USE OF NEW OXIDIZING AGENTS IN A REFINER – A ROUTE TO HIGH BRIGHTNESS PULP

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ABSTRACT

Literature review revealed that the addition of alkaline peroxide to wood chips prior to refining can improve the quality of pulp in terms of brightness and strength properties. In this work, we explore other alternatives in order to enhance the efficiency of the refiner bleaching process. These new options concern the use of sodium perborate and an activator for peroxide.

The results of this study demonstrate that sodium perborate is a more powerful bleaching agent than hydrogen peroxide; at equivalent charge of an oxidizing agent, up to 20 points ISO were gained for perborate compared to a 13-point ISO gain registered for the peroxide. Most of the strength properties have been improved. The use of the activator TAED is more efficient in terms of strength properties than brightness. The use of sodium perborate in the refiner represents an alternative that could be more economical than hydrogen peroxide.

KEYWORDS

Mechanical pulp, Refiner, Bleaching, Oxidizing agent, Hydrogen peroxide, Sodium perborate, Activator, Tetraacetyl ethylenediamine, TAED

INTRODUCTION

One of the most important quality criteria of the printing and writing grades remains the brightness of paper. In fact, the pulp could be bleached in the refining process or in post-bleaching. A review of the literature on the addition of alkaline peroxide to wood chips prior to refining processes indicates that important quality characteristics, such as optical and physical properties, can be improved.

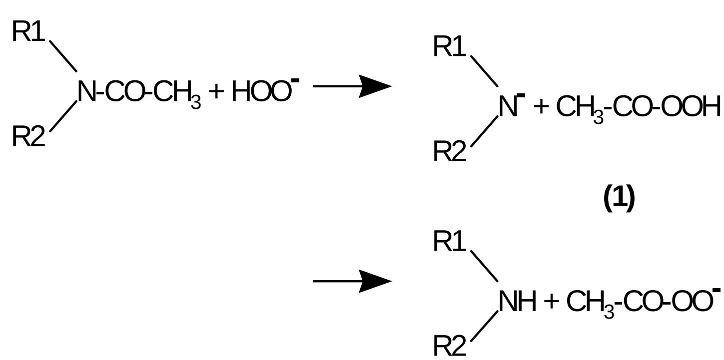
Heimburger *et al. (1)* have pointed out that alkaline peroxide treatment of thermomechanical pulp (TMP) may offer an economical option to upgrade the quality of newsprint or mechanical paper grades. This technology can be used to improve the brightness of the pulp. Their results show that a two-stage impregnation of the chips is superior in terms of efficiency of chemical requirements and tear strength index. This process can also have a significant effect on the reduction of shive content compared to TMP.

Williams *et al. (2)* have noted that less energy is required for refining when the chips have been pretreated with alkaline peroxide compared to unpretreated chips. Cort and Bohn *(3)* have used a two-stage impregnation for the alkaline peroxide mechanical pulping (APMP) process and have reported that less energy is required; burst and tensile strengths are slightly better than a bleached chemithermomechanical pulp (CTMP) with peroxide.

Varennes *et al. (4)* have reported that bleaching results of a thermomechanical pulp with sodium perborate are comparable to a conventional peroxide process. It is also reported *(5)* that sodium perborate decomposes rapidly in an aqueous solution to yield hydrogen peroxide and is active at temperatures above 80^{o}C. In this study, we have chosen to add different oxidizing agents, such as hydrogen peroxide, sodium perborate, and activated peroxide, in the eye of the refiner. Based on the literature findings, we propose to examine the effect of adding different oxidizing agents at temperatures above 80^{o}C for a short period of time. In-refiner residence time is less than 1 min.

Again, bleach activation using TAED (tetraacetyl ethylenediamine) is a promising way to improve peracetic acid generation *(6).* This chemical is a stable solid that is safe and easy to handle. It is biodegradable and nontoxic. It was recognized almost 40 years ago *(7)* that acyl transfer from an ‘activator’ molecule to hydrogen peroxide to yield a peracid should improve the performance of the peroxide bleaching system. *Davies et al. (7)* have pointed out that as bleaching agents, peracids are generally considered to be better than hydrogen peroxide. Hauthal *et al. (6)* have reported that it seems reasonable that peroxyacetic acid is a more active bleaching agent than hydrogen peroxide because the redox potential of peroxyacetic acid is higher than that of hydrogen peroxide. The bleaching activators are compounds with O- or N-bounded acetyl groups, which are able to react with the strongly nucleophilic hydroperoxy anion to yield peroxyacetic acid *(5).* The use of an activator in peroxide bleaching could represent an alternative to the pulp and paper industry.

Hauthal *et al. (6)* studied the reactions at relatively high concentrations of the bleaching activators (0.125 mol·L^{-1}) and of hydrogen peroxide or sodium perborate (corresponding to 0.25 mol·L^{-1} H_2O_2) in the presence of sodium acetate, sodium bicarbonate, or sodium hydroxide (0.1 mol·L^{-1} in each case). They noted that, during the reaction, the pH values decreased according to Eq. 1.



(1)

They also observed that the rate of peracetic acid formation increased with increasing alkalinity of the medium, probably due to the dissociation of peroxide and formation of the perhydroxyl anion, as illustrated in Eq. 2. They proposed that only the perhydroxyl anion, but not hydrogen peroxide itself, reacts with the bleaching activator.

$$H_2O_2 + OH^- \longrightarrow HOO^- + H_2O \qquad \textbf{(2)}$$

The concentration of peracetic acid went through a maximum in most cases. This means that, besides the formation reaction, there must also exist at least one decomposition reaction of peracetic acid. Their results demonstrated that the decomposition is more rapid if the medium is more alkaline. The hydrolysis of peracetic acid occurs according to Eq. 3, which D'Ans and Mattner *(8)* consider to be the main reaction of peracetic acid in dilute solution. However, in their experiments, alkaline solutions played only a minor role considering the conditions used; only in highly alkaline media did they observe a certain increase of hydrogen peroxide concentration over the maximum of the peracetic acid. In most cases, both the concentrations of peracetic acid and those of hydrogen peroxide decreased.

The second decomposition reaction, according to Eq. 4, must therefore take place. In fact, they detected by gas volumetry the oxygen that was expected to be generated. The formation of oxygen is probably a nonradical route because metal ions should have been deactivated with the addition of a chelating agent, such as the disodium salt of ethylene diamine tetraacetic acid (EDTA). Under these conditions, Hauthal *et al. (6)* assumed that they should expect, as a consequence of the spin-conservation rule, the formation of singlet oxygen, which actually was identified in the decomposition of peroxy acids.

$$CH_3\text{-}CO\text{-}OOH + OH^- \longrightarrow CH_3\text{-}COO^- + H_2O_2 \quad \textbf{(3)}$$

$$2\ CH_3\text{-}CO\text{-}OO^- \longrightarrow 2\ CH_3\text{-}COO^- + O_2 \quad \textbf{(4)}$$

No maximum of the peracetic acid could be detected when neutral or alkaline buffers and a very low concentration of the bleaching activators were used at 30^{o}C. But, at a higher temperature, the concentration of the peracetic acid went through a maximum. Theoretically, we must expect the formation of 2 moles of peracetic acid from 1 mole of the bleaching activator. However, about 1.5 moles of peracetic acid are formed from 1 mole of the bleaching activator. The lower yield is a consequence of the competition between peracetic acid formation and simple saponification of TAED with hydroxide anions.

