# Rewet in wet pressing of paper

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**ABSTRACT:** Wet pressing in papermaking removes water by pressure applied over time, but some of the expelled water may return to the web in an action called "rewet." This water, and the other remaining water, must be removed by drying. To understand the underlying factors of rewet, we have developed a mathematical model of it comprised of a time-dependent term that accounts for water flow from the felt to paper and a time-independent term that accounts for splitting of interfacial water between the felt and paper. Our model is consistent with measurements from the literature and can be used to understand how paper properties, press operation, and felt design can minimize rewet.

***Application:*** This paper provides a physical model that can describe and quantify rewet. This model can be used to guide work to minimize rewet by means of operational changes and through press and fabric design.

Wet pressing in papermaking removes water by pressure acting over time, but some of the expelled water may return to the web in an action called "rewet." At present, there is no method to directly measure rewet; therefore, its size has been estimated indirectly from laboratory and pilot machine experiments. In a previous paper [1], we summarized these estimates. For lightweight grades (≤100 g/m²), rewet was estimated to be as high as 35 g/m² in pilot machine studies and 72 g/m² in laboratory experiments. Rewet of 55 g/m² was measured after the couch on a pilot paper machine [2] and exceeded 1000 g/m² in a double-wire pulp machine [3]. Given these large values, there is a clear need to better understand and quantify rewet to guide strategies to minimize its effect.

For lightweight grades, rewet is a constant that depends on furnish and felt design, independent of basis weight. This can be expressed as follows [4,5]:

$$m = m_m + \frac{R}{W} \tag{1}$$

where:
$m$ = moisture ratio after the press
$m_m$ = minimum moisture ratio within the nip
$R$ = rewet, kg/m²
$W$ = basis weight, kg/m²

We propose that rewet proceeds by two mechanisms [6,7]: water flow from the felt back into the paper (flow rewet) and water remaining with paper surface during separation of the felt and paper (separation rewet). Wrist [6] concluded that capillary forces would cause in-nip rewet and that flow-rewet would be proportional to the relative difference in pore size between the felt and paper [8]. Noting that the film of water pressed from the paper is typically the same thickness as the pulp and felt fibers (at that time wool), he suspected that rewetting caused by film splitting between the two surfaces would dominate the capillary flow rewet in the expanding nip [6]. We now consider how these mechanisms can be modeled.

## ANALYSIS

### General

In previous work [1,9-11], we defined rewet as water that is expelled from the web by pressure but remains with paper on leaving the press. This concept was modelled in the decreasing permeability model equation, which can be used for single and double-felted nips [1,9-12]:

$$m = \left(m_o - m_e\right)\left(1 + \frac{An\left(m_o - m_e\right)^n I}{\nu W^2}\right)^{\frac{-1}{n}} + m_e + \frac{R}{W} \tag{2}$$

where:
$m$ = pressed moisture ratio defined as mass of water divided by mass of fiber
$m_0$ = incoming moisture ratio
$A$= specific permeability, g/m
$n$ = compressibility factor
$I$ = press impulse = press nip load divided by machine speed $P_l/V$, kPa.s
$W$ = basis weight, kg/m²
$\nu$ = kinematic viscosity, m²/s
$R$ = rewet, kg/m²
$m_e$ = equilibrium moisture ratio defined as the moisture attained when the peak pressure ($P_p$) is applied for infinite time:

$$m_e = \delta P_p^{-d} \tag{3}$$

where $\delta$ and $d$ are obtained by fitting Eq. 3 to experimental platen pressing data [10].

The operational parameters (impulse, basis weight, and temperature) can be easily measured. The furnish-dependent coefficients $A$ and $n$ in Eq. 2 can be determined by fitting the model equation to pilot or commercial pressing data [1,10-13]. The equilibrium moisture, which also depends on furnish, can be determined by fitting Eq. 3 to laboratory platen press data. Rewet can be determined for specific conditions on pilot machines [1,9] or pilot presses [9,11], but a procedure does not exist to apply these results to commercial machines. A more fundamental understanding of rewet is required to accomplish this. A number of publications have speculated on the mechanism for rewet, but as yet, there is no consensus [1,6,7,9,11]. In this paper, we propose a mechanism for rewet based on previous experimental observations.

### Postulated mechanism

In the converging side of the press nip, increasing pressure expels air and water from the paper. This water flows into the felt and from the felt into the cavities in the backing roll. After the point of peak nip pressure, pressure decreases in the expanding nip, causing air to enter the paper and felt. This creates surface tension, which at some point exceeds the diminishing hydraulic pressure, causing water to flow from the felt back into the paper, a process called "in-nip rewet." If the felt and paper remain in contact beyond the nip, where external pressure is no longer applied, this flow might continue. This is called "post-nip rewet." When the felt and paper separate, the water at their interface splits, leaving some of this water on the paper. This is called "separation rewet."

