Kraft Pulp from Acacia Mearnsii grown in Southern India

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Pulping characteristics of 14-year old Acacia Mearnsii were investigated using kraft pulping and C/D-E_{OP}-D-D bleaching. Results were compared with those obtained from eucalyptus, poplar, and bamboo pulped under similar conditions. We observed that Acacia Mearnsii wood had relatively low lignin content and high basic as well as bulk density. It gave high unbleached-pulp yield at low kappa number. It could be easily bleached to brightness levels of about 88% with low bleach chemical consumption, high bleached-pulp yield, and high strength properties. Fast-growth rate, adaptability to varying climatic conditions, and multi-utility nature of its wood make Acacia Mearnsii economically important tree.

Keywords: Acacia Mearnsii, Black wattle, Pulping, Bleaching, Papermaking, Strength properties

INTRODUCTION

The recent economic developments in Asia are leading towards a higher levels of education and quality of life of its people. There has been a phenomenal increase in production as well as consumption of paper products in China and many southeast Asian countries like Thailand, Malaysia, Indonesia, and Phillippines. The demand of paper products is also picking up in the south Asian region. However, the most important concern before the paper industry in the south Asian region is a sustained supply of fibrous raw materials.

Availability of pulpwood from natural forest resources is declining continuously due to dwindling forest area on one hand and increasing other social demands on the forest resources of the rapidly growing population on the other hand. Use of agricultural residues in papermaking furnishes has increased and relieved some pressure from the forest resources. Though the agricultural residues are environmenta--lly benign, but their collection, handling and storage are problematic and expensive. In addition, there have limitations in the quality of paper produced.

Tremendous efforts are underway to plant fast-growing trees to meet the pulpwood demands. Many species of eucalyptus, poplar, and acacia have been planted on large areas in Asia. There are many criteria for species selection for any reforestation program such as the growth performance, the quality of the wood produced, and its overall impact on the ecosystem. From a papermaker's viewpoint, the attributes of primary concern are the basic density of wood, proportions of holocellulose and lignin, fiber length, color, and extractives content.

Some species of acacia have proven suitability to commercial development for timber, pulpwood, tannin, and a wide range of purposes such as environmental amelioration, fuel wood, stock fodder and human food. Acacia is a diverse and enormous genus with more than a thousand species currently recognized. Species of acacia are dispersed widely in tropical and subtropical regions of Australia, South America, Asia, and Africa (1-7). Acacias exhibit great diversity in growth form, in longevity, and other important morphological, biological and ecological attributes. They are adapted to a wide range of soil types and climates, including drought-and frost-prone areas. Acacias have the ability to improve soil fertility through nitrogen fixation. Many species of acacia produce good quantities of wood biomass. Acacias are increasingly favored over eucalyptus as large-scale plantation species because of their nitrogen-fixing and soil-protecting abilities. Eucalyptus and poplar are known to degrade the land. Acacia plantation has been taken up in a big way in many countries of Asia, Australia, Africa and Central and South America. According to 1998 estimates (8), large-scale plantations of fast growing acacia species have already been established in Indonesia (> 430,000 ha), China (> 200,000 ha), Malaysia (> 100,000 ha), Vietnam (> 66,000 ha), Philippines (> 45,000 ha), and India (> 45,000 ha) for the production of paper pulp. In India, acacia has been planted in the states of Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu, and Uttar Pradesh.

A number of studies have been conducted on pulping characteristics of acacias (9-14). These studies identify potential acacia species for commercial exploitation as Acacia mangium, Acacia auriculiformis, Acacia aulacocarpa, Acacia crassicarpa, and Acacia mearnsii. *Acacia Mangium* is a major plantation species with a vigorous growth in the humid tropical lowlands of Asia. It is widely used for kraft pulping in Indonesia, Malaysia, China and Vietnam. Law and Daud (12) compared properties of CMP and CTMP of *Acacia Mangium* with the pulp made from Canadian hardwoods. They observed that in terms of physical and optical properties, pulps made from *Acacia Mangium* were generally inferior to those made from Canadian hardwoods. Further, the CMP effluent from *Acacia Mangium* was particularly high in solids content, total organic carbon, COD, and toxicity with respect to the Canadian hardwoods. *Acacia Auriculliformis* or Darwin Black Wattle is another fast growing variety of acacia that has been widely introduced in Asian and African countries. The tree is used for the cultivation of the lac insect in India. The wood from about ten-year old trees is suitable for pulping by kraft or neutral sulfite semichemical process. The Mysore Paper Mills in India uses *Acacia Auriculliformis* and *Acacia*

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Hybrid Clonal plantation wood for making high-yield cold soda refiner mechanical pulp (CSRMP) for newsprint manufacture. Acacia mearnsii, plantation grown in South Africa, is used for kraft and soda-AQ pulp production in South Africa. Kraft pulp mills in Japan also use Acacia mearnsii wood imported from South Africa (9).