Based on the above information, we also propose to study the effect of the bleach activator TAED on the refiner bleaching efficiency of wood chips. Emphasis has also been given to compare different processes, such as TMP, CTMP, peroxide, and sodium perborate.

MATERIAL AND METHODS

In this work, spruce (75%) / balsam (25%) chips have been used for the production of thermomechanical pulp. The pulps were produced using a CD300 Sunds Defibrator pilot-scale refiner. Prior to refining, chips were presteamed under atmospheric pressure for 10 min. Thereafter, they were introduced into a pressurized preheater with a plug screw, before subsequently being fed directly into a refiner, to produce thermomechanical pulp. Prior to the addition of each oxidizing agent, DTPA (diethylenetriamine pentaacetate) has been added after the plug screw in order to chelate metals ions, which are responsible for decomposition of peroxide. The preheater temperature was varied from 115 to 145°C. The production rate was kept at 0.55 kg/min with a measured discharge of approximately 20%. Charges of peroxide ranging from 2% to 5% (on oven-dried chips) and charges of sodium perborate ranging from 6% to 15% have been added in the eye of the refiner. The activator TAED has been added in the bleaching liquor at a constant charge of 8.05%. This dosage has been chosen with regard to the results that we obtained in a study of bleaching thermomechanical pulp with activated peroxide *(9).* Bleaching conditions for the refining step are described in **Table 1.** Pulps have been produced at different freeness levels. Optical properties (brightness, color coordinate *b**, opacity, absorption, and scattering coefficients) and physical properties (tensile index, burst index, tear index, specific refining energy, specific volume, fiber length, and rejects) have been measured.

Table 1 Bleaching conditions for the refining step

Bleaching conditions	Aged chips	Fresh chips
DTPA, %	0,20	0,20
Magnesium sulfate, %	0,05	0,05
Sodium silicate, %	3,00	3,00

Sodium hydroxide, %	3,00	2,0	3,0	4,0
Hydrogen peroxide, %	4,00	2,0	3,5	5,0
Sodium Perborate, %	11,74	6,0-10,5-15,0		
TAED, %	8,05	---		

After bleaching, the pulp was diluted and neutralized at pH 5.5 with sodium metabisulfite. The pulp suspension was thickened. The handsheets and measurement of optical and physical properties were done accordingly to the Canadian Pulp and Paper Association (CPPA) standards. Fiber length was measured using an FQA (fiber quality analyzer, OpTest Equipment Inc.). Pulmac on 0.006-in. screen was used to measured the pulp rejects.

RESULTS

PART 1 Efficiency of using different oxidizing agents in the refining step

In the first part of the study, we have evaluated the efficiency of adding, in the refining process, hydrogen peroxide (P), sodium perborate (SPB), activated peroxide generated from peroxide with TAED (PA), and activated perborate generated from perborate with TAED (SPBA) and compared the results to a conventional thermomechanical process. For this part, chips aged from 4 to 6 months were used. The temperature of the refining process was set to 128^{o}C.

Results from **Fig. 1** clearly show that the peroxide has a positive effect on the brightness level of pulp. The use of peroxide increases the brightness from 50% to an average of 63% ISO. The bleaching response of activated peroxide compared to peroxide alone is, however, lowered by 3 points. This could be due to the decomposition of the peracetic acid. **Table 2** shows that opacities of bleached pulp from peroxide and activated peroxide are approximately the same and lower than TMP.

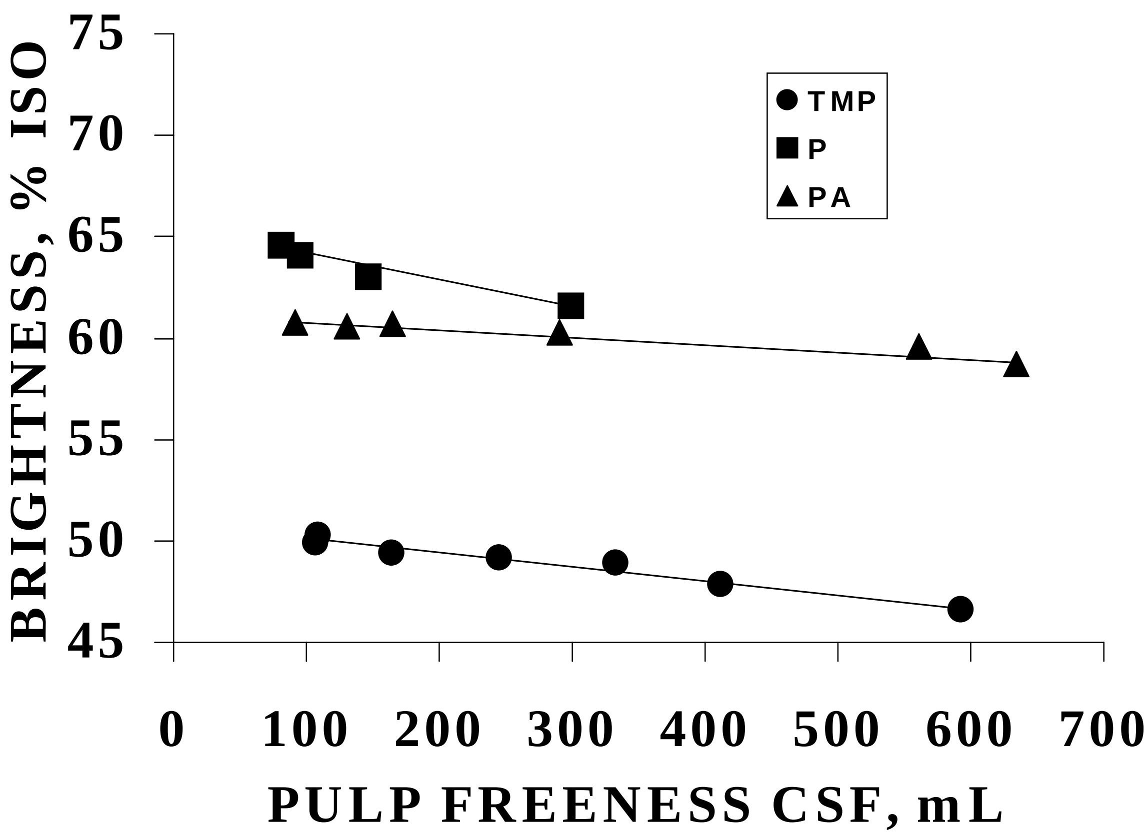


Figure 1 Brightness for bleaching with peroxide (P) and activated peroxide (PA) compared to thermomechanical pulp (TMP)

