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ADAPTATION OF PRESSING CONCEPTS TO REFINING

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ABSTRACT

The refining impulse is here defined as the product of the normal loading force by the time. The refining impulse can be used in a beater for understanding and controlling the refining effects on fibres. The *SR*-degree and *WRV* evolutions depend only on the proposed refining impulse. For the shortening evolution of fibres, the normal loading force has to be introduced as a supplementary variable. By analogy with the variables controlling the pressing operation, namely press impulse and maximal applied pressure, the refining impulse alone, or complemented with the normal applied force have been experimentally shown to control the kinetics effects of refining on the fibrous suspension.

INTRODUCTION

In 2009, the French Paper Industry consisted of 96 paper mills and 157 paper machines. The annual production was 8 331 000 Tons of paper and board. Based on European data, the mean electrical consumption per year for a paper mill was roughly 800 kWh/t. Considering the beating operation, the value was 200 kWh/t. Hence, based on a cost of the electricity of 0.07 €/kWh, a decrease of 5% of the consumption of the electrical energy per year in the beating operation would lead to save 5.83 M€ per year for the paper machines.

In paper industry, the press Impulse, introduced by Wahlström [1] has proved its utility for understanding and controlling the wet pressing operation. The press impulse and the maximal applied pressure on the wet web are the pertinent quantities that determine its behaviour in the compression controlled case whereas the only press impulse characterizes the flow controlled case. As pressing and refining are two unit operations involving the fibres consolidation in confined zones, namely gap clearance and press nips, an analogy exists between the press impulse and the refining impulse. It is the purpose of this presentation to develop this analogy to understand and control the refining effects on fibres.

The existing refining intensities, such as Specific Edge Load [2], Specific Surface Load [3], C-factor [4], based on energy are mainly dedicated to single pass industrial refiners, double disc or conical refiners. However, these indicators do not integrate the residence time of the pulp into refiners. We propose a new indicator that can be used in case of hydra cycle installations.

We demonstrate that the refining impulse, product of the normal force by the time, allows the papermaker controlling the kinetics of the fibrillation (*SR* degree), the hydration (*WRV*) of fibres whatever the normal forces applied on the pulp in the gap clearance of a beater machine. In the refining operation, the role played by the compressive normal forces and the shearing tangential forces is well established [5–7]. The refining impulse is found to be a pertinent quantity for a beater and should be used in that purpose. For controlling the shortening effect on fibres (L_f), the normal force must also be introduced.

The primary effects (external and internal fibrillation, shortening of fibres) are first analysed considering a constant normal loading force applied to the pulp in the gap clearance. Then, in analogy with multi press nips, complementary trials were performed considering a modification of the applied normal force when the *SR*-degree reached the value *SR-45*. We show that the total refining impulse, sum of successive refining impulses, controls the kinetics of the primary effects on fibres.

MATERIALS AND METHODS

Performing refining trials with a Hollander beater presents one advantage: it is possible to apply a constant normal loading force to the pulp suspension in the gap clearance. Different masses may be applied on the bed plate to modify the applied force. The additional weights varied here between *2 kg* and *6.5 kg*.

The kinetics of the fibre properties were evaluated from their initial values: bleached softwood Kraft pulp, once-dried, SR_i-15, $WRV_i = 0.74\ g_{H20}/g_{DM}$, $L_{fi} =$

1.84 mm. The fibre lengths were measured using commercial equipment (Morfi®). The low consistency range for the suspension, solid content = *1.57*$\%_{w/w}$, was identical for all the refining trials.

For a discontinuous beating process where a constant normal loading force, F_n, is applied, the net specific energy consumption, E_m t, may be calculated as:

$$E_m(t) = \frac{1}{M}\int_0^t P(t').dt' = \frac{1}{M}\int_0^t f\,(t').F_n.V_p.dt' \cong \frac{f.V_p}{M}.F_n.t \quad (1)$$

Where M, t, V_p, and P t represent the dry mass of pulp in the vat, the time, the constant peripheral speed of the roll, and the instantaneous net power consumed, respectively. The global friction coefficient, f, is assumed here as constant for the whole duration of a given refining trial, as shown in [8].