### Mathematical model of rewet

In-nip flow rewet

Our in-nip flow rewet model is based on a force balance on a water column perpendicular to the plane of web/ felt (**Appendix A**). The difference in surface tension on each end of the column acts to overcome viscous resistance to flow from the pore structure. The net force causing flow arises from differing pores size and surface tension properties between the felt and paper. Under some circumstances, centripetal force becomes important and is included in the force balance. This force is expressed as a limiting condition (Appendix A).

Separation rewet

Our model for separation rewet assumes that water at the interface between felt and paper splits in proportion to the surface tension forces exerted by each material, which in turn depends on their pore size and surface tension (**Appendix B**). The amount of "interfacial water" available to be split is deemed to be water that does not face hydraulic resistance in order to move between felt and paper. We assume this depth to be the sum of the pore sizes in the felt and paper surfaces.

Total rewet

The total rewet, R, is the sum of flow rewet $R_f$ and separation rewet $R_s$. From the appendices, this is given by:

$$R = R_f + R_s = a(m_m - m_e)^{1/2} t^{1/2} + bD \tag{4}$$

where:

$t$ = contact time between the felt and paper starting in the expanding nip, s

$D$ = diameter of the batt fibers, $\mu$m

$b$ = empirical factor related to the felt structure obtained by a fit to experimental data, Gg/m

$m_m$ = minimum moisture ratio achieved inside the press nip (see Appendix A, Eq. 11A):

$$m_m = (m_0 - m_e)\left[1 + \frac{An(m_0 - m_e)^n I}{\mu W^2}\right]^{-1/n} + m_e \tag{5}$$

$a$ is a furnish dependent constant, defined as:

$$a = \left(\frac{2\sigma_p r_{p,0}}{\mu}\right)^{1/2} \tag{6}$$

where:

$\sigma_p$ = surface tension of the water in the paper, N/m

$r_{p,0}$ = a constant representative of the paper, $(kg/m^2)^2$

$\mu$ = viscosity of water, Ns/m

The constant "a" is determined by a fit to laboratory or pilot machine data.

## COMPARISONS TO EXPERIMENTAL DATA

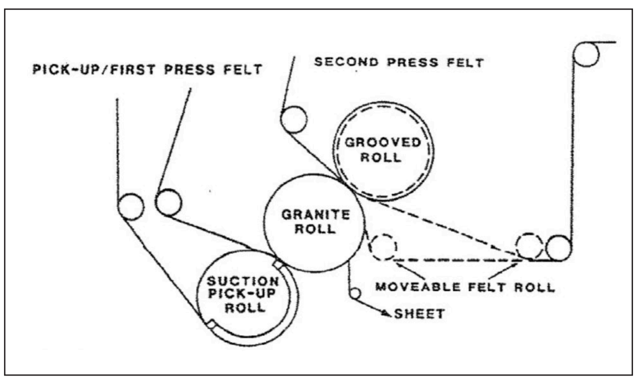
We now compare various aspects of our rewet model to experimental findings reported in the literature.

### In-nip rewet

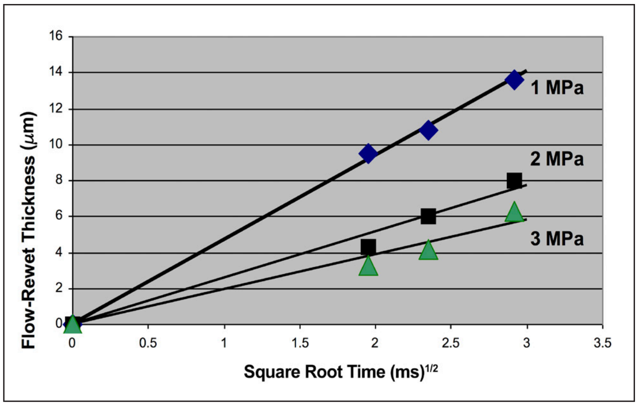
Bliesner and MacGregor [14] estimated in-nip rewet from measurements of post-nip rewet obtained by sampling paper for differing felt-paper contact distances using a press configuration similar to that in **Fig. 1** [15]. By extrapolating their post-nip rewet measurements to the center point of the nip, they obtained an in-nip rewet value of 7 g/m².

