Evaluation of APMP and BCTMP for market pulps from South American eucalyptus

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ABSTRACT

APMP and conventional CTMP processes were used to pulp eucalyptus wood from three different South American sources. The three pulps were similar in their responses to changes in process conditions. APMP and CTMP are similar in pulp strength development, in effluent loading, and in terms of controlling process energy consumption. At the same final brightness, the BCTMP process produced more COD discharge than did the APMP process. Another disadvantage of CTMP is its low brightness ceiling of <85% ISO, whereas APMP pulps could reach 89% ISO. For a two-stage impregnation APMP process, the distribution of chemicals between the two stages affected not only process chemical efficiency but final bleachability as well.

Application:

If pretreated properly with chemicals, eucalyptus mechanical pulps could be used in tissue and in printing and writing papers, which require high brightness.

EUCALYPTUS HAS BEEN USED IN mechanical pulping for a number of years, but can this fast-growing species be used for high-brightness papers such as tissue grades and printing and writing grades? A major concern over eucalyptus is the difficulty in bleaching it to a high brightness of at least 85% ISO. Eucalyptus wood is darker than the wood of North American aspen. How can the species be pulped to obtain suitable physical properties and still reach brightnesses of 85% ISO or higher?

Currently, there are three different commercial technologies for producing a pulp with suitable mechanical properties from eucalyptus. These processes are:

1. Alkaline peroxide mechanical pulping (APMP)
2. Cold caustic soda (CCS)
3. Alkaline sulfite mechanical pulping (CTMP).

In terms of process design and post-pulping bleachability, only CTMP and APMP are suitable. A study of APMP should also give a good indication of what to expect from the CCS process, if the conditions are varied suitably in the APMP pretreatment stage.

For this study, we chose three sources of South American eucalyptus: *E. grandis* from Argentina, *E. grandis* from Paraguay, and *E. saligna* from Paraguay. We studied the possibility of preparing these wood furnishes for high-brightness grades by using the APMP process or the conventional CTMP process. These processes were compared for energy consumption, pulp property development, and process effluent characteristics. The pulps produced were also compared in terms of bleachability.

BACKGROUND

The APMP process was first introduced at the 1989 International Mechanical Pulping Conference (*1*). Since then, a number of studies have been reported from the Andritz Pilot Plant in Springfield, Ohio on the characteristics of the APMP process, on how it compares to CTMP and pre-bleached CTMP, and on its application to various wood species (*2–5*).

APMP pulp mills have been successfully started up at Malette, Quebec, and at the Yalujiang Paper Mill, Dandong, People's Republic of China (*6, 7*). These mills have demonstrated a high flexibility in processing different types of wood on a commercial scale. They have also demonstrated that the energy consumption is likely to be lower than that of other processes and that the pulp quality is likely to be higher.

Generally, APMP is used most favorably for two special areas in high-yield pulping. One area involves high-brightness pulp grades when peroxide bleaching is necessary. The other involves a specific hardwood species for which caustic pretreatment is needed to reduce energy consumption and, more importantly, to obtain acceptable pulp strength.

In the area of achieving high brightness with peroxide bleaching, a certain amount of sodium hydroxide has to be applied. In the APMP process, both sodium hydroxide (NaOH) and hydrogen peroxide (H_2O_2) are applied prior to refining. Not only does the sodium hydroxide function as a necessary component of bleaching reagents, but it also softens the fibers. As a result, the refining energy is reduced, and the pulp is improved by having greater strength and lower shives content.

In this way, the chemical potential of sodium hydroxide is realized more fully, and the long fiber content is better preserved. In some cases, especially for hardwood, bleaching

	APMP			CTMP		
	1	2	3	1	2A	2B
First-stage impregnation						
NaOH, %	3.8	5.3	1.4	2.7	1.0	1.0
H_2O_2, %	0.0	0.0	1.0	0.0	0.0	0.0
DTPA, %	0.3	0.3	0.3	0.4	0.5	0.5
Silicate, %	…	…	0.9	…	…	…
$MgSO_4$, %	…	…	0.05	…	…	…
Na_2SO_3, %	…	…	…	2.5	2.5	2.5
Second-stage impregnation						
NaOH, %	2.1	1.5	3.2			
H_2O_2, %	1.7	2.2	2.8			
DTPA, %	0.1	0.1	0.15			
Silicate, %	1.8	1.7	2.6			
$MgSO_4$, %	0.03	0.05	0.04			
First and second stages						
Total NaOH	5.9	6.8	4.6			
Total H_2O_2	1.7	2.2	3.8			
First-stage refining						
Refiner type	Atm.	Atm.	Atm.	Press.	Press.	Press.
Speed, rpm	1200	1200	1200	1200	1200	1800
Consistency, %	20	20	20	22	22	22

Atm. = atmospheric . Press. = pressurized.

