



*Institute of Paper Science
and Technology*

**THE INFLUENCE OF YIELD, REFINING AND INGOING SOLIDS ON THE
IMPULSE DRYING PERFORMANCE OF A CERAMIC COATED PRESS ROLL**

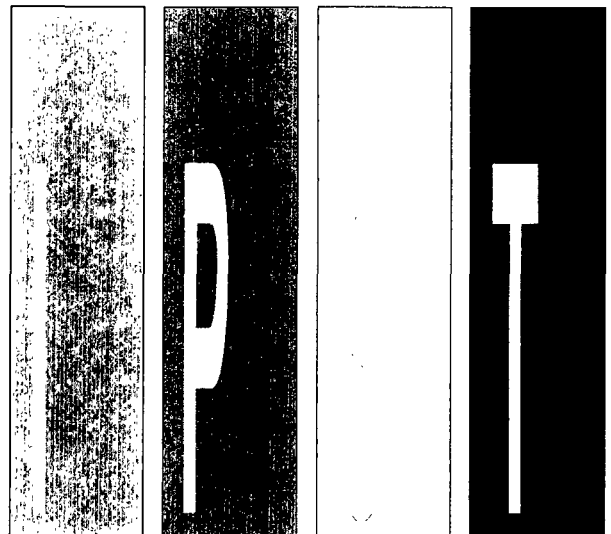
Project 3470

REPORT FOUR

to

MEMBER COMPANIES OF THE INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

October 1991



Atlanta, Georgia

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THE INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

Atlanta, Georgia

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A CERAMIC COATED PRESS ROLL

Project 3470

Report 4

By

David I. Orloff and Jeffrey D. Lindsay

To

MEMBER COMPANIES OF

THE INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

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BASIC UNITS AND CONVERSIONS

Mass	Kilograms (kg) = 2.20462 pound mass (lbm) Ton = 2000 lbm.
Length	Meters (m) = 3.2808 feet (ft).
Time	Second (s) = 1000 milliseconds (ms).
Volume	Cubic meters (m ³) = 106 milliliters (mL).
Force	Newton (N) = 0.22481 pound force (lbf).
Pressure	Pascal (Pa) = 0.000145 pounds per square inch (psi). MegaPascal (MPa) = 1×10^6 Pascal.
Temperature	Degree Celsius (°C) Degree Fahrenheit (°F) = °C x (9/5) + 32.
Energy	Joule (J) = 9.486×10^{-4} British Thermal Units (Btu). Quad = 1×10^{15} Btu.
Power	Watt (W) = 1 J/s Watt (W) = 9.486×10^{-4} (Btu/s).

SYMBOLS AND ABBREVIATIONS

α	Effective Volume Of Swollen Fibers, cc/g
Burst Index	Burst Strength Index, $\text{kPa}\cdot\text{m}^2/\text{g}$. Tappi Method T807.
c	Concentration, g/cc
ΔP	Pressure Drop In Direction Of Flow, Pa
ϵ	Porosity (Fractional Void Volume), m^3/m^3
ϵ_f	Flow Porosity, m^3/m^3
Freeness	Canadian Standard Freeness, mL. Tappi Method T227 OM-85.
K	Permeability, m^2
Kappa No.	Kappa Number. Tappi Method T236 CM-85.
k	Shape Factor (Kozeny Constant), unitless
L	Flow Distance, m
μ	Fluid Viscosity, $\text{kg}/\text{m}\cdot\text{s}$
S	Flow Exposed Surface Area Of The Fibers Per Unit Mass, m^2/g
S_o	Surface Area Per Unit Volume Of Solid Material, m^2/m^3
STFI Index	Compressive Strength Measured By STFI method, $\text{N}\cdot\text{m}/\text{g}$. Tappi Method T826 pm.86.
v	Superficial Velocity, m/s

SUMMARY

Impulse drying is an innovative process for consolidation and drying of paper that holds great promise for reducing energy consumption and facilitating the use of higher percentages of recycled fiber. Early attempts to commercialize the process have demonstrated that sheet delamination is a major obstacle that must be overcome.

Impulse drying research at the Institute of Paper Science and Technology (IPST) has focused on developing impulse drying process modifications that facilitate impulse drying of heavy weight grades while avoiding sheet delamination.

Previously reported laboratory scale experiments have shown that the thermal properties of the heated impulse drying roll have a significant effect on the maximum water removal that can be achieved without sheet delamination. In particular, it was found that by reducing the thermal conductivity and heat capacity of the press roll coating, impressive water removal could be achieved.

The results of pilot impulse drying trials, conducted with a ceramic-coated press roll and a southern pine furnish, are presented. The experiments cover a range of Kappa number, refining levels and ingoing solids, yielding a range of ingoing sheet permeability. The experiments demonstrate that the roll temperature at which sheet delamination first occurs is a function of the specific surface of the ingoing web, which in turn is a function of; cooking, refining and pressing variables.

LITERATURE REVIEW

Impulse Drying and Delamination

Early attempts by a consortium of IPST, Beloit and Weyerhaeuser to commercialize the impulse drying process were frustrated by the occurrence of sheet delamination. Since then, IPST research has focused on resolving this major technical obstacle.

The results of that early attempt are described in the work of Crouse et al (1). They reported pilot and laboratory scale impulse drying experiments carried out on Beloit's high temperature roll press, (HTP) and on laboratory-scale facilities at IPST.

The pilot-scale work was conducted with a chrome-plated steel press roll and single-ply handsheets made from Douglas Fir. Yield was varied from 50 to 65%, freeness was varied from 500 to 720 ml CSF and OCC was varied from 0 to 40%. Handsheets formed at a basis weight of 205 gsm were pressed to 35% solids prior to impulse drying. Sheets were impulse dried both with and without steam preheating. Press loading was varied from 350 to 1050 kN/m at a constant nip residence time of 35 ms. In a typical experiment, press roll surface temperature was increased until sheet delamination was detected by a drop in paper physical properties.

Crouse called the roll surface temperature where delamination first occurred the "incipient delamination temperature". He found that this critical temperature was 149°C with steam preheating and 190°C without steam preheating. Crouse also found that increasing the basis weight decreased the critical temperature. Beloit proposed that a weaker fiber

network, resulting from yield and refining, delaminated at a lower temperature than its stronger counterpart. Beloit found that refining alone did not seem to influence the delamination limit, but it did lower the achievable solids content. To explore the influence of species, southern pine handsheets were also impulse dried and were found to exhibit the same response.

To corroborate these findings, a series of laboratory scale impulse drying experiments were performed with the same Douglas Fir furnish. In those experiments, yield was varied from 50 to 55%, freeness was varied from 740 to 640 ml CSF and ingoing solids were varied from 35 to 50%. For each case, single-ply 205 gsm handsheets were steam preheated and impulse dried at successively higher platen temperatures until sheet delamination was detected. The results showed that the critical platen temperature increased with increased freeness but was insensitive to ingoing solids and yield. A critical temperature of 177°C was determined at 720 ml CSF while a critical temperature of 149°C was obtained at 640 ml CSF.

The key findings of Crouse's work were that at press roll surface temperatures above 150°C, the sheet can experience delamination regardless of its composition, structure, freeness, yield and press loading. At temperatures below 150°C, the benefits were not significantly different from those obtainable by conventional pressing using elevated sheet temperatures.

Lavery(2) presented the first impulse drying laboratory scale simulations where the influence of refining level on delamination was systematically investigated. In his experiments, southern pine unbleached kraft pulp was refined on a valley beater over a range of freeness from 750 ml CSF to 200 ml CSF at 50 ml CSF intervals. Handsheets were made from each pulp sample at a basis weight of 200 gsm and were pre-pressed to 35% solids before impulse drying on the lab scale impulse drying simulator. Using a chrome plated steel platen, unheated handsheets were impulse dried at 371°C and 2.8 MPa peak pressure for 30 milliseconds.

Delamination was detected by various physical measurements including, internal bond strength, apparent density and STFI compression tests. Reduction of freeness from 750 ml CSF to 600 ml CSF resulted in an increase in the internal bond strength, density and STFI compression strength. Further refining to even lower freeness resulted in a decrease in bond strength, density and compression strength. Hence, the onset of delamination occurred at freeness of slightly less than 600 ml CSF at the impulse drying conditions of Lavery's experiment.

