Rewetting in the expansion side of press nips

Youness Jaavidaan, William H. Ceckler, and Edward V. Thompson
Research associate, professor, and professor, respectively, Chemical Engineering Dept., University of Maine, Orono, Me. 04469.

ABSTRACT *The University of Maine Compression Tester has been modified so that water removal from the sheet can be measured directly. A comparison between this direct measurement and water removed based on thickness measurements indicates that as much as 30% of the total water removed in pressing is returned as rewet in the expansion side of the nip.*

A systematic study of this difference indicates that "rewet in the nip" is directly proportional to the total water removed, is strongly influenced by the permeabilities of both the sheet and the pressing media, and has a complex relationship with the expansion time on the exit side of the nip. Model studies suggest that rewet in the nip could be reduced by providing more effective ways for air to reach the interface between the sheet and the pressing media.

KEYWORDS
Analysis
Felts
Permeability
Press nip
Water removal
Wet pressing

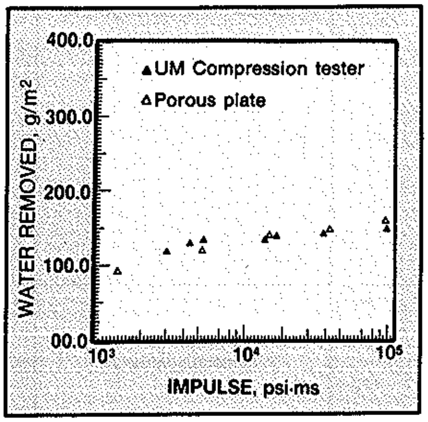
The University of Maine Compression Tester was originally conceived as a device to study the compression characteristics of paper under conditions similar to those encountered in press nips of modern paper machines (*1, 2*). **Figure 1** is a schematic drawing of the tester. The original design utilized eddy-current proximity gauges to measure the thickness of the paper being tested throughout the compression–expansion cycle. In dewatering studies, the amount of water removed was calculated from the initial water content of the sheet and the minimum thickness obtained during compression. In this calculation, it was assumed that the sheet is saturated at minimum thickness. The basis weight of the sheet, the initial weight of the sheet, the density of cellulose, and the density of water are used as factors.

During our work with the compression tester, we devised a system of cams that would allow us to separate the pressing media from the sheet immediately after the expansion phase of testing. The media could be either a porous stainless plate or a press felt. On a paper machine, this separation corresponds to the separation of the sheet from the felt immediately after it leaves the press nip. This development provided us with a means by which we could test paper samples under simulated pressing conditions such as those encountered in high-speed conventional presses (on the order of 2 ms) or in extended-nip conditions of 50 ms. We could also recover the sample from the press for further testing.

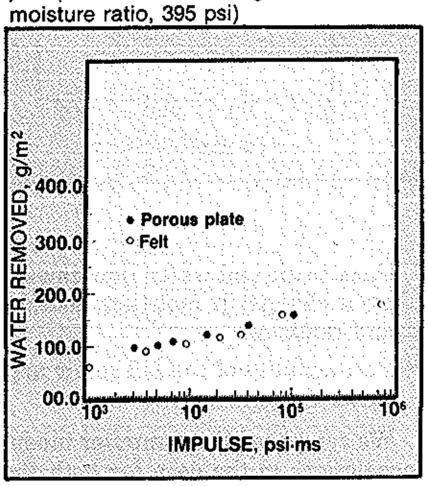
The first tests we performed with the modified compression tester were to compare the direct determination of dewatering in the compression tester to dewatering which we had observed earlier in pilot tests at the Beloit research lab on similar pulps (*2*). **Figure 2** shows this comparison for bleached softwood kraft of 300 mL CSF. The comparison shows that direct measurements of dewatering in the UM Compression Tester compare closely to those observed in tests on a Beloit pilot press. In a previous report (*2*), we have shown that pilot press results agree closely with mill test results for dewatering the same material at the same impulse. We can therefore conclude that direct measurements of dewatering with the UM Compression Tester should agree with dewatering under the same conditions in the mill.