I. APMP and CTMP process conditions for* E. saligna *from Paraguay

with alkaline peroxide after pulping is completed does improve strength properties (*8, 9*). However, the gain is generally less than that observed from the same bleaching treatment prior to refining.

As to the efficiency of hydrogen peroxide in the APMP process, the situation is more complicated. There are several advantages to using the APMP process. One is that the chips are bleached instead of the pulp. Pulp often suffers from darkening reactions caused by the thermal and refining processes (TMP, CTMP) and from darkening reactions caused by alkali in conventional alkaline CTMP. Another advantage is that the darkening reactions can be minimized throughout the refining process when the ratio of NaOH to H_2O_2 is properly adjusted.

A concern with applying hydrogen peroxide on chips, however, is that chips cannot be washed as well as pulp can be washed. Heavy metal ions (mainly iron, manganese, and copper) remain in the chips, along with H_2O_2-reactive compounds in wood that could otherwise be washed away. These impurities reduce the hydrogen peroxide efficiency in bleaching reactions.

To what extent is the hydrogen peroxide efficiency diminished by these side reactions? How much more difficult is it to bleach a pulp darkened from other pulping processes? The answers vary, depending on the wood species and the preconditioning. Without darkening prevention at the beginning of a process, the pulp may be so dark that final bleaching to a high brightness becomes difficult with conventional mechanical pulp bleaching methods.

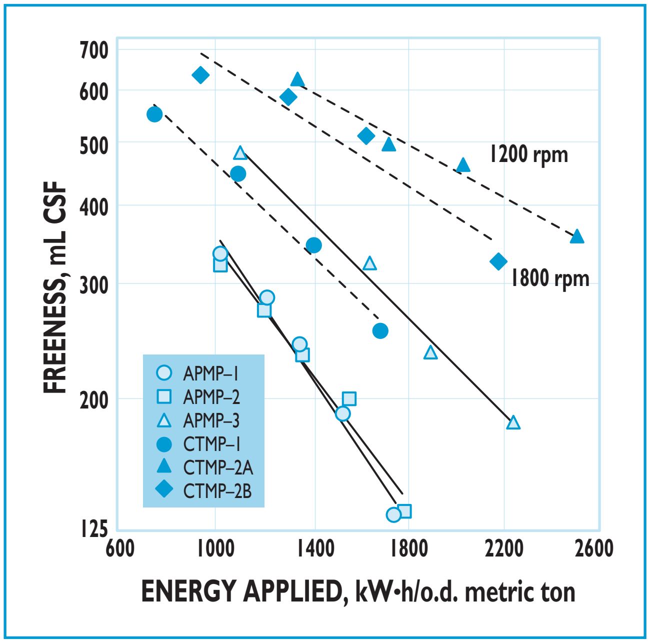
The APMP process, like conventional CMP or CTMP, consists of two primary components—impregnation and refining (*1–5*). During the impregnation stage, chips are steamed, pressed, chemically impregnated, and retained in the reaction bin to allow the chemical reactions to run to completion. Fiberization and fibrillation are completed with conventional atmospheric refining.

The key to the success of any APMP process lies in chip impregnation. The goal at the impregnation stage is to achieve the best efficiency with the chemicals used. These chemicals include not only caustic and peroxide chemicals but stabilizers as well. If this goal is to be met, the following parameters must be optimized:

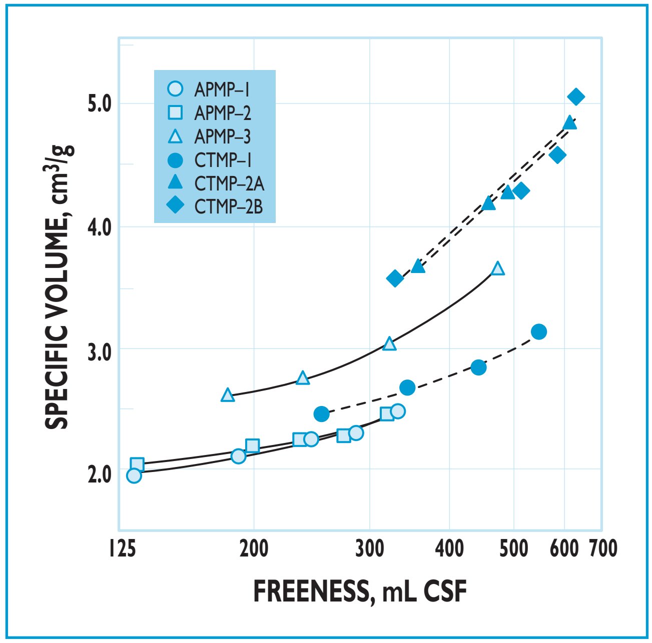
- Temperature and retention in chip presteaming
- Compression ratio in the impressafiner
- Chemical concentrations and the ratios among them in the chemical liquor
- Temperature and retention in impregnation
- Temperature and retention in the reaction bin

