Influence of the history of loading during beating on the evolution of the drainage resistance (SR)

Jean-Francis Bloch, Patrice Nortier, and Jean-Claude Roux

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SUMMARY: This paper concerns the different refining loading conditions of a bleached softwood Kraft pulp on a Valley beater. The refining trials were performed in two stages; each stage was characterized by a constant normal force applied on the pulp in the gap clearance. In the first stage, the pulp was refined from an initial to a given pulp slowness (SR-45), with a force $F_{nl}$. Then, the refining was continued from the intermediate (SR-45) to the final pulp slowness with the force $F_{n2}$.

By analogy with the pressing operation, we propose to introduce the concept of refining impulse defined as the product of the applied normal force by the duration time. This quantity is equal to the ratio of the refining energy to the peripheral speed. The refining intensity is proportional to the refining impulse divided by the number of crossing points. It was demonstrated that the pulp slowness evolution (SR) may be plotted as a master curve of the refining impulse. Consequently, the successive SR evolutions are only dependent on the refining impulse. It has to be noted that this quantity might be completed by the normal force itself to account for the prediction of the shortening of fibres.

ADDRESSES OF THE AUTHORS: Jean-Claude Roux (jean-claude.roux@grenoble-inp.fr) Jean-Francis Bloch (Jean-Francis.Bloch@pagora.grenoble-inp.fr) Patrice Nortier (Patrice.Nortier@grenoble-inp.fr) LGP2/Grenoble INP – Pagora/CNRS, 461 rue de la papeterie, 38400 Saint-Martin d’Hères, France

Corresponding author: Jean-Claude Roux

This article deals with the influence on the evolution of the drainage resistance, of different loadings for a given energy to be split in two refiners in serial connection. The refining impulse will be considered in this work as it is an indicator of the refining energy.

Recent developments (Martinez et al. 1997; Seng et al. 2004; Roux et al. 2009) proved that the normal force adequately quantifies the refining effects on fibres whatever the technology of the considered device, namely beater, disc or conical refiner may be analysed. The kinetics of the refining effects on fibres (shortening, internal and external fibrillation) were hence characterized considering the normal force applied in the gap clearance of a refiner. Therefore, two main parameters (the normal force and the duration time) control the evolution of the pulp. If the variation of the pulp slowness is given, for example, with successive refiners, the question is: how to choose these acting variables to obtain a given variation of the pulp slowness?

Materials and Methods

A set of experiments was undertaken on a Valley beater. This technology of refiner was chosen for both simplicity of its geometry and the easy change of normal force $F_n$. Indeed, by changing the applied mass, the normal force applied by the roll on the pulp suspension in the confined gap clearance may be modified. Considering the lever arm, when a mass $M$ is applied, the normal force in the gap clearance $F$ calculated taking into account the leverage ratio considering the geometry of the valley beater as follows:

$$F_s = mg \cdot r = mg \cdot \frac{1.943}{0.229} = 0.445$$

Both gap clearance and shear fields are modified changing the applied normal force. As we want to only global and external quantities, the normal force be considered.

The refining energy $E$ and the refining intensity $I$ be related to the refining impulse $I$, as follows:

$$I = F_s \cdot t = \frac{E}{V} = \frac{1.943}{V}$$

Where $N_{10}$ and $V$ represent the number of cross points and the peripheral velocity, respectively.

A bleached softwood Kraft pulp was used for the experiments. The low consistency range of pulp suspension is considered (Solid content = 1.57 wt% or consister 15.7 g.l$^{-1}$). The values for the initial SR, mean length WRV are SR-15, 1.84 mm, 0.74 g.m$^{-2}$ / 100 paper respectively. The slowness (SR) was chosen as the variable as it constitutes a standard parameter in industry. The main variables were the applied mass force and the duration time. The evolution of the SR was measured for different loading conditions.

A first set of experimental trials was under controlling the SR from its initial value SR, until a critical value SR, which was SR-45. A given trial was performed with a constant normal force applied $F_{nl}$, corresponding to a constant mass applied $m$. For the second part trials, a constant mass $m$ was then considered as the SR reached the chosen value SR - 45. Different masses $m$ and $m_2$ were chosen (2, 3.5, 4.5, 5, 6.5 kg). The evolution of the SR was then measured.

Results

For the sake of simplicity, the time considered in the paper is the duration time of a refining trial instead effective resident time of the pulp in the gap clearance of the beater.

