CMP and CTMP of a fast-growing tropical wood: Acacia mangium

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ABSTRACT

Pulping characteristics of young plantation-grown Acacia mangium *were investigated using alkaline sulfite chemimechanical pulping (CMP) and chemithermomechanical pulping (CTMP). Results were compared with those obtained from Canadian aspen, birch, and maple pulped under similar conditions. In general,* A. mangium *produced pulps that were comparatively inferior in physical and optical properties compared to those made from Canadian hardwoods. It was found that the CMP effluent from* A. mangium *was particularly high in solids content, total organic carbon, chemical oxygen demand, and toxicity with respect to the Canadian hardwoods studied.*

Application:

High-yield pulps from the fast-growing A. mangium *can be an important source of papermaking raw material for products requiring high bulk and moderate optical and mechanical properties.*

In recent years, Southeast Asian countries, such as Indonesia, Malaysia, Philippines, and Thailand, have been experiencing a phenomenal growth in production and consumption of paper products. The demand growth for the paper and paperboard, as well as other solid-wood products and fuel wood, will continue to develop because of the combined consequences of ever-increasing population, literacy rates, and quality of life. To maintain a sustainable development in this industry in the region, measures must be taken to prevent shortages in the supply of papermaking raw materials. To achieve this, plantations must be established to compensate for the dwindling supply from natural forests. A recent review *(1)* indicated that the ASEAN countries are indeed quite active in reforestation programs, using fast-growing species such as *Acacia, Eucalyptus, Gmelina,* and *Paraseianthes.* Among these species, *Acacia* and *Eucalyptus* appear to be the favorite choices because of their growth performance, disease resistance, and adaptability to various site conditions.

From a forestry point of view, growth performance is one of the most important criteria for species selection. However, the success of any reforestation programs would certainly depend on the quality of the wood produced. The definition of wood quality depends on the end usage of wood. For example, for construction use, mechanical properties are important, while for furniture manufacture and other finished products, machining characteristics are also important factors.

From a papermaker's viewpoint, the basic density of wood, fiber length, color, and extractives content are of primary concern. In spite of tremendous efforts made in the area of fast-growing trees, relatively few studies have been conducted on their pulping characteristics *(2–6).* Reports on high-yield and mechanical pulping have an important role in manufacturing printing and writing papers and paperboard. Therefore, the objective of this work is to examine the pulping behavior of one of the most prominent fast-growing species, *Acacia mangium,* using a chemimechanical and a chemithermomechanical process. Its pulp properties are compared with those made from Canadian hardwoods.

EXPERIMENTAL

Materials

The *Acacia mangium* trees used in the study came from a 12–13-year-old plantation located at Batu Arang in the state of Selangor (Malaysia). Chips were prepared at the Forest Research Institute Malaysia and shipped in air-dry condition to the Université du Québec à Trois-Rivières for processing. Canadian hardwoods, including trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), and mixtures of red maple (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.), were used for comparison. Chips of the Canadian hardwoods were produced locally using green logs. Prior to pulping, all chips were screened by a Rader chip classifier to remove the fine and over-thick particles. The accept range had a nominal thickness of 2–6 mm.

Chemimechanical pulping

In addition to *Acacia mangium,* two other Canadian hardwoods were also pulped for comparison: (a) the local hardwood of trembling aspen, a light-density wood, and (b) white birch, which has a density comparable to that of *Acacia mangium.* To minimize the effect of chip dryness on liquor penetration (*Acacia* chips were at 85% dryness), all chips were presoaked in cooking liquor overnight for about 18 hours.

The CMP conditions were as follows:

- liquor-to-wood ratio = 6
- liquor concentration = 48 g Na_2SO_3/L

Pulp type	CMP		CTMP	
Bleaching stage	P1	P2	P1	P2
DTPA, %	0.3	0.3	0.3	0.3
Magnesium sulfate, %	0.4	0.4	0.4	0.4
Sodium silicate, %	2.0	1.0	3.0	1.5
Sodium hydroxide, %	2.0	1.5	2.8	1.8
Hydrogen peroxide, %	3.0	2.0	3.0	2.0
Consistency, %	15	15	15	15
Temperature, °C	70	70	70	70
Time, min	60	60	60	60

I. Bleaching conditions for CMP and CTMP

- pH = 10.5
- cooking temperature (T_c) = 160°C
- time to reach T_c = 40 min
- time at T_c = 45 min.