The optimization of the conditions depends on the wood species and the requirements for pulp quality. A wood species like eucalyptus requires a high degree of sodium hydroxide impregnation if the pulp properties are to be acceptable and the energy consumption is to be held down. For eucalyptus, two or more stages of impregnation are recommended, and the optimization becomes more complicated.

The most important question in multistage impregnation is, How should the chemicals be distributed at each stage? An unbalanced distribution will lead to poor chemical efficiency, and it will pose difficulties in reaching a high brightness in final bleaching. The study of the effects of chemical distribution in two-stage



1. Refining energy vs. freeness for the pulps produced from **E. saligna** *under conditions described in Table I.*



2. Specific volume vs. freeness for the APMP and CTMP pulps produced from **E. saligna** *(Table I).*

impregnation is part of our continuing effort to understand and optimize the APMP process.

APMP has often been compared with conventional CTMP because the two processes are similar in configuration, they both can save on energy consumption, and they both benefit the physical properties of the pulp. Previous studies have compared APMP without post bleaching against CTMP with post bleaching (BCTMP) (*1–5*). In those studies, only one BCTMP process condition was used as the basis on which to compare different APMP conditions. In the study reported here, *both* processes are compared at different process conditions and in regard to the post bleachability of the pulps produced.

It is sometimes necessary in the APMP process to have a bleaching stage after pulping. Sometimes a high brightness of greater than 85% ISO is required. Sometimes the nature of the wood species makes it difficult to have a combination of chemicals at the impregnation stage that is optimal for both pulp quality development and pre-bleaching. The availability of a post-bleaching stage makes the process more flexible in changing pulp grades, which is particularly important for a market pulp mill.

APMP AND CTMP ON *E. SALIGNA*

The *E. saligna* wood from Paraguay was processed at three different chemical conditions for the APMP process and at two different chemical conditions for the CTMP process. The main process conditions used are listed in **Table I**. As the table shows, for CTMP at 1.0% NaOH applied, a comparison was also carried out for the conventional speed of 1200 rpm versus the high speed of 1800 rpm.

Chemicals and energy consumption

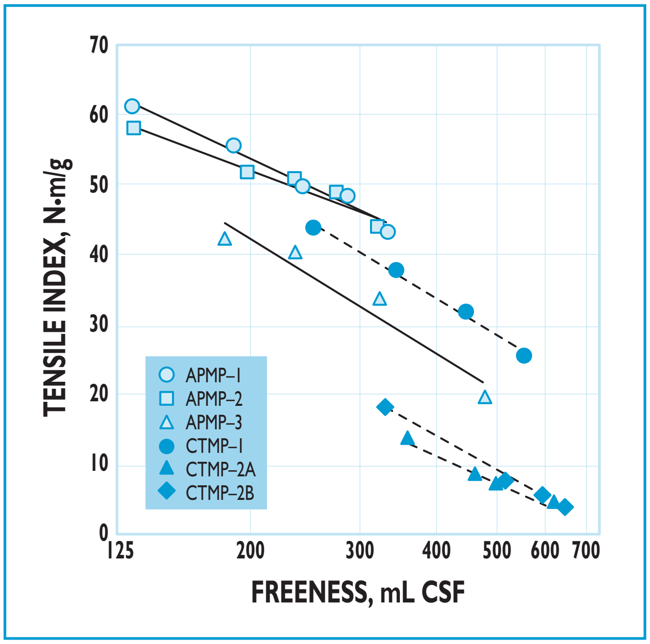
As expected, an increase in alkaline charge in the pre-treatment prior to refining led to a reduction in refining energy at any given freeness, as shown in **Fig. 1** for both APMP and CTMP. For APMP, there was a significant drop in energy consumption as the total sodium hydroxide charge increased from 4.6% (APMP-3) to 5.9% (APMP-1). A further increase of sodium hydroxide charge to 6.8% (APMP-2) had little effect on the energy relationship between caustic charge and refining energy.