Table 2 Opacity, tear index and specific refining energy for bleached pulps with peroxide (P), activated peroxide (PA) compared to TMP pulp

Peroxide (P) and activated peroxide (PA) compared to TMP pulp											
Pulp freeness CSF (mL)			Opacity (%)			Tear index ($mN*m^2/g$)			Specific refining energy (MJ/kg)		
TMP	P	PA	TMP	P	PA	TMP	P	PA	TMP	P	PA
592	299	634	95,2	89,8	86,4	8,92	12,21	8,70	2,94	8,49	3,34
411	147	561	96,3	89,1	87,0	10,37	11,03	10,13	4,35	5,91	4,57
332	95	290	96,8	91,3	90,1	11,38	10,14	12,34	5,31	8,76	9,29
245	81	165	96,8	91,3	91,5	11,17	9,57	10,84	7,95	9,55	7,55
164	---	130	97,5	---	91,1	10,12	---	10,92	7,88	---	8,69
109	---	91	97,6	---	92,2	9,42	---	10,24	8,51	---	7,89
107	---	---	98,0	---	---	8,63	---	---	7,55	---	---

Results of tensile index presented in **Fig. 2** are equivalent for the TMP and P processes. The addition of activated peroxide would allow an increase in the tensile index. The use of peroxide and activated peroxide improves the burst index compared to the results for the TMP, as illustrated in **Fig. 3.** Table 2 presents similar results for the tear index of the bleached pulp from peroxide and activated peroxide. But the addition of these oxidizing agents allows better tear index results than TMP. A possible explanation for the improvement of the strength properties for the activated peroxide system could be high residual alkalinity during the refining process. Table 2 shows results of the specific refining energy that were applied on the chips. The data present a large spread at low freeness, but it seems that the energy requirement is similar for all the processes.

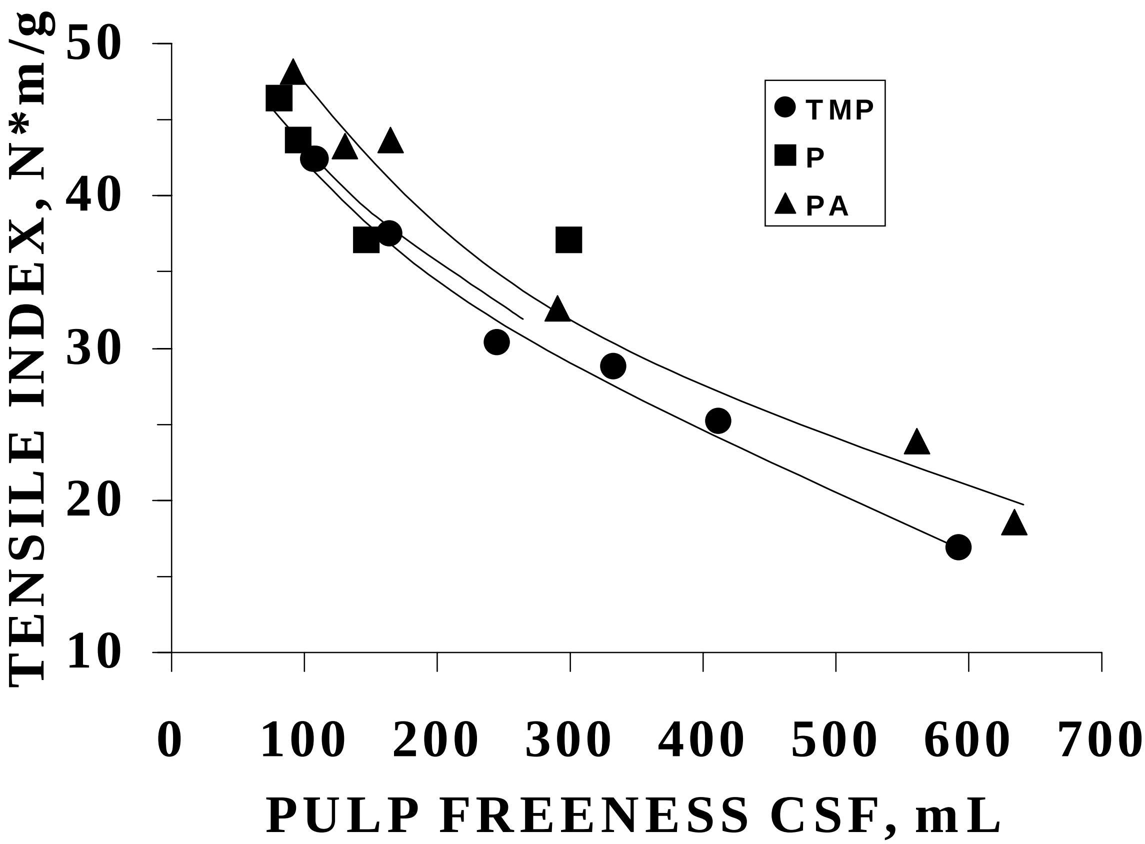


Figure 2 Tensile index for bleaching with peroxide (P) and activated peroxide (PA) compared to thermomechanical pulp (TMP)

