High-yield pulping of jack pine

ROBERT LANOUETTE, JULES THIBAULT, AND JACQUES L. VALADE

ABSTRACT

This paper reports on efforts to produce high-yield pulps from jack pine (Pinus banksiana Lamb.). Two technologies were initially investigated: biotreatment and an alkaline hydrogen peroxide interstage treatment. Biotreatment was ineffective because the experimental fungus would not grow on jack pine chips. The interstage alkaline peroxide treatment failed to reduce energy consumption (specific refining energy). Nevertheless, this investigation did identify peroxide treatments that reduced energy consumption below the level required by spruce thermomechanical pulp. Addition of 3.5% hydrogen peroxide in a two-stage impregnation (115°C, 5 min) reduced energy consumption while improving pulp mechanical properties and reducing pulp brightness. Addition of 3.5% hydrogen peroxide into the eye of the refiner with dilution water reduced energy consumption while maintaining pulp brightness and slightly decreasing pulp strength. Addition of 3% hydrogen peroxide during single-stage refining produced a pulp with higher brightness and good mechanical properties, but the specific refining energy was higher than for a two-stage process. This is an attractive alternative because it does not require special equipment. These results suggest that jack pine chips can be used to produce high-yield pulps.

Application:

Until now, jack pine chips could not be used to produce high-yield pulps because of pitch deposits and poor pulp quality. Alkaline peroxide treatment can mitigate these problems, resulting in high-yield pulps of acceptable quality.

Jack pine (*Pinus banksiana Lamb.*) continues to generate interest within the forest industry because it grows easily and possesses a natural resistance to decay. Numerous plantations of this species were introduced in previous decades, and these are now mature or overmature. The available volume of jack pine in Canada represents 20.4% of softwood volume *(1)*. That alone is ample justification for the industry's keen interest in this species.

BACKGROUND

A comprehensive literature survey by Valade and Law *(2)* clearly demonstrates that jack pine can be used in kraft pulping while noting the significant obstacles impeding the use of jack pine in high-yield pulping processes. Its high extractives content causes pitch problems on papermaking equipment and yields a pulp with low optical and strength properties. A phenolic heartwood extractive (flavanone pinobanksin) is the major source of the yellow discoloration of jack pine pulp. The high thickness of the cell walls is also problematic, since it leads to high specific energy consumption as well as poorer physical properties for the resulting pulps.

In recent years, the emergence of new technologies brought new hope for the potential utilization of jack pine in high-yield pulps. The technologies of particular interest include:

- Addition of alkaline peroxide (AP), which can reduce the specific refining energy and improve the pulp's physical properties
- The development of fungal inoculants that can reduce extractives content and degrade lignin prior to refining.

Over the past two years, both technologies have been tested at the Pulp and Paper Research Centre of the Université du Québec à Trois-Rivières. This paper reports the overall conclusions of this research.

Interstage alkaline peroxide treatment

Tyrväinen *et al. (3, 4)* explored pulping of jack pine using an alkaline peroxide treatment following a pressurized first-stage refining at low specific refining energy. The studied process consisted of obtaining a coarse pulp, treating it by multistage washing, a sodium hydroxide treatment, and a bleaching stage prior to a second atmospheric refining. The main goal was to reduce energy consumption as well as extractives content to obtain a pulp with properties similar to black spruce pulp. The final pulp was produced with a low consumption of specific refining energy and contained few extractives. However, this process led to excessive fiber cutting, resulting in poorer physical properties when compared with black spruce.

Lanouette *et al. (5)* assessed the influence of several process parameters with respect to the interstage chemical treatment of jack pine and attempted to optimize this complex process. The seven variables that were considered are shown in **Table I**.

To perform this optimization, a D-Optimal design was used, including 16 different points plus three replicates for the error determination. Furthermore, three validation points were added to evaluate the correctness of the proposed model.