Lavery argued that "incipient delamination" did not occur at freeness in excess of 600 ml CSF as the internal bond strength of impulse dried specimens were almost 20% higher than that of pressed and conventionally dried specimens.

The present authors interpret Lavery's data to mean that sheets refined to higher levels will be less permeable to flashed steam at the exit of the nip. As the permeability of the sheet at nip opening is impossible to measure, we have used the specific surface of the ingoing sheet as a relative measure of permeability.

In more recent impulse drying research by Orloff (3-5), a prototype ceramic coating was developed and its impulse drying performance was compared to that of steel surfaces. It was observed that ceramic platens can be operated at higher temperatures and pressures resulting in

improved water removal and physical properties without inducing sheet delamination.

Encouraged by the laboratory-scale results, a pilot impulse dryer was retrofitted with a prototype ceramic coated press roll and was used to evaluate its performance in impulse drying single-ply linerboard. Pilot-scale experiments were conducted over a range of ingoing solids and nip residence times for a southern pine kraft cooked to two different Kappa numbers and refined to two freeness levels.

The Relevance of Permeability

Darcian Permeability. In the paper industry, it is common practice to express paper permeability in terms of gas flow rates through a sheet. This practice is useful for comparing similar sheets, but does not truly characterize the interaction of flowing fluid with the porous structure and provides no direct information about flow in a wet sheet. The standard engineering definition of permeability provides a more useful parameter, though one less easily measured. The standard definition is based on Darcy's law (6), which, for one-dimensional flow, states that the velocity of fluid flow through a saturated porous medium is directly proportional to the pressure gradient:

$$v = \frac{K \Delta P}{\mu L}$$

(1)

where v is the superficial velocity (flow rate divided by area), K is the permeability, μ is the fluid viscosity, and ΔP is the pressure drop in the flow direction across a distance L . The units of K are m^2 . In Equation (1), the permeability is an empirical proportionality parameter linking fluid velocity to pressure drop and viscosity. For a homogeneous medium, K is not a function of ΔP , basis weight or viscosity but is an intrinsic parameter describing the flow resistance of the medium. In a compressible medium, permeability will be a strong function of the degree of compression. The permeability behavior of a paper sheet is affected by numerous factors, including refining, yield, fines content, pH and sheet formation. For example, Carlsson (7) found that permeability decreased with increased refining; high freeness pulp tends to have high permeability. Gren (8) examined the effect of cooking, finding that an increased Kappa number or higher yield resulted in increased permeability to water.

Permeability in Impulse Drying. Darcian permeability is a fundamental process parameter for wet pressing and other processes involving fluid flow in paper. In flow controlled pressing, the amount of water removed is directly related to saturated sheet permeability. In impulse drying, permeability is also expected to be of fundamental importance. Not only will permeability control the water removal ability of the sheet, as in standard wet pressing, but permeability will also directly affect the vapor phase in the sheet, making permeability an important factor in delamination control.

The importance of permeability in impulse drying can be explained in terms of the physics of impulse drying (9,10). Intense heat transfer from the high-temperature pressing surface can lead to vapor formation

in the form of a narrow dry zone and a larger two-phase zone. Apart from the effects of viscosity reduction and increased sheet compressibility due to elevated temperature, the pressurized steam in the sheet may assist in liquid water removal through a displacement process and by resisting rewet. The pressure of the steam zone is the saturation pressure of water at the equilibrium temperature of the two-phase region. Heat flux into the two-phase region by conduction results in vaporization; heat flux out of the two-phase zone by conduction into the liquid is balanced by condensation of vapor. The requirements of mass and energy conservation with phase equilibrium establish the temperature of the two-phase zone, and hence the vapor pressure.

The role of sheet permeability on these processes was simulated by Lindsay (9) in an idealized model of impulse drying. He found that the displacement velocity of the liquid zone decreases by roughly a factor of 3 with a tenfold decrease in permeability, which was also seen in predictions with a different model of the same process (11). Decreased permeability allows higher vapor pressures to be sustained, for there is less relief due to gas-phase volume expansion from the motion of the liquid seal. Not only will a low permeability sheet have a higher vapor pressure in the nip during impulse drying, but the decreased permeability means a reduction in vapor venting once the sheet leaves the nip. While the vapor might escape quickly as a high permeability sheet leaves the nip, the vapor pressure in a low permeability sheet may remain high with the possibility of delamination if the pressure drop in the escaping vapor across the thickness of the sheet exceeds the z-directional strength of the sheet.

Characterizing Permeability in Compressible Media. Formulas relating permeability and porosity can be derived by making simplifying assumptions about the structure of the medium. For example, by assuming that the pore network consists of many distinct, continuous and regular channels following from one end of the porous medium to another, the well-known Kozeny-Carman equation can be obtained:

$$K = \frac{1}{kS_o^2} \frac{\epsilon^3}{(1-\epsilon)^2} \quad (2)$$

where ϵ is the porosity (fractional void volume), S_o is the surface area per unit volume of solid material and k is a shape factor (the Kozeny constant) which accounts for effects of channel shape and orientation. The Kozeny constant can be derived for ideal, simple pore structures but becomes an empirical factor for real porous media. In many cases it is not constant but a function of porosity. For fibrous media, a value of 5.55 is a widely used value which works well in many cases (12), although values typically may lie in the range of 3-7 for porosities less than 0.8 (13).

During a process such as wet pressing or impulse drying, the permeability may change by an order of magnitude or more as the sheet undergoes various degrees of compression. When comparing permeabilities between various sheets and relating that information to wet pressing, it is not clear at what value of porosity to report the permeability. Correlations for the full permeability-porosity curve could be used, but a simpler means of comparison would be to use S_o , which is a measure of the flow-resisting surface area that fluid encounters in a porous medium. Using the Kozeny-Carman constant, measurement of permeability as a function of porosity can be used to obtain an estimate of S_o ;

however, the porosity used in the Kozeny-Carman equation is not the absolute porosity of a real system (volume fraction of the non-solid) but the volume fraction of the channels open to flow or flow porosity. Much of the water in paper may be in pores where flow is not possible, such as dead end pores and micropores in the fiber wall, and some of the water may be chemically bound to cellulose and other materials. The water which cannot flow under a hydraulic pressure gradient is the associated water or water of swelling, which in effect increases the apparent volume of the solid (immobile) phase. The effective volume of the swollen fibers is defined as α , with units of cc/g. At a concentration of c g/cc, the flow porosity is

$$\epsilon_f = 1 - \alpha c$$

(3)

which can be used instead of ϵ in Equation (2), with the assumption that $k = 5.55$, to yield

$$K = \frac{1}{5.55 S_o^2} \frac{(1-\alpha c)^3}{\alpha^2 c^2}$$

(4)

Now we note that $\alpha S_o = S$, where S is the flow-exposed surface area of the fibers per unit mass, commonly called the specific surface area. Incorporating this definition into Equation (5) and rearranging, we obtain

$$(Kc^2)^{1/3} = \left(\frac{1}{5.55 S^2} \right)^{1/3} (1-\alpha c)$$

(5)

which is a classic equation that has been applied frequently to pulp mats (14-17). By plotting permeability data from a single sample at various compressive plots as $(Kc^2)^{1/3}$ versus c , the specific volume, α , can be obtained from the intercept and the specific surface, S , can be obtained from the slope. The values obtained in this manner are subject to a number of errors but are still useful in characterizing the flow properties of fibrous mats. The specific volume tends to vary over a small range for typical pulps, but the specific surface parameter can vary widely and is useful in characterizing permeability differences between pulps.

EXPERIMENTAL METHODS

Pilot Impulse Drying Apparatus And Methods

Forty-two pound (205 gsm) single-ply liner was made from an unbleached southern softwood kraft bottom sheet linerboard pulp collected from the last stage washers. Two batches of pulp were used in the experiments. The first batch had a Kappa number of 74 while the second batch had a Kappa number of 65. Once received from the mill, the pulp was washed to remove residual black liquor and refined on a 2.3 kg Valley beater to the desired freeness. In order to achieve a range of ingoing solids from 30 to 50%, the linerboard was formed on the IPST slow-speed web former, unwound and pressed on the second nip of the pilot dryer to the desired dryness level. To characterize the pressed sheet, samples were tested for Kappa number, fiber length distribution and out-of-plane permeability.