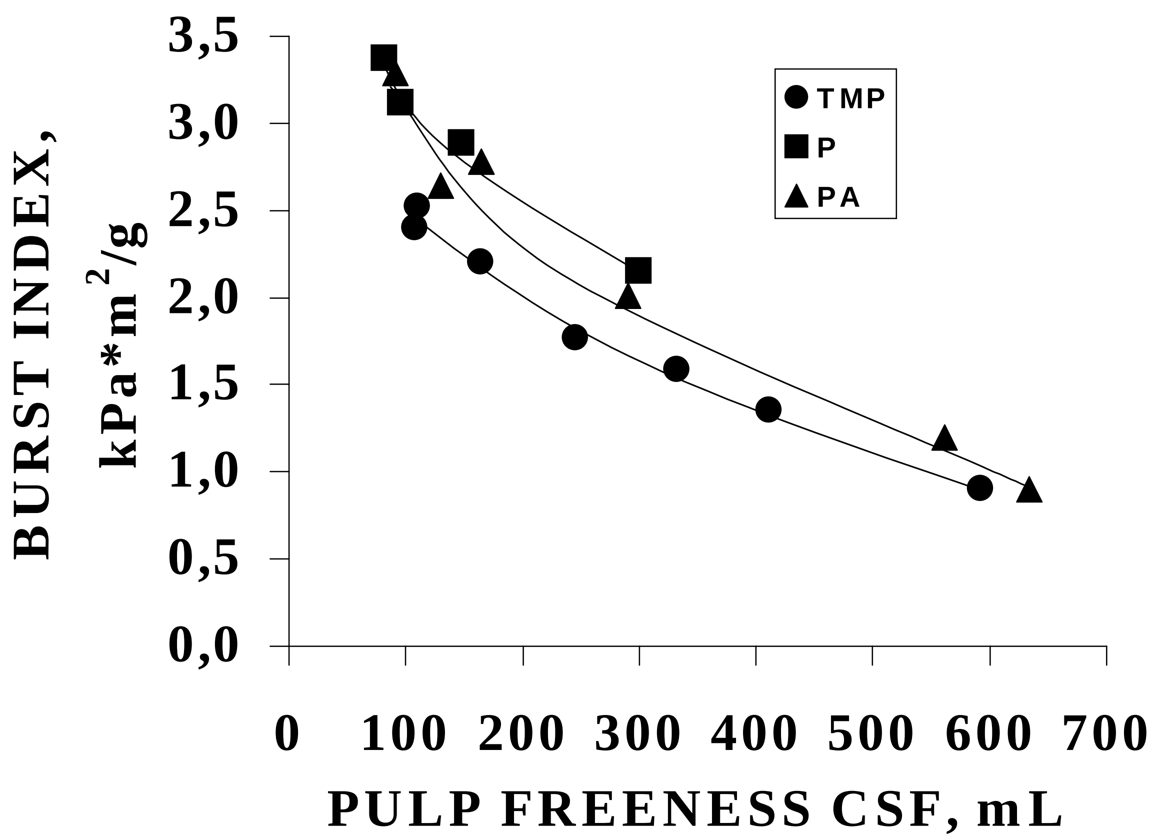


Figure 3 Burst index for bleaching with peroxide (P) and activated peroxide (PA) compared to thermomechanical pulp (TMP)

The use of sodium perborate in the refining step represents an efficient method for the bleaching of the pulp, as illustrated in **Fig. 4.** Brightness levels of 67 to 70% ISO have been obtained. This represents an average brightness gain of approximately 19 points. Premixing of TAED and perborate prior to their addition to the refiner eye did not produce positive results with respect to pulp brightness, if compared to perborate alone. Further work is needed to optimize temperature, pH, and point of addition of activator in the refiner.

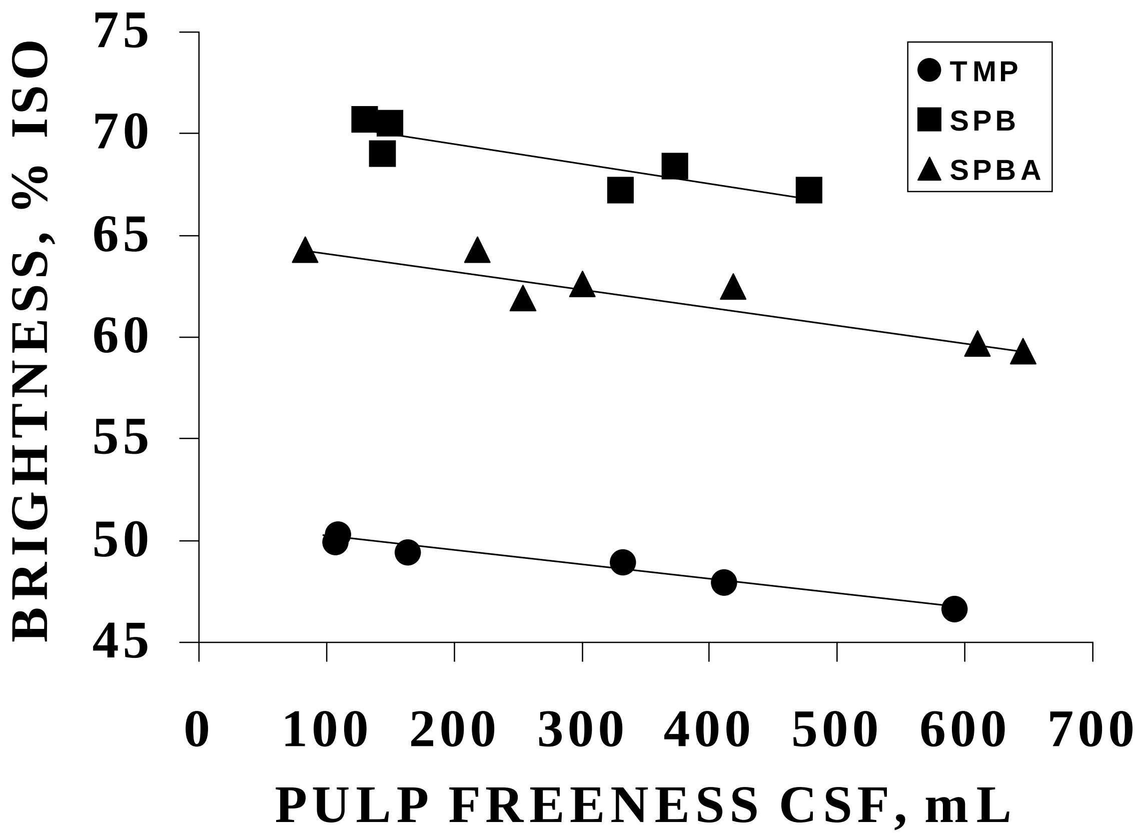


Figure 4 Brightness for bleaching with sodium perborate (SPB) and activated perborate (SPBA) compared to thermomechanical pulp (TMP)

As expected, the increase in brightness for the perborate and the activated perborate treatments also results in reduced opacity, as showed in **Table 3.** This loss is proportional to the brightness gain. Tensile index results presented in **Fig. 5** indicate that adding sodium perborate in the refiner seems to produce pulps with slightly better strength with regard to this property. Activated perborate did not affect the tensile index compared to the TMP.

Table 3 Opacity, tear index and specific refining energy for bleached pulps with perborate (SPB), activated perborate (SPBA) compared to TMP pulp

Perborate (SPB) and activated perborate (SPBA) compared to TMP pulp											
Pulp freeness CSF (mL)			Opacity (%)			Tear index ($mN*m^2/g$)			Specific refining energy (MJ/kg)		
TMP	SPB	SPBA	TMP	SPB	SPBA	TMP	SPB	SPBA	TMP	SPB	SPBA
592	478	645	95,2	86,5	88,1	8,92	11,77	9,20	2,94	5,56	3,90
411	373	610	96,3	87,8	88,7	10,37	13,00	9,79	4,35	6,90	3,83
332	330	418	96,8	88,4	88,5	11,38	13,17	11,75	5,31	6,45	5,73
245	150	300	96,8	91,2	90,0	11,17	9,81	11,30	7,95	9,94	5,98
164	144	254	97,5	91,4	91,2	10,12	9,89	10,15	7,88	9,14	6,28
109	130	218	97,6	91,4	90,3	9,42	9,78	9,79	8,51	10,01	8,08
107	---	83	98,0	---	94,0	8,63	---	8,97	7,55	---	13,44