	Variable	Conditions
First refining stage		
1	Digester operating temperature	115–135°C
2	Plate gap	0.7–1.0 mm
Interstage treatment		
4	Hydrogen peroxide charge	1–5%
5	Temperature	60–75°C
6	Retention time	15–75 min
7	Sodium hydroxide treatment	yes or no
Second refining stage		
3	Output pulp consistency	8–16%

***I. Process parameters used in a previous study* (5)**

Process	Description
TMP	standard TMP process with freshly cut wood chips
BTMP	same as TMP but using biotreated wood chips
PREX1	standard CTMP process
PREX2	similar to PREX1 but using two-stage impregnation of pulp
REFINER	same as TMP but with hydrogen peroxide and alkali injected directly into the eye of the refiner
INTER	optimized interstage alkaline peroxide process

II. Description of six process configurations tested in Part 1 of the study

	AP PROCESS CONFIGURATIONS			
	PREX1	PREX2	REFINER	INTER
First-pass impregnation conditions				
Temperature, °C	115	70	115	115
Retention time, min	5	30	5	5
H_2O_2 charge, %	3.5	0.5	3.5	…
Alkali charge, %	3.0	0.5	3.0	…
Sodium silicate, %	3.0	0.5	…	…
$MgSO_4$, %	0.05	0.01	…	…
DTPA, %	0.4	0.1	0.4	…
Second-pass impregnation conditions				
Temperature, °C		115		
Retention time, min		5		
H_2O_2 charge, %		3.0		
Alkali charge, %		2.5		
Sodium silicate, %		2.5		
$MgSO_4$, %		0.04		
DTPA, %		0.3		
Interstage treatment conditions				
Temperature, °C				67.5
Retention time, min				50
H_2O_2 charge, %				3.5
Alkali charge, %				3.0
Sodium silicate, %				3.0
$MgSO_4$,				0.05
DTPA, %				0.4

III. Chemical treatment conditions for alkaline peroxide process configurations tested in Part 1 of the study

The validation trials confirmed the utility of this design in simultaneously optimizing many variables. However, further investigation was judged necessary to elucidate the discrepancies for physical properties between the two sets of experiments (D-Optimal and validation).

The first step in accounting for the observed discrepancies was to look at the model that expressed the relationship among the various process variables. Traditionally, a linear model is used to express such a relationship, but this method fails to capture process nonlinearity. As an alternative modeling approach, neural networks were used because of their inherent plasticity and their ability to capture nonlinear behavior. Experimental data were reanalyzed using two different types of neural networks, and the results were compared with those obtained by multiple regression analysis *(6)*. A standard three-layer feedforward neural network (with quasi-Newton as the learning algorithm) was used first. Then a radial basis function (RBF) neural network was used. For the feedforward neural network, sigmoidal transfer functions of the hidden layer are normalized Gaussian activation functions, where the center and the standard deviation of each Gaussian function are adjusted to be a receptive field of the input space *(7)*. The models generated with neural networks removed a major portion of the discrepancies that were observed with the linear regression analysis. Nevertheless, for modeling variables with near linear behavior, linear regression analysis remains the best choice.

Biopulping

Biopulping was also evaluated as a technique for adapting jack pine for use in high-yield pulping processes. This approach involved inoculating wood chips with fungi to partially degrade the lignin and to remove extractives in the wood chips prior to refining *(8)*. The selected fungi are inoculated on freshly cut wood chips without previous sterilization, a crucial step for its potential commercial utilization. Although a three-week treatment improved pulp quality, the increase was not sufficient to match the quality of a spruce pulp.

Neither alkaline peroxide treatment nor biopulping satisfied the initial objectives of the project. Consequently, a new set of trials was performed to explore the possibility of a synergistic effect when the two processes are combined.