A schematic of the pilot impulse dryer is shown in Figure 1. The heated press roll was plasma-spray-coated with the same ceramic coating that had been previously applied to platens (5).

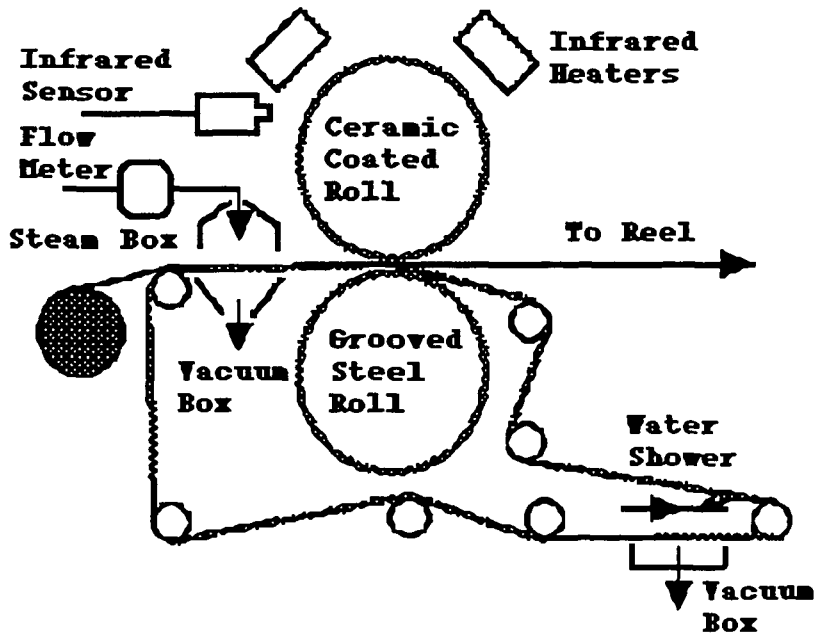


Figure 1. First nip of the pilot-scale two-nip impulse dryer.

The roll was heated by an external source of infrared radiation as controlled by an infrared sensor. The sensor was positioned just prior to the nip (within 0.38 m) to record the temperature of the roll and to

serve as the input to the temperature controller. The controller adjusted the output of the infrared roll heaters to maintain a constant ingoing roll surface temperature.

Sheet preheat temperature was adjusted using a steam box in combination with a vacuum box. The steam box was instrumented with a temperature and pressure compensated vortex flow meter. The steam box was also instrumented to measure the steam temperature and pressure just prior to exiting the steam box and the vacuum box operating pressure.

The primary variable controlling preheat temperature was the source pressure of the steam, which was set to 250 kPa. Under these conditions, the temperature of the steam entering the steam box was 110°C, the pressure in the steam box was 180 kPa, and the steam mass flow rate was 220 kg/hr. A vacuum box, positioned directly below the steam box and under the sheet and felt, drew a vacuum of 25 cm Hg.

Calculations showed that steam preheating the web at the above conditions resulted in ingoing sheet temperatures of 100°C. To verify this, thermocouples were placed between the sheet and felt to record sheet temperature during steam preheating. The results confirmed that, over the range of speeds and ingoing solids of these experiments, sheet temperatures were preheated to between 90°C and 100°C.

As steam preheating added water to the sheet, calibration experiments were conducted to measure the change in sheet solids due to steam preheating. Water gain from steam preheating was found to be independent of freeness and speed. Typically, sheets experienced a 1% drop in dryness due to steam preheating. All reported ingoing solids have been corrected to reflect the dryness of the sheet entering the impulse dryer.

Felt conditioning was achieved by spraying water on both sides of the felt following the nip. Excess water was pulled from the felt using a 30 cm Hg vacuum. This washed and cooled the felt and provided a consistent felt moisture ratio of 0.15 to 0.20.

It has been suggested that felt permeability may be a contributing variable to impulse drying. In this regard, the Frazier air permeability of the felt was measured before it was installed on the pilot dryer and when it was removed after completion of impulse drying experiments. When new, and prior to conditioning, the felt had an air permeability of about 7 m³/m² min. After conditioning, air permeability decreased to about 4.5 m³/m² min. After pilot-scale impulse drying experiments were completed the felt had an air permeability of 1.4 m³/m² min. While felt air permeability decreased with use, the felt was functional when it was removed.

In the present series of experiments, the nip was set to a peak pressure of 6.2 MPa. Peak nip pressure was verified using Fuji prescale LW pressure-sensitive film. The film was calibrated over a range of known pressures, using a laboratory-scale electrohydraulic press. Static nip impressions were then taken on the pilot impulse dryer to provide a measure of peak pressure, nip width and pressure uniformity. Based on these measurements, adjustments were made on independent hydraulic load

cells at each end of the roll to attain a uniform impression across the width of the roll. After balancing, a nip impression was taken and compared to the calibrated impressions. Peak nip pressures were found to be accurately predicted by load cell readings and the measured nip width.

Nip impressions demonstrated that the pressure distribution across the width of the prototype press roll was uniform and accurate. Based on a measured nip width of 20 mm at 6.2 MPa, a dryer speed of 60 m/min corresponded to a dwell time of 20 ms, while a dryer speed of 30 m/min corresponded to a dwell time of 40 ms.

In order to demonstrate the benefit of impulse drying over single felted wet pressing, drying experiments were conducted over a range of ingoing roll surface temperatures from 100°C to 430°C. To prevent the web from sticking to the heated roll at low temperatures, a polymeric release agent was applied to the ceramic roll. Experiments were conducted at 34% and 42% ingoing solids at nip residence times of 20 ms and 40 ms.

After obtaining the appropriate dryness, paper made on the web former was placed on the unwind stand of the pilot impulse dryer. Paper was then threaded into the pilot impulse dryer at 6 m/min with the nip open. After threading, the nip was closed and the steam and vacuum were turned on. Once the paper was threaded onto the reel, the controller would uniformly and quickly bring the machine up to the desired speed and hold that speed until the conclusion of the run.

The experimental objective was to assess whether the prototype ceramic-

coated press roll could be used to impulse dry heavyweight grades without inducing sheet delamination. To characterize the physical properties of the paper, samples of the wet pressed and impulse dried paper were finish dried on a drum dryer, conditioned to TAPPI standards and tested. Figure 2 shows the location of various tests performed on 0.22 m x 0.28 m samples. Sixty locations per sheet were tested by out-of-plane ultrasound and by STFI compression tests, and three locations per sheet were tested for burst strength. In addition, samples from each condition were also frozen in liquid nitrogen, fractured and cross sections analyzed using a scanning electron microscope.

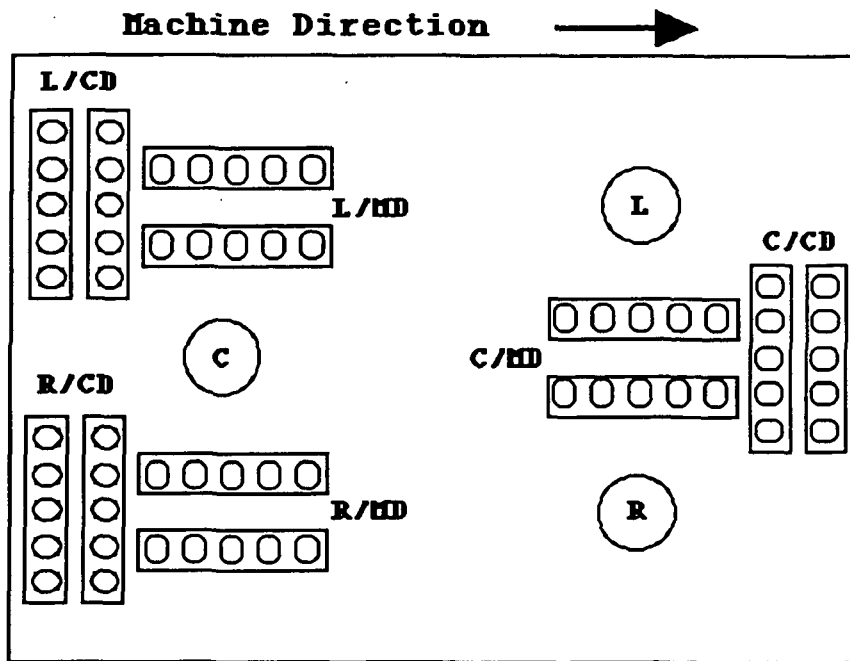


Figure 2. Schematic of sheet test locations.