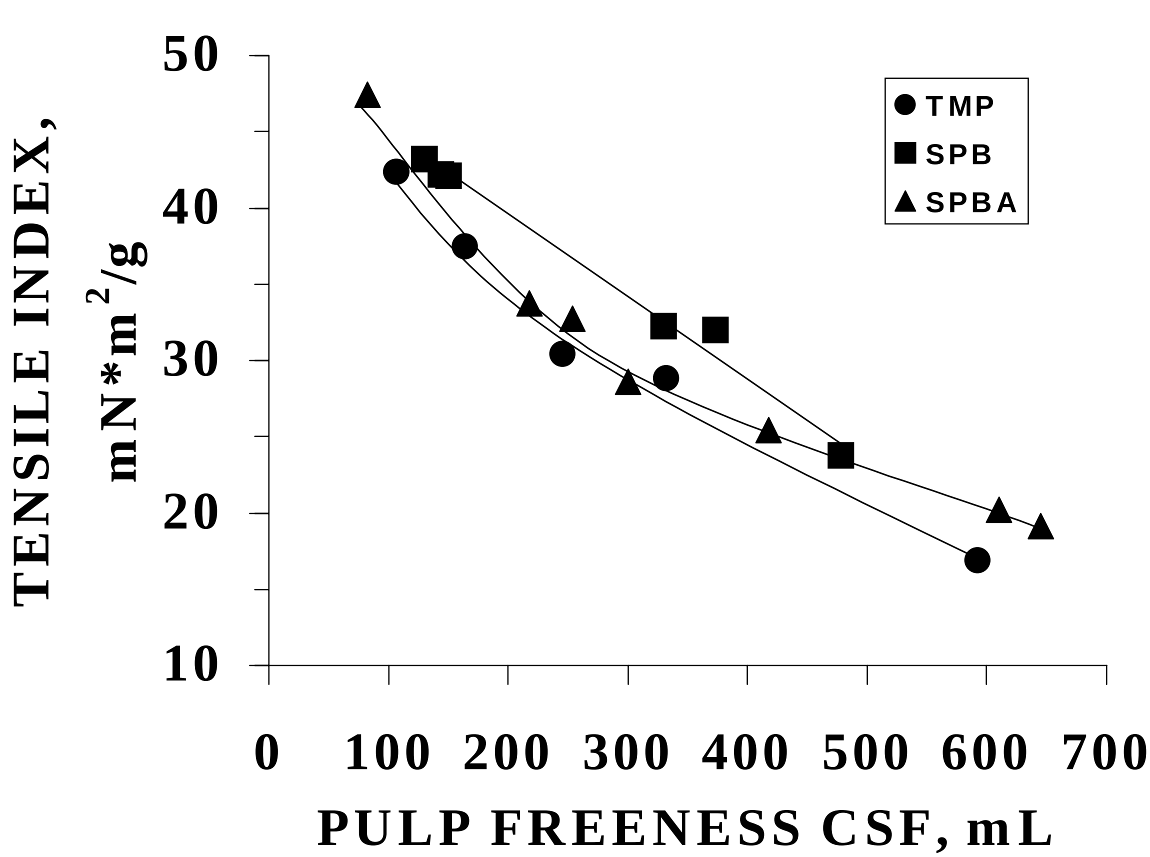


Figure 5 Tensile index for bleaching with sodium perborate (SPB) and activated perborate (SPBA) compared to thermomechanical pulp (TMP)

Sodium perborate alone improves the burst index compared to TMP, as illustrated in **Fig. 6.** But the addition of the activator produces pulps with burst indexes equivalent to TMP. Table 3 shows that tear index results obtained with the use of perborate maintain this property if compared at freeness levels lower than 200 mL. However, the addition of the activator reduces the tear index compared to TMP. With aged chips, the addition of perborate increases the specific refining energy requirement compared to the TMP process, as illustrated in Table 3. However in an SPBA system, aged chips need similar refining energy compared to the TMP process. A possible explanation could be a high residual alkalinity during the SPBA refining process.

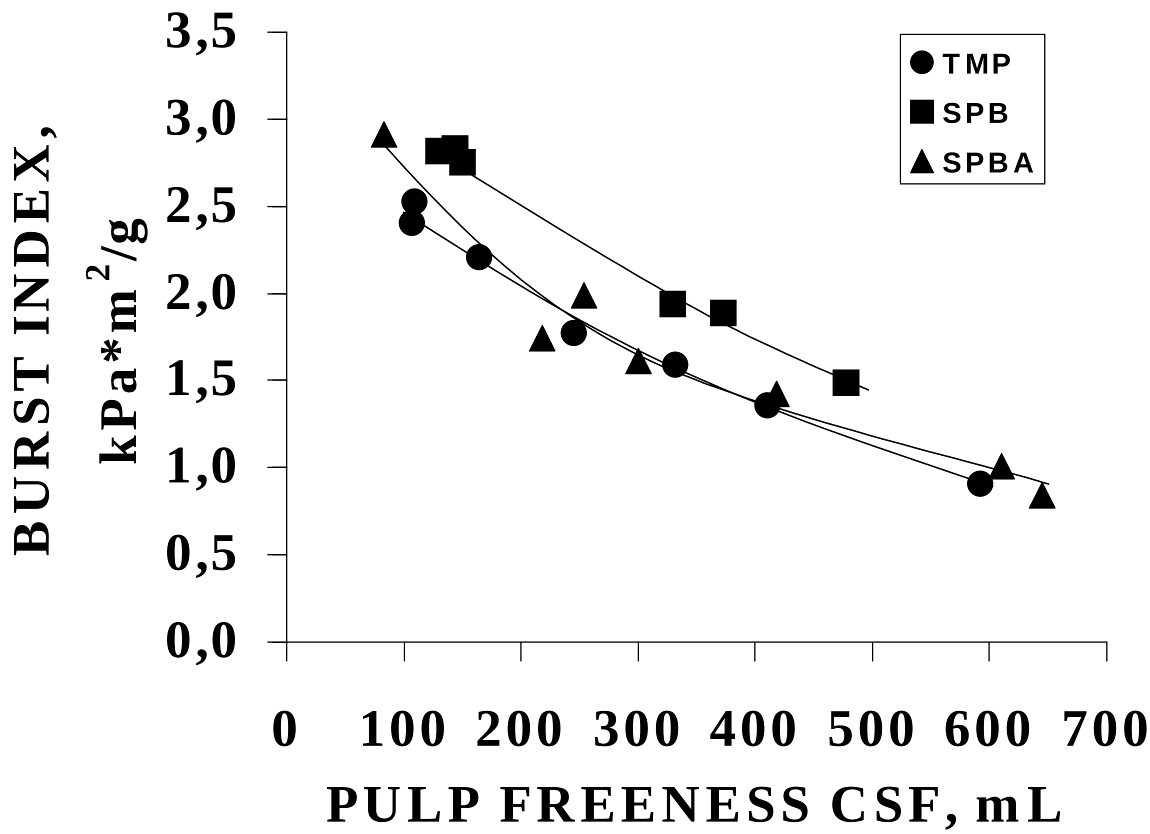


Figure 6 **Burst index for bleaching with sodium perborate (SPB) and activated perborate (SPBA) compared to thermomechanical pulp (TMP)**

PART 2 **Variation of the oxidizing charge and temperature used in the refiner**

In the second part of the study, we have used fresh softwood chips [spruce (75%) / balsam (25%)]. We have investigated two independent variables, such as the charge of peroxide or perborate applied on the chips and the temperature used in the refining step. A two-level factorial design has been chosen in order to evaluate the response of the dependent variables. The levels of peroxide charge are 2% and 5%. The levels of perborate charge are 6% and 15%. The temperature levels are 115°C and 145°C. In order to evaluate the pure error, we have done three runs at 3.5% of peroxide or 10.5% of perborate at 130°C.