### Post-nip rewet

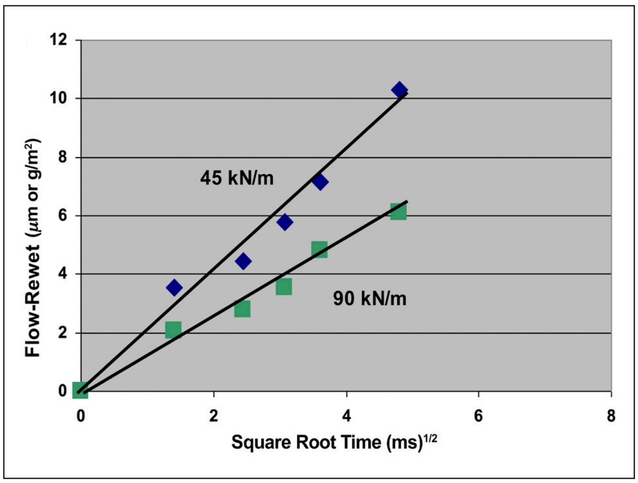
Post-nip flow rewet was determined by taking the difference between the paper moisture after a given post-nip paper-felt contact time and the paper moisture immediately after the nip. The first term of Eq. 4 includes in-nip and post-nip flow rewet. To isolate post-nip rewet, the flow rewet term is mod-




***1. Pilot machine press configuration to measure post-nip rewet by changing the felt-paper contact distance with a moveable roll [15].***




***2. Post-nip (flow) rewet is proportional to the square root of paper-felt contact time for measurements at 380 m/min. The rate of post-nip rewet (slope of the lines) was reduced as the nip pressure was increased from 1 MPa to 2 MPa to 3 MPa [14].***




***3. Post-nip flow rewet is proportional to the square root of paper-felt contact time for measurements at 800 m/min [15]. The web with a higher moisture content (nip load 45 kN/m) rewets at a greater rate than does the dryer web (nip load 90 kN/m). A water layer thickness of 1 µm is equal to 1 g/m² when the density of water is 1 g/cm³.***

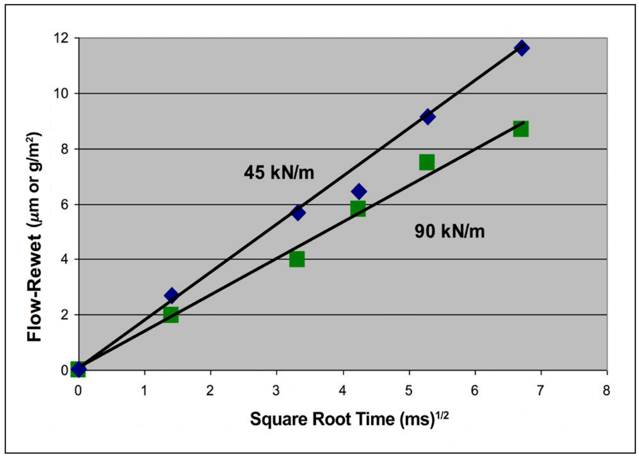
ified as follows (see Appendix A, Eqs. 17A and 18A):

$$R_f = a(m_p - m_e)^{1/2} t^{1/2} \tag{7}$$

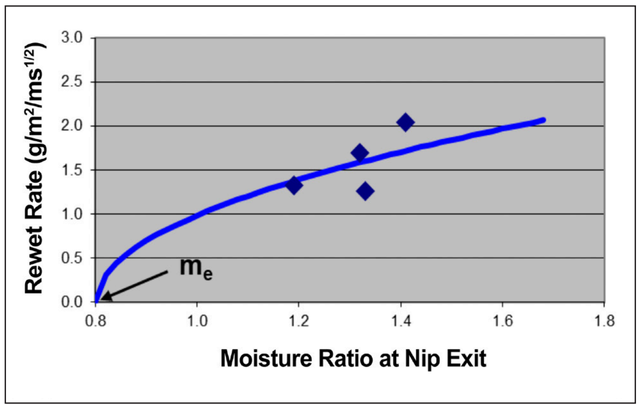
where $m_p$ is the moisture measured immediately after the nip.

As shown in **Fig. 2**, Bliesner's and MacGregor's [14] measurements of post-nip rewet are proportional to the square root of time, which is consistent with Eq. 7. Increasing nip pressure was found to diminish rewet (Fig. 2) because increased pressure has a larger effect on pressed moisture through press impulse and peak pressure than it does on equilibrium moisture through peak pressure alone. The increased pressure reduces the coefficient *a*, defined by Eq. 6, by reducing the average pore size of the paper $r_p$ (Eq. 10A).