Sheet delamination was detected by a three-step process. As a first step the micrographs were examined to search out samples showing visible delamination. This procedure tended to identify clear instances of delamination resulting from impulse drying at extreme roll surface temperatures. The second step consisted of examining the measured average strength properties as a function of roll surface temperature. Sheet delamination was identified when an increase in roll temperature resulted in a decrease in an average strength property. The third step in the procedure was to examine the coefficient of variation of the specific elastic modulus. Delaminated regions of a sheet exhibit lower out-of-plane specific elastic modulus than surrounding nondelaminated regions of the sheet. Hence, the coefficient of variation of the out-of-plane specific elastic modulus was helpful in detecting delamination in cases where small discrete delamination spots occurred.

Permeability Measurements

Transverse permeability measurements were made using equipment and techniques previously reported (18,19) although the water flow in the z-direction was no longer due to gravity alone but came from a pressurized tank at pressures of 7-30 kPa. A schematic of part of the permeability apparatus is given in Figure 3. Not shown is the modified Carver press which generates the compressive loads required to measure permeability as a function of porosity in a saturated sheet.

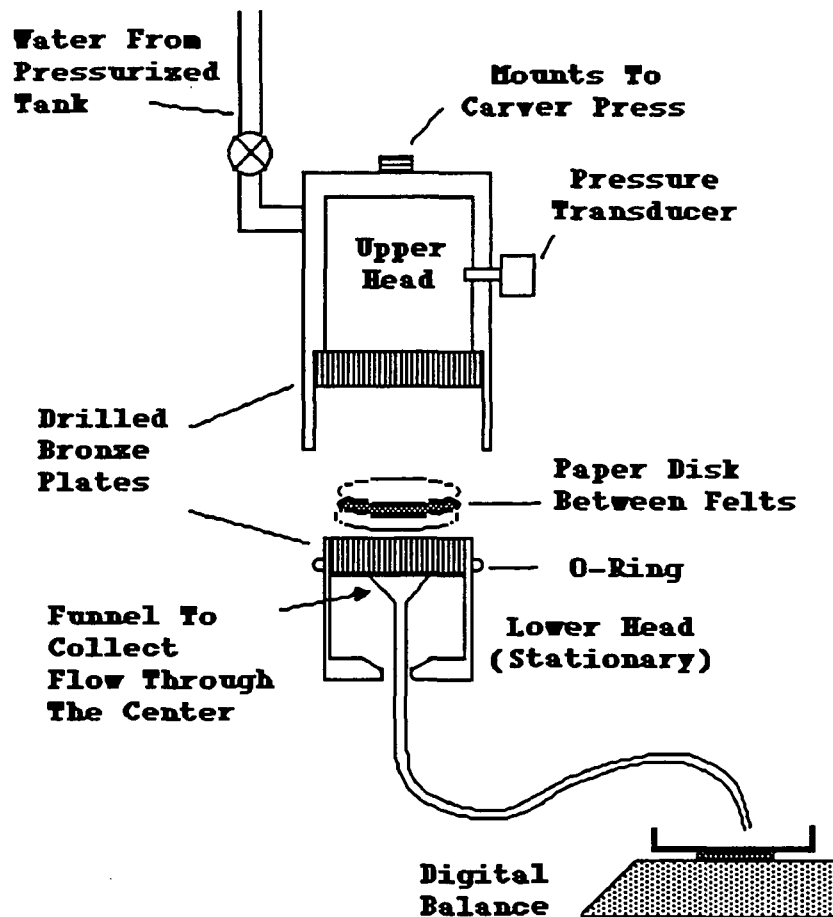


Figure 3. Schematic of the water flow system for transverse permeability measurements.

In making transverse permeability measurements, a saturated paper disk was compressed between two wet felts. The felts were in contact with finely drilled bronze plates that transmit mechanical pressure while allowing water to flow through. To eliminate problems with leakage around the edge of the paper, only the flow through the central region (comprising 23% of the area of the paper disk) was collected and measured. This fluid entered a funnel which led the fluid through plastic tubing to a digital balance in order to measure the accumulated flow as a function of time. Sheet thickness was obtained using a Kaman eddy-current transducer (ECT) and a technique described previously (19).

In transverse permeability measurements, water passes through the central region of the paper and felts with a known pressure drop. The permeability is given by:

$$K_z = \frac{L}{\frac{A_{\text{flow}} \Delta P}{Q \mu} - R_f}$$

(6)

where A_{flow} is the cross-sectional area of the flow collection region (23% of the sheet area) and R_f is the inherent resistance of the felts and flow system. R_f was usually of little importance because the paper

resistance was so much greater than the resistance of the felts or other components of the flow system.

For each load, knowledge of the compressed sheet thickness and the sheet basis weight are used to obtain the sheet concentration, c , in gm/cc.

EXPERIMENTAL RESULTS

The transverse permeability of ingoing sheets was measured as a function of porosity as shown in Figure 4. The data was then correlated to determine the corresponding specific surface as also reported in Figure 4. Consistent with the results of Carlsson(7) and Gren(8), the specific surface decreased with increasing Kappa number, increasing freeness and increasing ingoing solids.

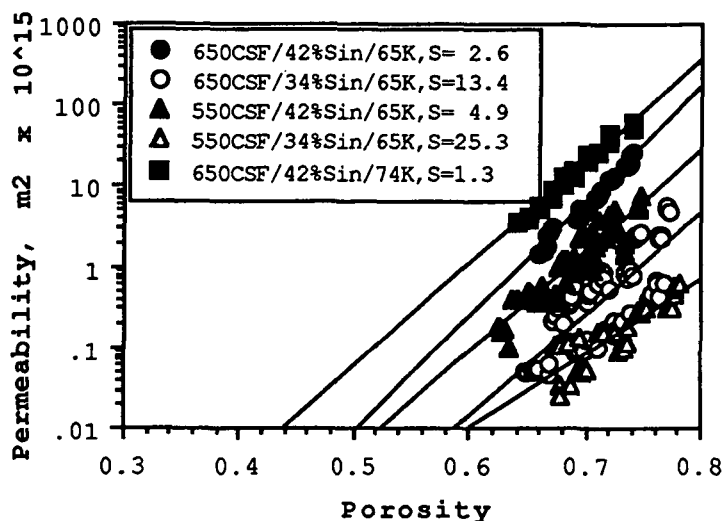


Figure 4. Out-of-plane permeability of ingoing sheets as a function of sheet porosity. Sheets formed into 205 gsm single-ply sheets using an unbleached southern pine furnish.

The results of the pilot-scale impulse drying experiments are shown in Figures 5 through 14. Outgoing solids for 20 ms and 40 ms experiments, shown in Figures 5 and 6, suggest that outgoing solids greater than 55% can be achieved at nip residence times of at least 40 ms and ingoing solids of at least 42%. Hence, we conclude that nip widths sufficient to achieve 40 ms are required and that the impulse dryer should be located as a third-press replacement or between the third press and conventional drum dryers.

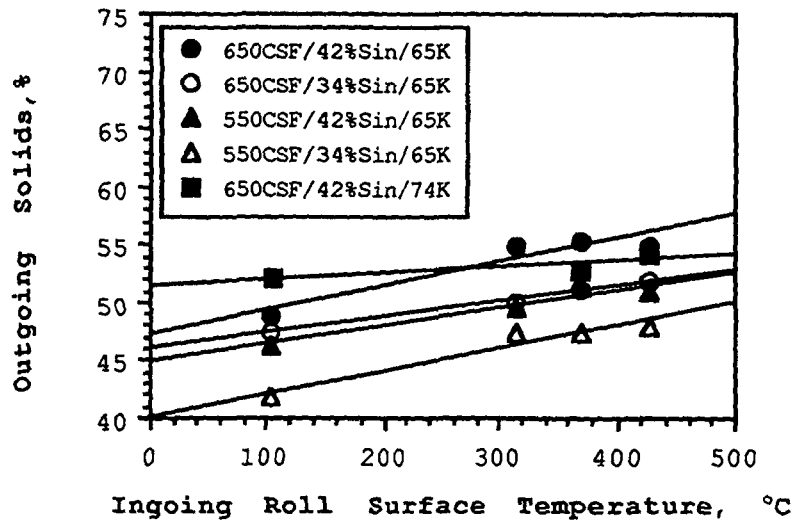


Figure 5. Outgoing solids as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 20 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.062 MPa·s.

