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Opening the Operating Window of Impulse Drying: I. The Effect of Ambient Pressure at Nip Opening

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OPENING THE OPERATING WINDOW OF IMPULSE DRYING - I. THE EFFECT OF AMBIENT PRESSURE AT NIP OPENING

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ABSTRACT

Application of increased ambient pressure during and after the nip opening process of impulse drying inhibits sheet delamination.

Handsheets, simulating 205 g/m^2 linerboard with hydrodynamic specific surface area of 29.5 m^2/g and solids content of 35%, were impulse dried at press surface temperatures from 120 to 330°C. When the nip opened to one atmosphere ambient pressure, sheets delaminated at and above a press surface temperature of 140°C. At successively higher press surface temperatures, it was found that the ambient pressure at nip opening could be raised to a level above which sheet delamination did not occur. This "critical" ambient pressure was found to be a function of press surface temperature, and ranged up to 411 kPa (abs) for a press surface temperature of 330°C.

Moisture ratio change was a linear function of press surface temperature and was independent of ambient pressure at nip opening. As long as the sheets were not delaminated, their strength was also independent of ambient pressure at nip opening.

BACKGROUND

Web delamination is of major concern during the impulse drying of linerboard, while it is of less concern for lighter weight grades. When delamination occurs, it manifests itself as a "blister" within or on the heated surface of the sheet. The blister normally results in a localized loss of sheet density and strength. The onset of blister formation can be detected by this loss of strength as characterized by the out-of-plane specific elastic modulus.

Delamination has been known to occur almost since the inception of the impulse drying concept.[2,3] However, it was believed that it could be overcome by proper control of ingoing sheet characteristics and dryer parameters.[4,5] While this has been accomplished, the operating window was still somewhat restrictive.

It has been shown that delamination results from the flashing of water into steam as the nip pressure is removed.[6] This steam is unable to escape from the sheet fast enough to prevent internal pressure from building past the internal bond strength of the paper. This pressure results in rupture of the bonds, causing the characteristic blisters to form as it vents to the atmosphere.[3,4,7-12] Orloff, Boerner, and Lindsay have shown that the critical temperature (T_C) for delamination is directly related to the permeability of the sheet.[5,11] This implies that as passageways for steam escape are increased, the T_C increases, lending credence to the steam/pressure mechanism of delamination.

Additional work by the Institute showed that there were other parameters that influence delamination. These include press temperature, nip pressure,[13] nip residence time,[6] nip pressure profile,[13] initial sheet and felt moisture content,[14] sheet basis weight,[5] refining level,[6] press roll surface material, and the hydrodynamic specific surface area of the sheet.

Institute researchers also determined that delamination was related to how energy was transferred to the sheet. They found that press surface materials having sufficiently low "thermal mass" could be operated at higher temperatures than press surfaces made of high thermal mass materials, such as steel.[4,7,8,15-17]

Researchers also found that the hydrodynamic specific surface area of the sheet was related to delamination. Sheets with a low specific surface, having a very open structure allowing for greater steam release, tend to resist delamination.[3,13,18,19]

Most of the focus of previous research has been to control the physical aspects of the sheet to make it less susceptible to delamination, or to modify the roll surface properties to control heat flux. No work has attempted to control the cause of delamination, i.e., flash vaporization. Work along these lines is presented in this paper.

EXPERIMENTAL

Hypothesis

The authors believe that during impulse drying water in the web is heated and pressurized such that it exists as a subcooled liquid just prior to nip opening. As the nip is opened, the water in the web continues to be heated by contact with the hot press roll surface while experiencing a sudden drop in restraining pressure. These conditions lead to a sudden increase in internal web pressure and rapid flashing of the subcooled liquid to vapor. The pressure difference (or pressure differential) between the inside and outside of the web can cause the disruption of the fiber network. In addition, vapor that lacks a clear path to exit the sheet and is trapped inside the web may prolong the time during which this extreme pressure difference is experienced. The net result is that the fiber network ruptures, resulting in the phenomenon known as delamination.

It is hypothesized that reduction of the pressure difference and suppression or reduction of vapor formation during nip opening would result in suppression of delamination. It is further proposed that the pressure difference may be significantly reduced by opening the nip to ambient pressures that are significantly higher than one atmosphere.

Experimental Matrix

In this exploratory work, a minimal number of parameters were varied to test the hypothesis. Furnish type (USWK), basis weight, press impulse, solids content, initial wet pressing technique, and platen type were held constant, as shown in Table 1. A detailed description of the experimental conditions and experimental methods was reported by Krause[20] and in a recent United States patent.[21]

Platen temperature and ambient pressure at nip opening were the only parameters that were varied in these experiments.

