profiles used in the summer 1997 experiments on the X2 pilot paper machine

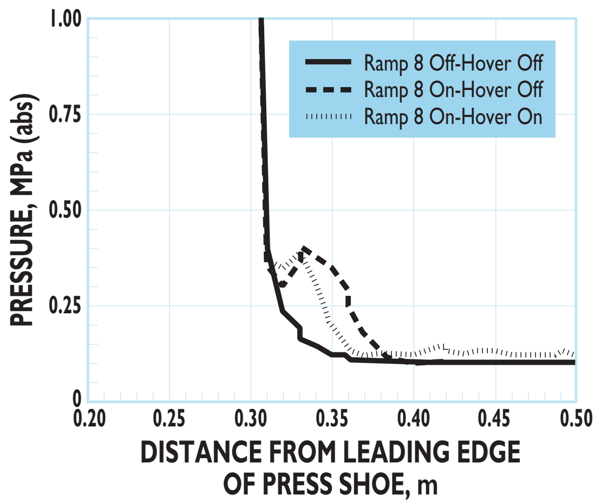
Date, ramp no. (PM speed, m/min)	Freeness, mL, CSF	Ingoing solids, %	Specific surface, m^2/g (Average/ std. dev.)	Specific volume, g/m^3 (Average/ std. dev.)	O.D. basis weight, g/m^2 (Average/ std. dev.)
Summer, Ramp 4 (380)	570	32.2	3.20/ 0.03	1.16/ 0.02	105.5/ 6.8
Summer, Ramp 5 (380)	570	31.5	4.07/ 0.87	1.10/ 0.03	105.5/ 6.8
Winter, Ramp 8 (380)	540	24.6	6.60/ 1.43	1.84/ 0.09	98.5/ 4.9
Winter, Ramp 8 (380)	458	27.5	11.16/ 1.28	1.75/ 0.09	97.6/ 2.9
Winter, Ramp 8 (760)	460	26.1	14.97/ 1.71	1.77/ 0.01	97.9/ 2.6

II. Ingoing web properties

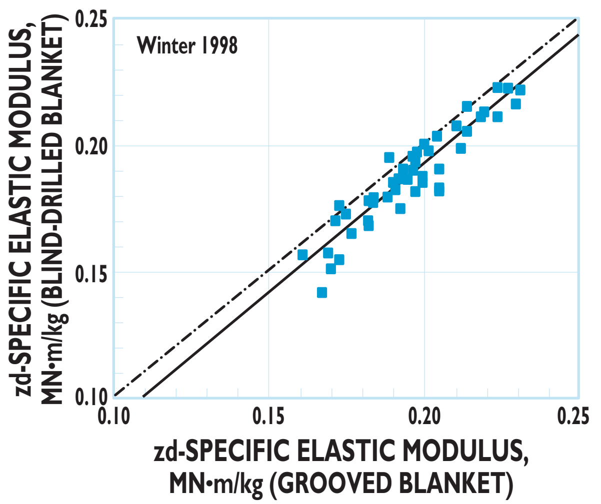
The first objective of the summer experiment was to characterize the performance of the standard 0.25 m shoe with and without the use of a steam box just prior to the impulse dryer. Based on zd-specific elastic modulus measurements, the critical impulse drying temperature of the unheated web was about 165°C, while that of the preheated web was less than about 154°C. As web preheating added an extra complication to the experiments and was generally ineffective for low freenesses, we decided to delete the steam box from future experiments.

The second objective was to determine whether the short shoe with the ramp could be used to increase the critical impulse drying temperature above that obtained using the standard 0.25 m shoe. The short shoe with the ramp was designed to generate the same impulse as the standard shoe. These experiments were conducted without the use of the steam box and yielded a critical impulse drying temperature of 204°C. We concluded that the modified profile resulted in an increase in the window of operation of about 40°C.

Additional, more detailed, experiments were also conducted. In these experiments, attempts were made to adjust the ramp profile shapes to more closely match those of laboratory simulations. The resulting ramps (nos. 4 and 5) bounded the pressure profile of ramp no. 2 and were still jagged in shape. **Table I** shows the setup conditions of the gap former and the impulse dryer. The furnish used for this as well as the earlier experiments and the later winter experiments was a once-dried virgin unbleached softwood kraft. For these specific experiments, the furnish was repulped and minimally refined to a freeness of 570 mL CSF. The ingoing solids to the impulse dryer were maintained at 31.5–32.2%, while the basis weight was set at a nominal 100 g/m^2. Permeability testing of the wet web showed that the specific surface was 3.2–4.1 m^2/g, as shown in **Table II.** The machine was operated at 380 m/min.