Chemical treatment was carried out in two laboratory digesters (M/K System Inc., Model M/K 409) of 6.5-L capacity each; the digesters were equipped with a liquor circulation system and indirect electric heating. Six hundred ovendry (o.d.) grams of chips were used in each cook. In addition, 50 g of chips contained in a stainless steel basket were also cooked along with other chips for determining pulp yield. After cooking, the chips were withdrawn from the digesters and soaked in cold water to stop further chemical reaction.

The cooked chips were defibrated in a Sunds Defibrator CD300 pilot refiner using a disk clearance of 0.5 mm for both flat and conical disks. The coarse pulp was thoroughly washed immediately after the defibration. Because of the small quantity of pulp produced (about 500 g), further refining of the coarse pulp was done in a PFI mill in which the refining consistency was 10%. Each pulp sample was refined to 3–4 levels of freeness. The cooked chips used for pulp yield determination were disintegrated in a 4-L Waring blender. Following washing, the pulp was dried at 105°C, and the yield was determined.

Chemithermomechanical pulping

Prior to processing, the air-dry chips of *Acacia mangium* were presoaked in water at room temperature for approximately 24 hours to ensure that they were saturated with water. Chemithermomechanical pulping (CTMP) was conducted using a Sunds Defibrator CD300 pilot-plant unit. In the process, the chips were presteamed at atmospheric pressure for 10 min and fed by means of a plug-screw feeder (compression ratio=2) into an impregnator located inside the digester of the unit.

The chips took up the treatment liquor as they left the feeder to enter the impregnator. The pulping solution consisted of sodium sulfite and sodium hydroxide. The uptake represented 3% of each chemical charge on an o.d. basis of chips. The impregnated chips were steamed at 130°C within the digester for 15 min before being refined under pressure at that temperature. The discharge consistency was about 15%. The first-stage pulp, which had a freeness of about 600 mL, was further refined under atmospheric pressure to various levels of freeness. All pulps were washed in a fine cotton-cloth basket loaded in a domestic washing machine.

Pulp characterization

All experimental pulps were disintegrated in hot water to remove latency. Freeness measurements, handsheet formation, and optical and mechanical property determinations were conducted in accordance with CPPA test methods. The content of acidic groups in pulp was determined using a method based on conductometric titration as described by Katz *et al. (7).*

Bleaching of pulps

Prior to bleaching, the pulps were pretreated with 0.5% diaminetriethylenepentaacetic acid (DTPA) at 80°C and 5% consistency for 5 min in a standard pulp disintegrator. The pulp was filtered, well washed with deionized water, and finally thickened to a consistency of about 40% using a hydraulic press. Two stages of peroxide bleaching were conducted for the CMP and CTMP. The conditions used are presented in **Table I.** The samples were heated in a water bath maintained at 70°C. After bleaching, residual peroxide (by titration with sodium thiosulfate) and pH were measured, and the pulp was neutralized using sodium metabisulfite to prevent yellowing.

Analysis of CMP spent liquors

At the end of each cook, about 1 L of spent liquor was collected from the sampling valve located beneath the digester. In the sampling process, the first 10–20 mL were discarded. The sample collected for analyses did not include the liquor that remained in the chips. However, when exact figures of each species—expressed in terms of unit weight of raw material—are required, the fraction of liquor remaining in the chips should be extracted and included in the test samples.

The analyses were conducted by the environment laboratory at the Université du Québec à Trois-Rivières. The solids contents (suspended solids and dissolved solids), color, total organic carbon (TOC), chemical oxygen demand (COD), and biochemical oxygen demand (BOD_5) were determined following the standard methods described in the literature *(8).* Toxicity of the liquors was evaluated in accordance with the Microtox method developed by Microbics Corp. in California.

RESULTS AND DISCUSSION

Wood properties

Comparative data on the physical and chemical characteristics of wood used are presented in **Table II.** As seen in the table, *Acacia mangium* is a moderately dense wood having a density similar to that of the Canadian white birch. It has relatively short fibers with a moderately thick cell wall. The most striking difference between *A. mangium* and the most commonly used Canadian hardwoods (i.e., *P. tremuloides* and *B. papyrifera*) is that the former has substantially higher lignin content than the latters. *A. mangium* also has a higher solubility in water and an ethanol–benzene mixture. However, the *Acacia* wood has a much darker color than the Canadian woods; this will certainly have an adverse effect on the bleaching responses as well as the attainable pulp brightness.

