Wet Pressing Models to Reduce Energy Consumption in Papermaking

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Abstract: Improved wet pressing reduces the need for drying and consequently energy needed in papermaking. Accordingly, it is desirable to optimize wet pressing, but the process is very complex with many interacting variables. It is therefore desirable to employ a mathematical model that accounts for the major variables to estimate the effects of changes in equipment and operating variables. This paper describes such a model called the Decreasing Permeability Model (DPM). Mill and pilot plant applications over a wide range of basis weights for paper and paper board are described.

Keywords: wet pressing; Decreasing Permeability Model (DPM); papermaking; water removal; rewet; mathematical model

1 Introduction

Improved wet pressing is a major means of energy conservation by reducing the need for drying in paper and paper board production. In non-integrated mills, steam for drying must be generated by combustion of gas, oil, coal or biomass. Kraft and TMP mills often have excess steam, but even low-pressure steam can now be used in condensing turbines to produce electricity rather than to dry paper. Thus, removing more water mechanically in the pressing process reduces energy consumption and may liberate steam that could be converted into high-value energy. There are other potential benefits as well, such as improved runnability and higher machine speeds which result in greater production rates. Given these benefits, there is a strong desire to optimize press sections. The objective of this study is to describe a model of wet pressing that enables this.

2 Overview

Pressing is a very complex process affected by many variables:
3.2 Equilibrium term, $m_e$

This term represents moisture after pressing for an infinite time. This equilibrium moisture depends on furnish coefficients $\delta$, $d$ and peak pressure, $P_p$:

$$m_e = \delta P_p^d$$  \hspace{1cm} (3)

The furnish coefficients are a function of pulp type, yield, drying history, refining and chemical treatment.

3.3 Rewet term, $m_r$

Rewet is water that has been pressed from the web but returns to the web after the press nip. As with the other remaining water, this must be removed in drying. Because rewet is a surface phenomenon that occurs at the web/felt interface, it is commonly expressed as mass of moisture per area of paper, $R$. Consequently, $R$ is divided by basis weight $W$ to be expressed as a moisture ratio:

$$m_r = \frac{R}{W}$$  \hspace{1cm} (4)

Rewet has two components: (a) flow rewet, $m_{rf}$, which is water that flows back into the web as a result of capillary forces and (b) separation rewet, $R_s$ which is the water layer between the felt and paper that stays with the paper when they separate. The total rewet has the following form\(^8\):

$$R = R_f + R_s = a(m_f t)^{\frac{1}{3}} + b D$$  \hspace{1cm} (5)

Where:

- $R$—rewet, g/m$^2$;
- $t$—the contact time between the felt and paper starting in the expanding nip, s;
- $D$—the diameter of the batt fibres, µm;
- $b$—a geometrical factor related to the felt structure, mg/m$^3$;
- $m_f$—the minimum moisture ratio achieved inside the press nip (Equation (2)).
\[ a = \left( \frac{2 \sigma_p \rho_0}{\mu} \right)^{\frac{1}{2}} \]  

(6)

Where:
- \( \sigma_p \) — surface tension of the water in the paper, N/m;
- \( r_p,0 \) — a constant representative of the paper, g²/m⁴;
- \( \mu \) — viscosity of water, N·s/m².

4 Full DPM equation

Combining the above terms, we obtain the full DPM[6-7]:

\[ m = (m_o - m_r)(1 + \frac{An(m_o - m_r)^2}{vW^2})^{\frac{1}{2}} \cdot m_r + \frac{R}{W} \]  

(7)

This equation describes the full range of wet pressing, for example over the full range of basis weights. As shown in Fig.1[1], at high basis weights, the flow term \( m_f \) dominates pressing, giving a “flow-controlled regime”. In contrast, at lower basis weights, equilibrium moisture and rewet dominate pressing, giving a “pressure controlled” regime.

5 Approximations

The full DPM in Equation (7) contains variables which may be unknown or difficult to determine. In these cases, some approximations are possible under certain circumstances.