5. Measured pressure profiles of various ramp decompression profiles used in the winter 1998 experiments on the X2 pilot paper machine



6. Comparison of the zd-specific elastic modulus of corresponding samples that were impulse dried using grooved and blind-drilled blankets at the same time and at the same process conditions

Using the short shoe with ramp nos. 4 and 5, impulse drying experiments were conducted at a press load of 1050 kN/m over a range of press roll surface temperatures of 190–250°C. Based on zd-elastic modulus data, the critical impulse drying temperature was about 218°C for ramp no. 4 and 209°C for ramp no. 5. Comparing the paper physical properties at the various critical temperatures and to corresponding wet pressing controls, impulse drying yielded an increase in press dryness, increased sheet smoothness, and Gurley as well as provided improvements in STFI compression strength and ring crush *(2)*.

In addition to demonstrating the usefulness of modifying the press shoe, the summer experiments also demonstrated the usefulness of using a heavily loaded special Teflon® doctor to minimize and, under some conditions, eliminate sheet/press roll picking. To further explore the variables influencing picking, a side experiment was conducted at various press loads while maintaining the press roll surface temperature at 204°C. We found that picking decreased with decreasing peak pressure.

The winter of 1998

There were a number of objectives for the winter experiments. These included the evaluation of an improved adjustable (on-the-fly) press shoe ramp and an evaluation of the initial version of a hover press. It was also desirable to determine the effect of refining and machine speed on critical impulse drying temperature and runnability (sheet/press roll surface picking).

The summer experiments had indicated that picking could be reduced by reducing the peak pressure. Hence, the press shoe profile should be designed to minimize the peak pressure while maximizing the impulse. The improved adjustable ramp was designed to follow a standard 0.25 m shoe. To contain the shoe and ramp within the existing open-extended-nip press, the new adjustable ramp length was limited to a length of 0.10 m. **Figure 5** shows three press shoe pressure profiles that were investigated during the winter experiments. The following nomenclature was used:

- Ramp 8 Off - Hover Off: The ramp as well as the hover press were installed but not pressurized.
- Ramp 8 On - Hover Off: The ramp was pressurized while the hover press was not pressurized.
- Ramp 8 On - Hover On: Both the ramp and the hover press were pressurized.

The winter experiments also provided an opportunity to explore whether blanket design would influence impulse drying. To accomplish this, the drive side of the blanket was grooved, while the operator side was blind-drilled. Table I documents the forming and pressing conditions that were used.

The furnish used in the summer experiments was also used in the winter experiments. The ingoing solids, hydrodynamic specific surface, and freeness of cases investigated are shown in Table II.

The experiments were conducted over a 3 day period. At the start of each day, single-felted wet pressing controls were run for each of the three press shoe profiles. Afterwards, the press roll was heated to a range of temperatures and impulse-dried samples were taken. The X2 machine was run at a speed of 380 m/min during the first 2 days and increased to 760 m/min on the third day. To investigate the effect of refining, the furnish was refined to 540 mL CSF on the first day and 460 mL CSF on the second and third days.

As in previous studies, the decrease of the zd-specific elastic modulus was used to indicate the critical impulse drying temperature. We observed that the grooved blanket consistently resulted in a higher modulus than did the blind-drilled blanket; see **Fig. 6.** This suggested that nip venting may be a more important factor in impulse drying than had been previously realized. It also suggested that the blanket groove geometry should be optimized.

Date, (Freeness, mL CSF/ PM speed, m/min)	Specific surface, m^2/g	Ingoing solids, %	Press shoe configuration	CRITICAL IMPULSE DRYING TEMPERATURE, °C Blind-drilled	Grooved
Summer, (570/380)	NA*	30.0	Std. - No ramp	NA	164
Summer, (570/380)	3.20	32.2	Short - Ramp 4	NA	218
	4.07	31.5	Short - Ramp 5	NA	209
Winter, (540/380)	6.63	24.6	Std. - Ramp 8 off - Hover off	188	203
			Std. - Ramp 8 on - Hover off	216	216
			Std. - Ramp 8 on - Hover on	217	217
Winter, (458/380)	11.16	27.5	Std - Ramp 8 off - Hover off	200	200
			Std - Ramp 8 on - Hover off	232	232
			Std - Ramp 8 on - Hover on	243	243
Winter (460/760)	14.97	26.1	Std - Ramp 8 off - Hover off	216	216
			Std - Ramp 8 on - Hover off	228	228