Experimental Plan

1) The critical temperature (platen surface temperature above which sheets delaminate) was determined for the case where the ambient pressure at nip opening was set at one atmosphere. This was accomplished by impulse drying at successively higher platen surface temperatures from 120°C until the sheets were found to delaminate. Ten replicate experiments were conducted at each temperature.
As in previous work at the Institute, delamination was verified by both visual inspection and out-of-plane ultrasonic testing methods.

2) At successively higher platen surface temperatures above the critical temperature as defined in step 1 above, the ambient pressure at nip opening was incrementally increased until sheet delamination was suppressed. The ambient pressure, so determined, was defined as the "critical ambient pressure" associated with the specific platen surface temperature. Once "critical ambient pressure" was determined over the range of platen surface temperature, a functional relationship was determined.

APPARATUS

Figure 1 shows the laboratory-scale high ambient pressure impulse dryer (HAPID) that was constructed. The device simulates an impulse drying roll-press or shoe-press where the nip can be made to open to any desired gas pressure and temperature.

In order to control ambient pressure at nip opening, the HAPID unit operates such that midway during the press impulse a valve is rapidly opened, which allows nitrogen gas at a prescribed pressure to fill the chamber surrounding the impulse dryer. Figure 2 shows typical load and gas pressure versus time during a HAPID experiment.

The impulse dried sheet experiences a higher than normal ambient pressure as it comes into contact with the surrounding nitrogen. Figure 3 shows the pressure that the sheet would experience if it opened to an ambient pressure of 1000 kPa absolute (131 psig).

RESULTS AND DISCUSSION

Table 2 shows the "critical ambient pressure" as a function of platen set-point temperature in these experiments. The set-point temperature was the temperature on the backside of the platen. It deviates by a small amount from the platen surface temperature, and was used because the surface thermocouple was inoperative during these preliminary experiments.

It is a significant result that by opening the impulse drying nip to elevated ambient pressures the platen surface temperature could be significantly increased without experiencing sheet delamination. The experiments further showed that water removal was independent of ambient pressure and linearly dependent on platen temperature. This result is shown graphically in Figure 4.

Of even more importance, when the ambient pressure was equal to the "critical pressures" as defined in Table 2, the STFI compression strength was found to be at least constant over the platen set-point temper range of 120°C to 200°C and may in fact reach a maximum value at 200°C. See Figure 5.

CONCLUSIONS

Delamination of simulated linerboard resulting from the severe conditions employed in impulse drying can be suppressed. This was achieved by pressurizing the atmosphere surrounding the sheet with compressed nitrogen after the close of the nip, but before nip opening. The amount of pressure required varied with platen temperature in a nonlinear fashion. Sheets dried in this manner showed the characteristic increase in moisture ratio change with temperature of impulse drying, and the physical properties of undelaminated sheets. These results directly support the flash vaporization theory for delamination and suggest methods for opening the process operating window of impulse drying technology, such as those suggested in a recent United States patent.[21]

The work has significant implications for commercialization of impulse drying for linerboard. The research showed that the ambient pressure to which the nip opens is a major variable influencing the critical impulse drying temperature. The work suggests that by sufficiently increasing the ambient pressure at nip opening, the press roll surface temperature can increased without inducing web delamination. The resulting increased press roll temperatures should result in increased water removal as well as optimized STFI compression strength. In a more general way, the work points out the importance of properly designing and controlling the nip opening process.

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TABLES

Table 1. Experimental Parameters That Were Held Constant.

Pulp:	Species	93% southern hard pine, 7% gum
	Kappa #	102
	Weight Weighted Fiber Length	2.3 mm
Sheet:	Basis Weight	205 g/m^2
	Ingoing Solids	35%
	Ingoing Density	0.7 g/cm^3
	Freeness	400 ml, CSF
	Hydrodynamic Specific Surface	29.5 m^2/g
	Hydrodynamic Specific Volume	0.823 cm^3/g
	Ingoing Temperature	85°C
Felt:	Sample Designation	BXC5
	Ingoing Moisture	16%
Impulse Drying:	Platen Material	Carbon Steel
	Peak Nip Pressure	4135 kPa
	Nip Dwell Time	60 ms

Table 2. Critical "Ambient" Pressure from HAPID Experiments.