In other work, McDonald and Pikulik [15] measured the solids content of webs after pressing for different web-felt




***4. Post-nip flow rewet is proportional to the square root of paper-felt contact time for measurements at 400 m/min [15]. The web with a higher moisture content (nip load 45 kN/m) rewets at a greater rate than does the dryer web (nip load 90 kN/m.) A water layer thickness of 1 µm is equal to 1 g/m² when the density of water is 1 g/cm³.***

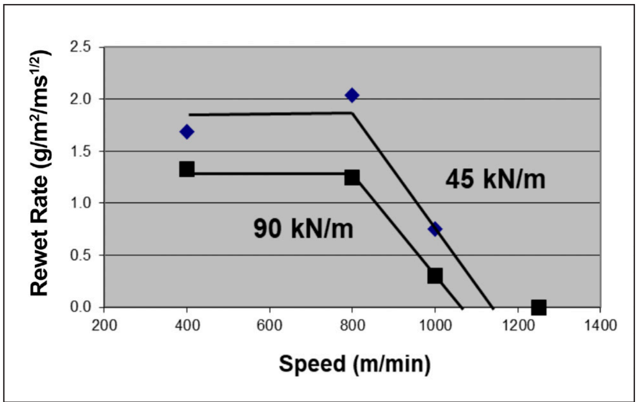



***5. Rewet rate (rewet/square root of time) is greater for wetter sheets at the nip exit. The fitted line is proportional to $m_p^{1/2}$. Data are from reference [15].***

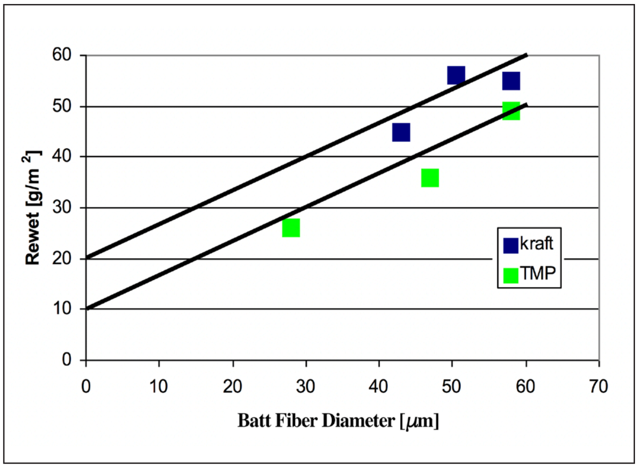
contact distances at several nip loads and speeds (**Fig. 3**). Using the pilot paper machine press configuration shown in Fig. 1 [15], they found that post-nip rewet increased with contact time and was larger for webs that leave the nip at lower solids contents (higher moisture ratio) produced by lower nip load (45 kN/m vs. 90 kN/m).

Plotting the data from McDonald and Pikulik [15] as the amount of rewet in micrometers (or g/m²) versus the square root of paper-felt contact time gives a straight-line relationship (Fig. 3 and **Fig. 4**), consistent with Eq. 7. In addition, higher nip loads (higher pressure) lowered the rate of rewet, likely due to diminished paper pore size as previously discussed.

The slopes of the lines in Figs. 3 and 4 reflect the rate of rewet. These rates increase with moisture ratio after pressing (**Fig. 5**), which is consistent with previous pilot press experiments that measured total rewet. In these experiments, we found that total rewet was proportional to $(m_o\text{-}m_e)^q$. The exponent *q* had an average value of 0.38, with a maximum




***6. In pilot machine experiments using the press section configuration shown in Fig. 1, centripetal force limited rewet rate (rewet/square root of time) at speeds above 800 m/min for two different second press nip loads [15].***




***7. Rewet versus batt fiber diameter for an ingoing moisture ratio ($m_o$) of 4 [11].***

0.44 [11]. This compares favorably to the theoretical value of 0.5 predicted in Eq. 7. The value of $q$ depends on the felt design, generally decreasing with increasing batt fiber diameter [11].

Previous pilot machine experiments for lightweight paper showed that pressed solids (and rewet) were independent of felt moisture content [16], indicating that most of the water carried by the felt into the nip is not available for rewet. This suggests that the water pressed from the web resides in a region of the felt adjacent to the paper and is available for rewet. A similar conclusion was reached for laboratory platen press experiments using a porous plate in place of a felt [17] and a felted laboratory shoe-press [18].

Lastly, McDonald and Pikulik [15] examined the effect of speed on rewet. Above a certain speed, depending on roll diameter (defined by Eq. 1A in Appendix A), centripetal force becomes important. In these experiments, because the paper was between the roll and felt, centripetal force was directed from the paper toward the felt, in effect diminishing rewet caused by surface tension forces (**Fig. 6**). We note here that the roll diameters on this pilot machine were 0.75 m, which are much smaller than typical rolls on commercial machines. Accordingly, the speed at which centripetal force will inhibit rewet is larger for commercial machines.