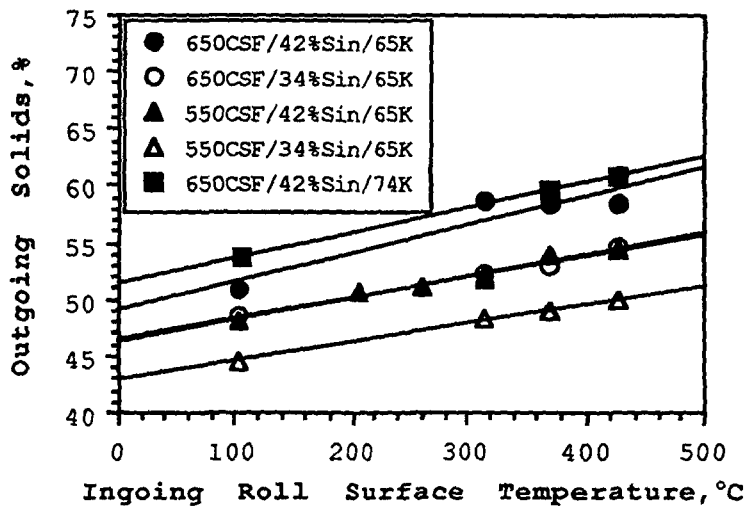


Figure 6. Outgoing solids as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 40 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.124 MPa·s.

The results of out-of-plane ultrasound measurements are shown in Figures 7 through 10. As expected, increased refining from 650 ml CSF to 550 ml CSF resulted in higher specific elastic modulus at the "control" roll

temperature of 106°C. An increase in press roll temperature resulted in an increase in modulus as long as the sheet did not delaminate. Figures 7 and 8 show that decreased freeness, decreased Kappa number and decreased ingoing dryness resulted in a drop-off in elastic modulus at lower roll surface temperatures.

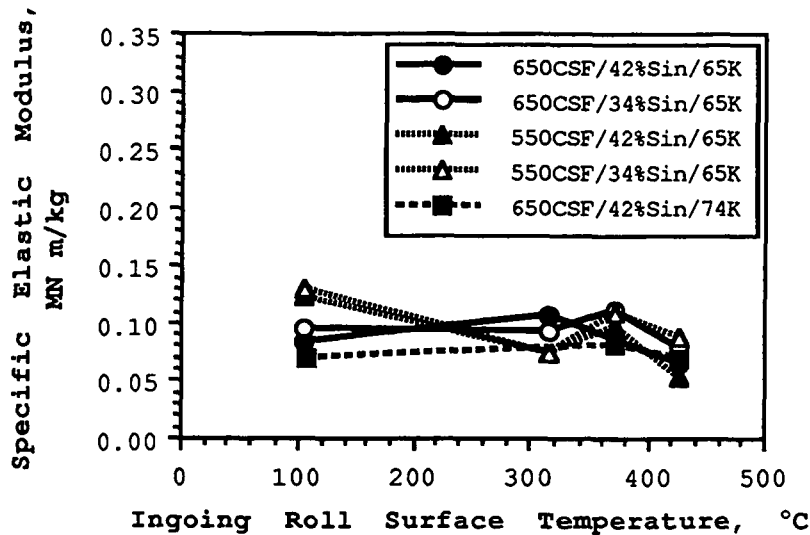


Figure 7. Out-of-plane specific elastic modulus as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 20 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.062 MPa·s.

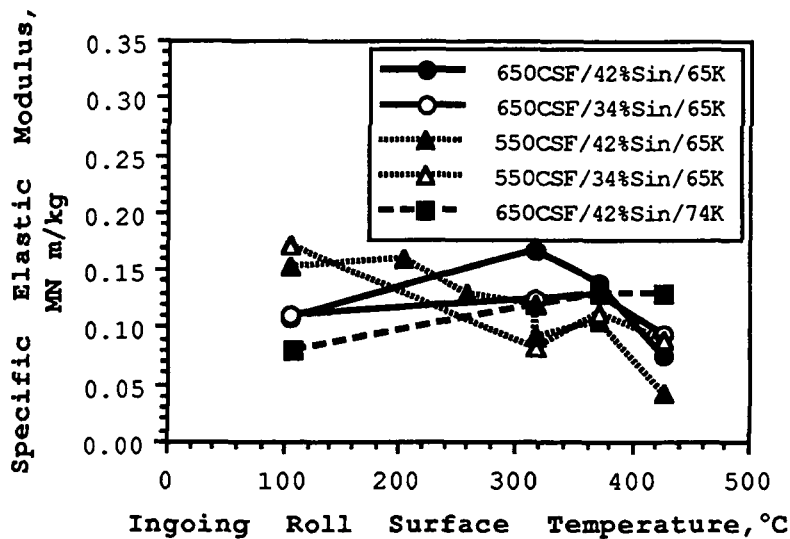


Figure 8. Out-of-plane specific elastic modulus as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 40 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.124 MPa·s.

The sheet average coefficient of variation of the specific elastic modulus is shown as a function of ingoing roll surface temperature in Figures 9 and 10. In laboratory scale simulations, Orloff(3,5) has used the rise in coefficient to define the temperature at which the onset of sheet delamination occurs.

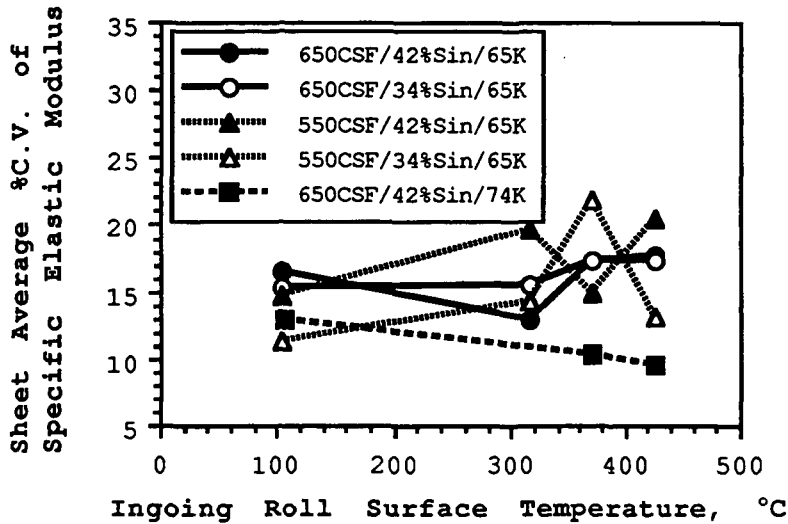


Figure 9. Sheet average coefficient of variation of the out-of-plane specific elastic modulus as a function of ingoing

roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 20 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.062 MPa·s.

While a rise in coefficient of variation occurs at roll temperatures where the average elastic modulus drops, the magnitude of the rise is not as great as has been observed in laboratory-scale experiments with handsheets.