Case	Platen Set-Point Temperature, °C	"Critical Ambient Pressure," kPa (abs.)
1	150	~110
2	175	152
3	200	170
4	260	315
5	330	411

ILLUSTRATIONS

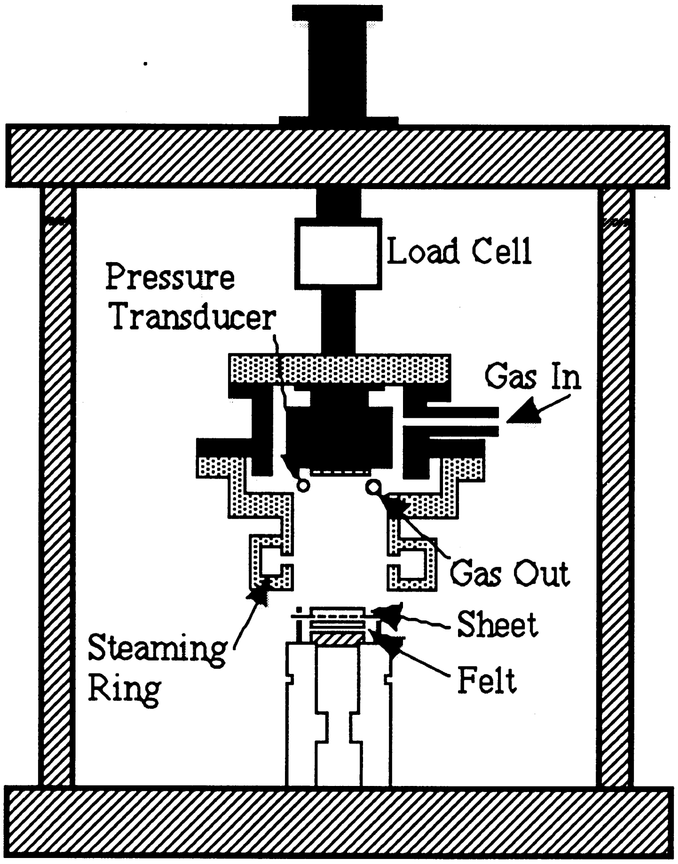

Figure 1. Laboratory-Scale High Ambient Pressure Impulse Dryer (HAPID).

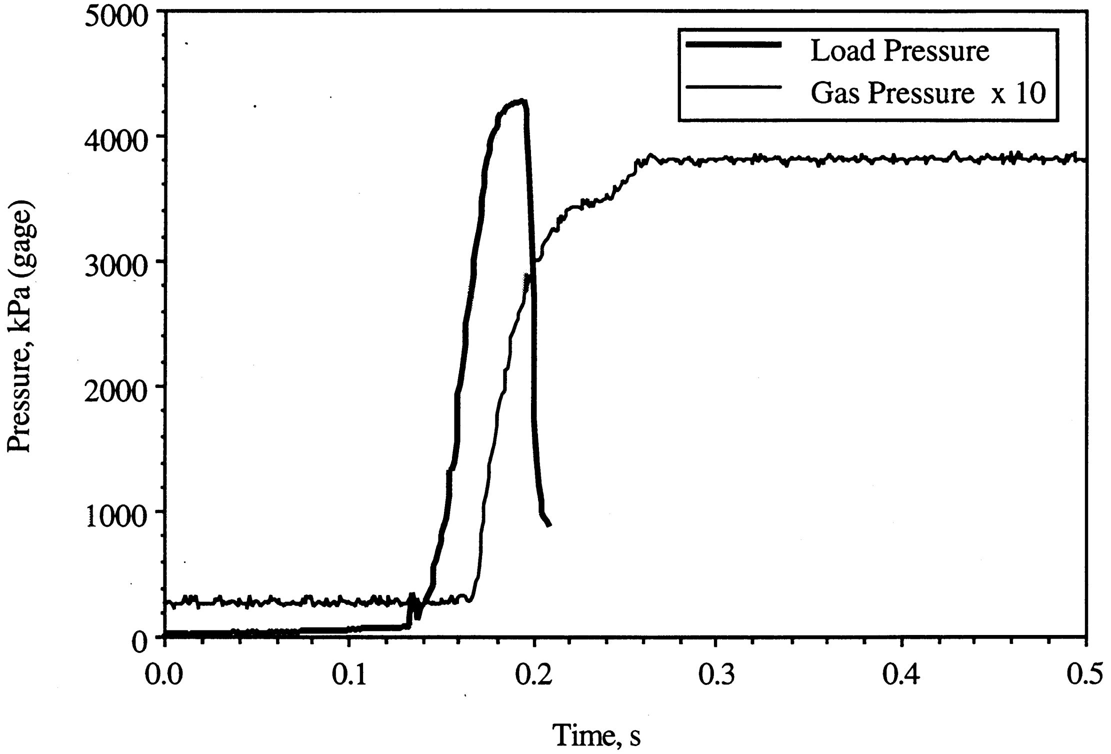

Figure 2. Load Pressure and Gas Pressure vs. Time During a HAPID Experiment.