Tables 4 and 5 present the optical and physical properties for the factorial design of peroxide and perborate, respectively.

Table 4 Optical and physical properties for the bleached pulps produced at different charge of peroxide and temperature

Properties	P1	P2	P3	P4	P5
Peroxide, %	2,0	5,0	3,5	2,0	5,0
Temperature, ^{o}C	115	115	130	145	145
Brightness, % ISO	64,4	69,9	65,0	60,0	64,8
b*	14,8	13,5	15,0	15,8	15,5
Opacity, %	89,9	88,3	89,3	92,3	88,7
Scattering C. , m^2/kg	50,6	49,9	49,3	49,7	48,3
Absorption C., m^2/kg	1,50	1,00	1,48	2,43	1,34
Tensile index, Nm/g	28,4	40,5	38,4	44,0	46,6
Burst index, kPa*m^2/g	2,32	2,35	2,54	2,75	2,70
Tear index, mN*m^2/g	9,56	9,05	10,80	11,21	10,97
Energy, MJ/kg	15,00	13,75	11,41	11,57	6,23
Specific V., cm^3/g	2,98	3,12	2,89	2,77	2,74
Fiber length, mm	1,80	1,83	1,84	1,94	1,95
Rejects, %	0,69	0,74	0,52	0,15	0,20
Consumption, %	1,69	4,39	2,98	1,65	4,31

Table 5 Optical and physical properties for the bleached pulps produced at different charge of perborate and temperature

Properties	SPB1	SPB2	SPB3	SPB4	SPB5
Perborate, %	6,0	15,0	10,5	6,0	15,0
Temperature, ^{o}C	115	115	130	145	145
Brightness, % ISO	67,1	72,2	67,9	63,2	65,0
b*	14,1	12,4	14,1	15,7	15,4
Opacity, %	90,6	88,6	90,0	91,3	89,8
Scattering C. , m^2/kg	52,0	51,7	50,6	50,7	49,3
Absorption C., m^2/kg	1,48	1,19	1,50	2,04	1,61
Tensile index, Nm/g	30,1	33,8	37,2	40,5	39,0
Burst index, kPa*m^2/g	2,30	2,49	2,41	2,52	2,44
Tear index, mN*m^2/g	9,78	9,79	10,08	11,07	9,55
Energy, MJ/kg	7,65	11,18	9,74	12,96	11,58
Specific V., cm^3/g	2,85	2,86	2,85	2,87	2,87
Fiber length, mm	1,69	1,76	1,73	1,87	1,77
Rejects, %	0,34	0,39	0,36	0,14	0,20
Consumption, %	4,42	8,89	8,49	5,11	12,58

Tables 6 and 7 show the statistical analysis for peroxide and perborate, respectively. Each table shows the model equation for each response, the F-Ratio of the chosen major effect or interaction, the validity of the model in terms of coefficient of determination (R^2), the pure error, and the lack of fit (LOF) of the model. The confidence level of each model is 95%. For several properties, no model has been able to fit the observed results.

Table 6 Statistical analysis for the design with peroxide

	MODEL EQUATION				F-RATIO			VALIDITY		
	Cte	P	Temp	P* Temp	P	Temp	P* Temp	R^2	Error, %	LOF, %
OPTICAL PROPERTIES										
ISO	64,871	2,575	-2,375	---	25,32	21,54	---	92,1	7,5	0,4
b*	14,943	---	0,750	---	---	6,83	---	57,7	19,0	23,3
OP	89,600	-1,300	---	---	6,95	---	---	58,2	13,1	28,7
CDIF	---	---	---	---	---	---	---	---	---	---
CABS	1,530	-0,398	0,318	-0,148	46,33	29,56	6,38	96,5	2,4	1,1
PHYSICAL PROPERTIES										
Tensile	39,229	3,675	5,425	---	4,48	9,76	---	78,1	9,9	12,0
Burst	2,533	---	0,195	---	---	13,87	---	73,4	25,6	1,0
Tear	10,454	---	0,893	---	---	11,11	---	69,0	14,3	16,7
Energy	11,539	-1,648	-2,738	-1,023	22,14	61,14	8,53	96,8	3,0	0,2
Volume	2,900	---	-0,148	---	---	13,08	---	72,3	19,1	8,6
Fiber L.	1,863	---	0,065	---	---	18,20	---	78,4	6,5	15,1
Rejects	0,479	---	-0,270	---	---	50,13	---	90,9	5,0	4,1
PEROXIDE CONSUMPTION										
Cons.	2,999	1,340	-0,030	---	15235	7,64	---	99,9	0,1	---

Table 7 Statistical analysis for the design with perborate

	MODEL EQUATION				F-RATIO			VALIDITY		
	Cte	B	Temp	B*Temp	P	Temp	B*Temp	R^2	Error, %	LOF, %
OPTICAL PROPERTIES										
ISO	67,314	1,725	-2,775	---	5,85	15,13	---	84,0	7,1	8,9
b*	14,329	---	1,075	---	---	7,88	---	61,2	9,1	29,7
OP	90,043	-0,875	0,475	---	15,08	4,45	---	83,0	15,5	1,5
CDIF	---	---	---	---	---	---	---	---	---	---
CABS	1,546	-0,180	0,245	---	17,01	31,52	---	92,4	3,7	3,9
PHYSICAL PROPERTIES										
Tensile	36,429	---	3,900	-1,300	---	49,72	5,52	93,2	0,8	6,0
Burst	---	---	---	---	---	---	---	---	---	---
Tear	---	---	---	---	---	---	---	---	---	---

Energy	---	---	---	---	---	---	---	---	---	---
Volume	---	---	---	---	---	---	---	---	---	---
Fiber L.	1,754	---	0,048	-0,043	---	6,10	4,88	73,3	11,7	15,0
Rejects	0,306	---	-0,098	---	---	10,36	---	67,5	3,0	29,5
PEROXIDE CONSUMPTION										
Cons.	8,067	2,985	1,095	0,750	82,43	11,09	5,20	97,1	0,8	2,1

Cte: Constant of the model equation
R^2 : Coefficient of determination
LOF : : Lack of fit of the model

ISO = Brightness	Tear = tear index
b*	Energy
OP = Opacity	Volume = Specific volume
CDIF = Scattering coefficient	Fiber L = Fiber length
CABS = Absorption Coefficient	TEA = Tensile energy absorption
Tensile = tensile index	Rejects
Burst = burst index	Cons. = Consumption of peroxide or perborate

The increase of the charge of peroxide or perborate and the decrease of the temperature in the experimental domain allow higher brightness levels. For the color coordinate *b**, lower temperature should be preferred in order to attenuate the yellow shade of the pulp. The decrease of the absorption coefficient takes place when the charge of oxidizing agent is increased and the temperature lowered.

