Optimum Refining of TMP Pulp by Fractionation after the First Refining Stage

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Abstract

The pulp used in this work was sampled after the first TMP refining stage of a Canadian newsprint mill. This pulp was fractionated with a pressure screen in two or more fractions of long fibres and fine fibres. We refined the fractions at high consistency in one or two stages or at low consistency. We recombined the refined fractions together to recreate the initial pulp. The initial pulp, itself refined at high consistency as in a typical TMP process, has been compared with the recombined pulps. It appears that refining consistency has strong effect on the quality of the recombined pulp and that it is possible to optimize the quality by this kind of treatment. This optimization is closely related with the fractionation efficiency. The best fractionation process is a pressure screen cascade using baskets with very small apertures. This process is very efficient in separating fibres by length but also able to separate fibres on the basis of wall thickness, leading to fractions of long fibres enriched in latewood and fractions of short fibres enriched of earlywood.

Introduction

Over the years, mechanical pulps have been greatly improved either in quality and energy consumption mainly by the development of the defibrating and refining processes. Nevertheless, there is still an increasing request of better quality mechanical pulps in order to meet the increasing exigencies on the quality and on the costs of the papers made with these pulps. The improvements also allow the use of these pulps as a replacement of more expensive chemical pulp in quality demanding products [**1**]. Besides, as in many other industries, the pressure for environmental protection also requires a mechanism of constant improvement of the processes directed toward the reduction of the pollutant emissions and the energy consumption. Therefore, new orientations are required to produce better and lower cost mechanical pulps. Extensive investigations have been developed all around the world in order to increase the quality of mechanical pulps by the mean of fractionation. Most of them have been carried out on fully refined pulp (i.e. posterior to secondary high consistency refining stage) and using different fractionation devices like spray disk [**2**], flotation cells [**3**] or even a tube [**4**], but meanly hydrocyclones [**5**, **6**, **7**, **8**] and pressure screens [**9**, **10**, **11**, **12**, **13**].

The quality of the fibres, which is deeply related to their morphological properties, is very important for the quality of the final sheet of paper. The long fibres create the main fibre network upon what the shorter fibres will be retained and agglomerate to form the sheet. The mechanical resistance of the sheet is closely related to this long fibres network. But in the same time, the long fibres are coarser and less flexible and prone to increase the roughness of the sheet. It is then interesting to develop the bonding ability of the long fibres what will produce a stronger network and, in the same time, increase the flexibility of the fibres and reduce the roughness of the sheet [**14**]. The long fibres have also a higher wall thickness which makes them have a smaller specific surface than that of thin wall fibres [**15**]. This is specifically true for the earlywood fibres. The short fibres in turn fill the long fibres network, consolidate the whole sheet and create a suitable surface for printing. The fines complete this structure contributing to opacity, roughness and porosity and thus the ink-paper relationship. Nevertheless, the role of the fines must be distinguished whether the fines are primary fines or secondary fines [**16**]. In the first case fines are produce during the first refining stage. They are mainly originated by the delamination of the primary wall, with a flake-like shape and contain a high amount of lignin. Secondary fines are generated in posterior refining stage by the delamination of the secondary wall. Because of their higher content of cellulose and fibrillary shape, they have better bonding ability than primary fines but less contribution to opacity. All those aspects validate a process with a specific approach for refining separately each type of fibres.

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Objectives of the Study

The main goal of our study is to propose a new way for enhancing thermomechanical pulp by the mean of refining selective fractions of primary refining stage pulp and recombining them. In order to achieve this goal, an industrial pulp from a Canadian newsprint mill has been used. This mill experiences TMP pulp quality variations during the year because of the seasonal variations of chips quality. Several reasons can explain those variations: one is that chips are stored a longer time in the wood yard during winter time than during the other seasons when chips come almost immediately from the forest, another is that the wood is harvested in different places during winter and the rest of the year for the same specie of tree. The first step of this study was the fractionation of the pulp followed by the refining of the fractions with several processes and finally the analysis of the recombined pulp properties.

Experimental Results

Fractionation:

Two series of trials are carried out with the industrial pulp and each one with a specific fractionation process involving slotted baskets and drilled baskets with low profile or smooth surface as shown in Figure 1. The screen baskets and the operational parameters are chosen in order to optimize the fractionation effect [**17**, **18**, **11**]. All trials are performed in batch sequences with the Black Clawson model 8P pressure screen at CIPP. This screen is equipped with a two foils rotor with a tangential speed of 20 m/s. Those processes are tested in order to evaluate their abilities to separate the fibres on the bases of length, flexibility, coarseness and other morphological characteristics such as wall thickness.

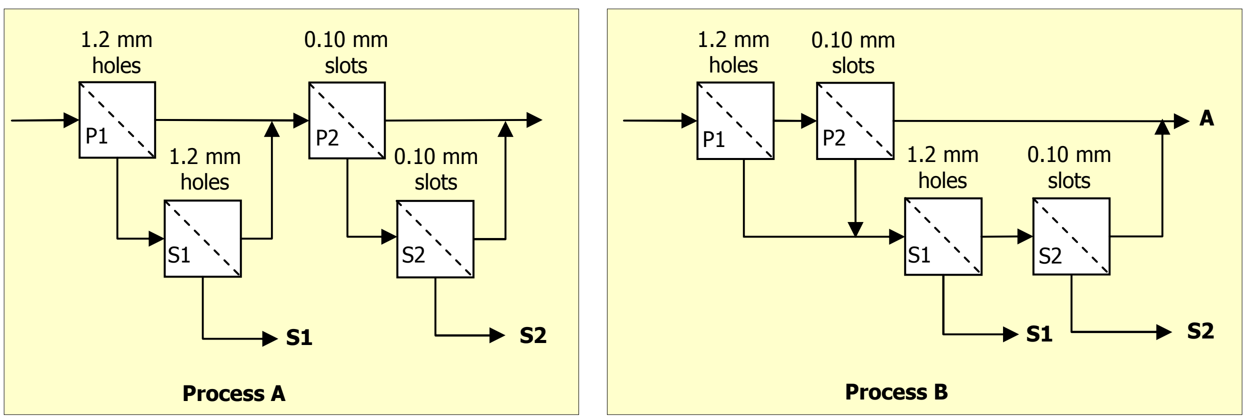


Figure 1: Fractionation processes used to create the fractions for refining and recombination trials.

The pulp was originated from Papier Masson Inc. and chosen at two key periods of the year: during spring when the pulp quality is expected to be optimum – this pulp is fractionated with process A – and in winter when the pulp is expected to have the lowest mechanical properties – this pulp is fractionated with process B. The pulps were sampled in the blow-line of the primary high consistency refiner and shipped to CIPP pilot plant. They were then diluted at 4% consistency and maintained at a temperature of 75°C for at least 45 min to remove the latency prior to the trials. A third pulp has also been sampled to test a third fractionation process – process C – involving small apertures screen baskets (figure 5). This process will be discussed later. The sheets properties have not been measured because of the high freeness. But to establish a reference, these pulps were refined in one stage at high consistency simulating the second refining stage of a TMP process and the properties were measured at 100 mL CSF.

Fractionation efficiency can be assessed using commonly used indexes such as Nelson index [**19**], Wahren retention probability [**20**] or passage ratio [**21**, **22**]. Nevertheless, because of the type of the rotor and the high rotation speed, this pressure screen produces a mixed flow rather than plug flow. Therefore, preference is given to Wahren index. This index has also the advantage of providing a good way to make predictions [**23**] of length based fractions. This index is equal to unity when the fractionation of a specific fraction is perfect toward the reject flow and tends to $-\infty$ when fractionation if perfect toward the accept flow. A null value does not mean zero fractionation efficiency as for the Q index. The zero fractionation efficiency for the Wahren index is actually reached at a critical value W_c which is specific of the pulp, the pressure screen configuration and the operational parameters. This value can be calculated by equation 1 where RTF is the thickening ratio and RR_W is the mass reject rate.

$$W_c = \frac{RTF - 1}{RTF - RR_W} \qquad \textit{Equation 1}$$

The Wahren retention probability, and also the Nelson index, does not allow comparing fractionation efficiency on the same basis whether a fraction is rejected or accepted. For example, the Q index of a fraction separated toward the reject flow will be in a range of 0 to 1. For a fraction separated toward the accept flow, the values will be between 0 and -∞. As a solution the indexes can be calculated inverting the role of reject and accept flows. The absolute values of indexes can then be compared. Fractions can be defined according to several criteria such as length (Bauer McNett fractions, fibre analyser's length classes), earlywood-latewood classes, etc. Bauer McNett fractions are very commonly used: they are easy to obtain and they can be precisely predicted with the Wahren index over a wide range of operational parameters with a few set of preliminary trials.

Refining:

The fractionation of pulps with processes A and B generates two long fractions and one short fraction. Those fractions are refined with the Metso CD-300 refiner available at CIPP at several levels of consistency: low consistency, one stage at high consistency and two stages at high consistency. High consistency refining is conducted at 30% consistency and atmospheric pressure, in one step or two steps and changing the distance between the plates to control the amount of energy applied to the pulp. Low consistency refining is conducted in the same refiner, at 6 to 8% consistency, with constant gap between the plates. Increasing amounts of energy are applied to the pulp by several passes through the refiner. Several pulps are obtained in a range of 200 to 50 mL CSF.

Recombining the Fractions:

The refined fractions are recombined together to recreate to original pulp i.e. the fractions are mixed according to the fractionation mass ratios. This stage is rather critical and care has been taken not to loose fines between every step of the process, specifically thickening for high consistency refining, as far as this could introduce some bias in the results. Care has also been taken in the calculations of the fractionation mass ratios : as far as the fractionation is performed in batch mode, the mass balances must be carefully reconstituted stage by stage.