The objective of this work is to examine the pulping behavior of one of the most prominent fast-growing species, *Acacia Mearnsii De Wild* or Black Wattle. This belongs to the species that display fast or moderately fast growth rates, produce high or moderately high volumes of wood biomass, and have potential to be cultivated over a reasonably wide geographic area. *Acacia Mearnsii De Wild* (Synonym: *Acacia Decurrens Var. Mollis, Acacia Mollissima*) is an evergreen tree, with a moderate rate of growth to 5 to 20 m tall or more and 0.1 to 0.6 m in diameter (3, 4). Its crown is conical or rounded and stems are without spines or prickles. The dried bark contains from 30 to 54 percent tannin used mainly for leather tanning. The bark is also used for wood adhesives and flotation agents (3).

MATERIALS AND METHODS

Wood

For the present study, we used *Acacia Mearnsii* wood of about 14-year old trees from forests in the ooty region of the state of Tamil Nadu in south India. For comparison, we included results of pulping studies conducted on eucalyptus (*Eucalyptus Hybrid*), poplar (*Poplus Deltoides*), and bamboo (*Dandrocalamus Strictus*), which are currently used in different integrated kraft pulp and paper mills of Ballarpur industries limited (BILT) (15).

Debarked wood logs were chipped in a laboratory chipper and screened in a laboratory screening system. The accepted chips (passing through 25x25mm screen and retained on 4x4mm screen) were air-dried and stored in polythene bags for use in subsequent experiments. Basic density of wood was determined by dividing the oven dry weight of chips by the green (maximum swollen) volume of the chips. The bulk density was obtained by dividing weight of air-dried chips by their bulk volume.

Proximate chemical analysis

Table 1
Proximate analysis

Characteristic	Acacia	Poplar	Eucalyptus	Bamboo
Ash, %	0.465	0.99	0.83	2.12
1% NaOH Solubility, %	19.82	17.4	13.3	22.71
Cold water solubility, %	3.75	0.86	2.96	3.15
Hot water solubility, %	5.7	1.8	5.08	6.32
Alcohol-Benzene solubility, %	3.3	1.46	1.87	3.3
Pentosan, %	15.15	16.7	15.88	15.65
Lignin, % extractive-free wood	19.63	21.71	24.96	23.37
Holocellulose, % extractive-free wood	76.4	77.32	69.66	73.93
Basic density of wood, kg/m^3	660	430	490	530
Bulk density of chips, kg/m^3	257	196	220	258

Table 2
Pulping conditions

	Acacia	Poplar	Eucalyptus	Bamboo
Active alkali (as Na_2O), %	17	15.5	17.5	16.5
Sulfidity, %	23.4	23.8	23.8	22.9
Unbleached Kappa No.	18.6	21.2	22.9	21
Unbleached Yield, %	54.3	56.2	46.6	52.7
Rejects, %	0.45	0.21	0.27	0.33
Residual alkali (as Na_2O), g/l	11.94	11.7	11.4	13
Unbleached Pulp Viscosity	32.84	32.7	15.5	33.1
Pulpwood productivity, kg/m^3	358	242	228	279

For proximate chemical analysis, the wood meal was prepared by cutting the chips into small pieces and subsequently grinding with the help of a mortar and pestle. The ground material was screened and -40+60 mesh (0.25 to 0.4mm) fraction was used for the analysis. Appropriate TAPPI methods (16) for used in the analyses. Ash was determined using method T 211 om-93, 1% NaOH solubility using T 211 om-98, cold and hot water solubility using T 207 cm-99, and Alcohol-benzene solubility using T 204 cm-97. For determination of pentosans, lignin, and holocelluloses, the wood meal was first extracted with alcohol-benzene following the method T 12 m-59. Pentosan in wood was determined using method T 19 m-50 and lignin (not hydrolyzed by acids) using method T 13 m-54. To determine holocellulose content, extractive-free wood sample was treated with sodium chlorite solution in acidic medium to remove lignin from the sample (17). 75-80 ml hot distilled water, 2 g sodium chlorite, and 0.75 ml acetic acid were added to 2 g extractive free wood dust in a 250 ml stoppered flask. The flask was placed in a thermostatic water bath at 70^0 C. After 45 min, another 1 g sodium chlorite and 0.6 ml acetic acid were added. These additions were repeated four times after every 45 min. The white residue in the flask was cooled in an ice bath, filtered through a G-2 crucible, washed thoroughly with cold distilled water and weighed to determine the mass of holocellulose. The proximate analyses are given in **Table 1.**

Pulping

We used a 6-L, electrically heated, tumbling (1.5 revolutions per minute) laboratory digester for kraft cooking of chips. The liquor to wood ratio of 3:1 was used in pulping. The digester temperature was raised from ambient conditions to 130 °C in 60 min, held there for 60 min, and finally raised to 160°C in 60 minutes. The digester was maintained for 105 min at the maximum temperature of 160 °C. The non-condensable were vented during the cook when the temperature reached about 105°C. At the end of each cook, the digester was depressurized and emptied into a 15-L container. The black liquor was collected and analyzed for residual alkali.