In summary, when the felt wraps the solid press roll and centripetal force equals or exceeds the net force from surface tension in the paper, there is no post-nip flow rewet.

### *Separation rewet*

As described earlier, separation rewet is the portion of water at the felt/paper interface that stays with paper upon separation. The analysis in Appendix B shows that this component of rewet, $R_s$, is linearly dependent on felt pore size, $r_f$. Assuming that felt pore size is proportional to the batt filament diameter, and that $b$ reflects the amount of available interfacial water, this gives:

$$R_s = bD \tag{8}$$

The average thickness of the available interstitial water has been estimated to be between 10 and 40 $\mu$m for press felts constructed with batt fibers ranging from 22 $\mu$m to 78 $\mu$m in diameter [19]. Measurements of rewet for different felt designs have shown that rewet is greater for larger diameter batt fibers [11,18,20-23], which is consistent with Eq. 8.

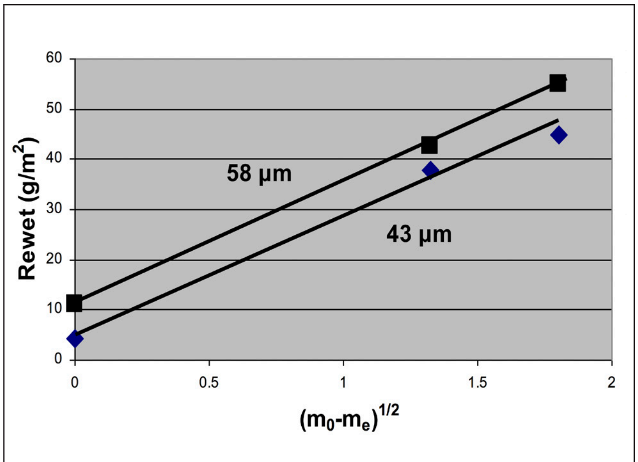
Total rewet calculated using the decreasing permeability model from pilot press experiments [11] is plotted against batt fiber diameter in **Fig. 7**. In these experiments, 60 g/m² papers made from kraft and thermomechanical pulp (TMP) were pressed using six different felts. The slopes of the lines are the coefficient $b$ in Eqs. 4 and 7 and have the same value of 0.67 for both furnishes. Coefficient $b$, which is derived in Appendix B, relates the amount of interfacial water to the felt and paper pore sizes. The value of 0.67 is similar to the ratio of the depth of interstitial water at paper/felt interface to batt fiber diameter measured by Axelsson et al. [19].

Extrapolating to zero batt fiber diameter, Eq. 4 gives the sum of in-nip and post-nip flow rewets. As shown in Fig. 7, the zero diameter intercept for kraft is larger than for TMP. This can be explained by the longer contact time in the expanding nip (press speed was 72 m/min for kraft experiments and 120 m/min for TMP). In addition, TMP had a larger equilibrium moisture ratio than kraft (0.95 vs. 0.75). For the conditions used, Fig. 7 shows that for the kraft paper in-nip "flow rewet" was 20 g/m² and separation rewet was 25–35 g/m², depending on felt design. Similarly, in-nip "flow" rewet for the TMP paper was 10 g/m², with separation rewet of 15–40 g/m².

Substituting approximate times and equilibrium moisture ratios for TMP and kraft in the flow rewet Eq. 7, gives the ratio of the $a$ furnish coefficients:

$$a_K = 1.5\ a_T \tag{9}$$

where $a_K$ and $a_T$ are the furnish dependent coefficients for the kraft and TMP furnishes.




***8. Plotting rewet data from reference [11] versus $(m_0-m_e)^{1/2}$ shows that rewet decreases as ingoing moisture, $m_0$, is reduced to equilibrium value (0.8). At this value, there is only separation rewet, which is about 10 g/m² for the felt with 58 µm batt fibers and 6 g/m² for 43 µm batt fibers.***

The consequence of this ratio in Eq. 6 is:

$$r_K = 1.5 \frac{\sigma_T}{\sigma_K} r_T \tag{10}$$

where the subscripts denote the surface tension and average pore size of the kraft and TMP papers.

This result is in accord with pore size distribution measurements, which have shown that kraft papers have larger internal pores than newsprint [24] largely because of the presence of fines in the mechanical furnish.

### *Total rewet*

We can now summarize total rewet as:

$$R = R_f + R_s = a(m_m - m_e)^{1/2} t^{1/2} + bD \tag{11}$$

where:

$$m_m - m_e = (m_0 - m_e)\left[1 + \frac{An(m_0 - m_e)^n I}{\mu W^2}\right]^{-1/n} \tag{12}$$

Simplifications to Eq. 12 are possible, as follows:

If $\left[1 >> \frac{An(m_0 - m_e)^n I}{\mu W^2}\right]$ in Eq. (5), then $m_m = m_o$ (Appendix A, Eq. 13A).