The current time t is often decomposed in n cycles of the same duration Δt_c. The time cycle Δt_c. may be split into an unload time, where the pulp is flowing in the vat, and in the effective time Δt_g., where the loading force F_n is applied on the pulp in the gap between the roll and the bed plate. This is analogous to the wet pressing operation in which the wet web is submitted to a press impulse in successive press nips. If L denotes the curvilinear length of the bed plate and l_0 is the width of the roll (or that of the bed plate), it is then possible to quantify the press impulse. Calculating the press impulse, l_{wp}, a cumulative value is obtained as the pulp is passing n times through the gap:

$$I_{wp} = \int_0^{n.\Delta t_g} \frac{F_n}{L.l_0}.dt = \frac{F_n}{L.l_0}.n.\Delta t_g \quad (2)$$

Experimentally, the time cycle Δt_c is proportional to the effective time : Δt_g: Δt_c. = $q.\Delta t_g$ where q is a constant. Consequently, the Equation 2 may be modified as:

$$I_{wp} = \frac{1}{q.L.l_0}.F_n.n.\Delta t_c = \frac{1}{q.L.l_0}.(F_n.t) \quad (3)$$

Considering both equations (1) and (3), the product of the normal loading force by the current time is introduced as the refining impulse, as presented in Equation 4:

$$F_n.t = (q.L.l_0)\,I_{wp} = \frac{M}{f}.\frac{E_m\ t}{V_p} \quad (4)$$

The unit of the refining impulse (*N.s*) differs from the one introduced in the pressing theory (*Pa.s*).

RESULTS AND DISCUSSION

We will consider first, refining trials where the applied mass is constant. Then, in a second series of refining trials, the applied mass is modified during the test.

1- Refining trials using a single constant load

The pulp slowness, the water retention value and the fibre shortening are analysed successively.

Kinetics of pulp slowness

A constant loading force F_{n1} is applied to the pulp in the gap clearance of the beater. The force is F_{n1} chosen considering weights from $m_1 = 3.5\ kg$ to $6.5\ kg$, see Table 1. *SR-45* is reached for the duration time t_1. The more is the force, the less is the duration time t_1.

The same refining impulse was necessary to reach *SR-45*, whatever the loading force F_{n1}.

The pulp slowness is a function of the refining impulse only as shown in figure 1.

Kinetics of water retention value

At the same *SR-45*, or for the same value of the refining impulse, whatever the normal loading force applied, water retention values were measured and found constant, as presented in Table 2.

Kinetics of fibre shortening

The refining impulse has to be completed by the normal loading force F_{n1} to evaluate the shortening effect on fibres, quantified here by the average weighted fibre length L_f. The experimental results are presented in Table 3.

Table 1. Duration time and refining impulse to reach *SR-45* considering different normal forces

$m_1\ (kg)$	*3.5*	*4.5*	*5.5*	*6.5*
$F_{n1}\ (N)$	*66.7*	*85.8*	*105*	*124*
$t_1\ (min)$	*46*	*37*	*29*	*26*
$I_{r1} = F_{n1}.t_1\ (kN.s)$	*184*	*190*	*182*	*193*

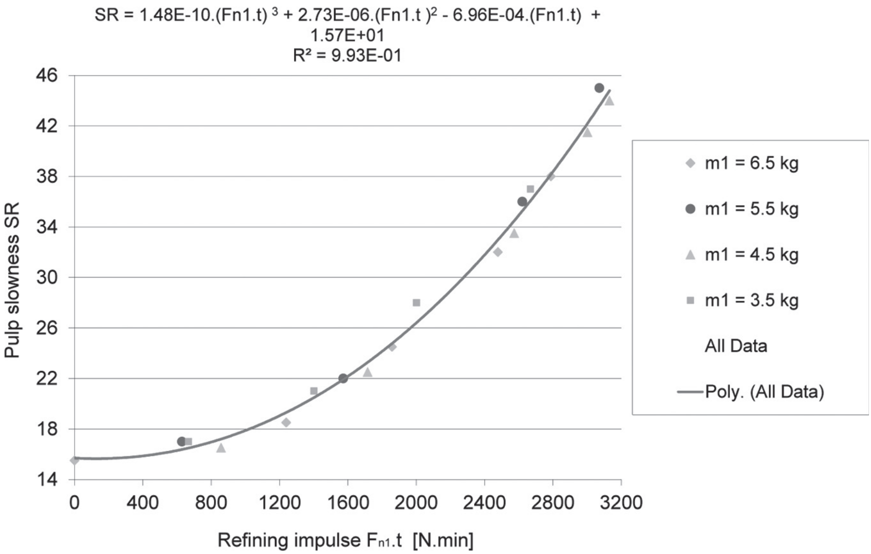

Figure 1. Pulp slowness vs. the refining impulse I_r (= $F_{n1}.t$).