The refined fractions are chosen to produce a recombined pulp with a CSF of 100 mL approximately (± 10 mL). The amount of possible mixes being elevated, some mixes are chosen and the other one are simulated with mathematical models established with the properties measured on the real mixes. The chosen model is a logarithmic model (equation 2) using 10 parameters and based on refining specific energy (first stage specific energy not included), freeness and tensile index. These expressions were suggested by studies from other authors [**24**, **25**, **26**] but adapted to increase the quality of the model and use it as a predictive model. For each component, an overall value is calculated as a linear combination of the logarithmic value of each property (equation 3). Then the value for the mix is calculated also as a linear combination of the logarithmic value affected by the mass ratio of each component in the mix (equation 2).

$$Y = K Y_1^{\omega_1} Y_2^{\omega_2} Y_3^{\omega_3} \qquad \textit{Equation 2}$$

$$Y_i = E_i^{a_i} CSF_i^{b_i} IR_i^{c_i} \qquad \textit{Equation 3}$$

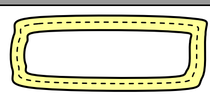
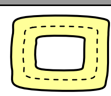
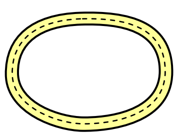
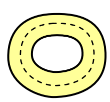
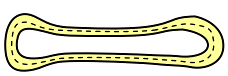
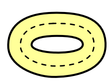
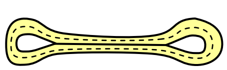
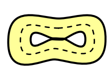
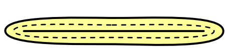
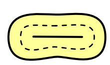
Fibres Analysis:

Fibres wall thickness is measured using the Morphi Wall Thickness (MWT) measurement device (figure 2) from CTP/TechPap: the device takes a sample of fibres from a diluted suspension of pulp (3 mg/L) and deposits it on a slotted plate (about 0.06 mm width). Then a micrograph of pulp is taken by means of a microscope and a digital camera. An image analysis algorithm measures the fibres wall thickness on each image. Series of 30 to 50 pictures analysis are performed until stabilisation of the average wall thickness. For better assessment, the pulp has been splitted into the Bauer McNett fractions and measurements have been carried out on fractions R28, R48, R100 and R200. R14 fraction was measured with the MWT because the long fibres and shives could plug the device.

Figure 2: Morphi Wall Thickness measurement device (CTP/TechPap)

Additional analysis has been made on those pictures to assess earlywood/latewood ratio, fibre width and wall thickness of earlywood and latewood. The fibres are classified into earlywood fibres and latewood fibres according to their morphological characteristics such as width, wall thickness and punctuations (amount and size). The transition fibres have been classified into one or the other category according to the most seemingly characteristics. The earlywood and latewood ratios obtained this way are number ratios. In order to achieve a mass balance of each fraction in the fractionation process, they have to be converted into mass ratios. This is obtained considering typical cross-sectional shapes for earlywood and latewood fibres (Table Itable) and average width and wall thickness.

Table I: Typical cross-sectional shapes of earlywood and latewood fibres of first refining stage pulp

Earlywood	Latewood	Shape
		Squared
		Rounded
		Flattened
		Partially collapsed
		Collapsed

Latewood fibres of primary pulp are very stiff and coarse fibres and keep more likely their original squared shape. On another hand, earlywood fibres are more flexible and tend to collapse. The coarseness can be calculated by equation 4 where ρ is the fibre wall density and A the surface area of the fibre wall cross-section. For squared cross-section and collapsed cross-section, coarseness can be approximated respectively by equation 5 and equation 6 where W is the fibre width and w_t the wall thickness. The fibre wall density still needs to be determined but for the purpose of our calculations, it is not necessary if assumed equal for latewood and for earlywood fibres.

$$\sigma = \rho A \qquad \textit{Equation 4}$$

$$\sigma_L = 4\rho(2W - w_t) \qquad \textit{Equation 5}$$

$$\sigma_E = 2\rho W w_t \qquad \textit{Equation 6}$$

Considering a mass balance on a unit length of fibres for a fraction of pulp obtained on the basis of fibre length fractionation such as Bauer McNett fractions R28 to R200 (earlywood fibres and latewood fibres have almost the same average length), the average coarseness of the pulp can be expressed as a function of the coarseness and number ratios of earlywood fibres and latewood fibres as expressed in equation 7 where p_E, p_L, and σ_E, σ_L are respectively the number ratios and coarseness of earlywood and latewood fibres.

$$\overline{\sigma} = p_E \sigma_E + p_L \sigma_L \qquad \textit{Equation 7}$$

With the same consideration, each part of the right member of equation 7 can be considered as the mass fraction of earlywood and latewood fibres. Then the mass ratios can be calculated by equation 8, which can by rearranged as equation 9 replacing the average coarseness by equation 7. These expressions are used to quantify and compare the amount of earlywood and latewood in the fractionated pulps throughout the process. To compare weight fractions instead of number fractions is important because of the morphological differences between earlywood and latewood fibres.

$$\omega_E = p_E \frac{\sigma_E}{\overline{\sigma}} \qquad \textit{Equation 8}$$

$$\omega_E = \frac{1}{1 + \frac{p_L \sigma_L}{p_E \sigma_E}} \qquad \textit{Equation 9}$$

$$\omega_L = \frac{1}{1 + \frac{p_E \sigma_E}{p_L \sigma_L}} \qquad \textit{Equation 10}$$

<u>Discussion</u>

Fractionation Efficiency:

Fractionation efficiency is assessed by the Bauer McNett for length based fractionation. Two fractionation processes have been used in order to generate the fractions (figure 1). Screen baskets with 1.2 mm smooth holes and 0.10 mm slots have been used. Those two processes provide two fractions enriched of long fibres and a fraction enriched of short fibres. Figure 3 presents the Bauer McNett distribution of each fraction. The reject flows S1 and S2 have significantly higher amount of long fibres (R48) and lower amount of short fibres (P48).

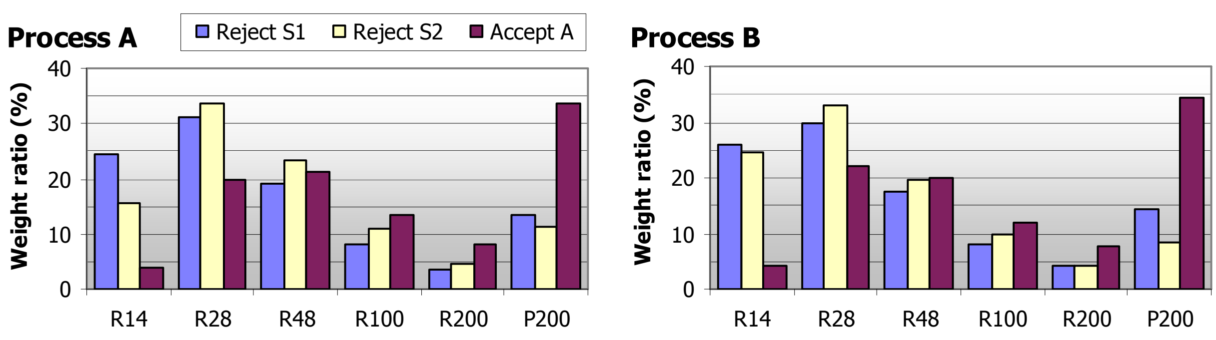


Figure 3: Bauer McNett distributions of the long and short fractions obtained with fractionation processes A and B.

Along with the mass balance, these processes generate three different fractions (figure 4): S1 flow contains most of R14 fibres and a important part of R28 and R48 fibres while S2 flow is mainly made of P14/R100 fibres and the accept A flow contains P48 fibres with a very high fines (P200) content. Nevertheless overlapping of fractions can be observed between the different flows. The accept flow still contains a significant amount of R28 and R48 fibres and the difference between the two long fibres fractions is also quite thin so that the two long fractions could actually be considered similar. Nevertheless, as described in the next part of the discussion, the recombined pulps have different properties even when the unrefined fractions do not. When the fractions present higher differences, it is possible to obtain more different behaviours of the recombined pulp and even better properties than the pulp refined at high consistency without fractionation. This behaviour validates the refining of splitted pulp and shows the need of a better separation of fibres.

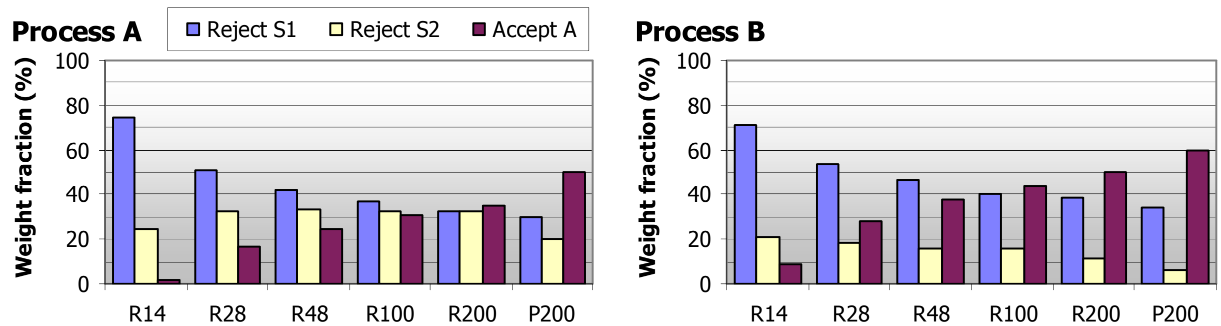


Figure 4: Mass balance of the Bauer McNett fractions for the fractionation processes A and B.