Temperature is the variable that has the greatest effect on physical properties. For the peroxide, a temperature increase improves tensile, burst, tear, and fiber length and reduces energy and pulp rejects. For the perborate, a temperature increase enhances tensile and fiber length and allows a reduction of the pulp rejects.

PART 3 Comparison of different processes such as TMP, CTMP, P, and SPB

In the third part of the study, we have evaluated the efficiency of thermomechanical pulp (TMP), chemithermomechanical pulp [3.0% of sodium sulfite, impregnation of the chips at 130^{o}C for 6 min. (CTMP)], the peroxide process [3.5% of peroxide (P)], and the perborate process [10.5% of perborate (SPB)]. The temperature in the refining process has been maintained at 130^{o}C.

Table 8 presents optical and physical properties for the TMP, CTMP, P, and SPB processes. Pulps have been produced at a freeness level of 200 mL. **Figure 7** significantly demonstrates that the use of oxidizing agents allows better brightness levels than the use of sodium sulfite.

Table 8 Optical and physical properties for the pulps produced with fresh chips (pulp freeness at 200 ml)

Properties	TMP	CTMP	P	SPB
Brightness, % ISO	56,3	58,3	65,0	67,9
b*	14,8	13,7	15,0	14,1
Opacity, %	94,6	92,8	89,3	90,0
Scattering C. , m^2/kg	51,9	47,1	49,3	50,6
Absorption C., m^2/kg	3,55	3,12	1,48	1,50
Tensile index, Nm/g	35,2	41,1	38,4	37,2
Burst index, kPa*m^2/g	2,18	2,70	2,54	2,41
Tear index, mN*m^2/g	10,31	11,35	10,80	10,08
Energy, MJ/kg	11,69	8,70	11,41	9,74
Specific V., cm^3/g	2,74	3,05	2,89	2,85

Fiber length, mm	1,73	1,96	1,84	1,73
Rejects, %	0,56	0,20	0,52	0,36
Consumption, %	---	---	2,98	8,49

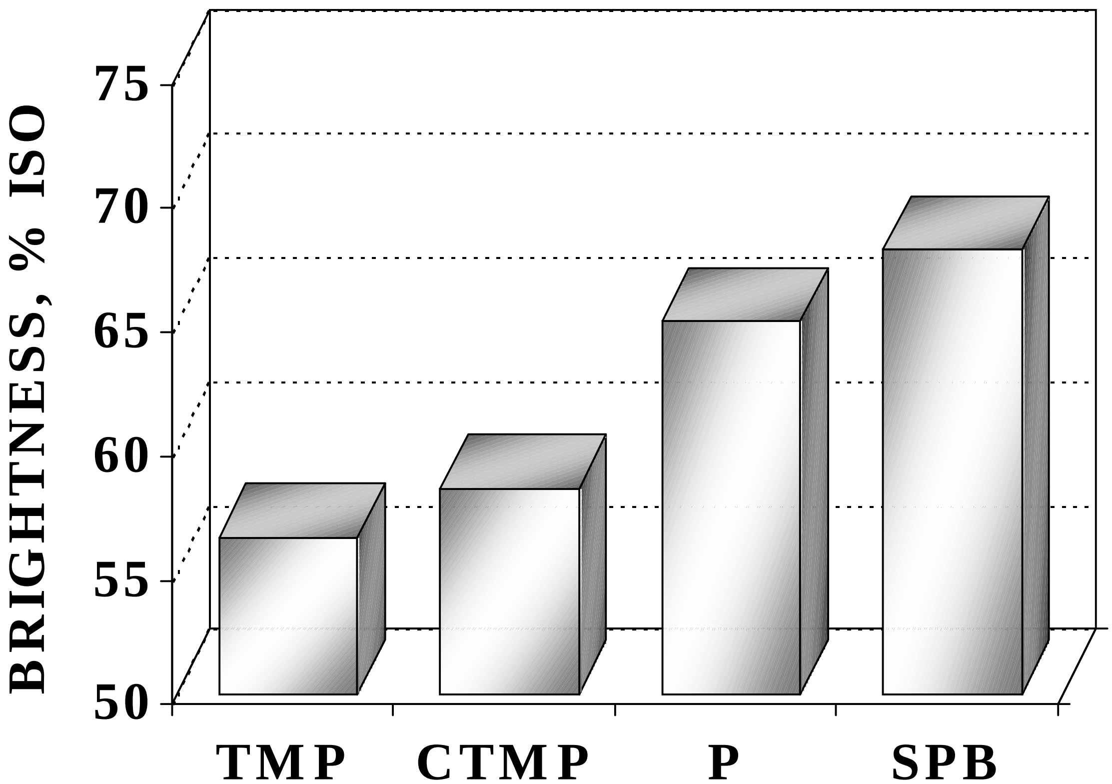


Figure 7 Brightness for the different processes (TMP, CTMP, P, and SPB)

Perborate bleaching gives a brightness of 67.9% ISO compared to 65.0% ISO for the peroxide. These results represent brightness gains of 11.6 and 8.7 points if compared to TMP. The CTMP and SPB processes produced pulps with a lower yellow shade. CTMP has the lowest scattering coefficient. The alkalinity of the oxidizing processes is probably responsible for the increase of the scattering coefficient. The absorption coefficients of the P and SPB processes are reduced and similar when compared to TMP and CTMP.

The CTMP process produces a pulp with higher physical properties [tensile (**Fig. 8**), burst, tear, specific volume, and fiber length], requires lower energy (**Fig. 9**), and reduces the level of pulp rejects when compared to the other processes.