For the CTMP process, the lower sodium hydroxide charge of 1.0% had little effect on the energy savings over the charge of 2.7% (CTMP-1). Increasing the refining intensity by setting the refiner speed to 1800 rpm did give a noticeable energy savings. However, the total energy consumption was still too high to be practical. An increase in sodium hydroxide charge from 1.0% to 2.7%, however, reduced the energy significantly. The refining energy fell to a level comparable to that of the AMPM process at 4.6% NaOH, suggesting that the sodium hydroxide charge has a stronger influence on the CTMP process than on the APMP process.

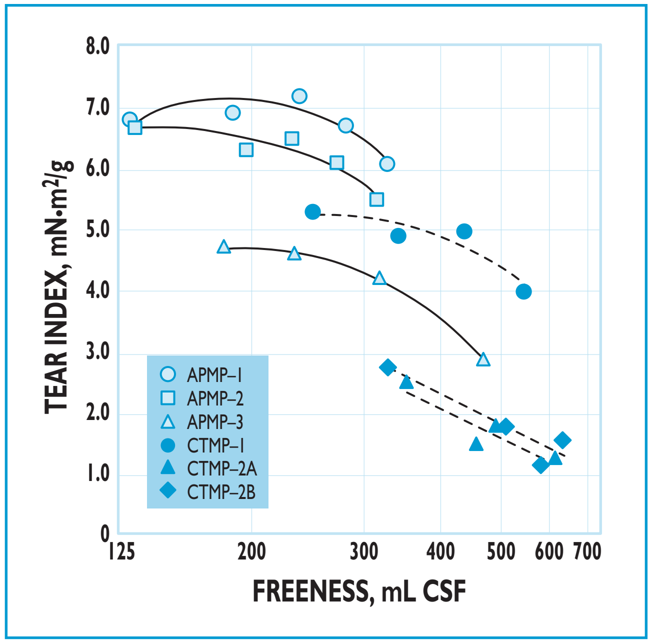
Pulp properties

The relationship between freeness and handsheet "bulk," or specific volume, shown in **Fig. 2**, correlated well with the relationship between freeness and refining energy, which is shown in Fig. 1. However, the relationship for the high-speed CTMP was the same as that for the CTMP refined at the conventional speed.

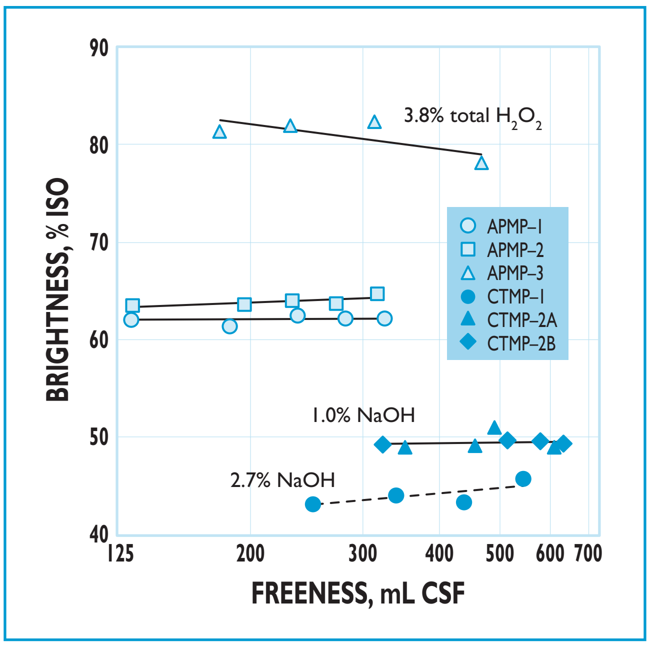
For both APMP and CTMP, the bulk–freeness relationship is dominated by the caustic charge. Sodium