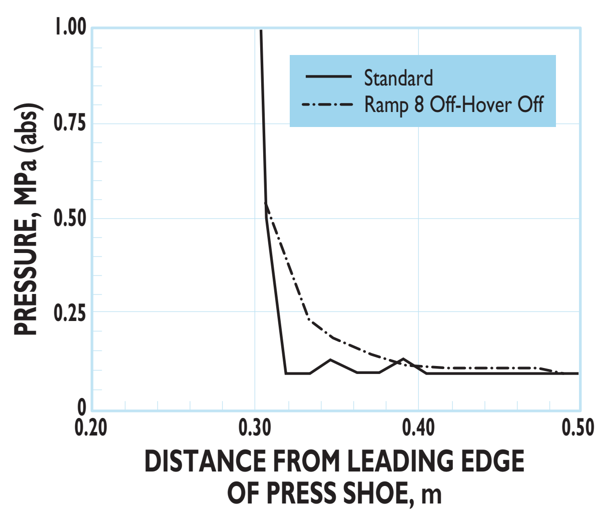
*Not available

III. Critical impulse drying temperatures

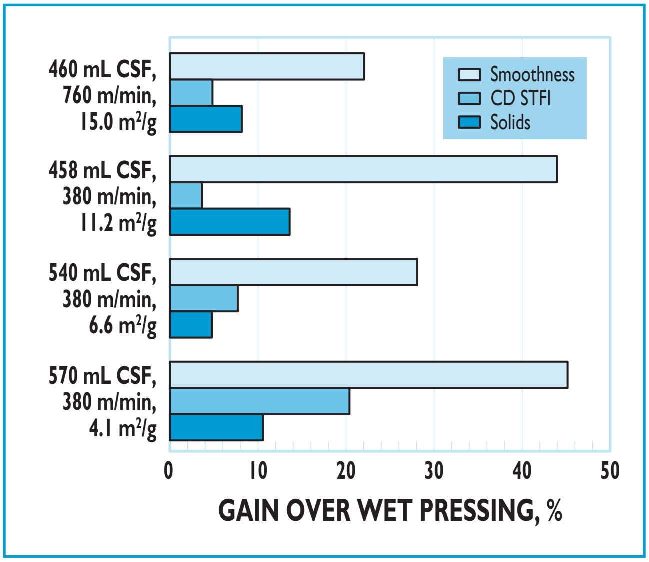
DISCUSSION

Table III summarizes the impulse drying critical temperatures that were determined in the pilot experiments that were conducted in the summer of 1997 and the winter of 1998. A few differences are particularly interesting. Note that the critical impulse drying temperature of the summer standard 0.25 m shoe (with no ramp) was 39°C lower than the critical impulse drying temperature for the winter standard 0.25 m shoe with ramp no. 8 and the hover press both unpressurized. A number of factors contribute to these differences. There are differences in ingoing solids and freeness (and hydrodynamic specific surface) and small differences in the pressure profiles. Based on previous laboratory simulations, we expected that a decrease in ingoing solids would decrease the critical impulse drying temperature. Likewise, an increase in hydrodynamic specific surface and a corresponding decrease in freeness would also result in a decrease in critical impulse drying temperature. As these trends were not observed, the differences in pressure profile were considered.