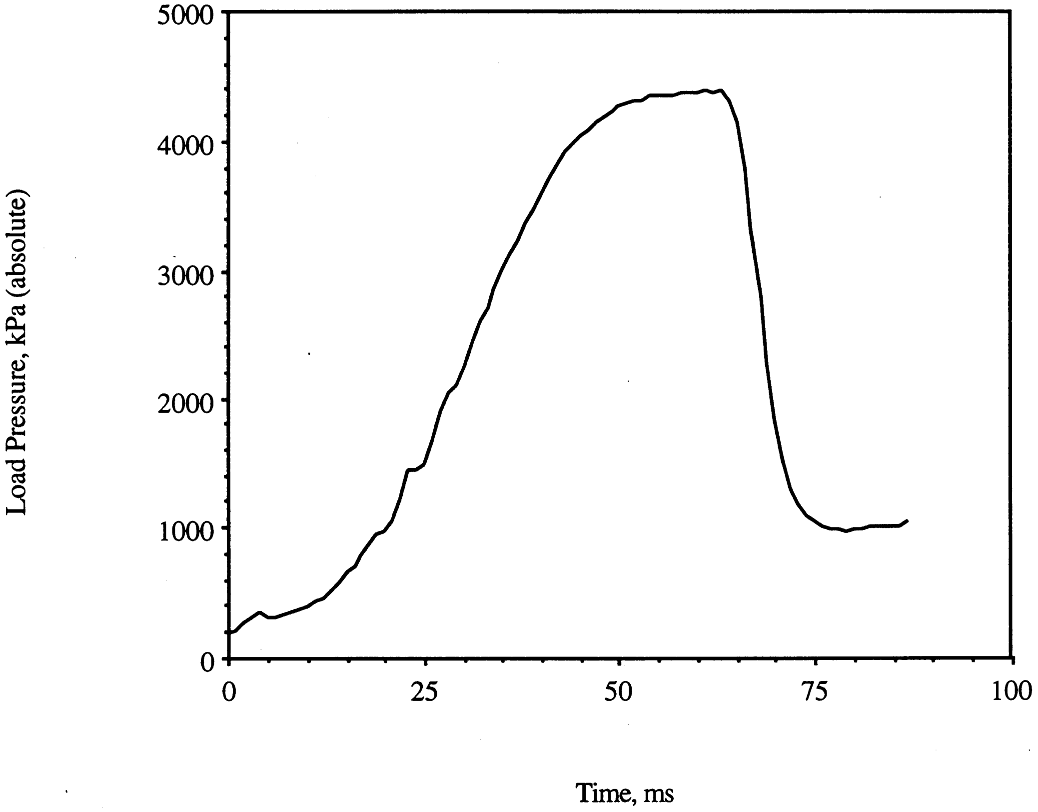

Figure 3. Load Pressure as Experienced by a Sheet Impulse Dried in the HAPID Apparatus at an Ambient Pressure of 1000 kPa (absolute).