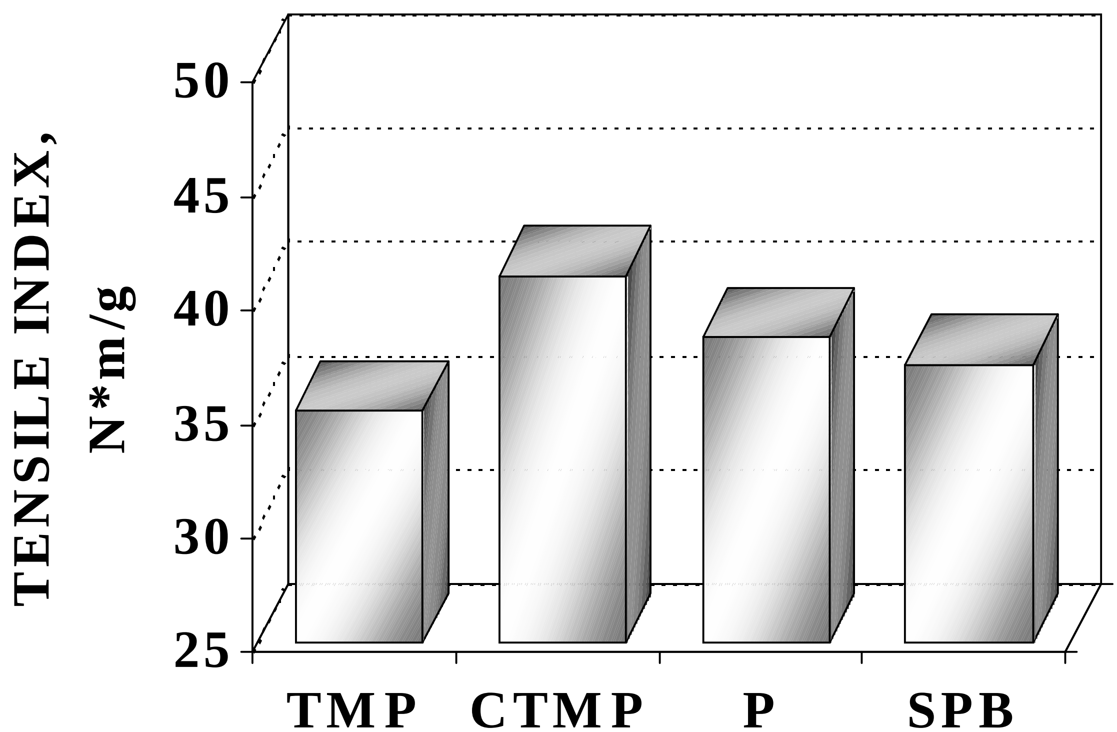


Figure 8 Tensile index for the different processes (TMP, CTMP, P, and SPB)

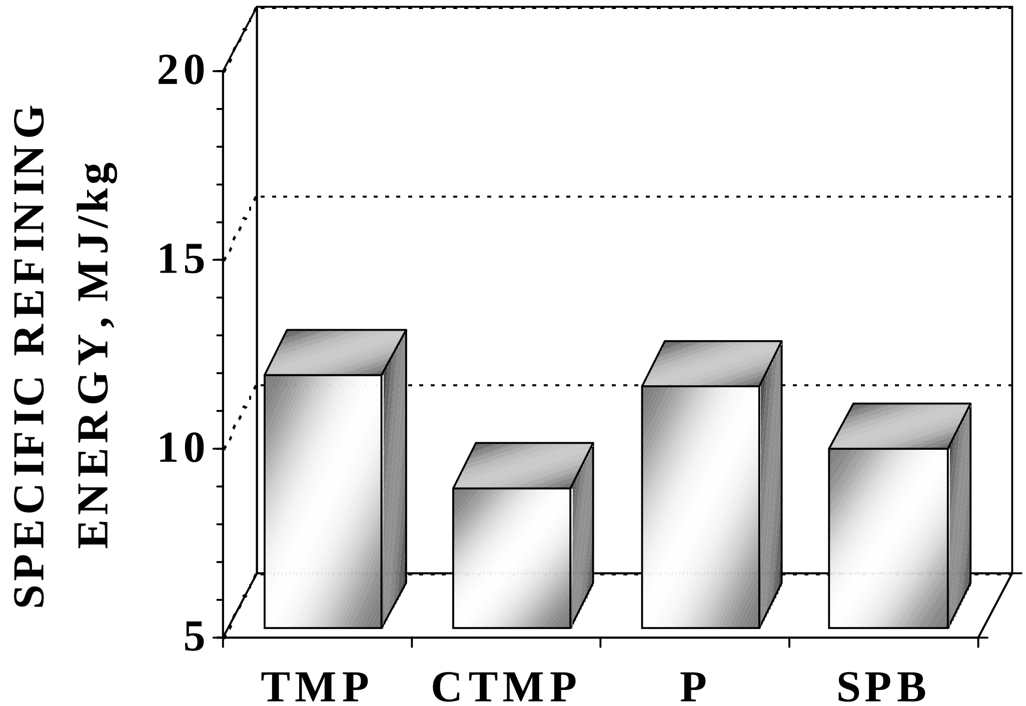


Figure 9 Specific refining energy for the different processes (TMP, CTMP, P, and SPB)

The peroxide process improves tensile, tear, burst, and fiber length when compared to the TMP process. The perborate process improves tensile and burst when compared to the TMP process. The advantage of this process over peroxide remains in the lower refining energy required and the reduction of the pulp rejects. It should be noted that for aged chips, we obtained a higher specific refining energy for perborate compared to the TMP process. A possible reason might be the more acidic nature of aged chips compared to the fresh ones. Further experimentation is needed to validate this presumption.

Table 9 shows the bleaching cost for peroxide and perborate. Results from this table demonstrate that the use of perborate compared to peroxide would allow a reduction in the bleaching cost of 16%, if we consider the added product, or 22%, if we consider the consumed product (consumption rate shown in Table 8).

Table 9 Bleaching cost for peroxide (P) and perborate (SPB)

Chemicals			Peroxide Bleaching		Perborate Bleaching	
Chemical for bleaching liquor	Chemical cost, [10] ($US/kg)	Chemical Concentration (%)	Applied Charge (%)	Cost for each chemical ($US/ton)	Applied Charge (%)	Cost for each chemical ($US/ton)
DTPA	1,1243	40	0,20	5,62	0,20	5,62
$MgSO_4$	0,3913	100	0,05	0,20	0,05	0,20
Na_2SiO_3	0,2105	41°Be	3,00	6,32	3,00	6,32
NaOH	0,3472	50	3,00	20,83	---	---
H_2O_2	0,7551	50	3,50	52,86	---	---
$NaBO_3.H_2O$	0,5511***	96	---	---	10,50	60,28
Total Bleaching Cost ($US/ton)				85,83		72,42

***** : this our estimated cost of sodium perborate monohydrate**

CONCLUSION

In this study, we evaluated the efficiency of adding different oxidizing agents, such as hydrogen peroxide, sodium perborate, activated peroxide generated from peroxide with

TAED, and activated perborate generated from perborate with TAED in the refining process of mechanical pulp.

The use of all the oxidizing agents improves the pulp brightness. However, the brightness gain achieved with perborate is superior to peroxide–20 points compared to 13 points. The addition of the activator TAED in the bleaching liquor of peroxide or perborate reduces the brightness level by 3 to 6 points due to possible decomposition of the peracetic acid.

The addition of peroxide allows better strength properties in terms of burst index and tear index compared to the thermomechanical pulp. The perborate added in the refining step enhances the tensile index and the burst index and maintains the tear index. The mixing of the activator with peroxide enhances the strength properties of the pulp.

The charge of oxidizing agent and the temperature used in the refining process have been studied. The increase of the charge of oxidizing agents and the reduction of temperature achieve better brightness levels. On the other hand, the increase in the temperature improves the strength properties.

We have compared peroxide and perborate processes to thermomechanical pulp (TMP) and chemithermomechanical pulp (CTMP) processes. The best results achieved in terms of brightness are the oxidizing processes. Brightness levels of 67.9, 65.0, and 58.3 are obtained for the perborate, peroxide, and CTMP processes. However, the

CTMP process achieves the best strength properties and reduces the energy and the pulp rejects.

The peroxide process enhances the paper strength when compared to the TMP process. However, perborate will be able to reduce the energy refining requirement, the pulp rejects, and the chemical cost as well as to improve the pulp quality.

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