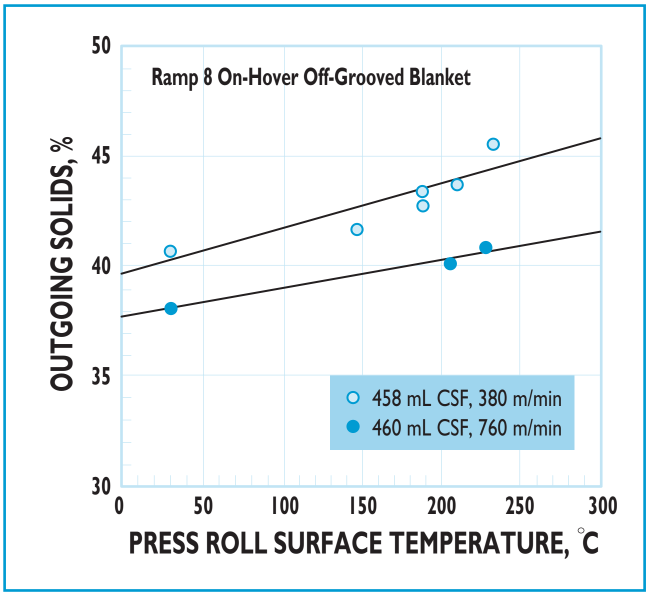
Referring to **Fig. 7,** the standard 0.25 m shoe pressure dropped the last 690 kPa in less than 0.025 m, while the standard 0.25 m shoe with the unpressurized ramp and hover press dropped the last 690 kPa in just over 0.05 m. Hence, the unpressurized ramp and hover press profiles would be expected to result in some reduction in the net pressure difference between the inside and outside of the web as it leaves the impulse dryer. This effect could have resulted in the observed increase in critical impulse drying temperature. As the ingoing temperatures for all cases were about the same (40°C), the pressure profile was most probably the cause of the observed difference. Hence, an attempt to impulse dry the winter furnishes with a standard 0.25 m shoe would have produced an even lower critical temperature than was observed in the summer.



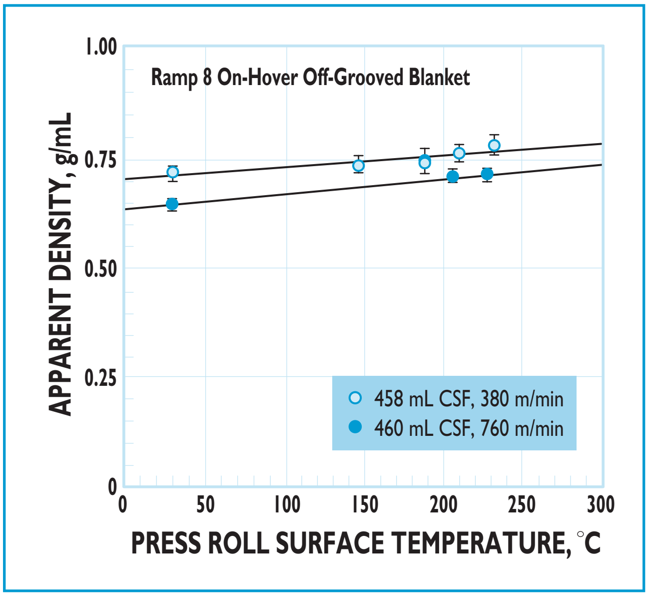
7. Comparison of pressure pulse shapes



8. Percentage gain in press dryness, CD STFI compression strength, and smoothness of impulse drying compared to wet pressing at the same press impulse



9. Outgoing solids as a function of press roll surface temperature for cases where the adjustable ramp was on, the hover press was off, and the grooved blanket was utilized



10. Apparent density as a function of press roll surface temperature for cases where the adjustable ramp was on, the hover press was off, and the grooved blanket was utilized

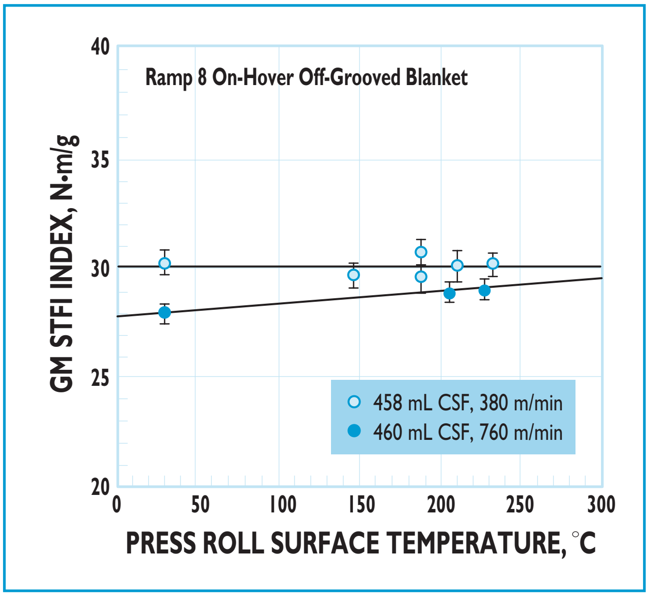
In the winter experiments, there was a consistent difference between the specific elastic modulus of paper produced with the grooved blanket and the blind-drilled blanket. In almost all cases, paper that was wet pressed or impulse dried on the grooved side was stronger than that wet pressed or impulse dried on the blind-drilled side. This was interpreted as resulting from higher amounts of rewet or lower press solids on the blind-drilled side, which would reduce web densification and strength. This would be consistent with the hypothesis that the blind-drilled blanket did not provide a sufficient path for venting of water from the felt while the paper web and felt are in the nip.