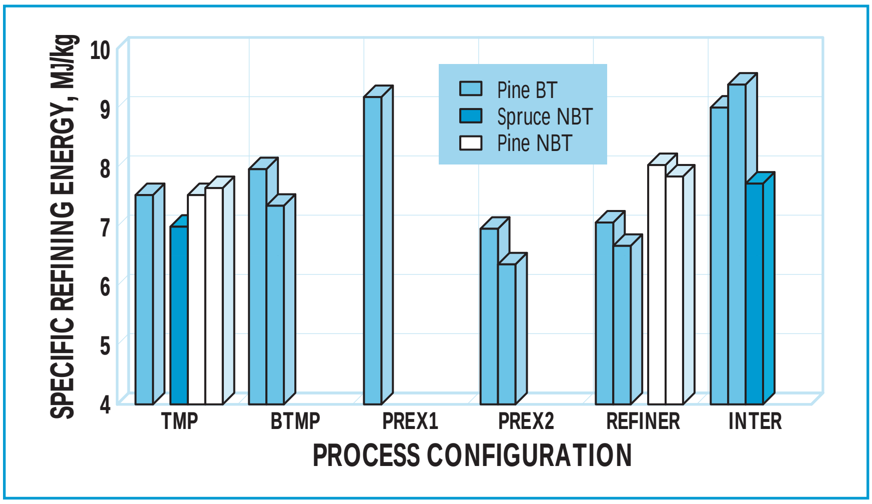
EXPERIMENTAL

Part 1

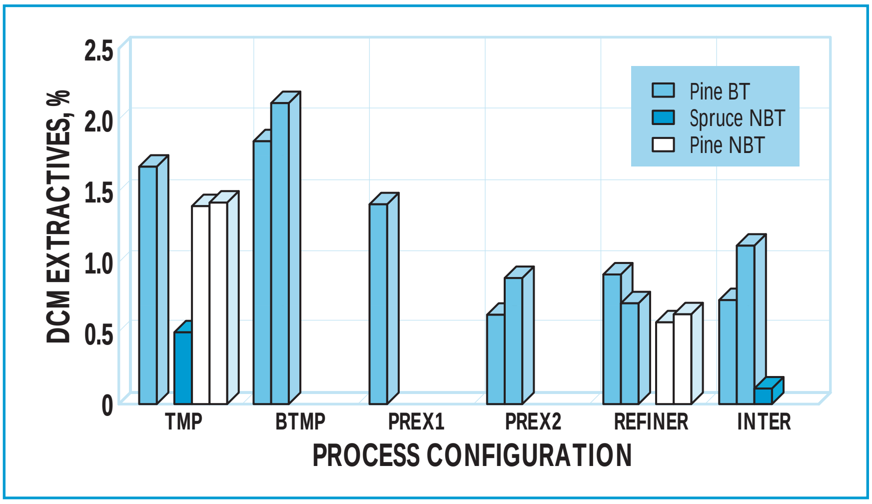
Freshly cut jack pine sawmill chips were inoculated with 0.001 AU (activity units)/ton of an experimental fungus diluted in water to permit good coverage of the chips. A vendor (Clariant Corp., Lexington, MA) provided the experimental fungus. The inoculated chips were stored at 20°C for three weeks prior to refining. (This experimental procedure was adopted based on previous results.)

To obtain a clearer picture of the synergistic effect of the two technologies, the fungus treatment was combined with several different process configurations. All of these process configurations comprise two stages of refining. The first-stage refining, in pressurized mode, was followed by a second atmospheric stage. Each trial was repeated twice in an effort to evaluate the experimental error. The six processes investigated during Part 1 of this study are described briefly in **Table II**. The treatment conditions for the four alkaline peroxide processes are listed in **Table III**.

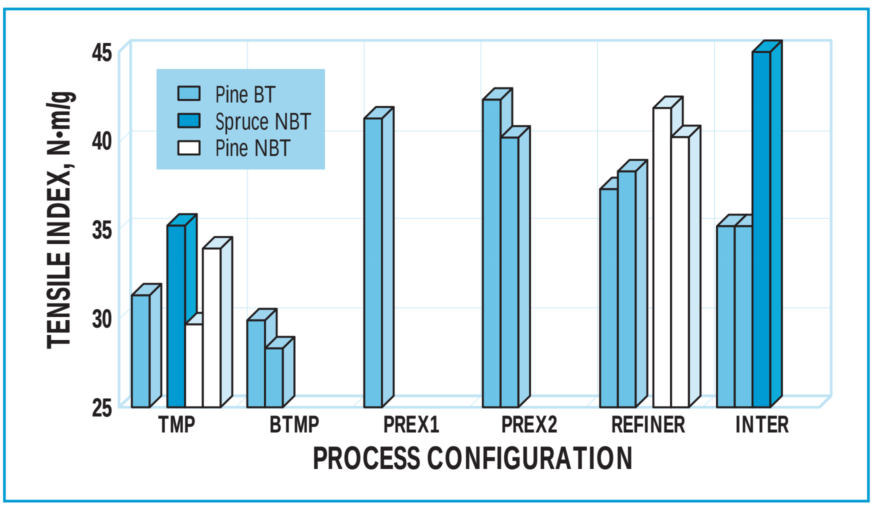
The first process was a standard thermomechanical pulping (TMP) process performed with the freshly cut wood chips. The second trial was also a standard TMP process, with the exception that the feed material was wood chips that had been biotreated