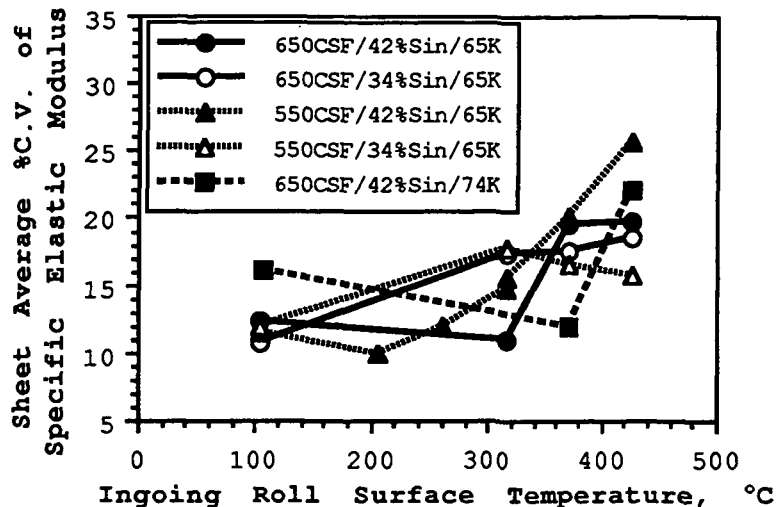


Figure 10. Sheet average coefficient of variation of the out-of-plane specific elastic modulus as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 40 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.124 MPa·s.

Figures 11 and 12 show geometric mean STFI index, while Figure 13 and 14 show burst index as a function of ingoing roll surface temperature. Both measures of sheet strength showed a drop-off at the same roll temperatures as was observed from the elastic modulus data of Figures 7 and 8.

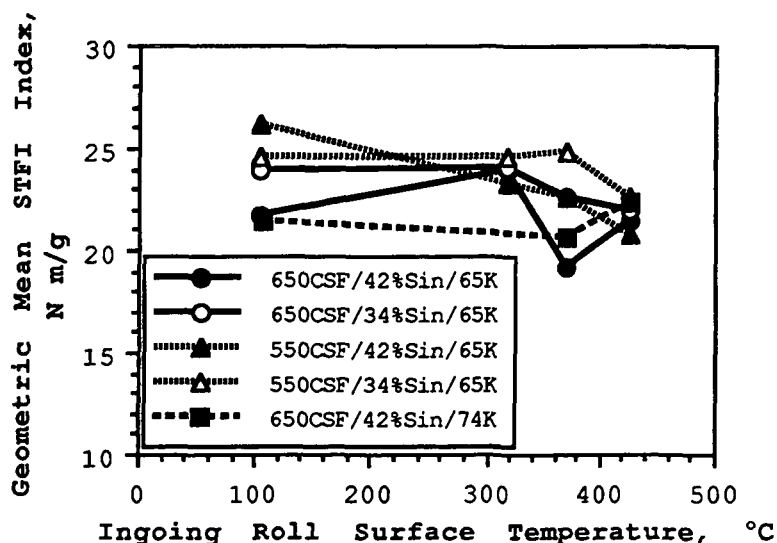


Figure 11. Geometric mean STFI compression index as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 20 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.062 MPa·s.

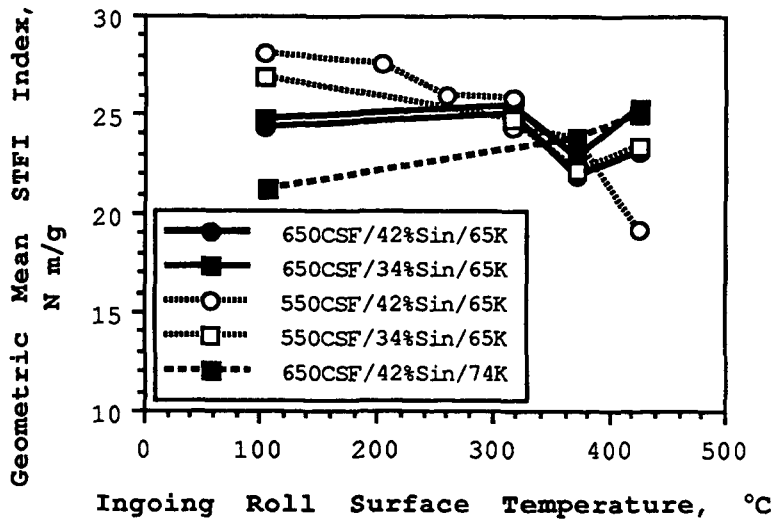


Figure 12. Geometric mean STFI compression index as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 40 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.124 MPa·s.

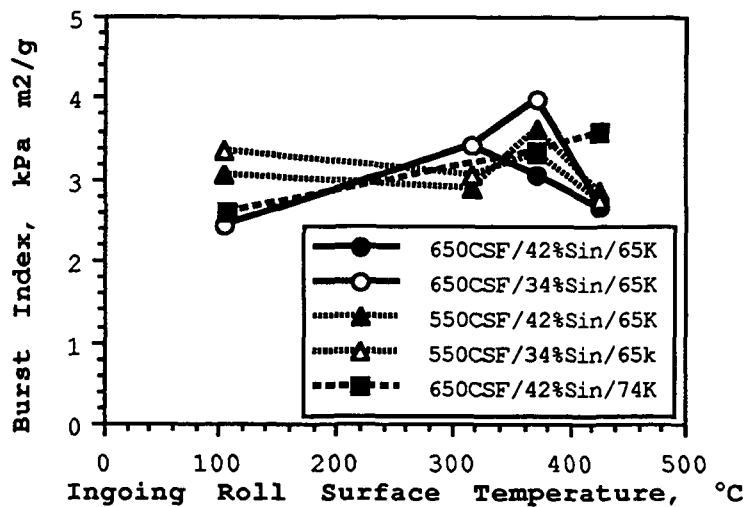


Figure 13. Burst index as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 20 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.062 MPa·s.

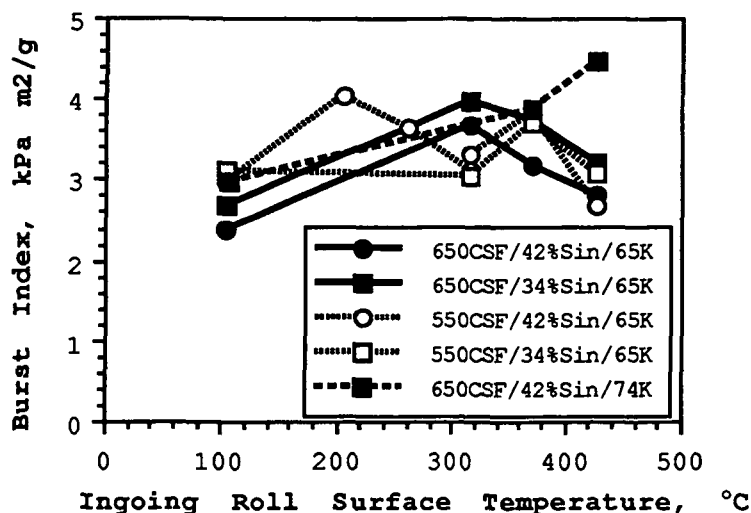


Figure 14. Burst index as a function of ingoing roll surface temperature. Pilot-scale impulse drying 205 gsm single-ply linerboard for 40 ms at a peak pressure of 6.2 MPa resulting in an impulse of 0.124 MPa·s.

Critical ingoing roll surface temperatures, corresponding to the onset of delamination, may be determined for the case of 42% ingoing solids at a nip residence time of 40 ms. Table 1 summarizes these critical temperatures and reports the outgoing solids and paper physical

properties attained at these temperatures. For comparison, Table 2 shows outgoing solids and paper physical properties attained at the "control" roll temperature of 106°C.

Table 1

Kappa No.	Freeness ml CSF	Spec Surf m ² /g	Crit Temp °C	Outgoing Solids %	IPC Density g/cc	Specific Elastic Modulus MN·m/kg	Burst Index kPa·m ² /g	Geometric Mean STFI Index N·m/g
74	650	1.3	371	59.6	0.79	0.13	3.9	23.8
65	650	2.6	316	58.7	0.80	0.17	3.7	24.9
65	550	4.9	204	50.7	0.76	0.16	4.0	28.2

Table 2

Kappa No.	Freeness ml CSF	Spec Surf m ² /g	Contr Temp °C	Outgoing Solids %	IPC Density g/cc	Specific Elastic Modulus MN·m/kg	Burst Index kPa·m ² /g	Geometric Mean STFI Index N·m/g
74	650	1.3	106	53.7	0.68	0.08	3.0	21.3
65	650	2.6	106	50.9	0.72	0.11	2.4	24.3
65	550	4.9	106	48.0	0.75	0.15	3.0	28.2

Drag forces, resulting in sheet delamination, will increase with increased specific surface. Hence, it was expected that an increase in specific surface would result in delamination at lower roll surface temperatures. Figure 15 shows the relationship between critical

temperature and specific surface for southern pine impulse dried from 42% ingoing solids. Outgoing solids achieved at the critical temperature is compared to that of the "controls" in Figure 16. The "controls" represent the best possible response expected from single-felted wet-pressing at the same impulse. Hence, Figure 15 implies that impulse drying results in enhanced dewatering when the specific surface of the pulp is less than about 7 m²/g.