As is tabulated in Orloff *(2),* impulse drying improved outgoing solids over wet pressing by 4–13%. Similarly, surface smoothness improved by 22–51% and cross-direction (CD) STFI index improved by 3–20%. These gains of impulse drying over single-felted wet pressing are summarized in **Fig. 8.**

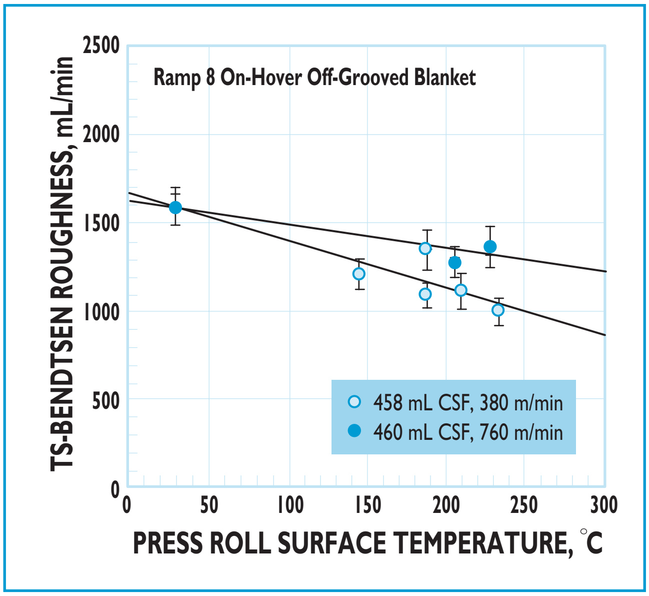
As the Std. - Ramp 8 On - Hover Off case was generally superior, it is instructive to examine the data for that case more closely. Impulse drying press solids and linerboard physical property development with press roll surface temperature is of particular interest for the low-freeness experiments. **Figure 9** shows the effect of press roll surface temperature on outgoing solids. **Figures 10–12** show the development of apparent density, geometric mean STFI compression strength index, and heated-surface Bendtsen Roughness with increasing press roll surface temperature. Note that the error bars represent 95% confidence limits. The results confirm a fairly strong dependence of dryness, apparent density, and Bendtsen Roughness on press roll surface temperature. A weaker dependence of STFI compression strength is also apparent.

CONCLUSIONS

The pilot paper machine experiments confirmed that the ramp decompression concept may be used to increase critical impulse drying temperature, thus opening the operating window of the technology. The adjustable shoe was found to work well, while the hover



11. Geometric mean STFI compression strength index as a function of press roll surface temperature for cases where the adjustable ramp was on, the hover press was off, and the grooved blanket was utilized



12. Heated surface Bendtsen Roughness as a function of press roll surface temperature for cases where the adjustable ramp was on, the hover press was off, and the grooved blanket was utilized

press, in its present form, was found to have increased rewet and to have negatively impacted paper properties.

A combination of the specially designed press roll surface and the Teflon doctor helped to minimize picking. Venting of the nip and the blanket groove geometry were found to be important variables that should be optimized in future work.

In general, improvements were found to be greatest at higher freenesses and ingoing solids and for longer nip residence times.

RESEARCH UPDATE

In the summer of 1998, additional experiments were conducted on the X2 pilot paper machine at higher basis weights and higher ingoing solids to match those required to produce 126 g/m^2 linerboard. These experiments were used to optimize press shoe pressure profile, blanket groove geometry, felt, and post-nip decompression.

Also in the summer of 1998, experiments were run on the 1 m wide X4 pilot paper machine at a basis weight of 150 g/m^2 and at an ingoing solids typical of current third-press applications. The objective of these experiments was to set up the machine for a long demonstration run. In September 1998, reels of impulse-dried linerboard were produced at a basis weight of 150 g/m^2. In October 1998, these reels were converted to corrugated board at a commercial box plant. The results of these pilot-production experiments will be reported at the TAPPI 1999 Engineering Conference. **TJ**

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