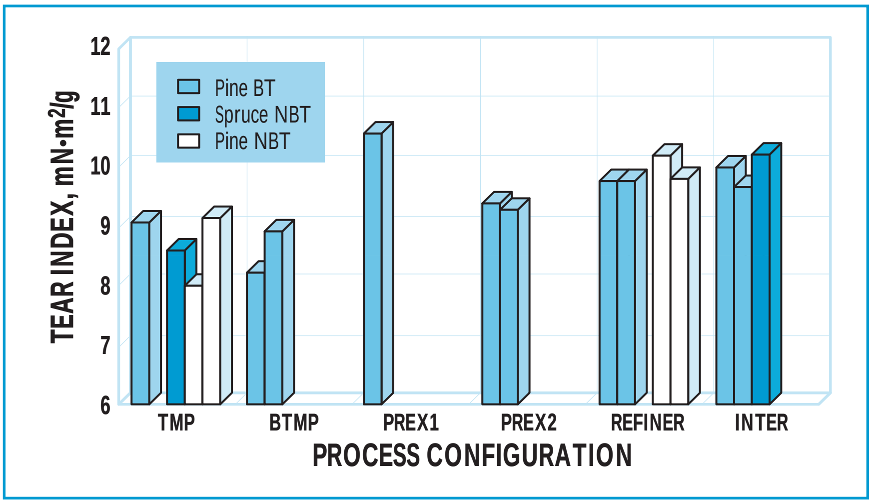
1. Specific refining energy for Part 1 experiments



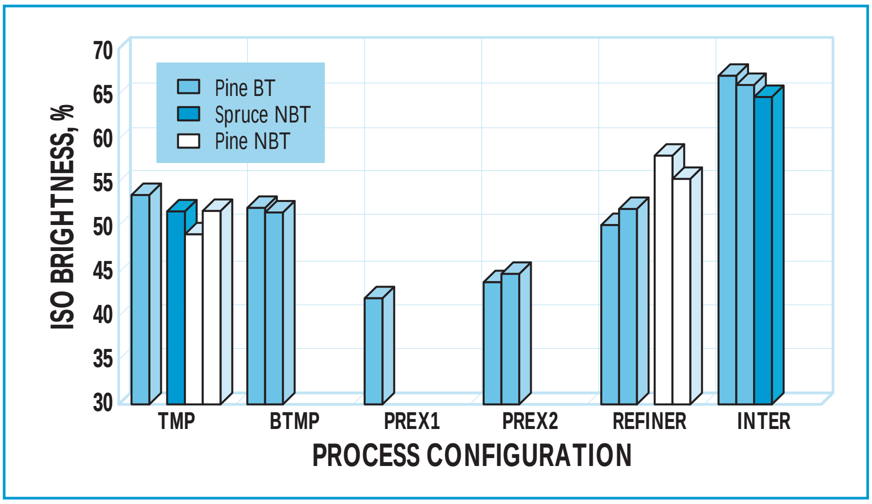
2. Extractives content for Part 1 experiments