We next compared the dewatering observed by direct measurement in the UM Compression Tester to dewatering calculated from thickness measurements on the same sheets during pressing tests. The comparison between the change of water based on minimum thickness and the change of water by direct measurement indicates that a substantial amount of the water that is pressed from the sheet during compression is returned during expansion on the exit side of the nip. Typically, about 30% of the water removed in compression returns during expansion. This rewet is obviously important in determining the effectiveness of operating presses. Furthermore, the technique of comparing the change in water in the sheet as determined by

2. Comparison of water removal in the UM Compression Tester (40 μm porous plate) and in the Beloit Pilot Press (300 mL CSF, 75 g/m^2, 4.0 initial moisture ratio, 400 psi)



3. Water removed with a porous plate and a felt, both having an average pore size of 40 μm (300 mL CSF, 73 g/m^2, 4.10 initial moisture ratio, 395 psi)

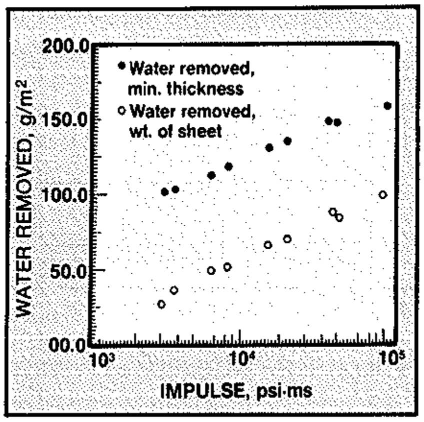


rewet, we decided to systematically study several of the variables we expected to be important. Among these are the amount of water removed from the sheet during pressing, the permeability of the sheet, and the expansion time of the sheet.

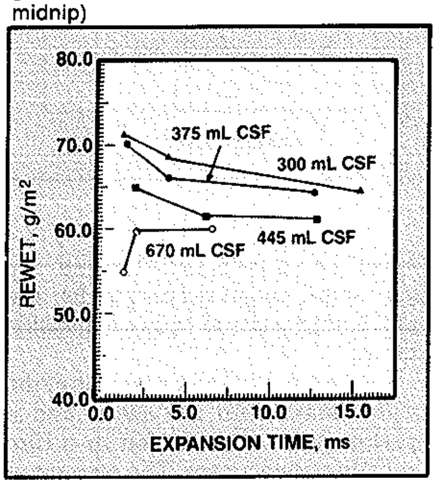
Effect of the amount of water removed

Preliminary testing indicates that the amount of water pressed from the sheet prior to expansion was one of the important factors affecting rewet in the nip. To study this phenomenon, we conducted a series of experiments in which impulse was allowed to vary while the amount of water removed during compression and the water content at minimum thickness were constant. We accomplished this by varying the initial water content of the

4. Comparison of the water removed based on the minimum thickness measurement and that removed based on the weight of the sheet after pressing (300 mL CSF, 76.70 g/m^2, 2.88 initial moisture ratio, 414 psi)



5. The effect of sheet freeness on rewet in the nip as a function of expansion time (150 g/m^2, 3.0 initial moisture ratio, 2.0 ratio at midnip)



sheet.

Several series of tests of this type were made, and two things are apparent from the results (*3, 4*). First, rewet is independent of impulse for a constant amount of water removed during compression. Second, rewet is strongly a function of the amount of water removed from the sheet during compression. The results indicate a linear relationship between rewet in the nip and the amount of water removed during compression. Typically, 30% of the water removed during compression is returned to the sheet as rewet in the nip for this furnish.

Texture of the pressing media

Papermakers have observed that press felts with fine surface fibers produce dryer wet-pressed paper than felts with coarse surface fibers. This phenomenon has been attributed to the effects of rewetting.

To study this phenomenon, we compared the rewet observed with porous plates having a pore size of 40 μm to that obtained with plates with a pore size of 100 μm. The 100 μm plate showed higher rewet than the 40 μm plate (*3, 4*). This observation is in agreement with operating experience with coarse felts.