So that:

$$R = a(m_0 - m_e)^{1/2} t^{1/2} + bD \tag{13}$$

Total rewet increases with the square root of initial moisture less equilibrium moisture ratio. When $m_0$ approaches the equilibrium moisture ratio, flow rewet (the first term in Eq. 13) disappears. Thus, water expelled from the web by pressure only fills the surface cavities of the paper and does not reach the felt. Separation rewet (the second term in Eq. 13) is now proportional to the surface pores of the paper so that $R_s = br_p$, giving:

$$m = m_e + \frac{br_p}{W} \tag{14}$$

Equation 14 has been confirmed in experiments in which a web was passed through a press nip many times until there is no further change on pressed moisture [11]. When the paper and felt separate, this water remains with the paper (**Fig. 8**). For the conditions of these experiments, equilibrium moisture ratio was about 0.8, and consequent separation rewet in the limit as $m_o$ approaches $m_e$ was 6-10 g/m², as given by Eq. 14.

## STRATEGIES TO REDUCE REWET

Equations 3 and 4 can be used to evaluate strategies to reduce rewetting such as the following:

- Using felts with smaller pore size to reduce separation rewet, recognizing that this could lead to more plugging and shorter felt life
- Pressing to low web moisture content
- Minimizing felt-web contact time by:
  - Minimizing post nip contact
  - Maintaining high pressure until abrupt decrease at nip exit [18]
- Increasing surface energy of felt material

## SUMMARY AND CONCLUSIONS

We have developed a theoretical model of rewet in wet pressing that is consistent with experimental observations from various sources. The model has two components. One is a time-dependent flow term governed by the web-felt contact time in the expanding nip and post-nip if the paper and felt remain in contact. The other component is a separation rewet term that is strongly related to the surface structure of the felt.

Our results are in line with Wrist's [6] and Norman's [7] conjectures that separation rewet dominates flow rewet in the expanding nip under commercial pressing conditions.

The model can be used with the decreasing permeability model to assess the effect of various factors on moisture content leaving press sections, such as pressure, press impulse, and paper and felt properties. However, a direct measurement of rewet is still needed. Determining this measurement is a topic worthy of further study, given the importance of rewet in reducing energy in papermaking. **TJ**

## APPENDIX A – MODEL OF FLOW REWET

We model flow rewet by a force balance in which a net surface tension force imposed by the felt and paper causes a laminar flow through the connected pores from the felt to the paper. Variables $r_p$ and $r_f$ are the respective pores sizes of paper and felt and there are $n$ paper pores for each felt pore [24,25]. We assume the walls bounding the pores to be infinitely thin. Thus, $nr^2_p = r^2_f$. We consider the connected lengths of pores in paper and felt to be $l_p$ and $l_f$. The force balance gives:

$$2\pi(nr_p\sigma_p - r_f\sigma_f) = \mu\left(n\frac{2\pi r_p V_p}{r_p} l_p + \frac{2\pi r_f V_f l_f}{r_f}\right) \quad (1A)$$

where:
$\sigma_f$ = surface tension for water and felt
$\sigma_p$ = surface tension for water and paper
$V_p$, $V_f$ = speed of water movement in paper and felt
$\mu$ = water viscosity

We note here that it is common in the expanding portion of a roll nip for the paper to follow the roll and the felt to pass straight out from the nip. Consequently, there is a centripetal force acting on the water in the paper. Equation 2A assumes this force to be negligible, i.e., it assumes:

$$nr_p\sigma_p - r_f\sigma_f >> nr_p^2 l_p \rho \frac{V_R^2}{R} \quad (2A)$$

Calculation using representative values shows Eq. 2A to be the typical case. If it is not, the centripetal force, $nr_p^2 l_p \rho \frac{V_R^2}{R}$, must be included as one of the driving forces in the left-hand side of Eq. 1A.

The assumption of infinitely thin walls implies that $V_p = V_f$. Assuming that the felt is fully saturated over length $l_{f,o}$ and that at $t = 0$, $l = l_{fo}$ and $l_p = 0$, Eq. 1A reduces to:

$$nr_p\sigma_p - r_f\sigma_f = \mu V_p(l_p(n-1) + l_{fo}) \quad (3A)$$

Substituting $n = \frac{r_f^2}{r_p^2}$, gives:

$$r_p\sigma_p - \frac{r_f\sigma_f}{n} = \mu V_p\left(l_p + \frac{r_p^2}{r_f^2}(l_{fo} - l_p)\right) \quad (4A)$$