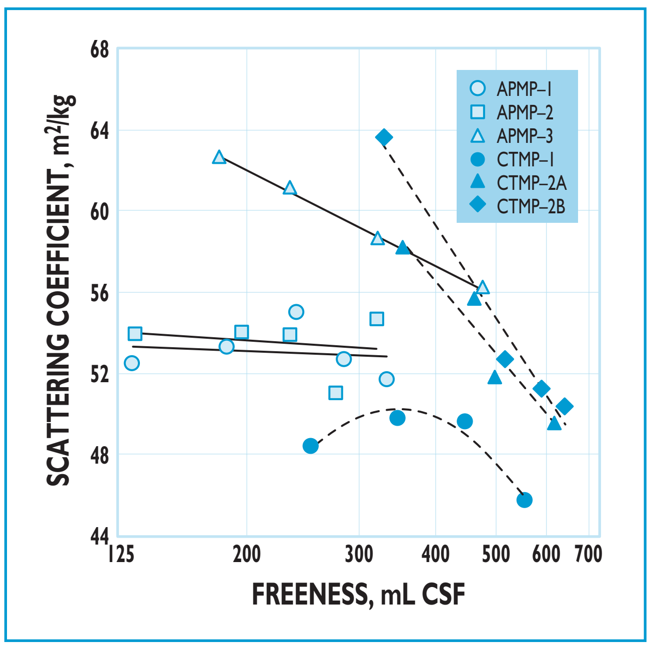
3. Tensile index vs. freeness for the APMP and CTMP pulps produced from **E. saligna** *(Table I). The improvement in APMP-2 over APMP-1 reflects better chemical efficiency in second-stage impregnation.*



4. Tear index vs. freeness for the APMP and CTMP pulps produced from **E. saligna** *(Table I). The higher NaOH charge of 2.7% for CTMP-1 led to a substantial increase in tear index over the charge of 1.0% for 2A and 2B.*



5. Brightness vs. freeness for the APMP and CTMP pulps produced from **E. saligna** *(Table I). The brightnesses of the APMP pulps depend mainly on the hydrogen peroxide charge.*



6. Light-scattering coefficient vs. freeness for the APMP and CTMP pulps produced from **E. saligna** *(Table I). The coefficient was sensitive to the sodium hydroxide charge for both APMP and CTMP.*

hydroxide again showed a stronger influence on CTMP than on APMP. A ceiling for APMP was observed at a sodium hydroxide charge of 5.9% (APMP-1).

The paper strength properties were influenced by the sodium hydroxide charge as expected for both processes. Freeness is plotted against tensile index in **Fig. 3** and against tear index in **Fig. 4**. As the figures show, there was a marginal improvement in tensile and tear indices for the high-speed CTMP-2B. For APMP, in going from 6.8% NaOH (APMP-2) to 5.9% (APMP-1), the tensile index improved slightly, and the tear index improved noticeably. These improvements indicate a better chemical efficiency at the second-stage impregnation. As observed for specific volume, the sodium hydroxide charge had a stronger influence on the CTMP process than on the APMP process.

The brightnesses of the APMP pulps depended mainly on the hydrogen peroxide charge, as shown in **Fig. 5**. At a total hydrogen peroxide charge of 3.8%, a brightness higher than 80% ISO was achieved. As to the brightness of the CTMP pulps, the pulp at the NaOH charge of 2.7% was darker than the pulps at the lower charge of 1.0% NaOH.

The light-scattering coefficient was sensitive to the sodium hydroxide charge for both APMP and CTMP, as **Fig. 6** shows. For APMP, the coefficient apparently reached a minimum at a sodium hydroxide charge of 5.9% (APMP-1). In contrast, 2.7% NaOH drastically reduced the light-scattering coefficient of CTMP to a level even lower than that of 6.8% NaOH in APMP. This observation is seen in the graph, where the maximum coefficient is about 50 m^2/kg for CTMP-1 as opposed to about 54 m^2/kg for AMPM-2. As expected, the high-speed CTMP gave a light-scattering coefficient higher than that for the CTMP refined at the conventional speed (*10*).

Discussion

For the APMP process, *E. saligna* from Paraguay followed a trend often observed for other hardwoods in terms of how the total sodium hydroxide charge affects the pulp property development and the relationship between refining energy and freeness (*1*, *3*, *5*). What is more interesting is that APMP at 5.9% total sodium hydroxide was comparable in energy consumption to APMP at 6.8% total NaOH but demonstrated better development of pulp strength.

In the case of 5.9% NaOH, 3.8% was charged at the first stage of impregation, and 2.1% was charged at the second stage. In the case of 6.8% NaOH, 5.3% was charged at the first stage, and only 1.5% was charged at the second stage. It appears that less total sodium hydroxide was required when more of the total was distributed to the second stage.