The effect of expansion time and freeness

In **Fig. 5**, we show the effect of expansion time on rewet for several different pulp freenesses. For sheets with a freeness of 670 mL CSF, rewet is a strong function of expansion time. Rewet increases up to expansion times of 2.5 ms and tends to plateau at longer expansion times. With sheets of 300 mL CSF, rewet is high at short expansion times, but it falls off at intermediate times and plateaus at long expansion times. At short expansion times, sheets of 300 mL CSF show higher rewet than sheets of 670 mL CSF. Sheets of both freenesses appear to approach the same plateau from opposite directions.

We consider it highly unusual behavior that 300-mL sheets experience higher rewet in the nip than 670-mL sheets, in light of our experience with rewet from the felt *after* the nip as reported elsewhere (*2*). The results of our earlier work indicate that permeability is the dominant factor affecting rewet from the felt after the nip and that low permeability reduced rewet. We also consider the fall-off of rewet with expansion time for the 300 mL sheets as unusual behavior in that our earlier experience indicates that increasing contact time increases rewet. These differences in behavior between rewet in the nip and rewet after the nip suggest that the mechanisms that control these two processes are different.

Mechanism of rewet in the nip

To explain these observations, we theorize the following mechanism for rewet in the nip.

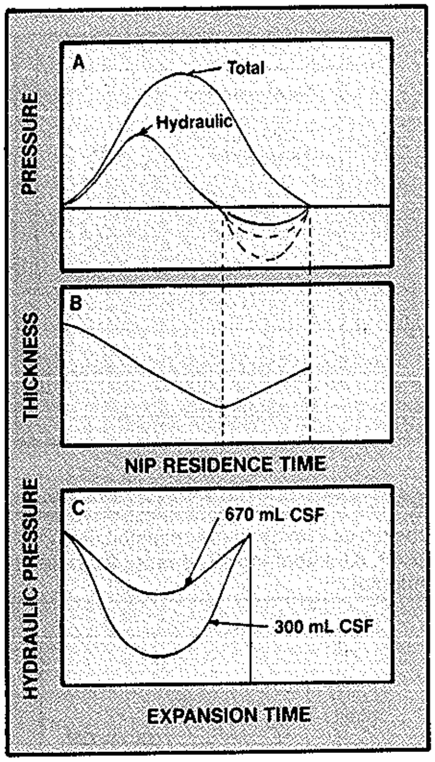
We assume that at the point on the exit side of the nip where expansion of the sheet begins, the following conditions exist:

- The paper sheet is close to saturation.
- The water expelled from the sheet is lying in the felt near the interface between the sheet and the felt. It has not yet had time to be distributed uniformly throughout the felt.
- The felt is unsaturated due to its expansion prior to sheet expansion, but the surface layers are closer to saturation because of the presence of water driven out of the sheet during compression.

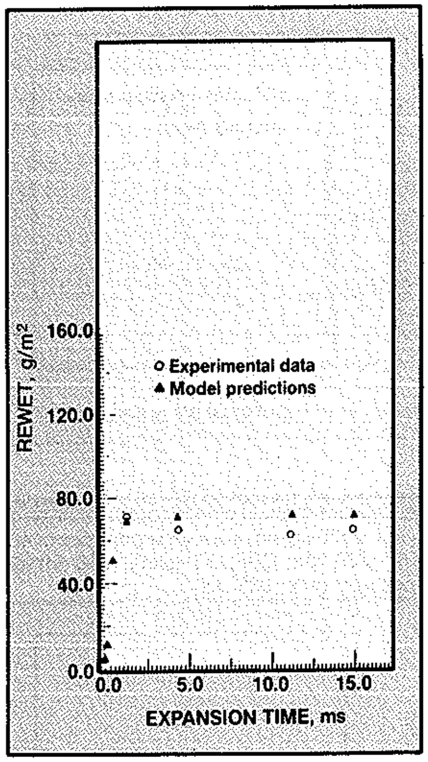
As the sheet begins to expand on the exit side of the nip, a negative pressure is created at the interface between the sheet and the felt. **Figure 6** shows the total pressure on the sheet as a function of time as it passes through the nip and also shows the thickness of the felt and the sheet and the negative hydraulic pressure that results from these dynamic actions. This negative pressure draws water from the "pool" in the surface layers of the felt into the space which is beginning to form between the sheet and the felt. Since the felt is much more porous than the sheet, essentially all the water drawn into the gap comes from the felt. This explains the lack of a positive correlation between sheet permeability and rewet in the nip. As the space between the sheet and the felt continues to grow, the negative pressure increases, and the flow is directly proportional to the magnitude of the difference between this negative pressure and the external pressure.