Characteristic	*Acacia mangium*	*Populus tremuloides*	*Betula papyrifera*	*Acer** (maple)
Basic density, g/cm^3	0.43	0.37	0.48	0.66
Fiber length, mm	0.90	0.94	1.20	0.80
Fiber diameter, µm	22.3	18.0	18.0	20.0
Cell wall thickness, µm	2.9	2.2	3.2	4.3
Length/width ratio	40	51	66	40
Lignin, %	25.6	18.1	18.4	24.3
Pentosans, %	17.35	17.20	24.00	19.20
Hot-water solubility, %	6.16	2.75	2.80	4.70
1% NaOH solubility, %	16.41	19.30	19.00	16.70
DCM solubility, %	1.53	1.50	-	-
Ethanol–benzene solubility, %	4.83	3.70	3.60	2.60

*Data on chemical composition taken from Berzins, V., 1966: *Chemical Composition of Woods,* Paprican Research Note No. 61

II. Characteristics of wood used in the study

Pulp	Pulp yield, %	Sulfonate, mmol/kg	Carboxylate, mmol/kg	Total, mmol/kg
A. mangium	83	93.7	77.9	171.6
CMP	-	95.7	83.5	179.2
P. tremuloides	86	51.7	189.8	241.5
CMP	-	51.2	194.0	245.2
B. papyrifera	85	44.8	206.3	251.1
CMP	-	44.2	218.5	262.7
A. mangium	-	1.7	134.8	136.5
CTMP	-	2.1	127.1	129.2
Mixed hardwood	-	9.4	144.5	153.9
CTMP	-	5.2	153.3	158.5

III. Sulfonate and carboxylate groups in CMP and CTMP

Characteristics of chemimechanical pulps

In CMP, the unscreened pulp yields for *A. mangium, P. tremuloides,* and *B. papyrifera* were 83.2%, 86.1%, and 85.6%, respectively. The higher water solubility of *A. mangium* was responsible for its lower pulp yield. Sulfite cooking results in the formation of carboxylate and sulfonate groups in the pulps produced. Handsheet strength and optical and wet-web properties depended on the total content of sulfonate and carboxylate of the pulps *(9).*

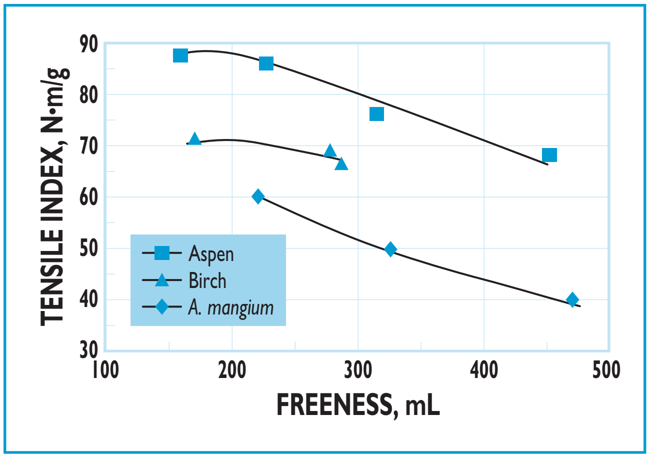
Table III shows that *A. mangium* had a lower total ion content than the two Canadian hardwoods, indicating the inferior bonding capacity of *Acacia* fibers. Some papermaking properties are illustrated in **Figs. 1–8.** *A. mangium* had significantly lower tensile and burst strengths when compared to the Canadian hardwoods (Figs. 1 and 2). However, it had comparable performance in tear index, as indicated in Figs. 3 and 4. It is well known that tensile strength directly correlates with sheet density. However, the tensile–density relationship is species dependent, as revealed in Fig. 5.

Note that for a given value of handsheet density, *A. mangium* exhibited substantially lower bonding capacity compared to *B. papyrifera.* Although sheets made from *A. mangium* had similar bulk as those from *B. papyrifera* (Fig. 6), the former had a much higher light-scattering coefficient than the latter, again implying poor interfiber bonding of *Acacia* fibers (Fig. 7). On the other hand, the thin-walled *P. tremuloides* yielded much denser sheets with low bulk and scattering coefficient.

