Role of fiber geometry in water removal by wet pressing

ABSTRACT

The development of ways to increase water removal in the wet press section of the paper machine is limited by a poor understanding of the role of web properties in dewatering. The effect of fiber geometry (as determined by species) on web dewatering was examined using 250-gram/m² handsheets of loblolly pine, spruce, and southern red oak. Dewatering behavior is analogous to the response of a Kelvin body to a compressive step input stress. Characteristics of this dewatering behavior are two web parameters: the dewatering time constant, \( T \), and apparent compressive modulus, \( C' \). Fiber geometry and freeness were found to have less effect on dewatering behavior than initial moisture content of the webs, as reflected by \( K \) and \( C' \) values. Under conditions of equal web flow resistance, \( R \), and equal initial moisture content, the dewatering time constants for the webs of different fiber types approach a common value. Web flow resistance is better suited than pulp freeness or pulp filtration resistance to predict dewatering behavior of consolidated webs of constant weight.

KEYWORDS
Wet pressing
Water removal
Press pressure
Fiber geometry
Compressibility
Flow resistance

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An increasing portion of the production cost of paper on paper machines is the cost of energy. Energy use on a paper machine is substantial in the dryer section, where approximately 80% of the energy consumed is used to evaporate water from the wet web (1–3). Any reduction in the amount of water in webs entering the dryer section would result in significant energy savings.

Ways to achieve energy savings include improving the paper machine design and optimizing the process. One way to optimize the papermaking process is by integrating process variables with fiber web characteristics to enhance dewatering in the wet press section. To do this, a better understanding is needed of the effects of web variables on water removal by pressing.

Two web characteristics recognized as influencing dewatering are flow resistance and compressibility (4,5). The role played by these characteristics in dewatering of hardwood webs has been studied (6). It was found that the dewatering characteristics of southern red oak handsheets could be modeled by a simple first order viscoelastic medium as represented by a Kelvin body (7).

When a wet fiber web is passed through a press nip, the fraction of water removed, \( \Delta MC/\Delta MC_{in} \), as a function of nip residence time appears to be equivalent to a first-order strain response of a Kelvin body to a step input compressive loading:

\[
\Delta MC = \frac{P}{C'} \left(1 - e^{-t/T}ight)
\]

where

\( \Delta MC = \) fractional change in moisture content (MC expressed as moisture ratio, g water/g fiber)
\( P = \) nip pressure
\( t = \) dewatering time constant
\( C' = \) apparent compressive elastic modulus

The quantity \( P/C' \) in Eq. 1 is equivalent to the maximum fractional change in water content, \( \Delta MC/\Delta MC_{in} \), at the nip pressure, \( P \), and very long nip residence times, \( t \rightarrow \infty \). The dewatering time constant, \( T \), is equivalent to the time in the nip necessary to remove \( 63.2\% \) of this maximum.

This simple analogy between the deformation response of a Kelvin body and the dewatering behavior of a wet web provides a means for obtaining the characteristic parameters \( T \) and \( C' \). These parameters reflect the two characteristics of the wet web that are influential in establishing its dewatering behavior: web flow resistance and web compressibility.

The purpose of this study was to determine the applicability of Eq. 1 to fiber webs of three different species which represent a typical range of fiber geometries. Handsheet webs weighing 205 g/m² formed from short, thick-walled fibers of southern red oak; long, thick-walled fibers of loblolly pine; and long, thin-walled fibers of spruce (8–10) at 630, 500, and 350 ml CSF were used to determine fiber geometry effects on the web dewatering time constant, \( T \), and apparent compressive modulus, \( C' \). In addition, the effects of web moisture content entering the wet press, \( MC_{in} \), and furnish freeness on the parameters \( T \) and \( C' \) were determined.
1. Fractional change in MC as a function of time for \(MC_{in}\) in the range of 3.0 to 3.6 for the three fiber types and freeness values.

2. Moisture dependence of the dewatering time constant for webs of loblolly pine.

3. Dependence of the dewatering time constant on pulp freeness for the three fiber types at \(MC_{in}\) values of 1.8 and 3.0.