In the flow-controlled regime, when the pressed moisture is much greater than equilibrium moisture, a simplified form of Equation (7) shown below may give a good approximation of the full DPM equation[4-5]:

\[ m = m_o (1 + \frac{Anm_o^2 I}{vW^2})^{\frac{1}{2}} \cdot R \]  

(8)

Equation (8) may also give a good representation of pressing when equilibrium moisture is important and the extent of rewet is unknown. This is possible by accounting for the effects of these variables through smaller values of \( A \) and larger values of \( n \) as shown in Table 1[6]. Physically, the changed coefficients represent a smaller effective permeability and higher power dependence on moisture ratio. An example of the usefulness of this approximation for \( R=0 \) is the excellent fit of Equation (8) to data from a Canadian newsprint machine survey[3]. The fit had a coefficient of determination \( (R^2) \) of 0.95.

Table 1 Approximate equations for newsprint[6]

<table>
<thead>
<tr>
<th>Equations</th>
<th>( n )</th>
<th>( A(\text{g} \cdot \text{m}^{-3}) )</th>
<th>( R(\text{g} \cdot \text{m}^{-3}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(8)</td>
<td>3.74</td>
<td>5.12 \times 10^{-9}</td>
<td>0</td>
</tr>
<tr>
<td>(2 &amp; 3)</td>
<td>2.97</td>
<td>6.84 \times 10^{-8}</td>
<td>0</td>
</tr>
<tr>
<td>(7)</td>
<td>2.65</td>
<td>1.03 \times 10^{-7}</td>
<td>5</td>
</tr>
<tr>
<td>(7)</td>
<td>2.32</td>
<td>1.52 \times 10^{-7}</td>
<td>10</td>
</tr>
</tbody>
</table>

On the other hand, when basis weight is small, the flow term \( m_f \) becomes small and therefore neither rewet nor equilibrium moisture can be neglected. This region depends on many factors such as furnish, press impulse, and incoming moisture. Generally, for basis weights less than 50 g/m², pressed moisture can be approximated as[8-9]:

\[ m = m_o + \frac{R}{W} \]  

(9)

Finally, we note here that caution must be exercised in use of these approximate equations to ensure that they are employed within their limits of applicability.

6 Multiple press nips and double-felted presses

Most paper machines have more than one press nip. The moisture after the last press nip can be determined by using the calculated moisture after the first press as the ingoing moisture to the second press in Equation (8) and repeating this process until the final press. The same result can be obtained more simply by using the sum of the press impulses from each nip in Equation (8), which has been shown to be mathematically equivalent[5].
Double-felting allows water to flow through both sides of the pressed paper such that it behaves like a sheet with basis weight \( W/2 \). Because of the \( W^2 \) factor in the DPM, this is equivalent to multiplying the specific permeability \((A)\) by \(4^{10}\). In addition, because there are two felt surfaces in contact with the paper, rewet \((R)\) will be doubled\(^{11}\).

7 Applications

7.1 Light basis weight grades

Pressing a 50 g/m\(^2\), 100% TMP furnish was evaluated on a pilot machine having a three-roll, inclined rolling nip press followed by a shoe press\(^5\). Moisture samples were collected after the shoe press for a variety of loadings, machine speeds, and web temperatures. The furnish dependent coefficients \((A\) and \(n)\) were determined independently by pressing handsheets on a pilot press. Moisture values after pressing were measured and compared to predicted values from Equation (8) with and without rewet, as shown in Fig.2. The difference between these of 9 g/m\(^2\) was interpreted as rewet.

7.2 Medium basis weight grades

A second pilot machine trial using the above newsprint furnish examined a range of basis weights from 25 to 100 g/m\(^2\)\(^{25-5}\). Moisture ratio was measured after the second rolling nip at a speed of 610 m/min with nip loads 60 and 80 kN/m. Fitting Equation (8) to this data gave the furnish dependent coefficients \((A\) and \(n)\) and the rewet \((R=23\) g/m\(^2\)). The fitted curves are shown in

Fig.3 Moisture ratio after the second press on a pilot paper machine loaded to 60 and 80 kN/m, the lines are fits to the DPM and the calculated rewet is 23 g/m\(^2\)\(^{4}\)

7.3 High basis weight grades

7.3.1 Corrugating medium

This study employed the DPM to improve pressing on a commercial paper machine for corrugating medium\(^{10}\). In the first pressing stage, two straight-through presses were replaced with a three-roll inclined press followed by a third press. In the second stage, the third press was rebuilt to increase the nip load by almost a factor of 2. Both rebuilds were accompanied by higher machine speeds to increase production. The DPM was employed to predict moistures for the contemplated changes. The estimates for the final press for the three configurations were in good agreement with the mill results, as shown in Table 2\(^{10}\).