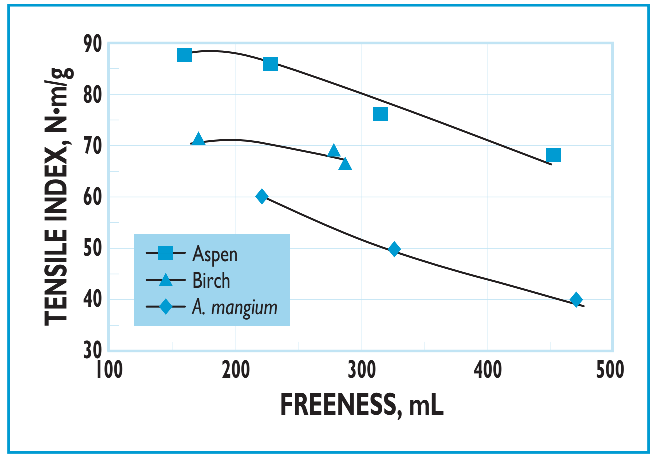
Unbleached CMP of *A. mangium* had a brightness (~30%) that was considerably lower than that for *B. papyrifera* (~53%), as shown in Fig. 8. Using two-stage peroxide bleaching with a total peroxide charge of 5%, we failed to increase the brightness above 60% for the *Acacia* pulp. The poor bleaching response of *A. mangium* is believed to be attributable to the inherent color of its wood; this represents a real challenge for forest biologists to produce lighter-color wood for papermaking.

Characteristics of CMP spent liquor

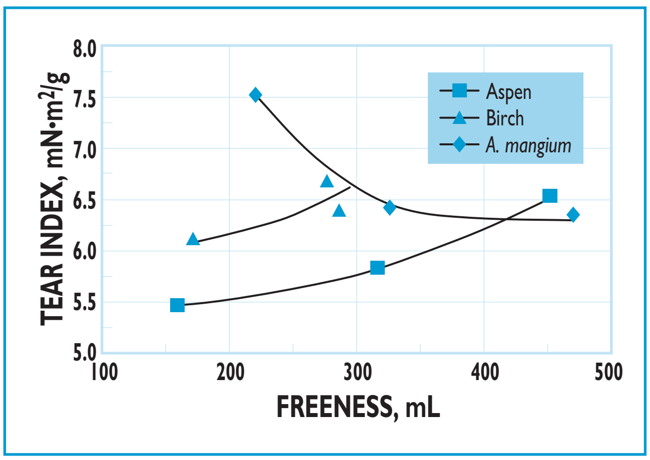
Analyses of the spent pulping liquors has yielded important information on the potential environmental impacts of the species used in pulping. **Table IV** reveals that, when cooked under similar conditions, *Acacia mangium* produced an effluent that generally placed a much heavier burden on the environment compared with *P. tremuloides* and *B. papyrifera.* The table also shows that, in spite of its particularly high load in total solids, total organic carbon, and COD, *A. mangium* showed a BOD_5 load that was lower than those for the two



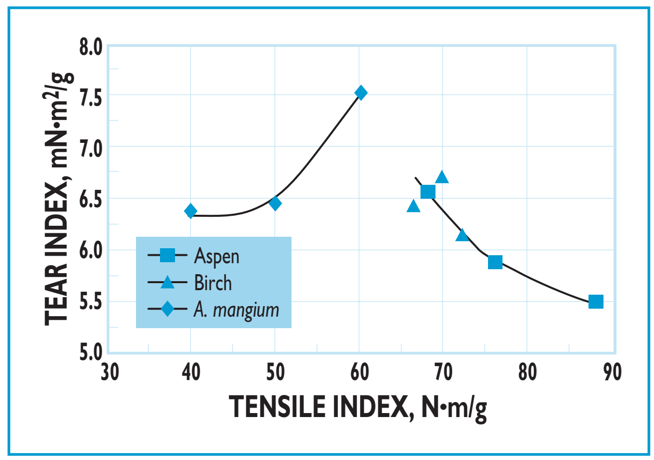
1. Tensile index as a function of freeness for CMP



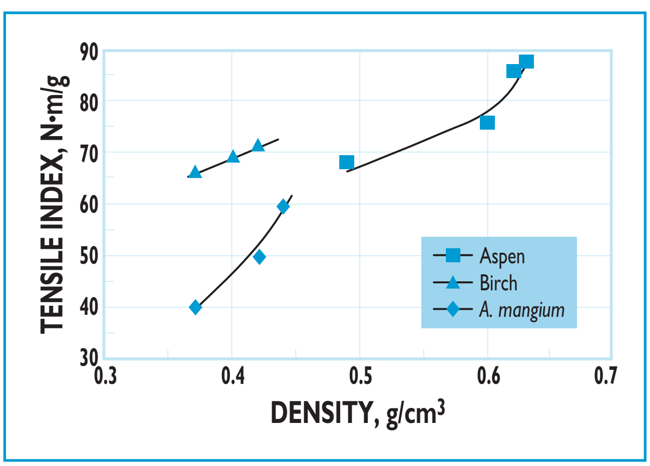
2. Burst index as a function of freeness for CMP