On that basis, a new process for fractionation has been proposed to separate more efficiently the fibres according to their length. This is achieved by the use of screen baskets with much smaller aperture than that of the screen baskets used in process A and B. This process is shown in figure 5.

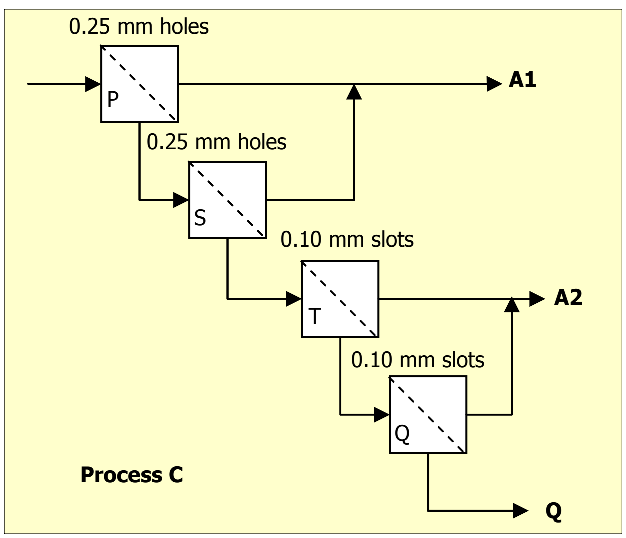


Figure 5: Fractionation process C featuring four screens in cascade with small aperture baskets

Because of the high thickening ratio of the small aperture screen baskets, several pressure screens have been placed in cascade. The first two screens with the smaller apertures (0.25 mm smooth holes) split the pulp between R48 and R100; the next two screens with bigger apertures (0.10 mm slots) split the reject pulp between R28 and R48 as shown in figure 6 below. The rejects of the last screen (Q) contains mainly R14 and R28 fibres. The accept flows of the last two screens (accept A2) contain the fraction R48 and R100 of the initial pulp and the accept flows of the first two screens (accept A1) contain most of the short fibres of the initial pulp. These figures show that the classes of fibres length are well separated across those three fractions. The average fibre wall thickness is also affected by the fractionation process.

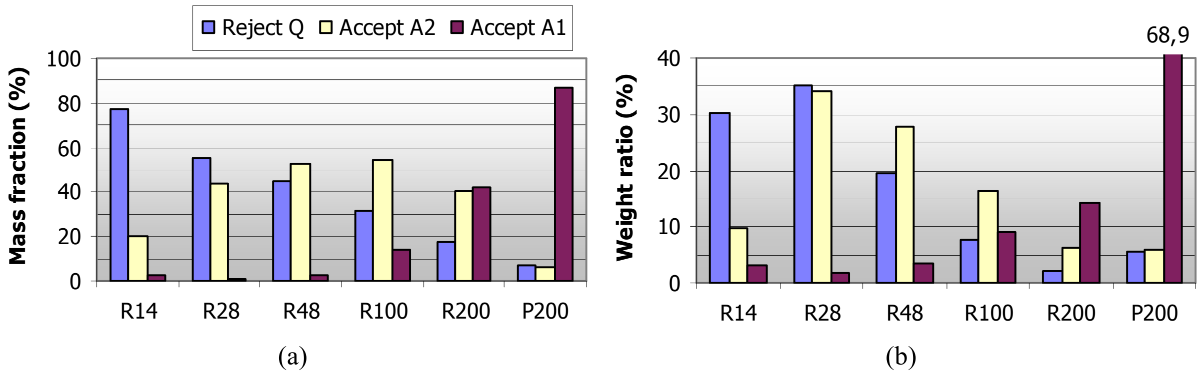


Figure 6 : (a) Mass balance of the Bauer McNett fractions and (b) Bauer McNett distributions of the long and short fractions obtained with fractionation process C.

As shown in figure 7, the long fibres fractions R28 and R48 have an increase in fibres wall thickness during the last two screens whereas no change is observed with the first two screens. Actually the first two screens fractionate the fibres on the basis of length because of the very small apertures. Those fractions are separated from R100, R200 and P200 but not modified as far as the corresponding fibres are not able to pass through the baskets. In the next screens (T and Q), the pulp is almost only composed of R14, R28 and R48 fractions. Some of those fibres are able to pass through the bigger apertures (0.10 mm slots) according to their length, coarseness and flexibility. The increase of fibres wall thickness for fractions R28 and R48 indicates that coarser and less flexible fibres are preferentially retained by the baskets. There is also a competition between fractionation by length versus fractionation by coarseness which is traduced by a smaller increase of fibres wall thickness for the R48 fraction than the R28 fraction. As far as the fibres are not physically modified by the fractionation process, those changes in fibres wall thickness are closely related to earlywood/latewood fractionation.

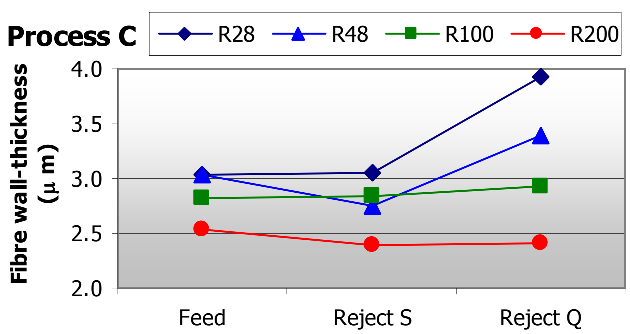


Figure 7 : Effect of the fractionation process C on the average fibre wall thickness

Separate Refining of Fractions:

The refining of each fraction with different refining processes and different operational parameters leads to different quality of recombined pulp. For a same freeness of the recombined pulp, fractions treated with different amounts of energy and different consistencies, generate recombined pulps with distinctive properties. Figure 8 shows the mechanical properties of several mixes obtained with fractions refined either at low consistency or high consistency. The mixes have been classified according to the refining process that have been used to develop the long fibres fractions, the short fractions being refined either at low or high consistency. It clearly appears that low consistency refining generates a loss of tear index while the tensile index remains unchanged or slightly higher. The way the short fibres are refined do not change this tendency but differences can be observed between the mixes where the short fibres are refined at low consistency and those at high consistency. Similar conclusions can be drawn for tensile energy absorption (TEA). In the case of the scattering coefficient, no significant differences are observed.

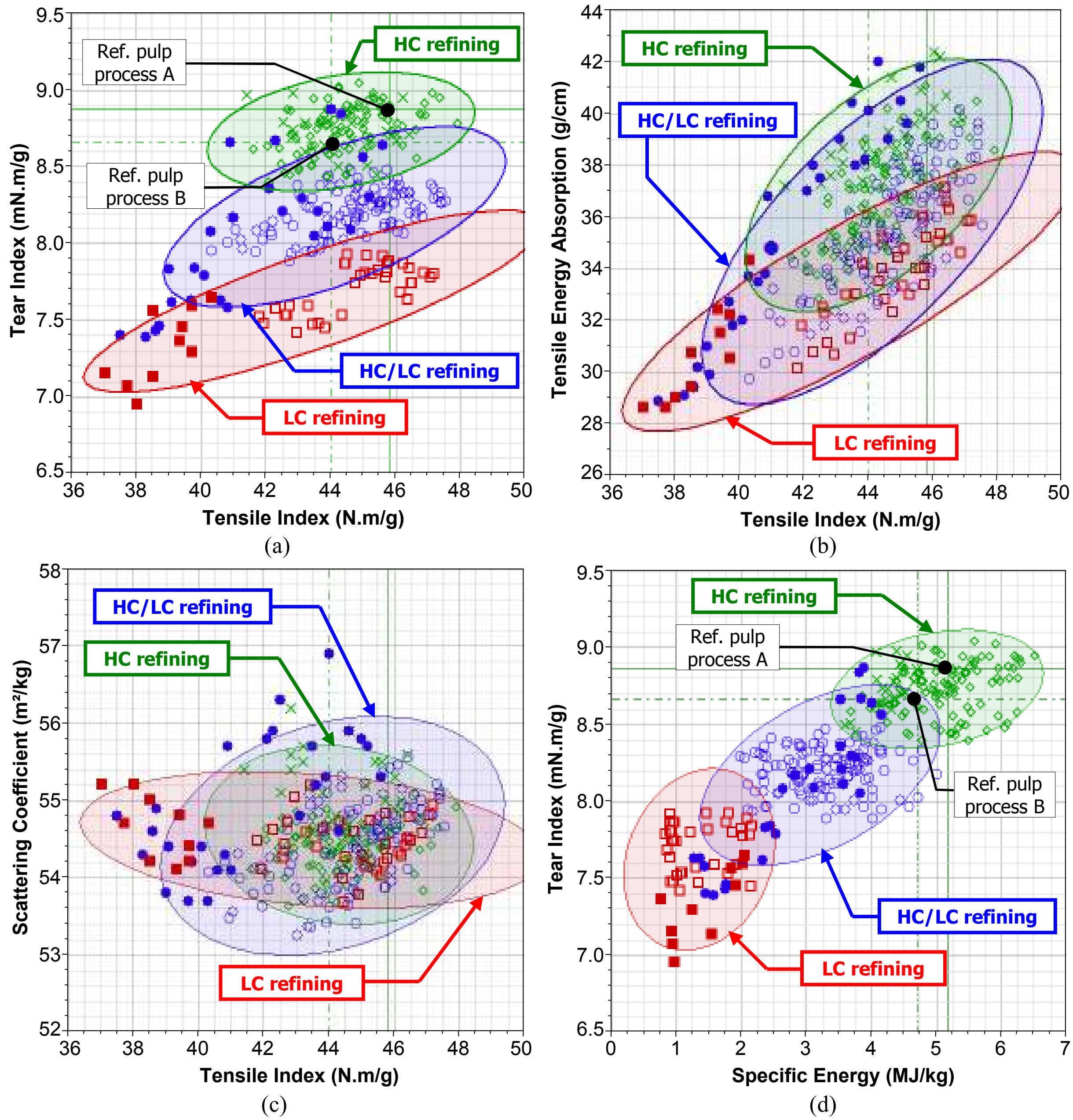


Figure 8: 95% probability density ellipses of recombined pulp mechanical properties according to the refining process applied on the long fibres fractions S1 and S2. Empty markers stand for process A and filled markers and crosses for process B; (a) Tear index vs. Tensile Index, (b) Total Energy Absorption vs. Tensile Index, (c) Scattering Coefficient vs. Tensile Index and (d) Tensile Index vs. Specific Refining Energy .