Besides water flow into the gap, there is also air flow through both the sheet and the felt. As the gap continues to open, this air flow reduces and ultimately eliminates the vacuum in the gap between the sheet and the felt. Since the sheet of 300 mL CSF is less permeable than the one of 670 mL CSF, we would predict that the vacuum in the case of the 300 mL sheet would be greater than that of the 670 mL sheet. This relationship is shown in Part C of Fig. 6. The higher vacuum in the case of the 300 mL sheet accounts for an increase in water drawn into the gap for this material as compared with the 670 mL sheet. This increase in water in turn accounts for the greater rewet in the nip. In effect, the 300 mL sheets form a better seal for air on the paper side of the gap. Ultimately, the sheet and felt open up to the point at which air flow eliminates the vacuum and flow into the gap stops, thus accounting for the plateauing action at longer expansion times.

6. Theoretical effect of sheet freeness on hydraulic pressure at the felt-sheet interface during expansion in the nip



7. Comparison between model predictions and experimental values for rewet in the nip for sheets with a freeness of 300 mL CSF (150 g/m², 3.0 initial moisture ratio)



As the gap expands, a portion of the water stays with the sheet, and a portion stays with the felt by a film splitting mechanism. The amount of water that will be returned to the sheet by rewet is determined once the water is in the gap and split. Therefore, in contrast to rewet from the felt after the nip, the permeability of the sheet to water is not a factor in determining the amount of rewet in the nip.

Test of the mechanism of the process

Based on these mechanisms, we developed a computer model to describe the flow of water into the gap as the sheet expands and separates from a felt or porous plate. The model took into account the following factors:

- Rate of expansion of the sheet
- Air flow and water flow through the felt
- Air flow through the sheet
- The change in permeability of the sheet to air and water flow caused by a change in moisture content and thickness
- Permeability of the felt to air and water flow.

We compared the computer model predictions to the data for both the 300 mL sheet and the 670 mL sheet taken from Fig. 5. There was close agreement between the model and the data for the 670 mL sheet (*4*). In **Fig. 7**, the comparison between the model predictions and rewet data for 300 mL sheets is shown. The model shows approximate agreement with these data in that it predicts the approximate amount of rewet in the plateau region and also predicts higher rewet for 300 mL sheets than for the 670 mL sheets.

However, the computer model does not show the drop-off in rewet as expansion time increases in the intermediate time range for 300 mL sheets. To account for this behavior, we found that it was necessary to allow the permeability of the felt to increase as expansion time increased, a reasonable assumption considering that the sheet will expand during this period and become less saturated. Because of the good agreement between the model and the experimental data, we conclude that the mechanism we proposed incorporates the important features of rewet in the nip.

Furthermore, this model implies that if we are to reduce rewet in the nip, we should be inventing ways to reduce the vacuum that is formed between the sheet and the felt on the expansion side of the nip. The type of change which should be effective is an increase in the permeability of compressed felts to air flow at high levels of water saturation in either the machine direction or in the z-direction or both.

Conclusions

Rewet in the nip is a sizable effect accounting for a return of as much as 30% of the water removed from the sheet during compression. The cause of this effect is a vacuum created at the interface between the sheet and the felt as they expand and separate. Means for reducing the vacuum should be effective in reducing rewet in the nip.

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Received for review June 1, 1987.

Accepted Oct. 27, 1987.

Presented at the 1987 Engineering Conference.