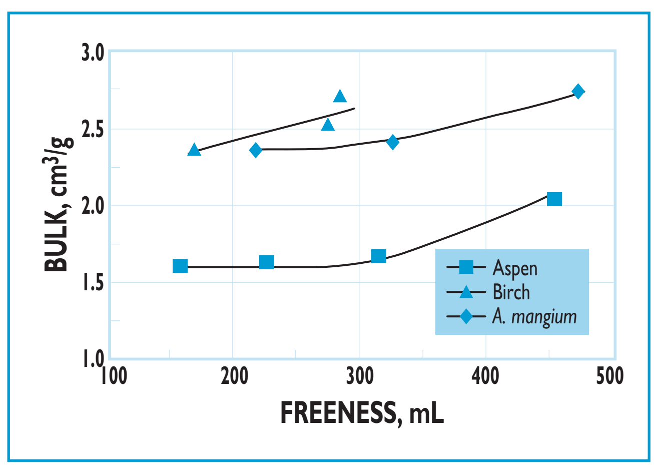
3. Tear index as a function of freeness for CMP



4. Tear index vs. tensile index for CMP



5. Tensile index vs. handsheet density for CMP



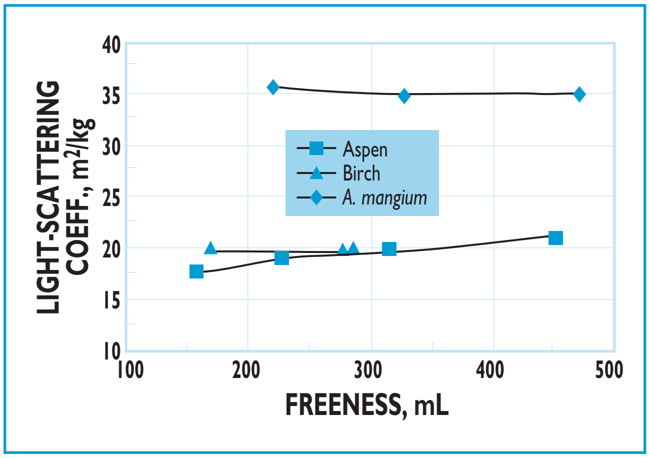
6. Bulk vs. freeness for CMP

Canadian hardwoods studied, indicating that this tropical species has different chemical properties.

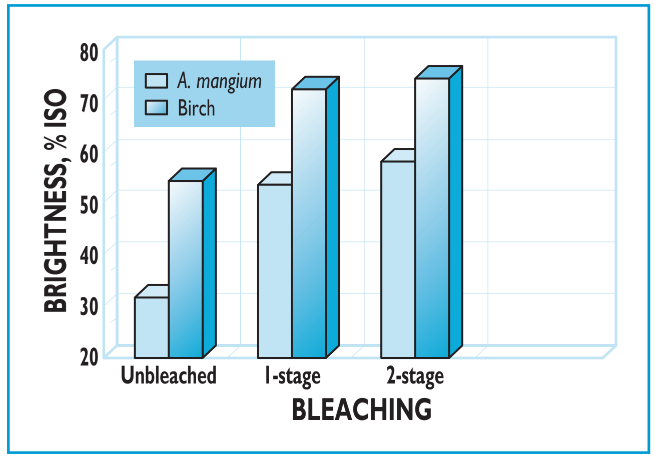
The property that drew our attention the most is that the spent liquor of *A. mangium* was about 40% more toxic than those of the two Canadian hardwoods. Also of great concern is that *Acacia*'s effluent had a color that was nearly 30 times darker when compared to the two Canadian species investigated. These findings present a major consideration for both forest biologists and mill superintendents responsible for wood supply.