Analysis of the influence of the normal force $F$ and the refining impulse needed $I$ to reach SR

For the first set of experiments (subscript 1), the required for the pulp slowness to reach the SR-45 was $m = F_{nl}$ and $V = \frac{1.943}{0.229}$.

$$I = F_s \cdot t = \frac{E}{V} = \frac{1.943}{V}$$
undertaken in order to obtain a good repeatability. The results obtained are presented in Table 1 for the 5 different masses \(m_1\).

For all set of data, increasing the normal force \(F_{n1}\) leads to a decrease of the time \(t_1\). In Table 1, considering the product of the normal force \(F_{n1}\) by the time \(t_1\), the refining impulse is nearly constant whatever the mass \(m_1\) chosen in the range between 3.5 kg and 6.5 kg:

\[
I_{r1} = F_{n1}t_1 = 3126 \pm 86\quad [N \times \text{min}] \quad [2]
\]

The mass 2 kg is not considered for this pulp suspension as it leads to an insufficient refining energy, as shown by the values of the refining impulses: 2783 N.min instead of 3126 N.min.

The predicted time \(<t_1>\) required to reach the value \((SR_1 - 45)\) for the pulp can be determined knowing the value of the mass \(m_1\) applied in the previous efficient range of mass, from 3.5 to 6.5 kg:

\[
<t_1> = \frac{K}{m_1}\quad [3]
\]

In Eq 3, \(K\) is a numerical constant for a given pulp and a given refining device. For example, the constant \(K\) is equal to 164 kg.min in the case of the bleached softwood kraft pulp analysed.

For this first set of experiments, the results obtained are:
- a range of mass (3.5 to 6.5 kg), or the associated loading loads, was found for the pulp analysed, to obtain an efficient refining;
- the gap of pulp slowness (from its initial to the intermediate value chosen at \(SR_1 - 45\)) only depends on the refining impulse \(I_{r1}\) (product \(F_{n1}t_1\)). In other words, any pair of values of normal force \(F_{n1}\) and duration time \(t_1\), whose product is equal to \(I_{r1}\), is a possible solution for the problem.

The next question is therefore: does the \(SR_1\)'s evolution only depend on the refining impulse \(I_{r1}\)? Fig 1 shows the master curve obtained for the evolution of the pulp slowness considering all the experimental trials (4 different masses considered in the efficient range) vs. the refining impulse.

From \((SR_1 - 45)\) to a final value: continuation of the pulp refining with a constant normal force \(F_{n2}\)

In the second set of experiments (subscript 2), the loading conditions on the pulp are identical to the first set; a constant normal force \(F_{n2}\) is applied on the pulp. The “initial” conditions considered for the pulp are: pulp slowness at \((SR_1 - 45)\), “initial” time translated from 0 to \(t_1\).

The initial kinetics of the pulp slowness depends on the value of the applied mass \(m_1\) (or the normal force \(F_{n1}\)). The time \(t_1\) required for reaching the \((SR_1 - 45)\) value is dependent on the mass \(m_1\). Different points A, B, C are shown for different masses \(m_1\) studied. They correspond to the reached value of pulp slowness (SR - 45).

Fig 2 shows the refining kinetics for the first and the second set of experiments performed. From the \((SR_1 - 45)\) (points A, B, C), one can observe that the 3 pulp slowness kinetics are identical (same slope) when the same mass \(m_2\) is concerned. Consequently, the 3 refining curves can be translated considering the delayed time \((t-t_1)\).

Since a constant normal force \(F_{n2}\) is applied in the

<table>
<thead>
<tr>
<th>(m_1) (kg)</th>
<th>2</th>
<th>3.5</th>
<th>4.5</th>
<th>5.5</th>
<th>6.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(t_1) (min)</td>
<td>73</td>
<td>46</td>
<td>37</td>
<td>29</td>
<td>26</td>
</tr>
<tr>
<td>(m_1 \times g) (N)</td>
<td>19.6</td>
<td>34.3</td>
<td>44.1</td>
<td>54.0</td>
<td>63.8</td>
</tr>
<tr>
<td>(F_{n1} = m_1 \times g) (N)</td>
<td>38.1</td>
<td>66.7</td>
<td>85.8</td>
<td>105</td>
<td>124</td>
</tr>
<tr>
<td>(I_{r1} = F_{n1}t_1) (N.min)</td>
<td>2783</td>
<td>3069</td>
<td>3174</td>
<td>3040</td>
<td>3221</td>
</tr>
</tbody>
</table>

| \(y = 1.46x - 0.90x^2 + 2.73x - 0.66x^3 - 0.90x^4 + 1.97x^5 - 0.63x^6\) |
|\(R^2 = 0.938\) | All Data | Polynomial (All Data) |

Fig 1. Pulp slowness evolution vs. the refining impulse \(I_r\) (or the product \(F_{n1}t_1\)).