The way the long fibres have been refined is a key factor for the overall quality of the recombined pulp. Low consistency refining leads to poor tear index whereas high consistency allows better tear index. The refining of the short fibres has much less effect on the recombined pulp properties, most probably because the cut of fibres is not so critical for the mechanical properties of the short fibres and leads more to wall exposure by cross sectioning, splitting or delamination, contributing therefore to increase the capacity of fibre bonding. At constant freeness, the reduction in fibre length between high consistency refining and low consistency refining is higher for the long fibre fractions than for the short fibre fraction. Figure 9 below shows that at a freeness of 100 mL, the reduction of length is 2 to 4 times higher for the long fractions than for the short fractions when it is refined at low consistency instead of high consistency. Therefore, the refining strategy must be carefully defined for the fractions in order to improve the quality of the recombined pulp and this strategy should consider mainly high consistency refining.

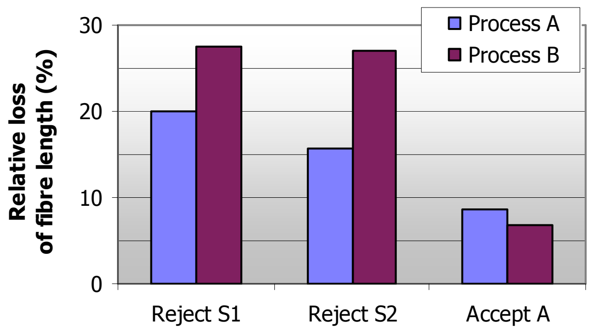


Figure 9: Relative loss in fibre length (length weighted average) for each fraction between refining at high consistency and low consistency at 100 mL CSF.

Most importantly, refining by fractions allows obtaining better properties than the whole pulp refined at high consistency like in a traditional TMP process. As shown in figure 10 where the mixes with best mechanical properties have been selected, an improvement can be observed between each reference pulp and its corresponding recombined pulps. Also, it can be observed that the lower quality pulp (B) can reach the properties of the higher quality pulp (A). This process could therefore be used to compensate the seasonal pulp quality variations and maintain constant quality all the year.

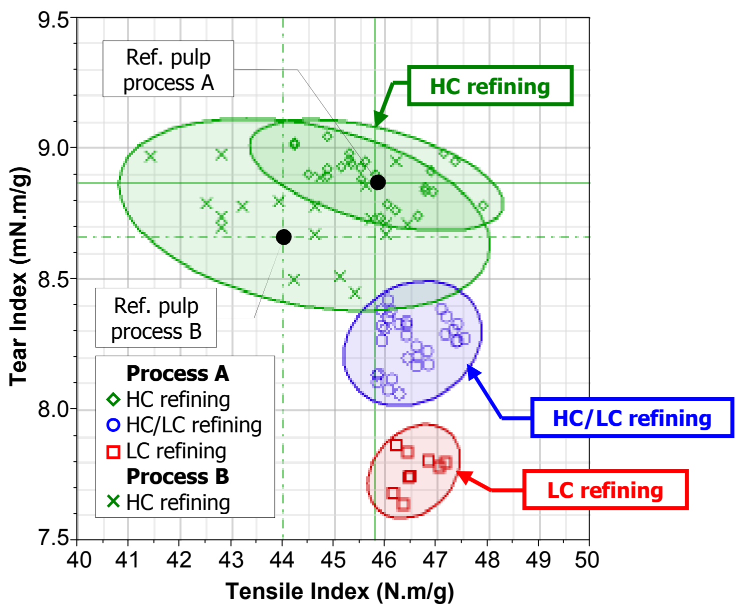


Figure 10: Recombined pulps showing best mechanical properties with HC refining, HC/LC refining and LC refining on process A fractions compared with best results obtained with HC refining on process B fractions.

Conclusions

Two original aspects have been developed throughout this study: the use of a screen basket with very small apertures as a mean of fractionation and the use of mechanical pulp from the primary refining stage.

The small aperture basket by itself is a very good length-based fractionator but because of this, it does not allow to fractionate efficiently according to other characteristics such as coarseness or cell wall-thickness. Besides, this screen basket requires low reject rates because of its high thickening ratio in order to have a proper balance between the reject flow and the accept flow. Therefore, another screen with bigger apertures is required as a posterior stage.

This sequence provides a way to increase the amount of latewood fibres in the reject flow and the amount of earlywood fibres in the accept flow of the slotted baskets.

The way the specific energy is applied to the fractionated pulp has a significant effect on the properties of the recombined pulp. Low consistency can be used to reduce the energy consumption but the pulp can be damaged. For the long fibres, high consistency is preferable and several stages can be performed to reduce the refining intensity while maintaining the same specific energy. The impact of short fibres and fines in the quality of the recombined pulp is lower than that of long fibres regarding the consistency of refining.

This study is still in progress and the new process should allow studying more precisely the effect of the refining stage on long and short fibres by means of well separated fractions. It should also provide a better insight on earlywood and latewood fibres role during refining and their contribution on the recombined pulp quality.

Acknowledgements

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Optimum Refining of TMP Pulp by Fractionation after the First Refining Stage

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S. Bussières, Papier Masson Ltée

Introduction

- Need to produce better pulp with less energy
- Pulp is composed from heterogeneous material
  - earlywood
  - Latewood

Introduction

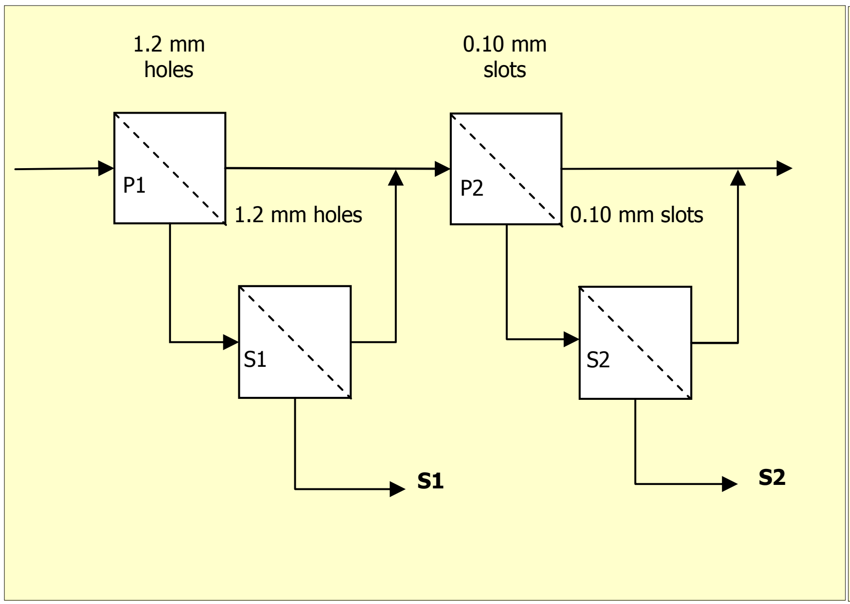
- Adapted refining process should lead to some improvements
- Need to fractionate early in the process to maximize the effect

Objectives

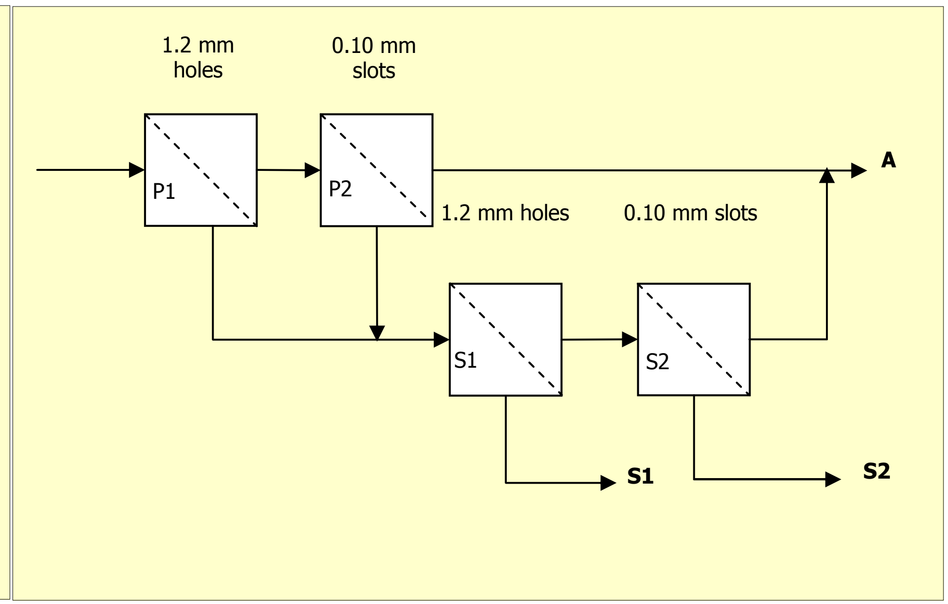
- To study the fractionation after the first stage of refining, followed by a specific refining of each fraction
- To promote:
  - Reduction of specific refining energy
  - Increase of physical properties