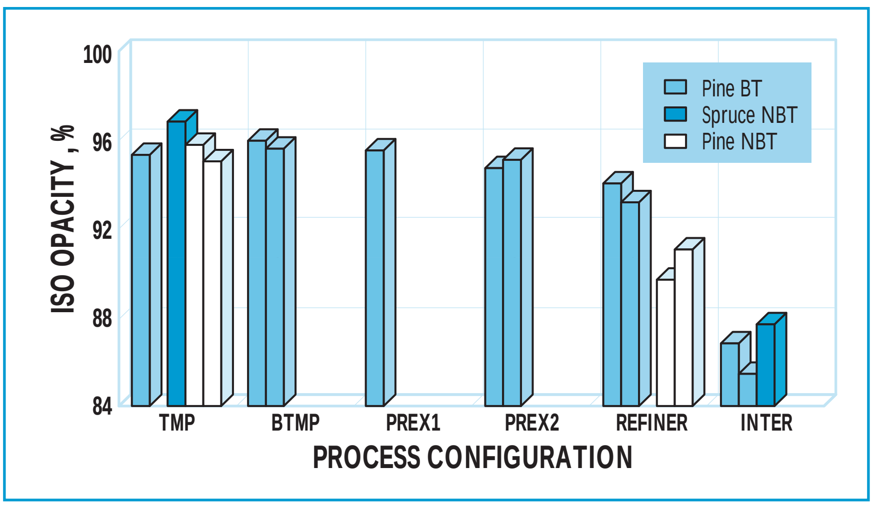
3. Tensile index for Part 1 experiments



4. Tear index for Part 1 experiments



5. ISO brightness for Part 1 experiments



6. ISO opacity for Part 1 experiments

with fungus (BTMP). The third trial (PREX1) explored the possibility of using a standard chemithermomechanical process (CTMP) configuration to improve the quality of jack pine pulp. A full bleaching liquor was injected directly into the impregnation screw. Pulp residence time was 5 min at 115°C, as seen in Table III. The fourth trial (PREX2) was nearly identical to the previous one with the exception that the pulp was subjected to two-stage impregnation. A first stage with a low peroxide charge was done at 70°C, whereas the second stage was identical to the third trial (PREX1). The fifth trial (REFINER) was performed to study the TMP process coupled with the injection of hydrogen peroxide and alkali directly into the eye of the refiner. This particular configuration has the distinct advantage of being easy to implement in a mill, since it does not require additional equipment. Previous results *(9)* have shown that some components of the bleaching liquor can be removed without significantly affecting pulp quality because of the very short reaction time. Based on those results, these "nonessential" components were eliminated, as indicated in Table III. The last trial (INTER) corresponds to the optimized interstage alkaline peroxide process.

All these refining experiments were performed in our pilot plant (Sunds Defibrator CD-300). For each configuration, four pulps with different freeness levels were evaluated following CPPA standards. In the figures presented subsequently, the data were interpolated to a Canadian standard freeness of 200 mL.

Part 2

A second series of experiments was later performed to gain more insight on the hybrid process and to confirm some conclusions obtained in Part 1. The objective of the additional experiments was to further investigate the addition of peroxide within the eye of the refiner with and without fungal pretreatment. Two different hydrogen peroxide charges (P 3% and P 5%) were tested, and two alkali-to-peroxide ratios were used at each charge (A/P 0.70 and A/P 0.85 for P 5%; A/P 0.85 and A/P 1.0 at P 3%). Following a three-week fungal treatment, the best alkali-to-peroxide ratio was applied to see if the impact of the fungal treatment could have a synergistic effect with the hydrogen peroxide.

RESULTS AND DISCUSSION

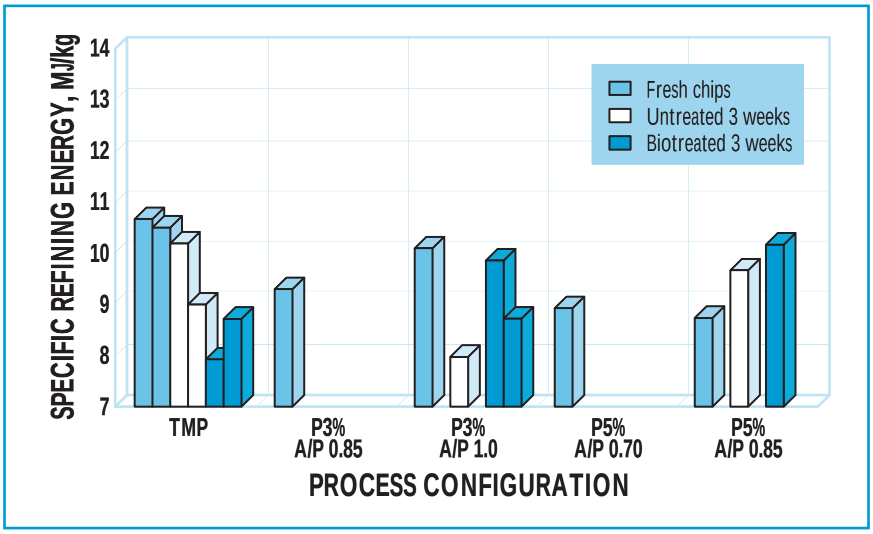
Part 1

One of the main objectives of this study was to reduce the consumption of specific refining energy while maintaining good mechanical properties. **Figure 1** shows the specific refining energy for the six process configurations. These results show that there is no significant difference between the biotreated pine pulp (Pine BT) and the untreated pine pulp (Pine NBT) under conventional TMP conditions. In the PREX1 and INTER configurations, the specific refining energy consumption increases. The PREX2 and REFINER configurations lead to a 10% reduction for the specific refining energy, bringing it to a level comparable with untreated spruce TMP (Spruce NBT).