Evidently, chemicals (particularly sodium hydroxide) can be used more efficiently if they are preferentially distributed to the later stage of a multistage impregnation. In fact, it is normal practice to allocate chemicals in this way in a typical mill having a multistage impregnation system (*6*). An obvious explanation for this improved efficiency is that less of the chemically active, water-soluble material remains in the chips at the later stages of impregnation, so more reactions will occur on wood fiber. Another possible reason is that the higher charge in the first stage leaves a substantial amount of unreacted sodium hydroxide, which is lost at the second-stage press. Therefore, the effective sodium hydroxide charge is less than the applied charge.

There was a substantial change in energy consumption and pulp property development as the total sodium hydroxide application increased from 4.6% to 5.9%. Apparently, the APMP pulping process was more sensitive to the caustic charge in a range of about 4–6% than it was at percentages outside that range. This phenomenon has also been observed on other eucalyptus species processed at the Andritz Pilot Plant (*5*).

The greater sensitivity of the CTMP process to sodium hydroxide was probably a result of the combined effects of sodium sulfite and the temperature of cooking, which was higher than the temperature for APMP. The higher temperature softened the fiber wall more thoroughly and allowed the chemical to penetrate deeper inside the fiber, and the sodium sulfite made lignin more hydrophilic, resulting in more fiber softening. We see evidence of this effect in the low specific volume (Fig. 2) and in the low light-scattering coefficient (Fig. 6).

APMP AND CTMP ON *E. GRANDIS*

E. grandis species from Argentina and from Paraguay were studied in both the APMP and CTMP processes. As with the *E. saligna*, different process conditions were investigated. All three pulps were found to be similar in property development in relation to process conditions.

Results from the three wood specimens are summarized in **Table II**. At similar charges of sodium hydroxide, the pulps required similar amounts of energy for the same freeness. At similar charges and the same freeness, all the pulps had similar development in the sheet properties of bulk, tensile, tear, light scattering, and opacity. The fines content (–200 mesh) and the Pulmac shives content (0.10 mm) were fairly close within the respective levels of freeness. In general, the shives content was low—less than 1% at 400 mL CSF and less than 0.2% at 200 mL CSF.

For tissue (freeness of about 400 mL) and printing and writing grades (freeness of 200–300 mL), the eucalyptus pulps from both the APMP and CTMP processes showed impressive strength properties. Compared with commercial chemimechanical hardwood pulps, the handsheets from these pulps have a higher specific volume at any given tensile strength or tear strength. The specific volume is an important parameter for these grades, especially for tissue grades. The values for light-scattering coefficient were also relatively high. This level of quality would render these eucalyptus pulps quite competitive in the market.

Variety	Freeness, mL CSF	NaOH,[a] %	Energy, kW h per o.d. metric ton	Bulk, cm^3/g	Tensile, N m/g	Tear, mN m^2/g	Scattering coeff., m^2/kg	Fines content, %	Pulmac shives content, %
				APMP					
E. grandis, A	200	7.5	1450	2.0	61	7.9	54.8	17.5	0.02
E. grandis, P	200	7.2	1480	2.0	58	7.2	53.0	16.0	0.07
E. saligna, P	200	6.8	1480	2.2	53	6.5	54.0	16.7	0.15
E. grandis, A	400	7.5	920	2.6	36	5.8	51.5	14.5	0.80
E. grandis, P	400	7.2	880	2.3	45	6.5	52.0	10.0	0.80
E. saligna, P	400	6.8	900	2.6	41	4.7	54.0	14.0	0.90
				CTMP					
E. grandis, A	200	2.7	1900	2.2	47	7.1	50.0	19.5	0.05
E. grandis, P[b]	200	3.0	2070	…	…	…	…	…	…
E. saligna, P	200	2.7	1920	2.3	49	4.9	46.0	18.2	<0.01
E. grandis, A	400	2.7	1230	2.5	32.5	5.4	49.0	13.0	0.75
E. grandis, P[b]	400	3.0	1300	…	26	4.5	50.0	13.0	0.15
E. saligna, P	400	2.7	1200	2.7	33	5.0	49.0	12.5	0.30

[a]Percentage based on o.d. chips in the impregnation stage. [b]Estimated by averaging lab results from 1% and 5% caustic runs.
Properties were obtained by extrapolating or interpolating results to the targeted freeness.

II. Pulp and handsheet properties for the varieties of eucalyptus from Argentina and Paraguay

PROCESS EFFLUENT

The total COD discharged from each process was also studied for all three wood furnishes. For both processes, the COD discharge was predominantly controlled by the sodium hydroxide charge, as shown in **Table III**. The three pulps behaved similarly in regard to process conditions.