Experiment

- Primary pulp from Papier Masson mill



Process A



Process B

- Fractions refined in 1 or 2 HC stages or at LC

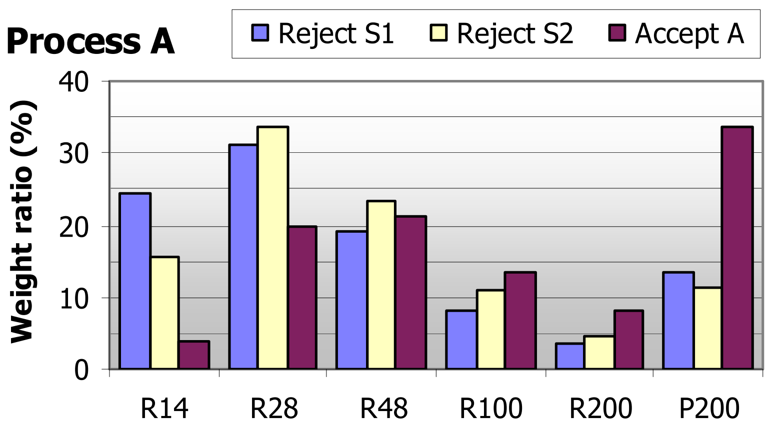
Experiment

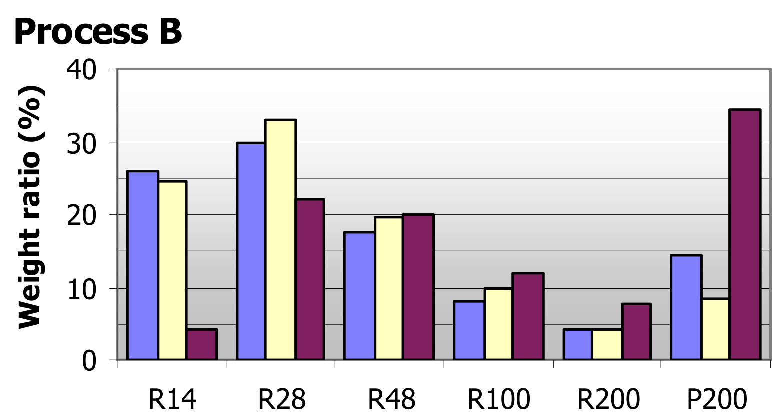
- Modeling based on Wahren index

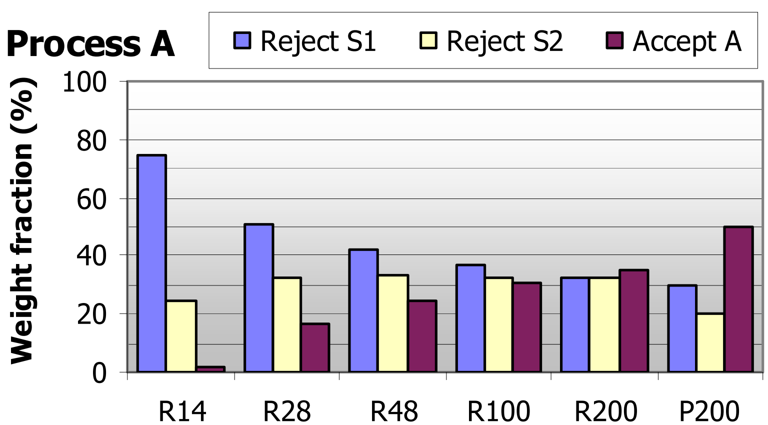
$$W_c = \frac{RTF - 1}{RTF - RR_W}$$

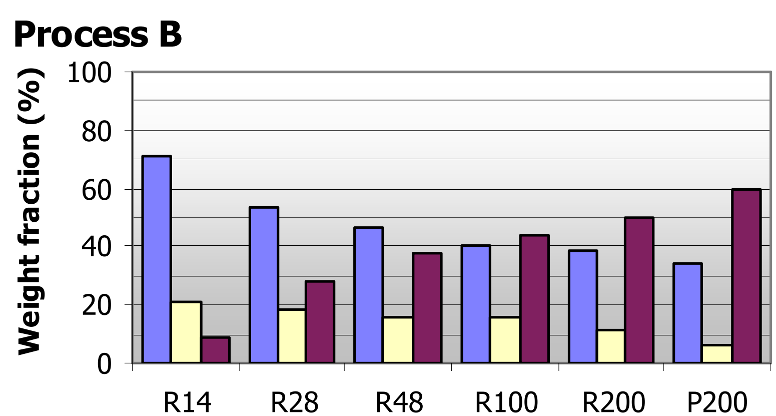
  - RTF: the thickening ratio
  - RRW: the mass reject rate