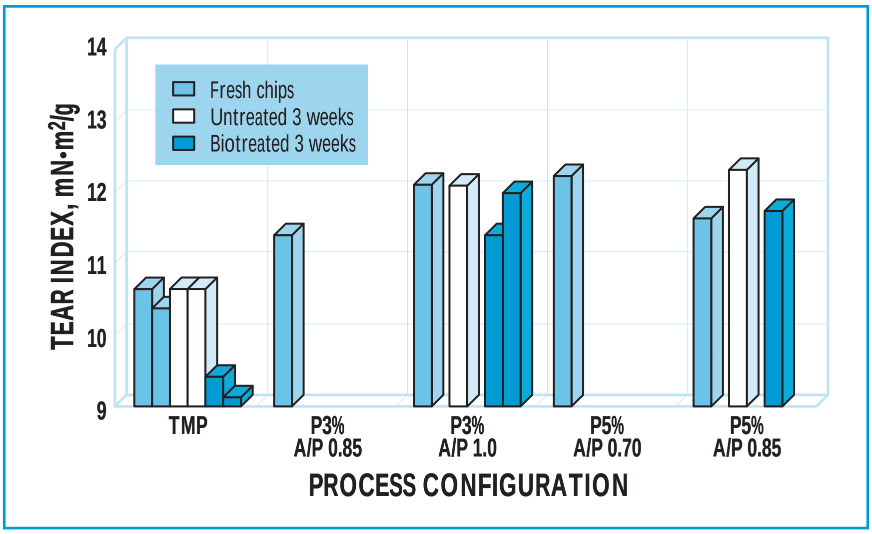
The second objective was to obtain a pulp with an extractives content around 0.5%, similar to a two-stage TMP using spruce chips. Results for the DCM (dichloromethane) extractives content are presented in **Fig. 2**. The 0.5% objective was far from satisfied by the BTMP and the PREX1 configurations. For the three other configurations, the final extractives content was reduced to approximately 0.8%, which is considered to be an acceptable level.

The last objective was to increase the handsheet mechanical properties. **Figures 3 and 4** show, respectively, the tensile index and the tear index achieved with each process configuration. Results show that all alkaline peroxide (AP) treatments can improve the tensile index to a level comparable with or higher than that obtained with spruce TMP. The most efficient configurations are PREX1 and PREX2, for which a tensile index value of 41.8 N·m/g was achieved. The next-best configuration was the REFINER configuration, where a direct injection of hydrogen peroxide and alkali in the eye of the refiner was performed. This process produced a tensile index of 37.8 N·m/g. Furthermore, for the four AP configurations, the tear index value was kept around 10 mN·m^2/g, which is equivalent to that of spruce AP TMP and higher than spruce TMP.

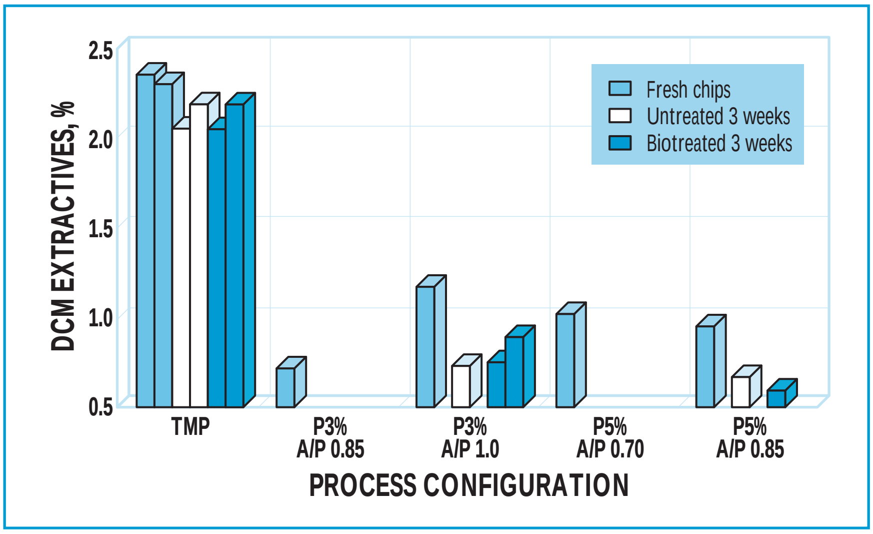
Figure 5 shows the ISO brightness of the pulp obtained with each process configuration. Three of the four AP configurations require that the bleaching liquor be injected at 115°C. This promotes hydrogen peroxide degradation (as supported by the absence of hydrogen peroxide residual at the end of the process),