Characteristics of chemithermomechanical pulps

In this work, *A. mangium* was compared with a mixture of three common Canadian hardwoods, which



7. Scattering coefficient vs. freeness for CMP



8. Hydrogen peroxide bleaching of CMP

were composed of equal proportions of *P. tremuloides, B. papyrifera,* and *Acer* L. (a mixture of sugar maple and red maple). This mixture, consisting of three species that are considered to be light, moderate, and dense, respectively, could produce pulps with relatively good bulk and strength properties. Some of the pulp characteristics are presented in **Figs. 9–16.**

A. mangium was slightly weaker than the mixed hardwoods in tensile and burst indices (Figs. 9 and 10) over a wide range of freeness. In fact, we have observed only a small difference in acidic groups between the two types of CTMP (Table III). However, *A. mangium* had a substantially lower tear index, particularly in the lower freeness range (Figs. 11 and 12), which is probably due to its relatively short fibers (Table I). Again, we observed (in Fig. 13) that *A. mangium* exhibited a tensile–density relationship that was different from that for the mixed hardwoods by having poorer bonding strength for a given density. This was observed in spite of the fact that handsheets made from *A. mangium* showed a somewhat lower bulk for a given level of freeness, as illustrated in Fig. 14.

Similar to its CMP counterpart, *Acacia*'s CTMP gave a greater light-scattering coefficient (Fig. 15) and had particularly poor brightness (Fig. 16). However, it showed good response to one-stage 3% peroxide bleaching by gaining nearly 30%. Because of *Acacia*'s very low initial brightness (27%), it required another 2% peroxide in a second-stage bleaching to reach a brightness above 60%—which is suitable for newsprint production. To produce pulp of higher brightness from *A. mangium,* more aggressive bleaching sequences, involving oxygen, ozone, and chlorine dioxide, for example, would be required.

Characteristic	*Acacia mangium*	*Populus tremuloides*	*Betula papyrifera*
Suspended solids, mg/L	70	72	75
Dissolved solids, mg/L	78,000	69,600	69,800
Total solids, mg/L	79,300	70,100	70,100
COD[a] (unfiltered), mg/L	45,650	37,900	37,175
COD (filtered), mg/L	44,625	35,625	35,900
BOD_5[b] (unfiltered), mg/L	11,700	13,900	13,000
BOD_5 (filtered), mg/L	10,000	12,800	11,850
TOC[c], mg/L	14,365	10,910	10,125
Toxicity (Microtox), % v/v	0.29	0.48	0.51
Color (apparent)	151,800	4,400	13,950
Color, Pt-Co units	147,100	3,760	7,140
pH	8.12	6.97	6.93

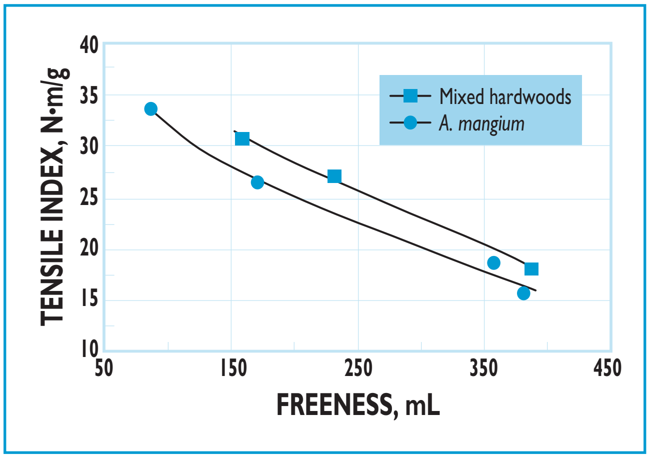
[a]Chemical oxygen demand
[b]Biochemical oxygen demand
[c]Total organic carbon

IV. Characteristics of CMP spent cooking liquor

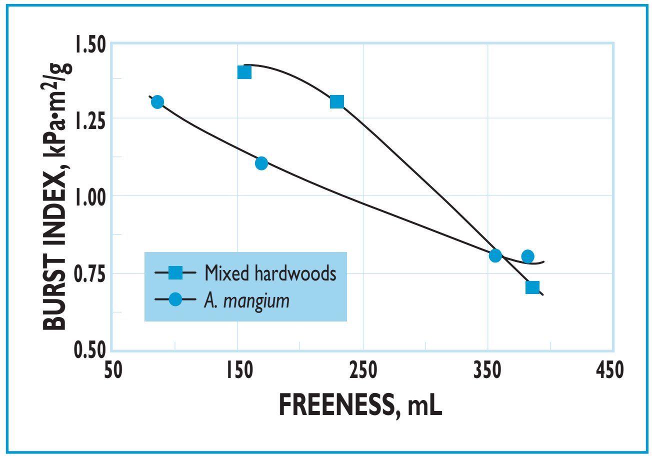
CONCLUDING REMARKS

Acacia mangium, a moderately dense tropical wood, produces chemimechanical pulp (about 83% yield) with significantly lower tensile, burst, and tear strengths when compared to Canadian hardwoods such as *P. tremuloides* and *Betula papyrifera* cooked under similar conditions. The pulps produced from *A. mangium* are particularly low in brightness and have a low response to peroxide bleaching. The spent cooking effluent from this tropical species has high solids contents and dark color and is particularly toxic when compared to the two Canadian hardwoods studied.