Fractionation Efficiency

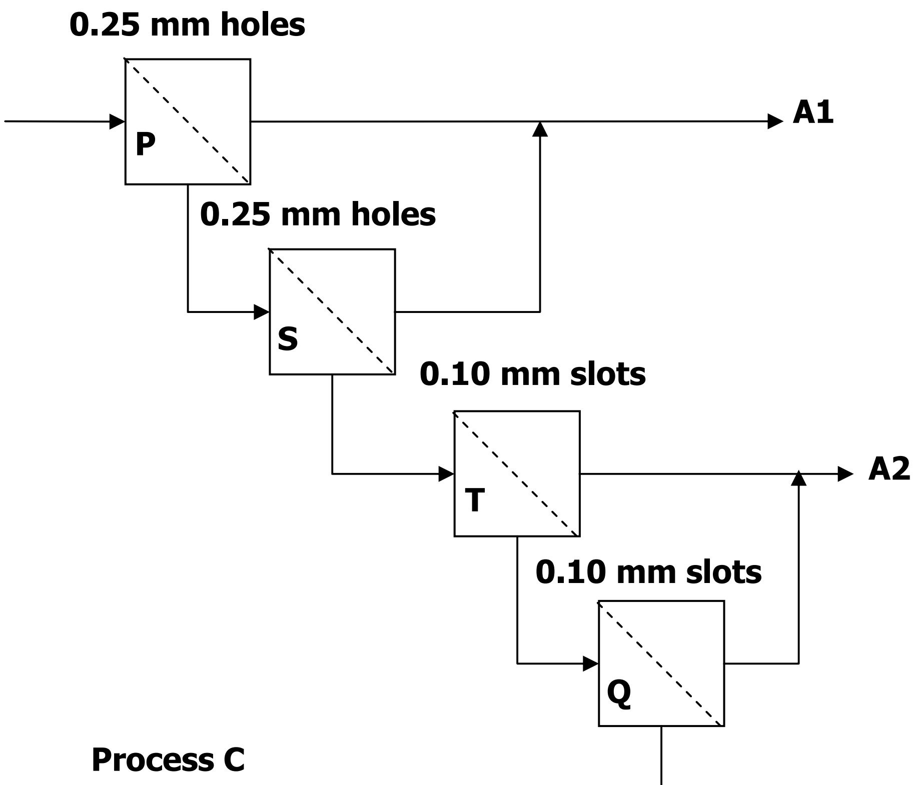


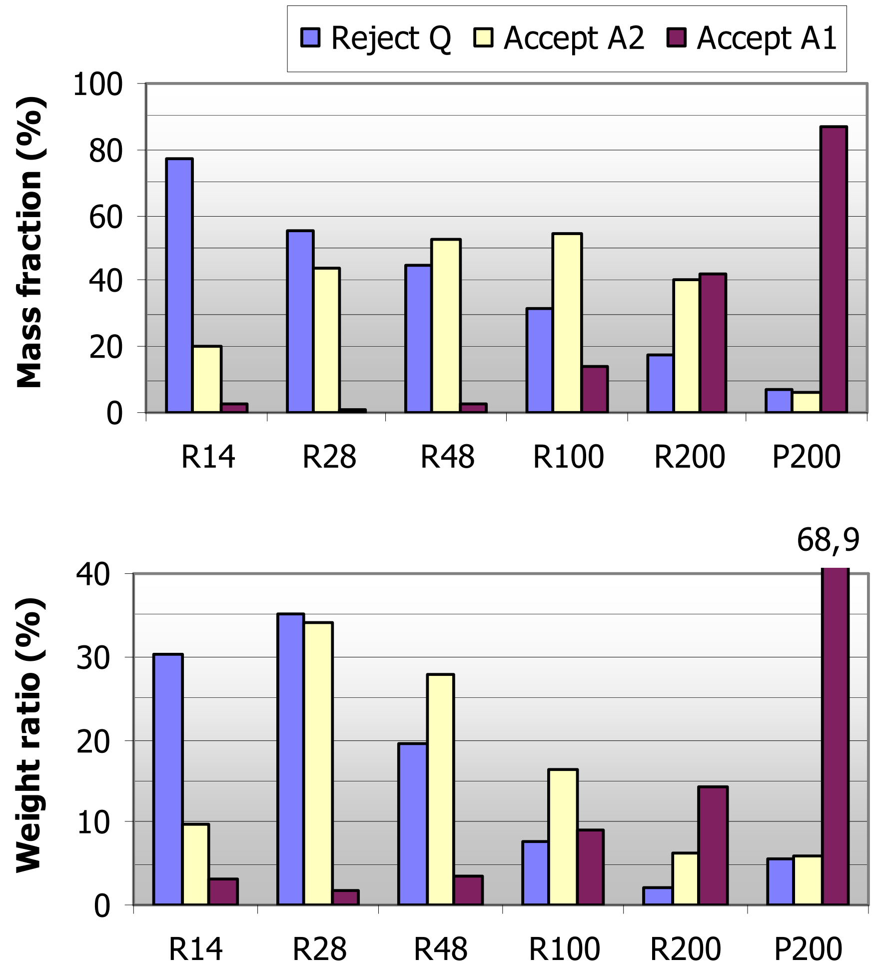




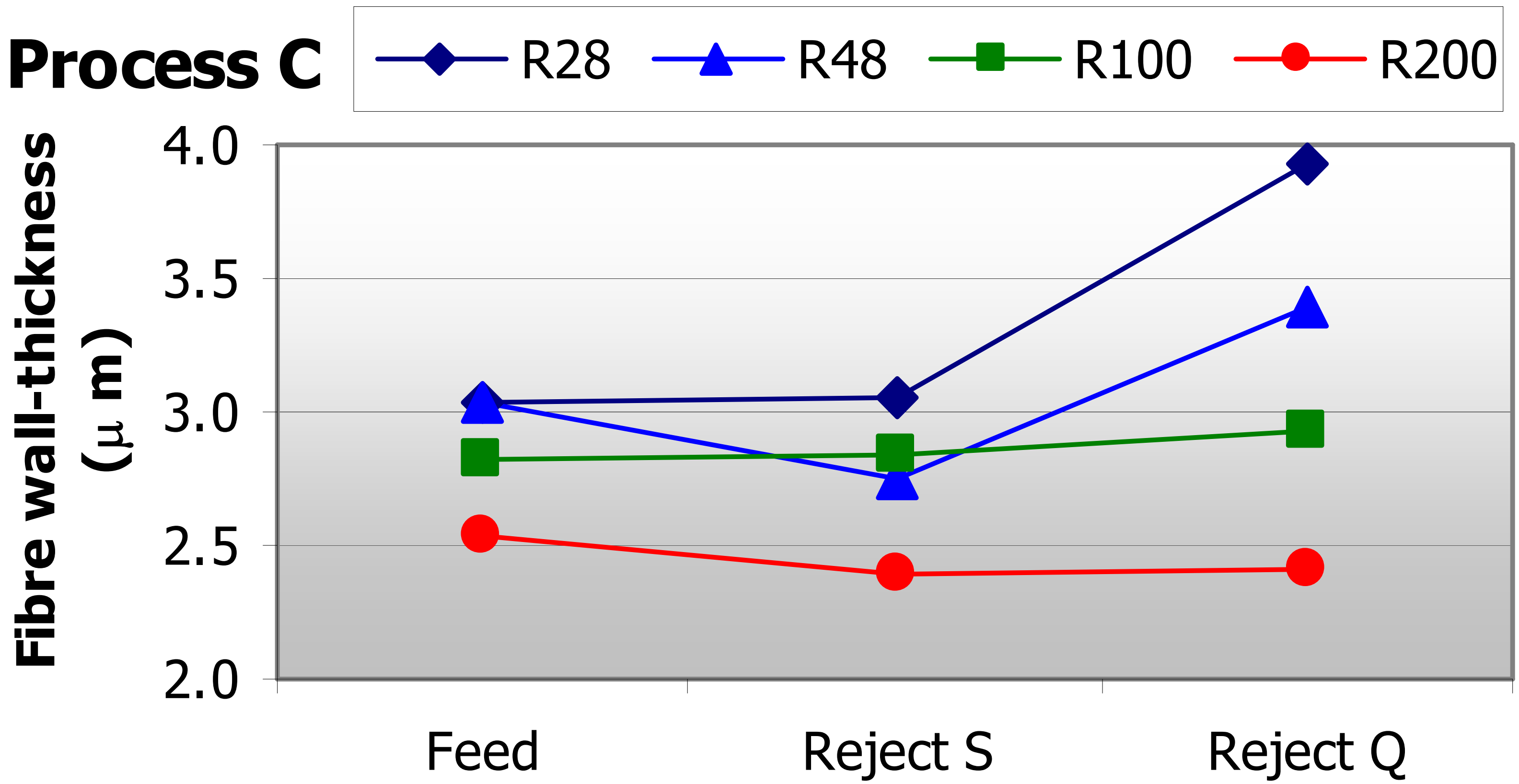


Fractionation Efficiency

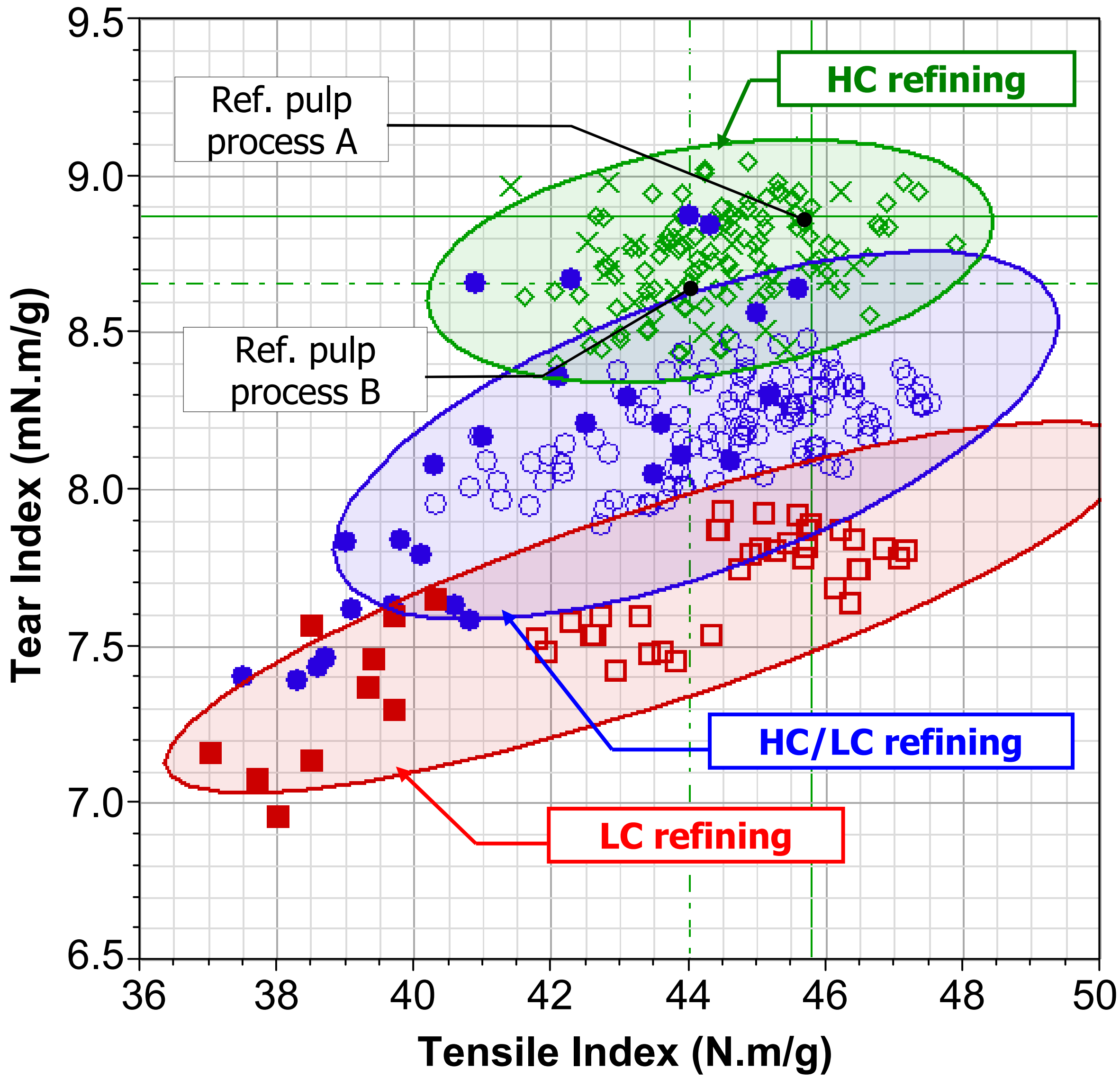




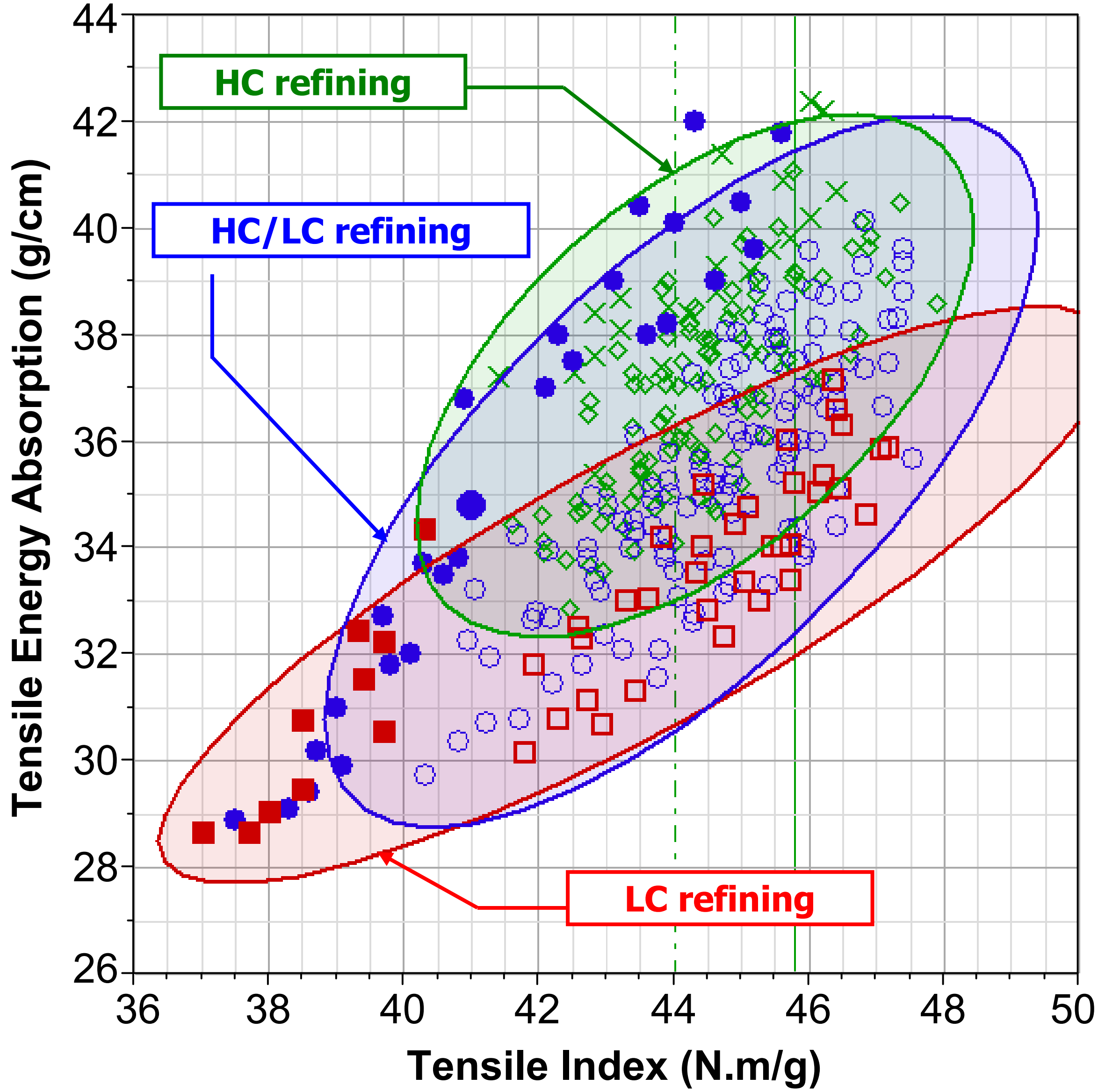
Fractionation Efficiency



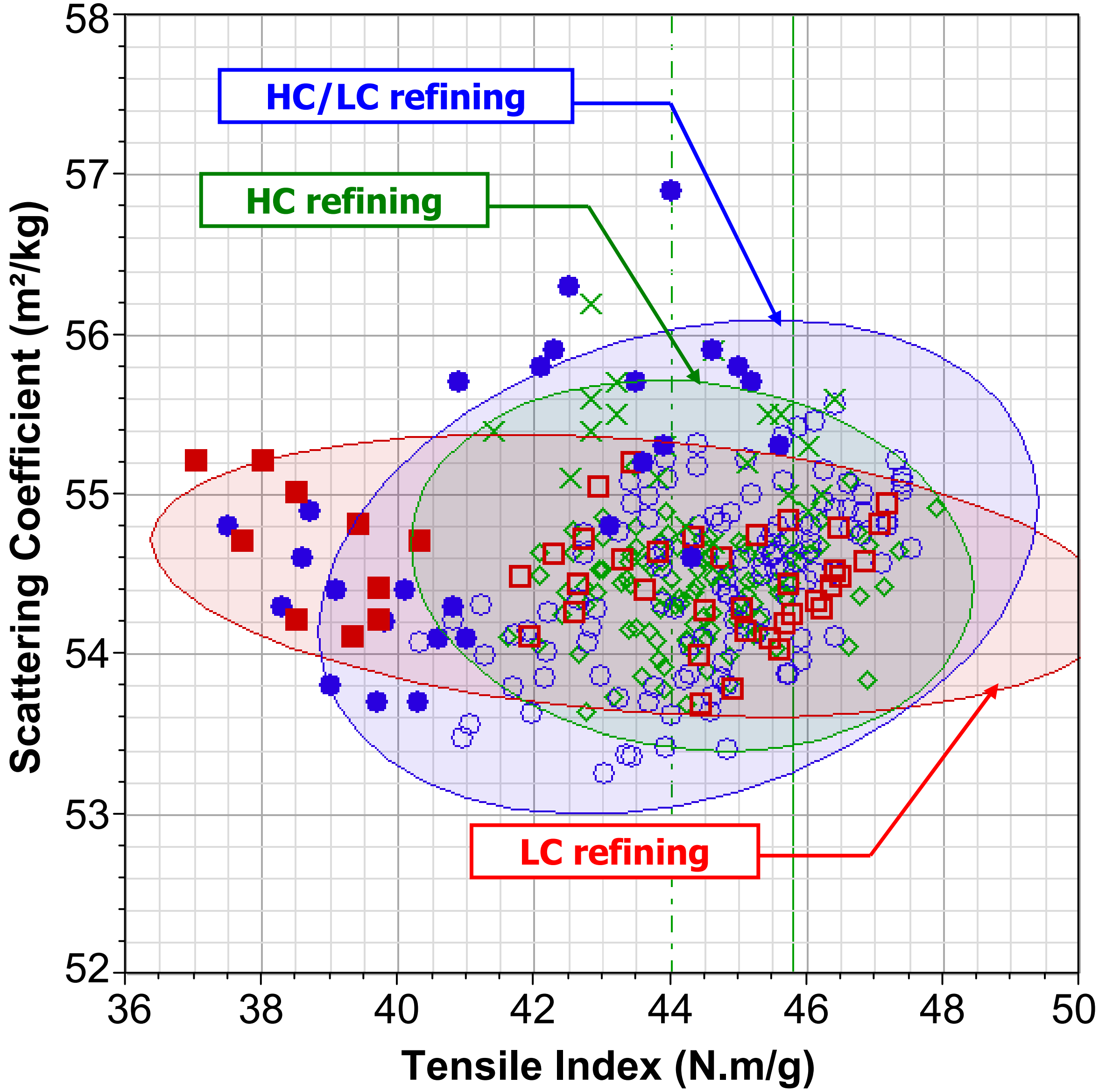
Separate Refining of Fractions



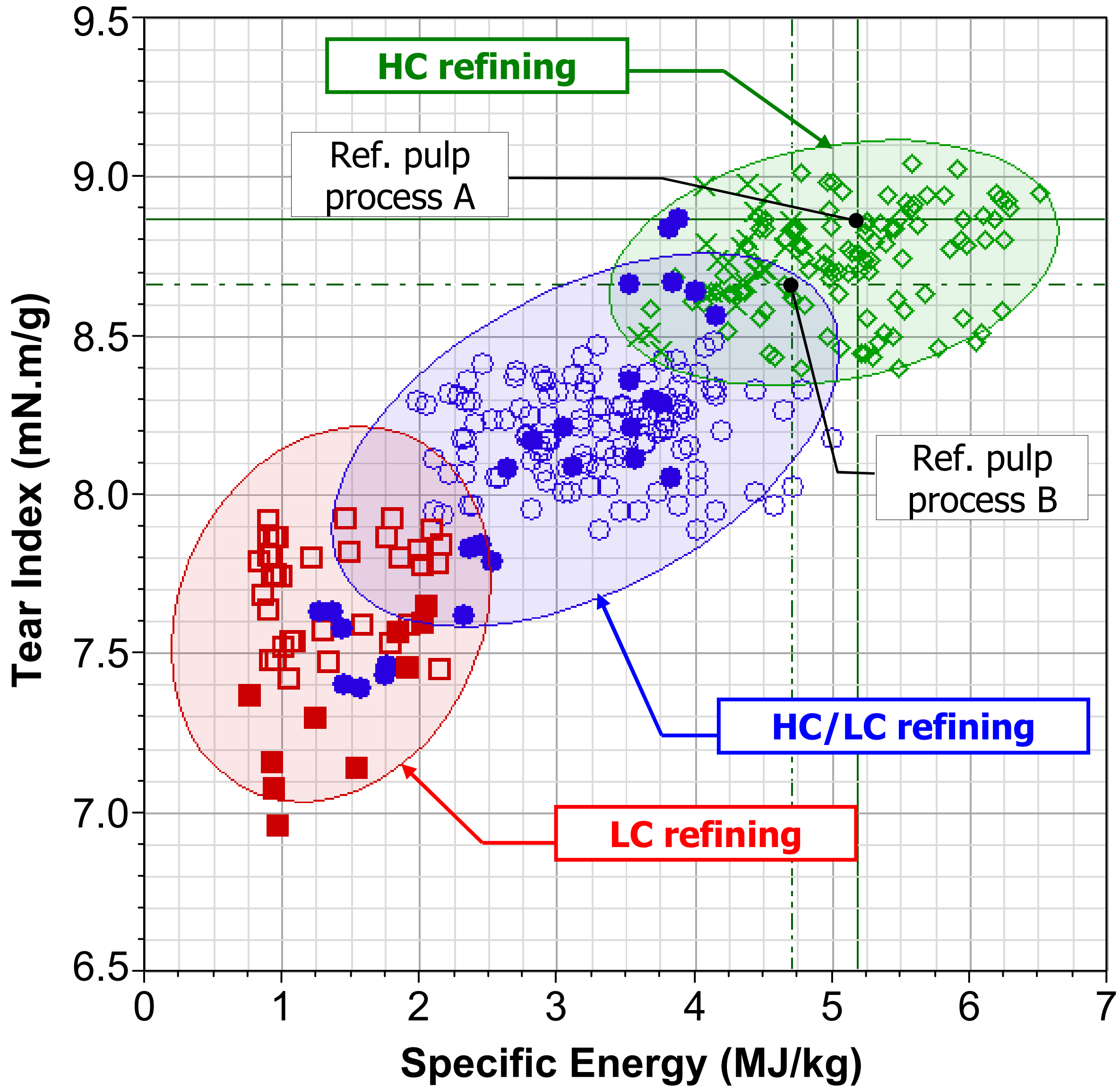
Separate Refining of Fractions



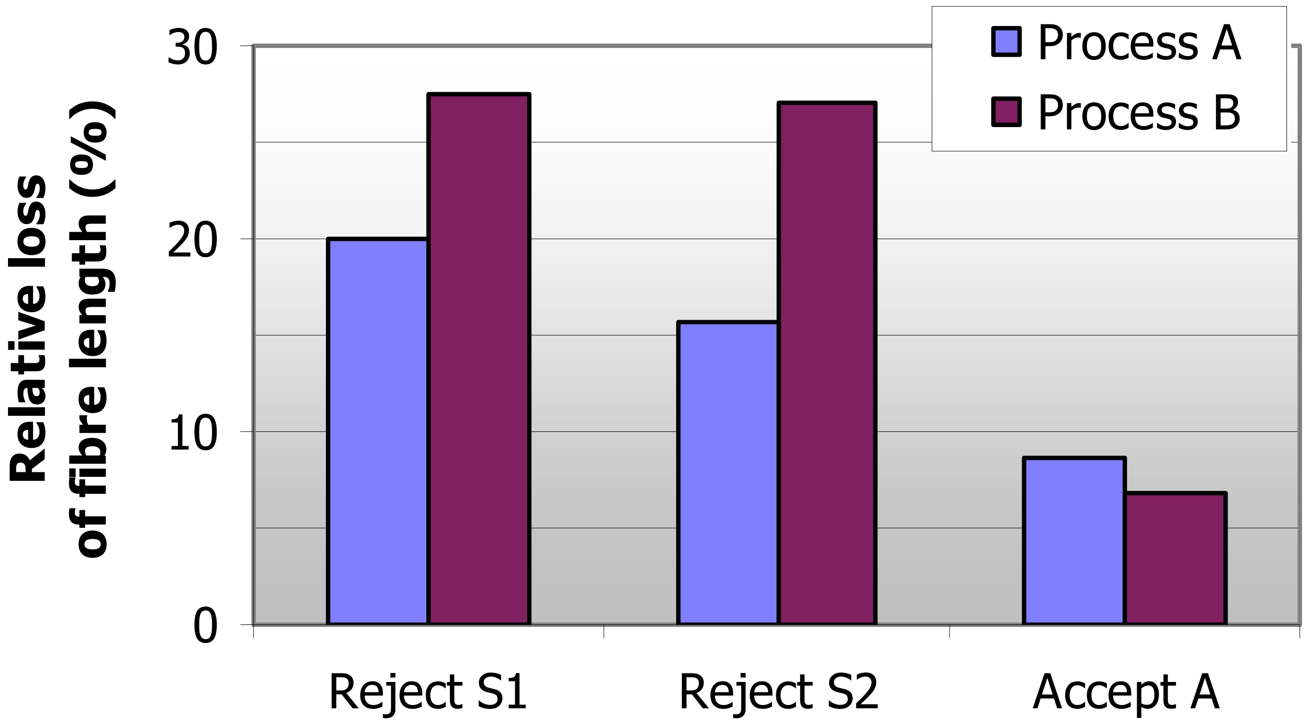
Separate Refining of Fractions



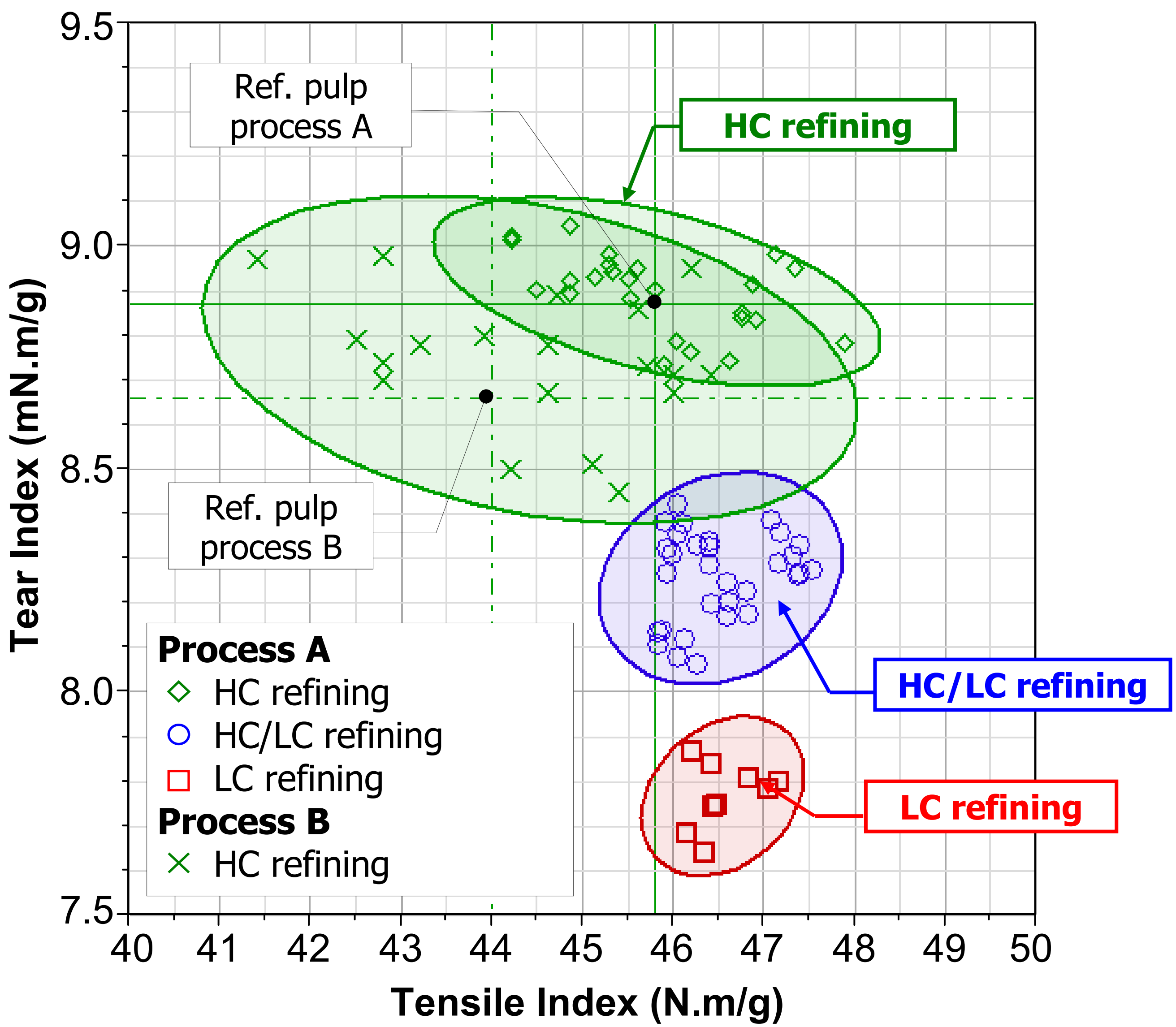
Separate Refining of Fractions



Separate Refining of Fractions



Separate Refining of Fractions



Conclusions

- Two original aspects have been developed
  - the use of a screen basket with very small apertures
  - the use of mechanical pulp from the primary refining stage.

Conclusions

- The small aperture basket
  - very good length-based fractionator
  - does not allow to fractionate efficiently according to other characteristics such as coarseness or cell wall-thickness
  - requires low reject rates because of its high thickening ratio in order to have a proper balance between the reject flow and the accept flow.

Conclusions

- Therefore, another screen with bigger apertures is required as a posterior stage.
  - provides a way to increase the amount of latewood fibres in the reject flow and the amount of earlywood fibres in the accept flow of the slotted baskets.

Conclusions

- The way the specific energy is applied has a significant effect:
  - Low consistency can be used to reduce the energy consumption but the pulp can be damaged.
  - For the long fibres, high consistency is preferable and several stages can be performed to reduce the refining intensity while maintaining the same specific energy.
  - The impact of short fibres and fines in the quality of the recombined pulp is lower than that of long fibres regarding the consistency of refining.

Conclusions

- This study is still in progress
- The new process should allow studying more precisely
  - the effect of the refining stage on long and short fibres by means of well separated fractions.
  - a better insight on earlywood and latewood fibres role during refining
  - their contribution on the recombined pulp quality.

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Questions?