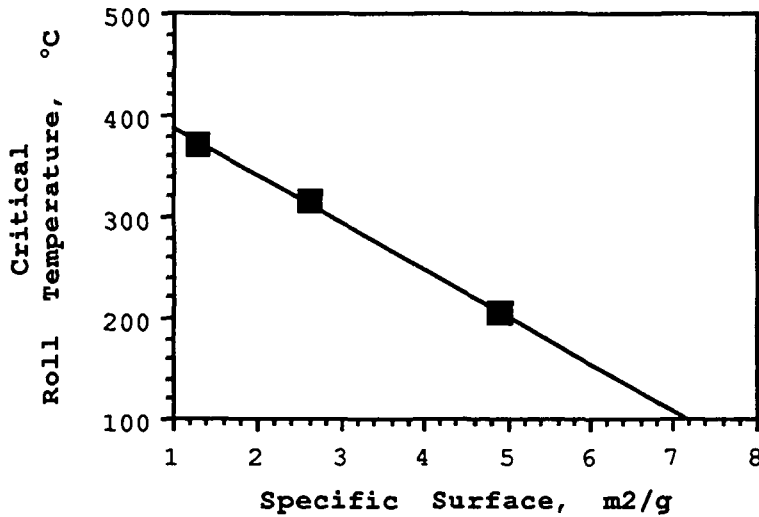


Figure 15: Critical roll surface temperature as a function of the specific surface of the ingoing sheet for impulse drying 205 gsm single-ply linerboard for 40 ms at a peak pressure of 6.2 MPa from an ingoing solids of 42%.

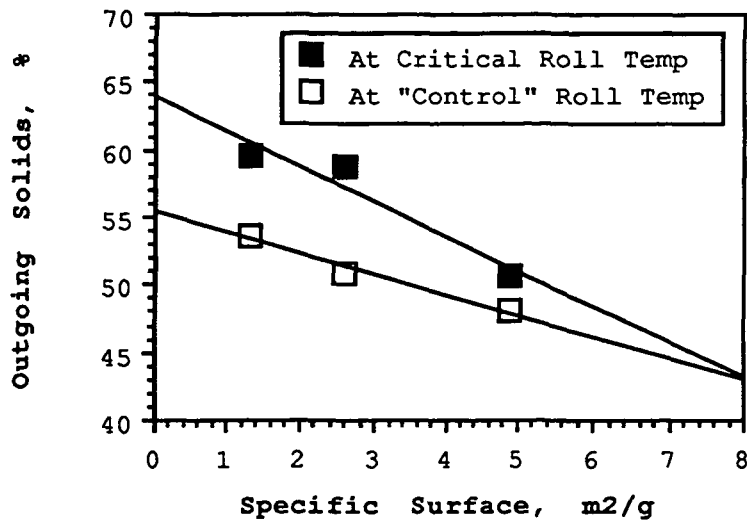


Figure 16: Outgoing solids as a function of the specific surface of the ingoing sheet for 205 gsm single-ply linerboard impulse dried for 40 ms at a peak pressure of 6.2 MPa from an ingoing solids of 42% at the critical roll surface temperature and at the control temperature of 106°C.

CONCLUSIONS

The pilot-scale experiments confirm earlier laboratory scale findings that a low thermal conductivity low heat capacity ceramic roll coating allows impulse drying of heavy weight grades without sheet delamination. The roll coating allowed high operating temperatures which resulted in improved water removal and property development as compared to wet pressing at the same impulse.

The experiments further demonstrated that nip residence times of at least 40 ms and ingoing solids of a least 42% are required in order to achieve dryness in excess of 55%. At commercial speeds of 760 m/min, press shoes of 0.5 m will be required. At the present time, commercial shoes are available at a maximum length of 0.3 m. Hence, it is recommended that longer shoes be developed.

Critical impulse drying temperatures were shown to decrease when the specific surface of the ingoing sheet was increased. As cooking, refining and pressing control specific surface, the experiments help to bracket ranges of these variables that would benefit from impulse drying. In that regard, maximum benefit from impulse drying may be expected for high-yield furnishes that have been minimally refined and pressed to high dryness levels.

REFERENCES

1. Crouse, J.W., Woo, Y.D., and Sprague, C.H., "Delamination-A Stumbling Block To Implementing Impulse Drying Technology For Linerboard," Tappi Journal, p.211-215, 1989.
2. Lavery, H.P., "High-Intensity Drying Processes-Impulse Drying," Report 3, DOE/CE/40738-T3, February 1988.
3. Orloff, D.I., "Impulse Drying of Linerboard: Control of Delamination," Presented at the 77th Annual Meeting of the Canadian Pulp and Paper Association, To be published in Journal of Pulp and Paper Science, January 1992.
4. Orloff, D.I., "Impulse Drying: Controlling Delamination in Heavy Weight Grades," Institute of Paper Science and Technology 1991 Executives' Conference Proceedings, p.24-27, May 1991.
5. Orloff, D.I., "High-Intensity Drying Processes-Impulse Drying," Yearly Report for Department of Energy Contract FG02-85CE40738, DOE/CE/40738-T6, June 1991.
6. Dullien, F.A.L., "Porous Media: Fluid Transport and Pore Structure," Academic Press, New York, 1979.
7. Carlsson, G. et al, "Permeability to Water Of Compressed Pulp Fiber Mats," Svensk Papperstidning, R128, 1983.
8. Gren, U.B., "Compressibility and Permeability of Packed Beds of Cellulose Fibres," Svensk Papperstidning, Nr.19, p785-793, 1972.
9. Lindsay, J.D., "The Physics of Impulse Drying: New Insights From Numerical Modeling," Fundamentals of Papermaking, Transactions of the Ninth Fundamental Research Symposium, Cambridge, England, Sept. 1989, ed. C.F. Baker and V.W. Punton, vol. 2, pp. 679-729, Mechanical Engineering Publications, London, 1989.
10. Lindsay, J.D., "Discussion of Impulse Drying Physics: Comments on E. L. Back's 'Why is Press Drying/Impulse Drying Delayed?' Tappi J., 74(9): 238, 240, 242(1991).
11. Lindsay, J.D., and Sprague, C.H., "MIPPS: A Numerical Moving Boundary Model For Impulse Drying," J. Pulp Paper Sci., 15(4):J135-141(1989).
12. Fowler, J.L., and Hertel, K.L., "Flow Of A Gas Through Porous Media," J. Appl. Physics, 11:496-502(1940).
13. Chen, F.J., "The Permeability Of Compressed Fiber Mats And The Effects Of Surface Area Reduction And Fiber Geometry," Ph.D. Dissertation, The Institute Of Paper Chemistry, Appleton, Wisconsin, June 1982.
14. Carroll, M., and Mason, S.G., "The Measurement Of Fiber Swelling By The Liquid Permeability Method," Can. J. Tech., 30(12):321(1952).
15. Ingmanson, W.L., and Andrews, B.D., "The Effect Of Beating On Filtration Resistance And Its Components Of Specific Surface And Specific Volume," Tappi J., 41(1):29(1959).

16. Ellis, E.P., Jr., "Compressibility and Permeability Of Never Dried Bleached Softwood Kraft Pulp And Its Application To The Prediction Of Wet Press," Ph.D. Thesis, Chem. Eng. Dept., Univ. Of Maine, Orono, Maine, 1981.

17. Bliesner, W.C., "A Study Of The Porous Structure Of Fibrous Sheets Using Permeability Techniques," Tappi J., 47(7):392(1964).

18. Lindsay, J.D., "The Anisotropic Permeability Of Paper," Tappi J., 73(5):223-229 (May 1990).

19. Lindsay, J.D., and Wallin, J.R., "Characterization Of In-Plane Flow In Paper," AIChE Forest Products Symposium, Tappi Press, Atlanta, GA, (in press, 1992); also presented at the AIChE Annual Meeting, Chicago, Nov. 1990.