Table 2. Water retention values WRV_1 at *SR-45* for the same refining impulse $I_{r1} = 187$ *kN.s* whatever the normal force F_{n1} applied

m_1 (kg)	/	3.5	4.5	6.5
F_{n1} (N)	/	67	86	124
WRV_1 (g_{H20}/g_{DM})	0.74	1.49	1.51	1.52

Table 3. Average weighted fibre length L_{f1} at *SR-45*, for the same refining impulse $I_{r1} = 187$ *kN.s*

m_1 (kg)	2.0	3.5	4.5	6.5
F_{n1} (N)	38	67	86	124
L_{f1} (mm)	1.44	1.25	1.15	1.09

This case is analogous to the compression controlled case in the wet pressing interpretation. Indeed, the mechanical pressure has to be introduced, in complement with the press impulse to quantify the dewatering of the wet web in a press section. For a given value of the refining impulse, the average weighted fibre length also depends on the value of the normal force applied. The average weighted fibre length may be postulated as a function of the refining impulse I_{r1}:

$$L_{f1} = L_{fi}.exp[-\lambda.I_{r1}] \tag{5}$$

Where L_{fi} represents the initial average length of the fibres and λ depends on the normal applied force F_{n1}.

The parameter λ is an increasing function of the normal loading force F_{n1} in the range that can be practically applied with the used beater as shown in the Figure 2.

The prediction of the average weighted fibre length (Equation 5) requires therefore the knowledge of both the refining impulse I_r and the normal loading force F_n (or equivalently the parameter λ).

2- Two step refining trials

Two normal loading forces were successively applied to the pulp. The whole duration of a trial is noted t_f. A total refining impulse may be evaluated in that case. The first normal loading force F_{n1} is applied during the time t_1 until the pulp reaches the *SR-45* value. The second normal loading force F_{n2} is applied for the duration $(t_f - t_1)$. Consequently, the following expressions of the total refining impulse may be introduced for the two step refining trials:

$$\begin{aligned} 0 \le t \le t_1: &\quad I_r(t) = F_{n1}\,.\,t \\ t \ge t_1: &\quad I_r(t) = F_{n1}\,.\,t_1 + F_{n2}\,.\,(t - t_1) \end{aligned} \tag{6}$$

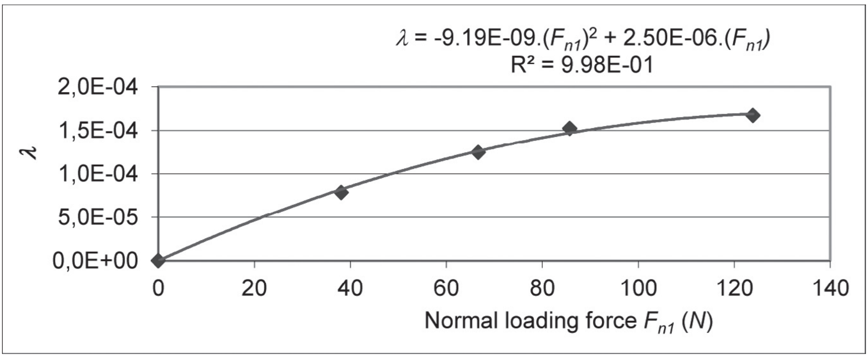

Figure 2. Parameter λ *vs.* the normal loading force F_{n1}.

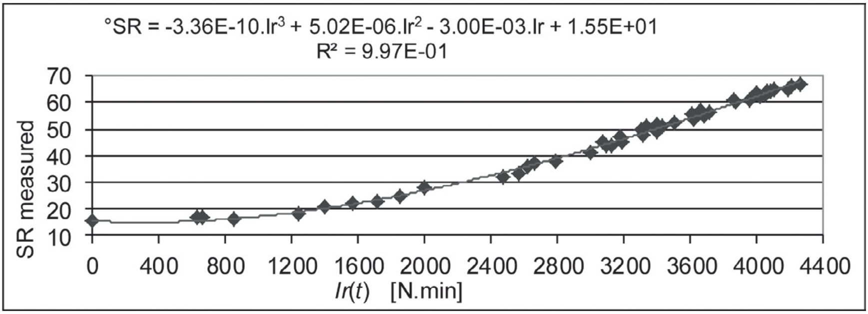

Figure 3. Pulp slowness vs. the refining impulse I_r for all the refining trials.

Kinetics of pulp slowness

The evolution of the <u>*SR* degree does only depend on the refining impulse $I_r(t)$</u> defined in Equation (6), as presented in figure 3 for the whole range of data for all the refining trials.

Kinetics of water retention value

The evolution of the internal fibrillation effect (*WRV*) was found to only depend on the refining impulse for one given *SR* degree. The experimental results are shown on Table 4 for a given *SR* degree (*SR-65)*. In the first column of data, no change of mass was performed however, in all other cases, a change of mass (or a change of the applied normal force) occurs when the *SR* degree of the pulp was equal at *SR-45*.

Similar values of the *WRV* values were obtained for the same refining impulse ($I_r = 248$ *kN.s*), whatever the two normal loading forces applied to the pulp during the two step refining trials.