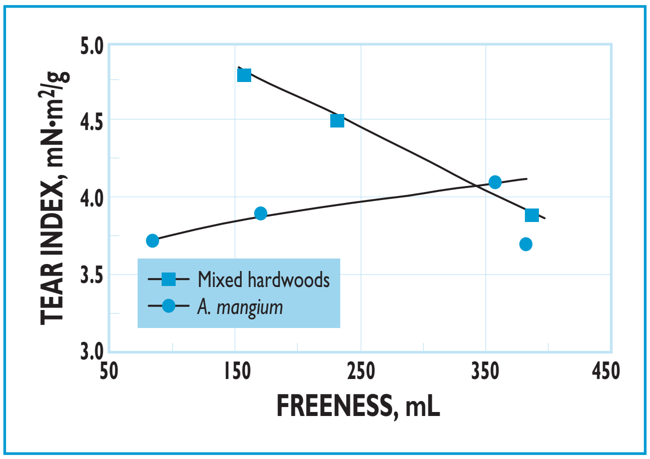
The pulp produced from *A. mangium* requires a reinforcement component of long fibers to improve its mechanical properties.



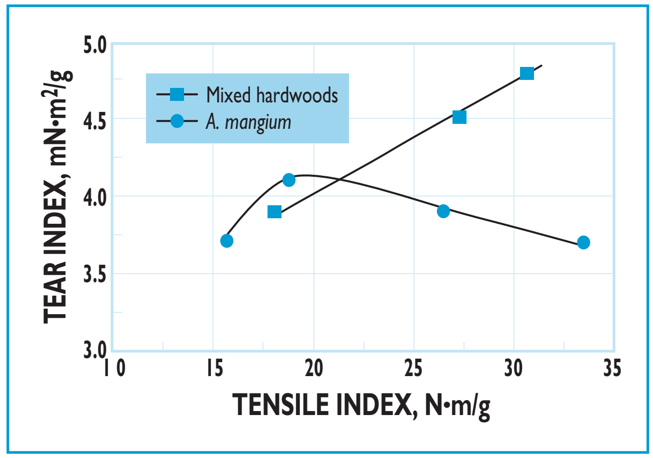
9. Tensile index as a function of freeness for CTMP



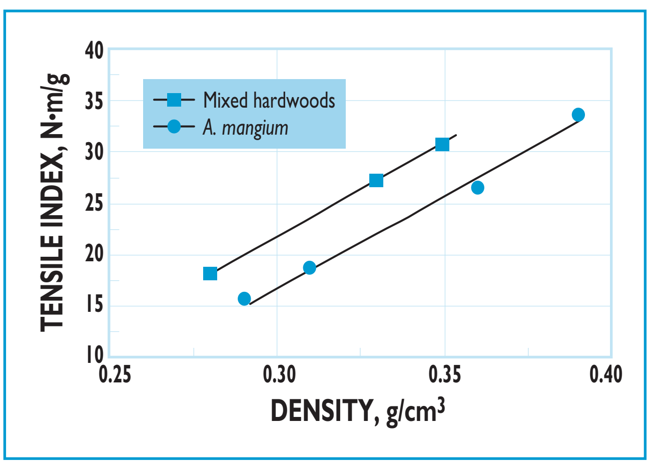
10. Burst index as a function of freeness for CTMP



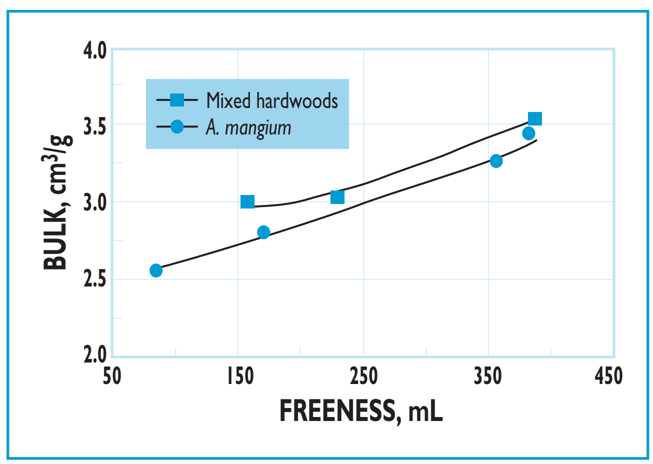
11. Tear index as a function of freeness for CTMP



12. Tear index vs. tensile index for CTMP



13. Tensile index vs. handsheet density for CTMP



14. Bulk as a function of freeness for CTMP

Its relatively high bulk value made it suitable for products where high bulk is of importance—such as paperboard.