Compared to APMP, the CTMP process released much more COD at a given sodium hydroxide charge, which is probably attributable to the sodium sulfite in its ability to make degraded lignin compounds more water soluble.

For *E. saligna*, the amount of COD discharged from 5.9% NaOH APMP (182 kg/o.d metric ton) was higher than that discharged from 6.8% NaOH APMP (175 kg/o.d metric ton). This result is consistent with the effects on pulp property development and can also be explained by variations in chemical distribution at the different impregnation stages.

POST BLEACHABILITY

An important part of this work was to study the bleachability of pulp from these eucalyptus logs and the pulping process conditions necessary to achieve brightnesses of more than 85% ISO.

In the studies of post bleaching, the strategy was first to establish an NaOH–H_2O_2 curve for optimum conditions for bleaching with hydrogen peroxide and then to bleach the pulps at different hydrogen peroxide charges under the optimized sodium hydroxide conditions. Only silicate was used as a stabilizer, and it was controlled at a level equivalent to the hydrogen peroxide charge. In most cases, a second-stage bleaching was also performed to identify the maximum bleachability of the pulp.

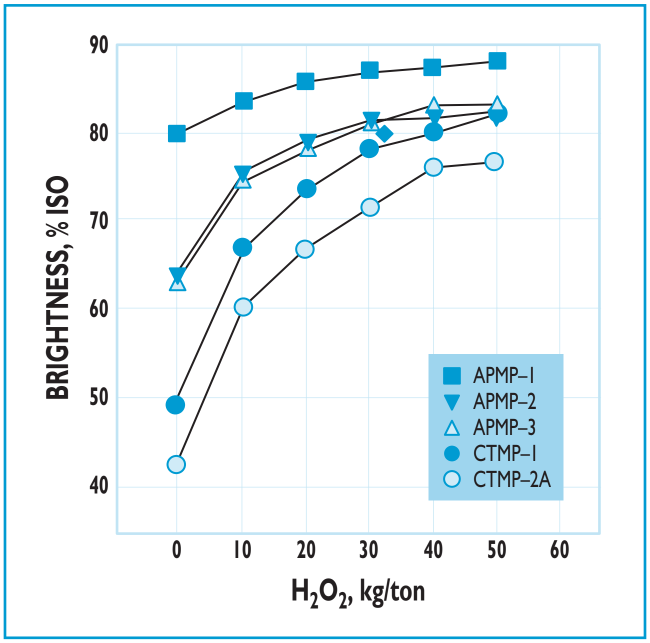
Bleaching results indicated that the three eucalyptus pulps were similar in bleaching response to hydrogen peroxide charge and in the relationship between bleachability and pulping process conditions. To simplify the matter, we are presenting only the results from *E. saligna* in this report.

Figure 7 summarizes the results from single-stage peroxide bleaching. As the graph shows, the pulping process conditions had a profound influence on pulp bleachability. For both APMP and CTMP processes, an increase in the sodium hydroxide charge at the impregnation stage reduced the maximum brightness in post-bleaching. The bleached CTMP pulps had a lower brightness ceiling than the bleached APMP pulps had. In the case of BCTMP, the pulp from 1% NaOH pre-treatment showed the potential to reach 83% ISO or slightly higher, while that from the 2.7% NaOH pre-treatment had a ceiling below 80% ISO.

These results show that APMP pulps can be bleached to 88% ISO or higher. For these brightnesses, it is necessary to have the proper distribution of bleach chemicals and the proper NaOH–H_2O_2 ratio at both stages of impregnation. This requirement is apparent when APMP-2 is compared with APMP-3, because APMP-3 achieved a similar brightness at a reduced total chemical charge.

Process	TOTAL CHEMICALS NaOH, %	H_2O_2, %	Na_2SO_3, %	COD, kg/o.d. metric ton
	E. grandis, Argentina			
APMP	4.9	3.3	…	174
APMP	7.5	5.0	…	206
CTMP	2.2	…	2.2	162
	E. grandis, Paraguay			
APMP	7.2	2.4	…	206
CTMP	0.94	…	2.2	128
CTMP	5.4	…	2.5	223
	E. saligna, Paraguay			
APMP	5.9	1.7	…	182
APMP	6.8	2.2	…	175
APMP	4.6	3.8	…	177
CTMP	2.7	…	2.2	155
CTMP	1.0	…	2.5	134

III. COD on process effluent



7. Brightness vs. hydrogen peroxide charge for the APMP and CTMP pulps produced from E. saligna *(Table I) and bleached at optimized NaOH conditions.*

A comparison of the chemical applications at the second-stage impregnation shows that a reduction in the NaOH–H_2O_2 ratio at this stage had little effect on improving bleachability after pulping. These charges were 1.5% NaOH and 2.2% H_2O_2 for APMP-2 versus 2.1% NaOH and 1.7% H_2O_2 for APMP-3. Obviously the ratio of chemicals in the first stage is critical, as is proper distribution across the impregnation stages.