Results and discussion

Kelvin body model applicability

The dewatering characteristics of moisture-conditioned handsheet webs of the three different fiber geometries can be adequately described by the simple Kelvin body model. The dewatering behavior of the fiber webs in the wet press section is that of a first-order Kelvin body response to a compressive step input stress, as described by Eq. 1. In the case of the fiber webs, the stress is the nip pressure and the web response is the fractional moisture change, \(\Delta MC/MC_{in}\). For example, Fig. 1 shows that a linear relationship exists between \(\Delta MC/MC_{in}\) and \((1 - e^{-t/t})\) as predicted by Eq. 1 for a given initial moisture content, \(MC_{in}\), and nip pressure, \(P\). The slope of the line is \(P/C'\), where \(C'\) is the apparent compressive modulus.

Dewatering time constant

The dominant factor influencing dewatering time constants for each of the three fiber geometries investigated is the web’s \(MC_{in}\) on entering the wet press. The relationship between web \(MC_{in}\) and dewatering time constant is shown in Fig. 2 for loblolly pine. Time constants decrease with increasing \(MC_{in}\) for all three fiber types and freeness levels. Time constants for the three different fiber types and freeness values can best be compared when \(MC_{in}\) values are equal.

At equal \(MC_{in}\) and freeness values, different fiber geometries have different time constants, as shown in Fig. 3. For \(MC_{in}\) values of 1.8 and 3.0, the dewatering time constant increases with decreasing freeness in each fiber geometry case. At an \(MC_{in}\) of 3.0, as the freeness decreases from 630 ml to 350 ml, the time constant increases from 4 to 24 ms.

Although directional changes in the dewatering time constant with freeness at equal \(MC_{in}\) values are evident, freeness alone cannot predict dewatering behavior because no single relationship

<table>
<thead>
<tr>
<th>Canadian standard freeness</th>
<th>Lobolly pine</th>
<th>Spruce</th>
<th>Southern red oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MC_{in}) g water/g fiber</td>
<td>t (ms)</td>
<td>(C') (MPa)</td>
<td>t (ms)</td>
</tr>
<tr>
<td>630</td>
<td>1.8</td>
<td>35.2 ± 2.1</td>
<td>7.7 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>14.3 ± 0.8</td>
<td>7.2 ± 1.7</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>(9.3)</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(R = 3.81 \times 10^{10}) cm(^{-1})</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>1.6</td>
<td>48.5 ± 6.6</td>
<td>10.1 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>(37)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>30.1 ± 1.5</td>
<td>7.7 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.6</td>
<td>6.6 ± 0.7</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(R = 2.63 \times 10^{10}) cm(^{-1})</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>1.7</td>
<td>52.9 ± 7.1</td>
<td>13.2 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>(49)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>33.6 ± 2.6</td>
<td>9.5 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>(16.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>12.2 ± 0.6</td>
<td>6.6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(R = 6.42 \times 10^{11}) cm(^{-1})</td>
<td></td>
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</tbody>
</table>

*a Variability of data expressed as standard deviation of the mean, sd/\(\sqrt{n}\).

*b In parentheses are interpolated values used for comparison of \(t\) values at equal initial moisture contents.
between freeness and τ exists independent of fiber geometry (Fig. 3). Furnishes whose drainage behavior on the paper machine wire are similar [equal freeness or equal filtration resistance (FR) (Fig. 4)] may be consolidated into fiber mats which exhibit marked differences in flow resistance. For different fiber geometry types, web flow resistance is better than pulp freeness for predicting dewatering behavior in the wet press at a given MCω. Under conditions of equal flow resistance and equal MCω, the dewatering time constants for webs made from the three fiber geometry types come closer to a common value than when compared at equal freenesses and equal MC in. This is apparent when comparing Figs. 3 and 5 for MCω of 1.8 and 3.0. Regardless of fiber geometry type examined in this work, a single linear relationship between web dewatering time constant and web flow resistance exists at each MCω.