Assuming $r_p << r_f$, and $V_p = \frac{dl_p}{dt}$, Eq. 4A reduces to:

$$r_p\sigma_p - \frac{r_f\sigma_f}{n} = \mu V_p l_p = \mu l_p \frac{dl_p}{dt} \quad (5A)$$

Only water that has been pressed from the paper is available for rewet, which means there is an upper limit given by:

$$l_{p,\max} = \frac{W}{\rho}(m_o - m_e) \quad (6A)$$

Integrating Eq. 5A gives the rewet $l_p$ at time t;

$$\int_0^t \left(r_p\sigma_p - \frac{r_f\sigma_f}{n}\right)dt = \int_0^{(l_{p,\max})} \mu l_p \, dl_p \quad (7A)$$

Substituting $n = \frac{r_f^2}{r_p^2}$ gives:

$$l_p = \left(\frac{2r_p t}{\mu}\right)^{\frac{1}{2}} \left(\sigma_p - \frac{r_p\sigma_f}{r_f}\right)^{\frac{1}{2}}$$

for

$$0 \le l_p \le l_{po} \quad (8A)$$

We note that for the case of drawing water into pores of radius $r_p$ from an infinite reservoir ($r_f \to \infty$), Eq. (8A) reduces to Eq. 9A below. This is similar to the Washburn equation derived from Poiseuille's equation, which assumes water penetration from a reservoir into cylinders of radius $r_p$ [26]:

$$l_p = \left(\frac{\sigma_p r_p 2t}{\mu}\right)^{\frac{1}{2}} \quad (9A)$$

When $\sigma_p \approx \sigma_f$ and $r_p << r_f$, we may use Eq. 9A as an approximation of rewet.

The extent of rewet clearly depends on the relative pore sizes of the felt and paper. Pore size is a material property, but in the case of paper, it is also a function of the degree to which paper has been compressed. The relationship between pore size and moisture ratio is the basis of the decreasing permeability model, and similarly we can relate pore size in the nip to the minimum moisture in the nip, $m_m$. This minimum will occur when the applied pressure in the expanding nip becomes less than pressure from surface tension causing rewet. Thus, we assume that the "openness" of the paper to receive water is proportional to the moisture ratio of the paper, $m_m$, less the equilibrium moisture, $m_e$, which gives:

$$r_p = r_{p,o}(m_m - m_e) \quad (10A)$$

where $r_{p,0}$ is a constant that is representative of the paper.

The minimum moisture reached in the press nip ($m_m$) is given by the first two terms on the right-hand side of the decreasing permeability model equation (Eq. 1):

$$m_m = (m_0 - m_e)\left[1 + \frac{An(m_0 - m_e)^n I}{\mu W^2}\right]^{-1/n} + m_e \quad (11A)$$

So that:

$$r_p = r_{p,0}(m_m - m_e) = r_{p,0}(m_0 - m_e)\left[1+\frac{An(m_0 - m_e)^n I}{\mu W^2}\right]^{-1/n} \quad (12A)$$

When the ingoing moisture equals the equilibrium moisture, no water is pressed out because the pores are closed off. Consequently, no rewet can take place.

For light pressing, when the impulse $I$ is small, such that:

$$\left[1 \gg \frac{An(m_0 - m_e)^n I}{\mu W^2}\right], \text{ then } m_m = m_0 \quad (13A)$$

and

$$r_p = r_{p,o}(m_0 - m_e)\,. \quad (14A)$$

When the press impulse $I$ is large, such that:

$$\left[1 \ll \frac{An(m_0 - m_e)^n I}{\mu W^2}\right] \text{ then } m_m = \left(\frac{\mu W^2}{AnI}\right)^{1/n} + m_e \quad (15A)$$

$$m_m - m_e = \left(\frac{\mu W^2}{AnI}\right)^{1/n} \text{ and } r_p = r_{p,0}\left(\frac{\mu W^2}{AnI}\right)^{1/n} \quad (16A)$$

There is no simple or direct way to measure the position or the size of the minimum moisture, $m_m$, inside the press nip. Values for $m_m$ were calculated by Bliesner and MacGregor [14] by extrapolating post-nip rewet measurements into the nip and by Beck [27], who measured the distance between press rolls online to infer the thickness of water and fiber in the nip. Both results are calculations that have limited accuracy. Thus, in the absence of better measurements, our best estimate of $m_m$ at present comes from Eqs. 11A, 13A, and 15A.