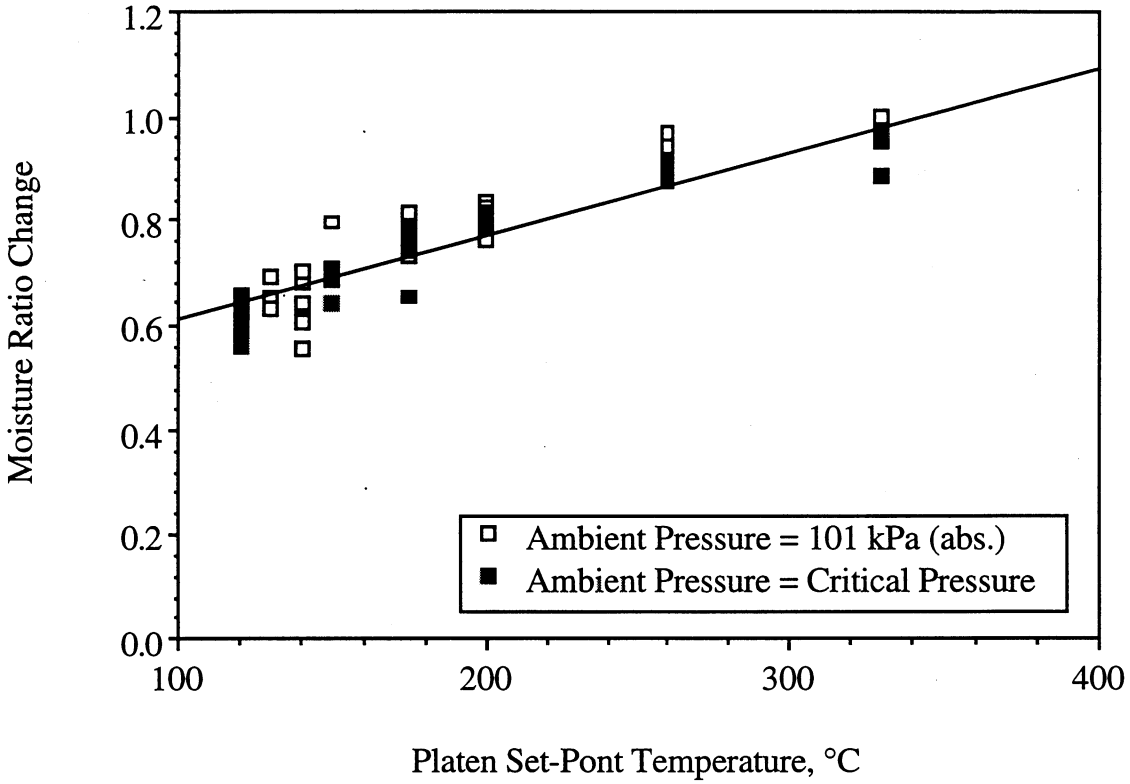

Figure 4. Moisture Ratio Change as a Function of Platen Set-Point Temperature at an Ambient Pressure of 101 kPa (absolute) and at the Corresponding Critical Pressures.

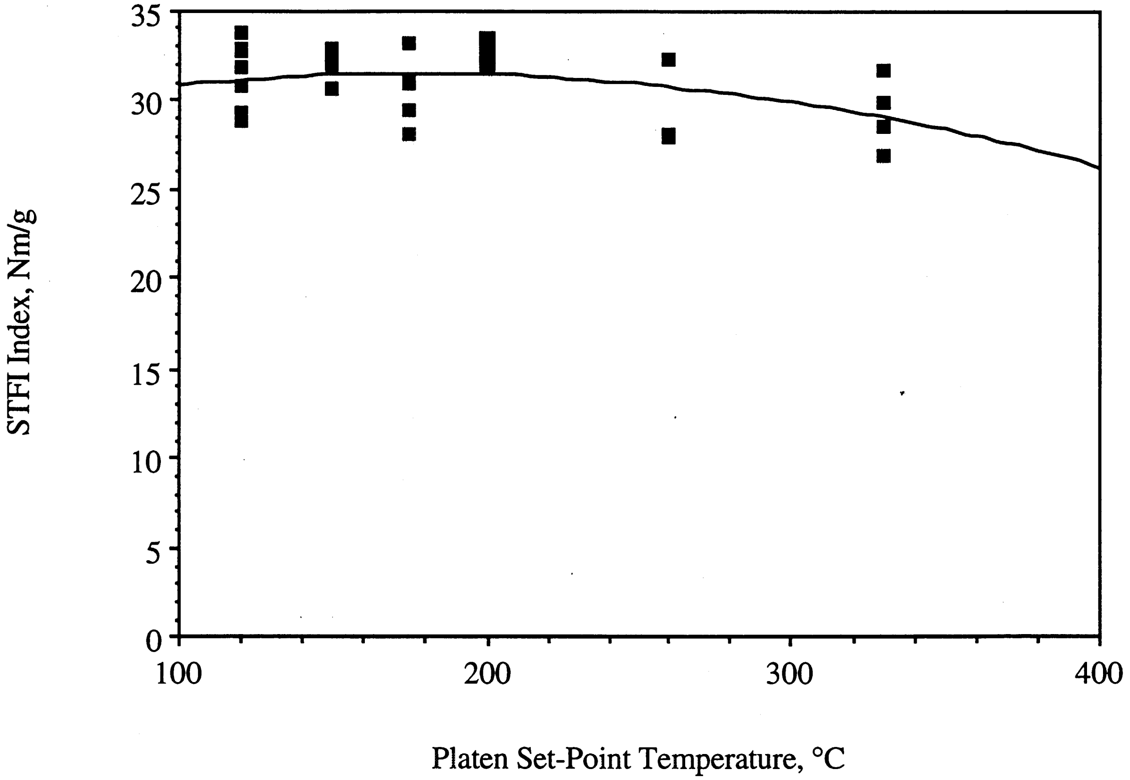

Figure 5. STFI Compression Strength as a Function of Platen Set-Point Temperature at the Corresponding Critical Pressures.