APPENDIX: TABLES OF EXPERIMENTAL DATA

Table 3. Specific Surface Data

Kappa No.	Freeness ml CSF	Ingoing Solids %	Specific Surface m ² /g
65	550	27.2	27.0
65	550	28.9	22.8
65	550	34.5	28.2
65	550	34.8	23.2
65	550	41.3	3.6
65	550	41.7	2.9
65	550	42.5	5.6
65	550	42.7	7.4
65	650	33.9	21.3
65	650	35.4	19.1
65	650	36.2	4.7
65	650	36.9	8.6
65	650	41.6	1.7
65	650	43.0	1.7
65	650	43.9	5.6
65	650	44.4	1.6
74	650	43.9	1.0
74	650	44.6	1.2
74	650	47.4	1.1
74	650	47.5	1.3

Table 4.
Impulse Drying 205 gsm Single-Ply Linerboard For 20 ms At A Peak Pressure Of 6.2 MPa.

K a p p a #	Freeness ml CSF	%S Into Steam Box	B.W. g/m ²	%S Into Impulse Dryer	In- going Roll Temp °C	NRT ms	%S Out of Impulse Dryer	IPC Density g/cc	Spec. Elast Modulus MN·m/kg	C.V. Spec. Elast Modulus %	Burst Index kPa·m ²	MD STFI Index M·m/g	CD STFI Index M·m/g	Geom Mean STFI Index M·m/g
65	550	27.2	215	25.9	104	20	41.8	0.68	0.13	11	3.3	28.7	21.1	24.6
65	550	34.5	200	33.1	316	20	47.4	0.71	0.07	14	3.1	29.2	20.7	24.6
65	550	34.8	202	33.4	371	20	47.3	0.74	0.11	22	3.3	29.0	21.4	24.9
65	550	29.0	182	27.6	427	20	47.9	0.66	0.09	13	2.8	27.8	18.5	22.7
65	550	41.3	204	39.8	104	20	46.3	0.67	0.12	15	3.1	31.6	21.8	26.2
65	550	42.5	210	41.0	316	20	49.6	0.67	0.07	20	2.9	27.4	19.8	23.3
65	550	42.6	207	41.2	371	20	51.3	0.72	0.10	15	3.6	26.4	19.5	22.7
65	550	41.7	208	40.2	427	20	50.9	0.66	0.05	21	2.9	25.8	16.8	20.9
65	650	36.2	224	34.8	104	20	47.5	0.67	0.10	15	2.4	27.8	20.7	24.0
65	650	35.4	198	34.0	316	20	49.9	0.69	0.09	15	3.4	30.7	18.9	24.1
65	650	34.0	199	32.6	371	20	51.2	0.70	0.11	17	4.0	29.1	17.6	22.6
65	650	36.9	210	35.5	427	20	51.9	0.68	0.08	17	2.7	26.5	18.3	22.0
65	650	41.5	237	40.1	104	20	48.8	0.67	0.08	17	2.4	25.5	18.5	21.7
65	650	44.0	199	42.5	316	20	54.9	0.71	0.11	13	3.4	28.8	19.9	24.0
65	650	44.4	200	42.9	371	20	55.4	0.72	0.09	17	3.0	22.2	16.6	19.2
65	650	43.0	223	41.6	427	20	54.9	0.69	0.07	18	2.7	26.0	17.8	21.5
74	650	44.0	244	40.7	106	20	52.0	0.67	0.07	13	2.6	26.2	17.6	21.5
74	650	44.2	217	40.9	371	20	52.8	0.66	0.08	10	3.3	25.8	16.6	20.7
74	650	47.5	219	43.7	371	20	53.2	0.66	0.06	11	1.9	27.0	16.7	21.2
74	650	44.6	197	41.3	427	20	54.1	0.67	0.07	10	3.6	27.2	18.5	22.4
74	650	47.2	211	43.4	427	20	53.9	0.66	0.06	12	3.3	25.4	16.4	20.4

Table 5.
Impulse Drying 205 gsm Single-Ply Linerboard For 40 ms At A Peak Pressure Of 6.2 MPa.

K a p p a #	Freeness	%S	B.W.	%S	In- going Roll Temp	NRT	%S	IPC Density	Spec. Elast Modulus	C.V. Spec. Elast Modulus	Burst Index	MD STFI Index	CD STFI Index	Geom Mean STFI Index
	ml CSF	Into Steam Box	g/m ²	Into Impulse Dryer	°C	ms	Out of Impulse Dryer	g/cc	MN·m/kg	%	kPa·m ²	M·m/g	M·m/g	M·m/g
65	550	27.2	214	25.9	104	40	44.4	0.68	0.17	12	3.1	31.4	23.1	26.9
65	550	34.5	199	33.1	316	40	48.3	0.72	0.08	18	3.0	29.4	20.8	24.7
65	550	34.8	211	33.4	371	40	49.0	0.67	0.11	17	3.7	26.7	18.4	22.2
65	550	29.0	197	27.6	427	40	49.8	0.70	0.09	16	3.1	27.9	19.6	23.4
65	550	41.3	220	39.8	104	40	48.0	0.75	0.15	12	3.0	33.2	23.9	28.2
65	550	43.0	231	40.6	204	40	50.7	0.76	0.16	10	4.0	32.7	23.3	27.6
65	550	43.0	240	40.6	260	40	51.1	0.75	0.13	12	3.6	31.4	21.4	25.9
65	550	42.5	233	40.1	316	40	51.9	0.76	0.12	15	3.1	30.6	21.7	25.8
65	550	42.5	213	41.0	316	40	52.0	0.77	0.09	15	3.3	28.4	20.8	24.3
65	550	42.6	201	41.2	371	40	54.0	0.74	0.11	20	3.8	27.6	20.4	23.7
65	550	41.7	211	40.2	427	40	54.4	0.68	0.04	26	2.7	22.6	16.4	19.2
65	650	36.2	222	34.8	104	40	48.4	0.69	0.11	11	2.7	27.2	22.5	24.7
65	650	35.4	213	34.0	316	40	52.2	0.73	0.12	17	4.0	30.9	20.8	25.4
65	650	34.0	198	32.6	371	40	53.1	0.76	0.13	18	3.8	28.3	18.4	22.8
65	650	36.9	218	35.5	427	40	54.6	0.77	0.09	18	3.2	30.3	21.1	25.3
65	650	41.5	230	40.1	104	40	50.9	0.72	0.11	12	2.4	28.9	20.4	24.3
65	650	44.0	198	42.5	316	40	58.7	0.80	0.17	11	3.7	28.2	22.0	24.9
65	650	44.4	202	42.9	371	40	58.4	0.81	0.14	20	3.2	25.5	18.7	21.8
65	650	43.0	222	41.6	427	40	58.4	0.73	0.07	20	2.8	27.0	19.8	23.1
74	650	43.1	213	39.9	106	40	53.7	0.68	0.08	16	3.0	26.6	17.0	21.3
74	650	46.2	202	42.5	106	40	57.3	0.69	0.08	14	3.2	25.6	18.9	22.0
74	650	44.1	201	40.9	371	40	59.6	0.79	0.13	12	3.9	28.5	19.9	23.8
74	650	47.4	211	43.6	371	40	59.7	0.75	0.12	11	3.7	29.1	19.9	24.1
74	650	47.2	208	43.5	427	40	61.6	0.79	0.13	21	4.1	29.9	20.9	25.0
74	650	44.6	200	41.3	427	40	60.7	0.77	0.13	22	4.5	30.5	20.5	25.0

ACKNOWLEDGMENTS

The work reported was supported by the member companies of the Institute of Paper Science and Technology and by the U.S. Department of Energy Office of Industrial Programs through Grant No. DE-FGO2-85CE40738. Their support is gratefully acknowledged. In addition, the fine efforts of all the members of the impulse drying project team at the Institute are acknowledged.

The authors would also like to recognize the valued assistance of W. Lenling of Fisher-Barton Corporation and Sandia National Laboratory for coating the prototype pilot press roll. The authors are also grateful to Professor R. Ellis for his many helpful suggestions.

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