On one hand, we recommend that research on pulping of *A. mangium* should be conducted extensively using trees from different sources to identify the possible influences of growth environment. On the other hand, efforts on tree improvement using genetic engineering should also be made to produce clones that are more suitable for papermaking, e.g., producing trees having low lignin and extractives contents. **TJ**

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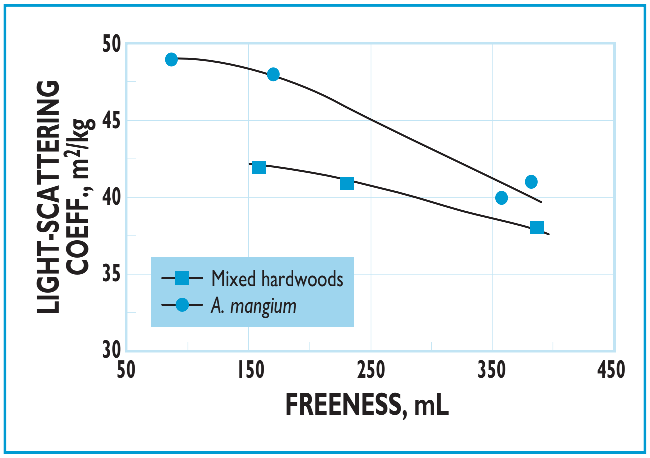
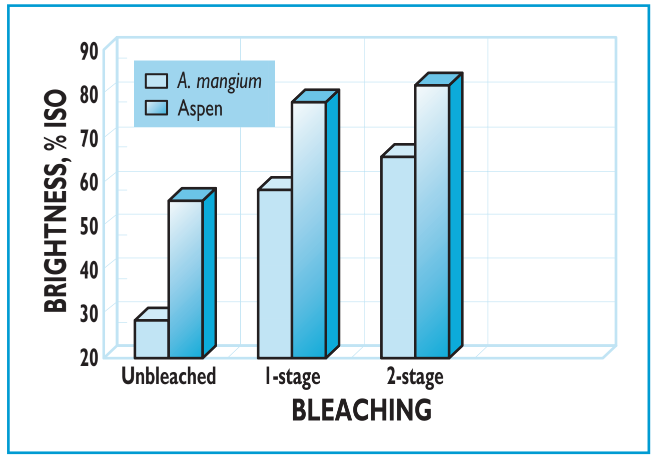


15. Scattering coefficient as a function of freeness for CTMP



16. Hydrogen peroxide bleaching of CTMP

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LITERATURE CITED

1. Valade, J. L. and Law, K. N., *Potential use of* Acacia *species as a raw material for the pulp and paper industry,* paper to be presented at the First International Conference On Acacia Species, March 16–18, 1998, Penang, Malaysia.
2. Chang, F. J., Tech. Bulletin No. 163, Dept. of Forestry, National Chung-Hsing University, Taiwan, 1977.
3. Logan, A. F. and Balodis, V., *The Malaysian Forester* 45(2): 217(1982).
4. Ku, Y. C. and Cheng, S. T., *Pulp & Paper* 73(8): 5(1983).
5. Chen, O. B. and Wu, K. T., *Quarterly J. of Chinese Forestry* 22(2): 75(1989).
6. Yamada, N., Khoo, K. C., and Mohd. Nor Mohd. Yusoff. *J. Tropical Forest Sci.* 4(3): 206(1992).
7. Katz, R., Beatson, R. P., and Scallan, A. M., *Svensk Papperstid.* 87(6): R48(1984).
8. Anon. in *Standard Methods for the Examination of Water and Wastewater* (A. E. Greenberg, L. S. Clesceri, and A. D. Eaton, Eds.), 18th edn., American Public Health Association, Washington, 1992, pp. 2-2 to 5-14.
9. Heitner, C. and Atack, D., *Proceedings of the International Sulfite Conference,* TAPPI PRESS, Atlanta, 1982, p. 219.

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