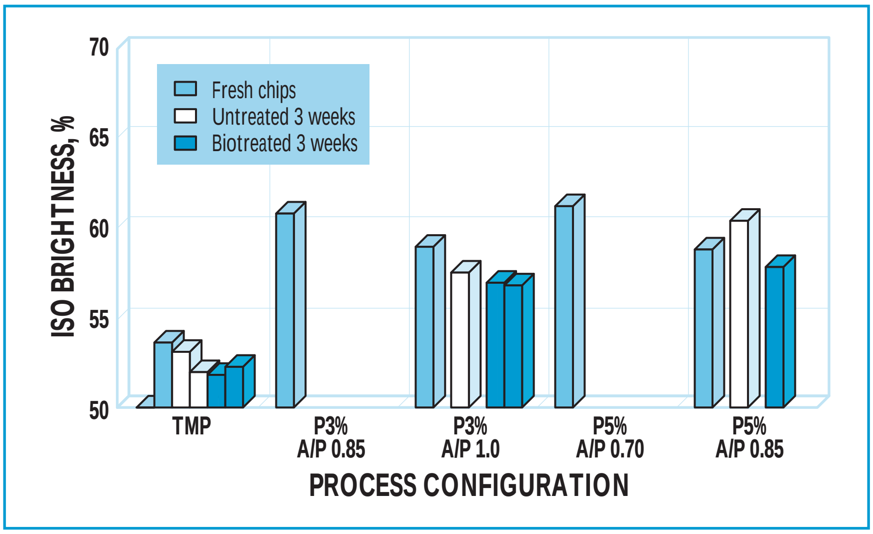
7. Specific refining energy for Part 2 experiments



8. Tear index for Part 2 experiments



9. Extractives content for Part 2 experiments



10. ISO brightness for Part 2 experiments

and the remaining sodium hydroxide leads to a reduction in brightness. The short retention time used in these experiments did not significantly reduce this darkening effect.

In a recent study, Hill *et al. (10)* showed that it was possible to bleach mechanical pulps with hydrogen peroxide at high temperature. They obtained a 12-point gain in brightness with a retention time of less than 10 min at 120°C. While this is not comparable with the brightness gain of standard bleaching, it is sufficient to provide valuable information for the present investigation. It appears that the poor deactivation of metallic ions combined with the presence of saturated steam led to an important loss in brightness instead of the expected gain. The worst results were obtained when the bleaching liquor was added directly in the impregnator (PREX1 and PREX2). When the bleaching liquor was injected into the refiner, the initial brightness value was maintained, mainly because of the shorter retention time. Using only one-stage refining or stabilization and washing between the two stages should lead to an improvement in brightness. With the interstage treatment, a brightness value of 66% ISO can be achieved because of the lower temperature used for the treatment, as seen in Fig. 5. However, this gain is obtained at the expense of a major reduction in opacity, as seen in **Fig. 6**.

In the research direction adopted, the emphasis was mainly placed on the interstage alkaline peroxide treatment, which was expected to improve pulp quality. Unfortunately, the previous results do not show such an improvement. Instead, the results point out two other interesting possibilities: a two-stage impregnation (PREX2) and direct injection of hydrogen peroxide into the refiner (REFINER). The two-stage impregnation leads to a better pulp quality and a lower investment cost when compared with the interstage treatment. Unfortunately, the cost is moved to the post-bleaching process if a higher brightness is required. On the other hand, the injection of hydrogen peroxide into the refiner leads to a better brightness, accompanied by slightly lower physical properties. Furthermore, this process does not require special equipment, since the bleaching chemicals can be added directly to the standard TMP process. Because the bleaching liquor does not require stabilization, there is no need to add sodium silicate into the refining plates. This further reduces chemical costs while eliminating the deposition problems associated with the silicate.

These conclusions led to a new set of experiments to confirm these results and to verify that fungal pretreatment would demonstrate some benefit in this particular process.

Part 2

Refining of jack pine chips in a single stage requires a higher specific refining energy than two-stage refining (Fig. 1). **Figure 7** shows the specific energy consumption for the second series of trials. Seasoning of wood chips for three weeks at 25°C promoted a slight reduction of this energy without altering the tear index for conventional TMP pulps, as seen in **Fig. 8**. Biotreatment significantly decreased the specific refining energy but at the expense of a reduction in physical properties.