Kinetics of fibre shortening

We propose a decreasing exponential model taking into account the influence of the normal loading force on the parameter λ, to determine the evolution of the fibre length:

$$\begin{cases} 0 \leq t \leq t_1 : L_f(t) = L_{fi}.exp[-\lambda(F_{n1}).F_{n1}.t] \\ t \geq t_1 : L_f(t) = L_{f1}.exp[-\lambda(F_{n2}).F_{n2}.(t-t_1)] \\ \lambda(F_n) = \alpha.F_n^2 + \beta.F_n \end{cases} \quad (7)$$

Where α and β represent the constants whose numerical values are given on Figure 2, for the given pulp analyzed.

Table 4. Water retention values *WRV* at *SR-65*, for the same refining impulse $I_r = 248\ kN.s$

F_{n1} (*N*)	*124*	*124*	*124*	*66.7*	*66.7*	*38.1*	*85.8*
F_{n2} (*N*)	*124*	*38.1*	*85.8*	*38.1*	*85.8*	*124*	*124*
WRV (g_{H20}/g_{DM})	*1.68*	*1.66*	*1.71*	*1.61*	*1.65*	*1.65*	*1.67*

The average weighted fibre length calculated using the proposed model (Equation 7) are compared to those measured for the whole set of data in the two step cases. The results are presented in Figure 4.

CONCLUSION AND PERSPECTIVES

The refining impulse, introduced by analogy with the mechanical impulse defined in the pressing operation, demonstrated its efficiency in characterizing the qualitative and quantitative kinetics of the modification of fibre properties. Indeed, single curve *SR* degree vs refining impulse is obtained meaning that the evolution of the *SR* degree is only a function of the refining impulse. No other variable is required to describe the kinetics of the *SR* degree. In order to identify numerically the model parameters, it is necessary to run a single trial on the refiner.

Considering constant factor of friction during a given refining trial, the refining impulse is proportional to the net energy consumption. The evolution of the friction factor during refining will be analysed in future research. Medium consistency may also be considered in the developed model as an increase of the pulp consistency leads to an increase of the friction factor. The concept of the refining impulse will be strengthened considering other raw materials, consistencies and technologies such as disc and conical refiners.

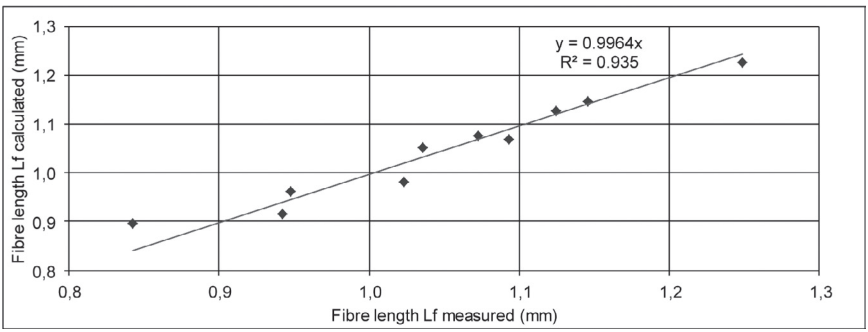

Figure 4. Calculated fibre length vs measured fibre length L_f (mm)

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Transcription of Discussion

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Wolfgang Bauer Graz University of Technology

Have you tried to apply this concept to industrial refining?

Jean-Claude Roux

The pulp state can be defined by 3 parameters: average fibre length, °SR (Schopper-Riegler degree) and WRV (Water Retention Value). Refining impulse can help you to control °SR and WRV – it was one of our aims to better understand refining but also to achieve better control. But you have to be very careful because fibre length depends more on the normal force. So, obviously, any type of refiner, even a disc-refiner or conical refiner, can be run using this concept, although industrial refining will usually involve either multiple passes or multiple units depending on the pathway of the pulp suspension through the system. This is a very complex problem and we have not yet solved all of it, only a small part.

Gil Garnier Monash University

Very elegant work. How can we use this work to improve refining or to decrease energy?

Jean-Claude Roux

In fact, there are many aspects of refining that can be improved. It depends if you want to develop pulp properties, paper properties or to reduce energy. In 1989, I did some work on the Voith beater that we have at Pagora and, by considering physical modelling based on ideal hydrodynamics and the Reynolds equation, it was possible to minimize the energy consumption and at the same time to optimise the pulp and paper properties. So this can be done, but in another context without this new concept of refining impulse. I remember Professor Silvy demonstrating fibre-cutting to a student by breaking a stick of chalk – I was one of his students myself a long time ago. In fact, the cutting effect on fibre can be obtained by ortho-axial constraint, that is if you exert any force perpendicular to the fibre axis.

Jean-Francis Bloch did his PhD thesis 18 years ago, myself 27 years ago, both on wet pressing and modelling, so that is why probably we are influenced by the pressing process and why we extended the concept of pressing impulse to refining impulse in this presentation.