**Apparent compressive modulus**

Of the three papermaking variables investigated—fiber geometry, freeness, and MCω—only web MCω has an appreciable effect on the apparent compressive modulus, C'. Figure 6 is a plot of apparent compressive modulus as a function of web MCω. In the MCω range studied, the influence of fiber geometry and freeness on compressibility was minimal. However, at MCω values lower than those studied, intrinsic fiber mechanical properties may become more important and fiber geometry effects on compressibility may become significant. In practical terms, on the first press of the paper machine, where high MCω is the overriding influence, the compressibility characteristics of the web are little affected by fiber geometry variations or changes in furnish species. However, as the dewatering progresses in subsequent presses where MC values on entering the nips are lower, the effect of species on compressibility may be significant.

In a plot of maximum fractional MC change obtained at a press pressure of 3.8 MPa versus C' (Fig. 7), the data points for all three species and freeness values over the range of MCω studied fall close to the curve predicted by Eq. 1 when t = ∞ and P = 3.8 MPa. As the apparent compressive modulus increases, the maximum fractional change in MC at any given pressure decreases. The role played by the apparent compressibility of the mat, therefore, becomes more significant in second and third presses where ingoing MC values are lower.

**Conclusions**

1. The dewatering characteristics of 205-g/m² handsheet webs formed from three different fiber types—loblolly pine, spruce, and southern red oak pulps—can be modeled by a simple first-order viscoelastic material as represented by a Kelvin body. Over the range of experimental conditions investigated, dewatering behavior on the press appears analogous to that of a first-order strain response to a compressive step input stress. Parameters characterizing this dewatering behavior are the dewatering time constant, τ, and the apparent compressive modulus, C'.

2. The MCω of the web is the dominant variable influencing τ and C' values. Pulp freeness and species have less effect on dewatering behavior than MCω.

3. Under conditions of equal sheet basis weight and equal MCω, the dewatering time constants for webs of the three fiber types are closer in value when compared at equal web flow resistance than when compared at equal pulp freeness. Whereas pulp freeness and filtration resistance, FR, may be adequate to predict drainage behavior in the forming zone, web flow resistance, R, is better suited than freeness for predicting dewatering behavior of the consoli-

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6. Moisture dependence of the apparent compressive modulus for the three fiber types.

7. Maximum fractional MC change vs. the apparent compressive modulus. The solid line is defined by Eq. 1 when t = ∞.
Experimental
Pulp and handsheet preparation

Handsheet webs were formed from kraft pulps produced from southern red oak (*Quercus falcata* Michx.), loblolly pine (*Pinus taeda* L.), and black spruce (*Picea mariana* (Mill.) B.S.P.). Pulp yields and kappa numbers were 52.4%, 22; 52.0%, 73; and 54.9%, 60, respectively. Pulps were processed in a laboratory Valley beater to nominal CSF levels of 630, 500, and 350 ml and formed into 250-g/m² handsheets according to TAPPI Method T 205.

Pulp properties

Filtration resistance, FR, measurements as a function of freeness for the pulps were obtained using a constant flow rate filtration apparatus (12, 13).

Handsheet web properties

The flow resistances of water-saturated webs at each freeness for the three pulp species were measured using a constant-pressure compression - permeability cell (6). Web flow resistances, R, were obtained from linear pressure drop-flow rate relationships as a function of compression pressure using Darcy’s Law.

Wet pressing of moisture-conditioned webs

Dewatering measurements were carried out using the first press of an experimental paper machine. The wet press consisted of two 254-mm-diam. rolls with a single, dry 75% wool/25% synthetic felt. The top roll was neoprene covered and the bottom roll was steel. Compression pressures ranged from 2.2 to 3.8 MPa, and nip residence times ranged from 2.5 to 220 ms.

The never-dried handsheet webs were moisture-conditioned without compression to moisture contents ranging from 1.1 to 3.6 g of water/g of o.d. fiber. Each web was taped along two sides onto a plastic carrier and fed into the press nip. The upper press roll was designed such that only the untaped portion of the web was compressed in the nip. The web was positioned on the carrier so that it reached felt speed before entering the nip. For each web tested, thickness and MC before and after passing through the press nip were measured as a function of press pressure and nip residence time.

Literature cited


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