Fig 2. Pulp slowness kinetics for the same mass \(m_2 = 4.5\) kg after reaching \((SR_1)\) (points A, B, C) with respective loads \(m_1 = 6.5\) kg (lozenge); 5.5 kg (circle) and 3.5 kg (square).

Fig 3. The pulp slowness evolution after reaching \((SR_1 - 45)\) as a function of the refining impulse \(I_{r2} = F_{n2}t_2\).
second step of experiments, the slowness evolution SR only depends on the product of the applied normal force $F_1$ by the delayed time ($t_{1}$), in other words, the refining impulse $I_{r1}$. The predicted results are confirmed on Fig 3, comparing to the measured values.

**Total refining impulse**

A global analysis may be carried out from the initial to the final pulp slowness, by considering the following quantities: the predicted time $<t_{1}>$ to reach the (SR - 45) and the total refining impulse $I_{rT}$. From Eq 2, we get the numerical value of the refining impulse $I_{r1}$ to reach the intermediate pulp slowness SR$_1$ - 45: $I_{r1} = 3126$ N.min. Then, the predicted time is calculated from the refining impulse $I_{r1} = F_{r1}$. $<t_{1}'>$:

$$<t_{1}'> = \frac{I_{r1}}{F_{r1}} \tag{4}$$

The normal force $F_{r1}$ is applied during the time $<t_{1}'>$ and the normal force $F_{r2}$ is applied during the remaining time ($t - <t_{1}'>$). Then, the total refining impulse is the sum of the refining impulses defined by the following expressions:

$$I_{rT} = I_{r1} + I_{r2} = F_{r1}. <t_{1}'> + F_{r2}. (t - <t_{1}'>) \tag{5}$$

In these expressions, the numerical values of the mass $m_0$ and $m_2$ are chosen in the efficient range of the considered beater for the pulp analysed, between 3.5 and 6.5 kg. Fig 4 shows the tendency obtained for the 52 pairs of experimental data representing the evolution of the SR as a function of the refining impulse, considering different masses $m_0$ and $m_2$.

It was demonstrated that the pulp slowness evolution was only dependent on the refining impulse. The analysis was completed with the other refining effects, namely the internal fibrillation (swelling and hydration) and the shortening effect on fibres. Table 2 gives the different average weighted fibre lengths and the water retention values measured, obtained at the same intermediate pulp slowness SR$_1$ - 45, which means for the same refining impulse $I_{r1}$.

In the considered case, the water retention values obtained were roughly identical (low differences), for the same intermediate pulp slowness, independently of the normal force. The shortening effect on fibres therefore depends both on the refining impulse and the normal force. Hence, for the same applied refining impulse, the average fibre lengths were different when different normal forces were applied on the pulp. The higher the normal forces are, the shorter the fibres.

It may be clearly observed that the evolution of the SR depends only on the total refining impulse defined in Eq 5.

**Fig 5** proved the validity of the proposed analysis for a Valley beater with this pulp is

| Table 2. Average weighted fibre length $L_n$ and water retention values WRV for the same refining impulse $I_{r1}$ = 3126 N.min |
|---|---|---|
| m$_0$ (kg) | 3.5 | 4.5 | 6.5 |
| F$_r1$=m$_g$.g (N) | 67 | 86 | 124 |
| L$_n$ (mm) | 1.25 | 1.15 | 1.09 |
| WRV (g/sec/100 gcm) | 149 | 151 | 152 |

**Conclusion and perspectives**

It was demonstrated that, for a Valley beater, the refining impulse is the only parameter governing the evolution of the pulp slowness (SR). The refining impulse characterizes the refining effects related to the external fibrillation. The refining impulse has to be completed by the normal force if one wants to characterize the shortening and internal fibrillation on fibres. The concept of refining impulse will be extended to other pulps and technologies of refiners in future works.

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**Literature**