The use of 3% hydrogen peroxide with an alkali-to-peroxide weight ratio of 1.0 leads to a slight energy reduction, accompanied by an increase of the tear index. No significant improvements are expected by natural aging nor by biotreated aging with the peroxide treatment. However, **Fig. 9** shows that the storage of chips for three weeks, with or without fungus, reduces the extractives level to the level of black spruce TMP pulp when hydrogen peroxide is used during the refining step. Furthermore, using 3% peroxide in single-stage refining increased the ISO brightness by 6 points, to approach the 60% level, as seen in **Fig. 10**.

SUMMARY AND RECOMMENDATIONS

Efforts to produce high-yield pulps from jack pine (*Pinus banksiana Lamb.*) focused on two different technologies: biotreatment and an alkaline hydrogen peroxide interstage treatment.

Under the conditions used in this investigation, the experimental fungus was not aggressive enough to grow on jack pine chips, which are known to be naturally resistant to fungal attack.

The interstage alkaline peroxide treatment failed to reduce energy consumption. Consequently, it is not the best alternative to improve pulp mechanical properties.

The addition of 3.5% hydrogen peroxide in a two-stage impregnation for 5 min at 115°C had two beneficial effects. It reduced the specific refining energy consumption below that required by spruce TMP, and it increased the physical properties to values comparable with spruce alkaline peroxide TMP. Unfortunately, the resulting brightness was lower than its initial value.

The addition of hydrogen peroxide directly into the eye of the refiner with the dilution water gave the same reduction of the specific refining energy but slightly lower mechanical properties. However, the initial brightness of the wood was maintained. This process has the distinct advantage of not requiring special equipment, since the bleaching liquor is added directly to the standard TMP process.

The latter two processes show a significant reduction of the extractives content to a level acceptable for the papermaking equipment.

The addition of 3% hydrogen peroxide in a single-stage refining achieves an acceptable level of DCM extractives accompanied by good physical properties. However, the specific refining energy used in a single-stage is much higher than for two-stage refining. Two-stage refining, including an interstage washing step, would undoubtedly satisfy both the ISO brightness and the energy requirement targets.

These conclusions suggest new possibilities for using jack pine chips in high-yield pulping processes. TJ

Lanouette and Valade are professors at the Centre de Recherche en Pâtes et Papiers, Université du Québec à Trois-Rivières, P.O. Box 500, Trois-Rivières, Québec, Canada G9A 5H7. Thibault is a professor in the Département de Génie Chimique, Université Laval, Sainte-Foy, Québec, Canada G1K 7P4.

The authors thank the Ministry of Natural Resources of Quebec, Canada, for partial funding and Sarjit Johal (Clariant Corp.) for providing the experimental fungus.

Received for review June 7, 1997.
Accepted November 25, 1997.

LITERATURE CITED

1. *Forestry Can.* 1991.
2. Law, K. N. and Valade, J. L., *Can. J. Forest Res.* 24: 2078(1994).
3. Tyrväinen J., Law, K. N., and Valade, J. L., *Pulp Paper Can.* 98(6): 57(1997).
4. Tyrväinen J., Law, K. N., and Valade, J. L., *Pulp Paper Can.* 98(7): 26(1997).
5. Lanouette R., Valade, J. L., and Thibault, J., *Can J. Chem. Eng.* 75(2): 1(1997).
6. Lanouette, R., Thibault, J., and Valade J. L., *83rd CPPA Technical Section Meeting Proceedings*, CPPA–TS, Montreal, 1997, p. A1.
7. Hertz, J., Krogh, A., and Palmer, R. G., *Introduction to the Theory of Neural Computation*, Addison–Wesley, Reading, MA, 1991.
8. Lanouette, R., Valade, J. L., Thibault, J., *et al.*, *Les Papetieres du Quebec* 7(4): 34(1996).
9. Valade, J. L., Lanouette, R., Law, K. N., *et al.*, "Mise en pâte de l'érable pour papiers fins et cartonnages à haute valeur ajoutée (deuxieme étape)," Report to Ministry of Natural Resources of Quebec, 1995.
10. Hill, R., Hill, P., Huey, J., *et al.*, *TAPPI 1996 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p. 349.