These results also suggest that a CCS process (cold caustic soda) would not be suitable if a brightness of greater than 82% ISO is required (*11*).

To further explore the final bleachability, we carried out two-stage hydrogen peroxide bleaching by applying a 1.5% H_2O_2 charge at the first stage and various hydrogen peroxide charges at the second stage, with the maximum being 5.0%. Pulps after the first-stage bleaching were washed prior to the second stage. The highest brightnesses for each were:

APMP-1, 89.1% ISO
APMP-2, 84.4% ISO
APMP-3, 84.9% ISO
CTMP-1, 84.2% ISO
CTMP-2, 80.5% ISO

According to these results and those from single-stage bleaching, the CTMP process is not feasible for pulping these eucalyptus species for bleaching to a brightness of 85% ISO or higher, unless the sodium hydroxide charge at the impregnation stage is reduced to less than 1%. The pulp strength properties would suffer however, and the energy consumption would be too high to be practical. Therefore, a conventional CTMP process is not suitable for processing these eucalyptus species for pulp grades of such high brightness. Also, the APMP process is more capable of converting these South American species into high-grade market pulps.

CONCLUSIONS

E. grandis from Argentina and *E. grandis* and *E. saligna* from Paraguay are similar in their responses to different process conditions. In a mill, no major process change would be required when a different furnish among these three is supplied. Furthermore, these wood sources can be utilized for high-grade papermaking, such as tissue grades and printing and writing grades.

Both the APMP and CTMP processes can produce a pulp with good physical properties. However, the APMP process is more suitable for high-brightness grades. The APMP pulp could be bleached to 89% ISO, whereas the CTMP pulp was difficult to bleach to a brightness of 85% ISO. Finally, in a multistage APMP system, the distribution of chemicals at the impregnation stages has a substantial influence on final bleachability.

EXPERIMENTAL PROCEDURES

Wood furnish

Eucalyptus grandis was supplied from Argentina, and both *E. grandis* and *E. saligna* were supplied from Paraguay. Logs with the bark still on were shipped in sea containers and were placed in cold storage prior to processing. The logs were debarked, chipped, and screened at the Andritz Pilot Plant in Springfield, Ohio.

APMP

The screened chips were steamed for 20 min at atmospheric pressure and were compressed and macerated in an Andritz Model 560GS Impressafiner at a compression ratio of 4:1. At the discharge of the impressafiner, a chemical liquor containing sodium hydroxide, hydrogen peroxide, and stabilizers was injected to give specific chemical charges on the chips.

After the chemically impregnated chips were steamed for 20 min at atmospheric pressure, the same procedure was repeated for the second-stage impregnation. These chemically treated and macerated chips were retained for 40 min at 45°C prior to atmospheric, two-stage refining in an Andritz Model 401, 36 in. (914 mm), double-disc refiner.

CTMP

The chips were impregnated in the same manner as in the APMP process, except that Na_2SO_3 and sodium hydroxide were used instead of NaOH and H_2O_2 and only one impregnation stage was used. The impregnation stage was followed by pressurized cooking at 1.73 bar for 0.5 min with saturated water steam. Refining was carried out in an Andritz Model 418, 36 in., double-disc refiner at the same pressure. The pulp produced was further refined in the atmospheric Model 401 refiner.

Post-bleaching

All the pulps used for post-bleaching were pre-washed at a pH of 5.5. All bleaching experiments were performed on bench scale with the pulp in plastic bags. All bleachings were carried out at 65°C for 5 h at 15% consistency, with various charges of sodium hydroxide, hydrogen peroxide, and silicate. The silicate was added at the same amount by weight as was the hydrogen peroxide.

For each selected pulp, we first established the NaOH–H_2O_2 curve for optimum efficiency in hydrogen peroxide bleaching. Different hydrogen peroxide charges at optimum caustic conditions were then explored to determine the pulp's bleachability.

Pulp test

Pulp freeness was determined according to the Canadian standard freeness method. TAPPI procedures were followed for all of the handsheet tests. **TJ**

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