7.3.2 Linerboard

This application considered pressing a 205 g/m\(^2\) linerboard composed of a 160 g/m\(^2\) filler layer with either a white or brown 45 g/m\(^2\) top-liner\(^{10}\). The board was pressed in two top-felted press nips followed
by two bottom-felted nips. The furnish dependent coefficients for each furnish (A and n) were determined by pressing handsheets in a pilot press. The filler layer was the most difficult component to dewater, followed by the brown and white liner. The pressed moisture was approximated by weighting the calculated pressed moisture ratios of each component by their relative fibre masses:

$$m = \frac{(m_1 W_1 + m_2 W_2)}{(W_1 + W_2)}$$  \hspace{1cm} (10)

Estimates from the DPM gave solid contents of 38.8% and 39.4% for the brown and white liner respectively. This agreed well with the measured solid content of 39% after the final press. Additional estimates were employed to justify the installation of a shoe press to increase the machine speed and production.

8 Theoretical estimate of upper limit of pressing

This case addressed a question often asked by papermakers: what is the upper limit of dryness from wet pressing? Equally important, what are the barriers to reaching this limit? These issues were addressed recently by application of the DPM for both low basis weight and high basis weight (11).

In the pressure-controlled regime, as expected, equilibrium moisture content and rewet are critical. Thus, lowering either of these will permit higher dryness. For grades that are not bulk sensitive, increasing the peak pressure in the nip will lower the equilibrium moisture although high pressure has a diminishing effect as shown by Equation (3).

The influence of rewet is shown in Fig. 4 as the slope of the line $1/W$. Three levels of rewet are shown with the smallest approaching $R=0$. At this level, equilibrium moisture would be the only water left in the paper.

In recent work (8), we explored the factors which affect rewet. In the pressure-controlled regime, the limit is primarily a function of felt design and contact time between felt and paper after the press nip. Appropriate choice of felt and immediate separation of the paper from the felt at the nip exit will lower rewet (7-8,12). In the flow-controlled regime, rewet is not independent of basis weight. As we have shown (8,12), for heavy-weight papers, rewet increases with pressed moisture ratio. Combining Equations (1), (4) and (5), we obtain:

$$m = m_f + m_e + \frac{a(m_f^1) + bD}{W}$$  \hspace{1cm} (11)

![Table 2: Measured and predicted solid content for different operating conditions (corrugating medium machine)]

<table>
<thead>
<tr>
<th>Press configuration</th>
<th>Machine speed/(m·min⁻¹)</th>
<th>Press loads/(kN·m⁻¹)</th>
<th>Total press impulse/(kPa·s)</th>
<th>Solid content after final press/%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>First</td>
<td>Second</td>
<td>Third</td>
</tr>
<tr>
<td>A</td>
<td>535</td>
<td>79.0</td>
<td>122</td>
<td>—</td>
</tr>
<tr>
<td>B</td>
<td>580</td>
<td>74.4</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>C</td>
<td>640</td>
<td>78.8</td>
<td>105</td>
<td>193</td>
</tr>
</tbody>
</table>

Web temperature=55°C; $v=5.11 \times 10^{-7} \text{ m}^2/\text{s}$; couch solid content=24%.
Basis weight=0.127 a.d. kg/m²; 0.120 o.d. kg/m².

![Fig.4: The influence of diminishing rewet ($R$) on final moisture ratio (11)]

![Fig.5: Effect of rewet for a TMP furnish assuming machine speed of 1500 m/min, web temperature of 50°C, basis weight of 50 g/m², and incoming web solid content of 20%]
Lastly, an example of an upper limit of pressing is shown in Fig. 5 at differing levels of rewet for a TMP furnish at 50 g/m$^2$. In the absence of any rewet, it is apparent that the upper dryness limit would approach 65%.\[^{11}\]

9 Summary and conclusions
This paper has described applications of the DPM to improve wet pressing in order to reduce energy consumption in drying. Questions remain, however, on the upper limit of dryness attainable, in particular factors affecting rewet and equilibrium moisture content. A better understanding of these variables may lead to higher dryness contents that are currently attained.

References