On the other hand, post-nip flow rewet can be measured when moisture immediately after the press nip, $m_p$, is known. The following equation gives the additional rewet flow as a function of paper/felt contact time outside the nip:

$$l_p = \left(\frac{\sigma_p r_p 2t}{\mu}\right)^{\frac{1}{2}} = \left(\frac{2\sigma_p r_{p,o}(m_p - m_e)t}{\mu}\right)^{\frac{1}{2}} \quad (17A)$$

Equation 17A implies that post-nip rewet is proportional to the square root of time $t$ and $(m_p - m_e)$. Thus, post-nip flow rewet can be represented by:

$$R_f = a(m_p - m_0)^{1/2} t^{1/2} \quad (18A)$$

where:

$$a = \left(\frac{2\sigma_p r_{p,o}}{\mu}\right)^{\frac{1}{2}} \quad (19A)$$

Given that $m_m$ is difficult to determine and in-nip rewet should be accounted for in a useable rewet model, we must make approximations to obtain predictive equations for rewet. We do so by considering in-nip and post-nip rewet together as different phases of flow rewet starting from moisture $m_m$ and extending in time from the point of peak pressure in the nip, which in the case of rolls is mid-nip.

We note here that this is an approximation of the starting moisture and time of rewet. In reality, in-nip rewet will commence in the expanding part of the nip where applied pressure is decreasing from peak pressure and, consequently, time of rewet will be shorter. Improving the model to account for these factors must await improved knowledge of nip mechanics in wet pressing.

In summary, the flow rewet equation may be expressed as follows:

$$R_f = a(m_0 - m_e)^{1/2}\left[1+\frac{An(m_0 - m_e)^n I}{\mu W^2}\right]^{-1/2n} t^{1/2} \quad (20A)$$

## APPENDIX B – MODEL OF SEPARATION REWET

As described earlier, separation rewet is water that stays with the paper upon separation of the paper and felt. The mechanism is film splitting of water located in the interstitial zone between the felt and paper. The depth of water available in this zone is not precise, but it can be considered to be water that requires no flow to stay with either the felt or paper upon their separation.

We consider the amount of water available for splitting to be $Q_T$ and this to split into water on paper, $Q_p$, and water on felt, $Q_f$. Thus:

$$Q_t = Q_p + Q_f \quad (1B)$$

As above, we consider paper to have $n$ pores of size $r_p$ facing one pore of size $r_f$ on the felt. We assume that water $Q_t$ will split in proportion to the surface tensions acting on water from the felt and paper. This gives:

$$\frac{Q_p}{Q_f} = \frac{n r_p \sigma_p}{r_f \sigma_f} \quad (2B)$$

Further, we note that:

$$n r_p^2 = r_f^2 \quad (3B)$$

Substituting Eqs. 2B and 3B into Eq. 1B, we obtain:

$$Q_p = \frac{Q_t}{(1+\frac{\sigma_f r_p}{\sigma_p r_f})} \quad (4B)$$

We note that if $\sigma_f = \sigma_p$, then:

$$Q_p = \frac{r_f}{r_f + r_p} Q_t \quad (5B)$$

We further note that if $r_f = r_p$ (and $\sigma_f = \sigma_p$), rewet splits evenly, i.e., $Q_p = 0.5Q_t$.

If the available water for film splitting is proportional to the combined depth of the fabric and paper pore sizes, i.e., $Q_t = k(r_p + r_f)$, then:

$$Q_p = kr_f \quad (6B)$$

In short, for the assumptions made, felt pore size determines the amount of water that splits onto paper.

There is little information on the pore size of felts, but some on the filament sizes, $D$. If we assume that $r_f \propto D$, then:

$$Q_p \propto D \quad (7B)$$

or when expressed as separation rewet,

$$R_s = bD \quad (8B)$$

This result is valid when the amount of water in the felt available for rewet exceeds $bD$. If this is not the case, then rewet is dominated by the paper pore size:

$$R_s = br_p \quad (9B)$$

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## ABOUT THE AUTHORS

Rewet in wet pressing lowers the solids content of the web entering dryers, leading to higher energy use. It is a controversial subject, and there are many speculations about its mechanism and magnitude. Through modelling, we thought that we could identify the important factors and devise strategies to minimize rewet.

Previously, we developed the decreasing permeability model to predict dewatering in a press nip and used an empirical constant to account for rewet. This research provides a mechanistic explanation of rewet and equations to predict its magnitude under different conditions.

Rewet is a combination of in-nip and separation rewet. The most difficult aspect of this research was devising the means to quantify each contribution separately.

Rewet in the expanding press nip depends on the properties of the paper. Separation rewet, which occurs when the felt and paper separate, is a function of the surface structure of the felt.

One of the most interesting findings from this study is that the model predictions agreed extremely well with experimental data from a number of different sources.


McDonald


Kerekes

Mills could use the results of this study to reduce energy in the dryers by minimizing press rewet.

A better understanding of the effect of felt construction on rewet could lead to further improvements in dryness after the press.

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