The cooked chips were disintegrated in a laboratory agitator at 3% consistency for 20 minutes and washed thoroughly over a 250-mesh screen with warm water and finally with hot water until the filtrate was colorless. The washed pulp was then screened over a 1.5 mm-slots Somerville screen. The weights of rejects and accepts from the screen were taken and unscreened and screened yields were calculated. The accepted portion of the pulp was dewatered on a 250-mesh screen and

Canadian standard freeness (CSF) of pulp	Tappi T 227 om-99
Grammage of paper	Tappi T 410 om-98
Thickness of paper	Tappi T 411
Tear strength	Tappi T 414 om-98
Tensile strength	Tappi T 494 om-96
Burst strength	Tappi T 403 om-97
Folding endurance	SCAN P-17:77
Air resistance (Gurley method)	Tappi T 460 om-96

Table 3
Bleaching conditions and properties of bleached pulps

	Acacia	Poplar	Eucalyptus	Bamboo
C/D STAGE (Room temperature, Consistency 3%, Residence time 45 min)				
Chlorine charge (as Cl_2), % O.D pulp	4.09	4.66	5.04	4.62
Cl_2: ClO_2 ratio	90:10	90:10	90:10	90:10
pH (initial)	1.97	1.65	1.45	1.78
Residual chlorine, %	0.017	0.005	0.02	0.114
E_{OP} STAGE (Alkali charge 2.5%, H_2O_2 charge 0.5%, Temperature 75 °C, Consistency 10%, Residence time 120 min, Oxygen pressure, 5 bar for 30 min and 2.5 bar for 90 min)				
pH initial/final	11.95/10.7	11.8/10.6	11.8/10.5	11.9/10.8
K. No.	1.4	1.5	1.8	1.7
D1STAGE (Temperature 70 °C, Consistency 10%, Residence time 180 min)				
ClO_2 charge, %	1.0	1.2	1.2	1.0
pH final	3.8	4.0	3.8	3.7
Residual ClO_2, %	0.055	0.074	0.074	0.0729
D2STAGE (Temperature 70 °C, Consistency 10%, Residence time 180 min)				
ClO_2 charge, %	0.2	0.2	0.2	0.3
pH final	4.8	4.9	4.8	3.3
Residual ClO_2, %	0.028	0.024	0.027	0.037

Table 4
Clark Fiber classification (Mass percentage)

	Acacia		Poplar		Eucalyptus		Bamboo	
	Unbleached	Bleached	Unbleached	Bleached	Unbleached	Bleached	Unbleached	Bleached
+30 mesh							64.6	64.5
-30+50 mesh	66.6	64.7	64.3	65.9	52.4	56.9	7.7	8.6
-50+100 mesh	15.2	19.5	15.4	16.7	24.1	23.0	10.5	10.7
-100 mesh	18.2	15.8	20.3	17.4	23.5	20.1	17.2	16.2

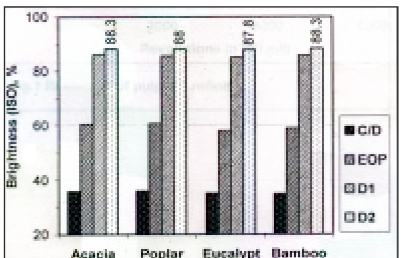

Fig.1 Brightness of pulp at different stages of bleaching.

stored in polythene bags. The screened pulp was analyzed for kappa number and CED Viscosity using Tappi methods T 36 om-99 and T 230 om-99 respectively. Results of pulping experiments are given in **Table 2**.

Bleaching

The screened pulp was bleached in the laboratory using C/D-E_{OP}-D_1-D_2 sequence. The bleaching conditions and the properties of the bleached pulps are given in **Table 3**. Chlorination and chlorine dioxide stage bleaching operations were carried out in polythene bags. A thermostatic water bath was used for maintaining the desired temperature. The E_{op}-stage was carried out at 75°C in a tumbling type digester that was connected to an oxygen cylinder. Pulp with required amounts of alkali and hydrogen peroxide was charged to the digester. Oxygen pressure was maintained at 5 bar for first 30 minutes and at 2.5 bar for the remaining 90 minutes.

Evaluation of pulps

Both unbleached and bleached pulps were analyzed in a Clark fiber classifier using the Tappi method T 233 cm-99. Table **4** shows the results of fiber classification. For evaluation of physical properties, we refined unbleached and bleached pulps in a PFI mill to different freeness levels using method T 248 sp-00. We prepared standard handheets of 60±2 g/m^2 in a laboratory sheet making machine following the standard procedure T 205 sp-95. Standard procedure T 220 sp-96 was used for physical testing of the handsheets. The following standard methods (16, 18) were used to determine various properties of the handsheets.

RESULTS AND DISCUSSION

Chemical analysis

The proximate analysis data shown in Table 1 reveal that the chemical composition of acacia wood is not significantly different from other raw materials. Differences of such magnitudes are possible within single species as the chemical composition depends on tree age as well as position of wood in the trunk. However, we can make the following general observations:

- The acacia wood has low ash content and there should be no serious scaling problems in evaporators used for concentrating the black liquor resulting from the pulping of acacia.

- Acacia has slightly higher alcohol-benzene solubility than poplar or eucalyptus has and that is undesirable from the point of view of pitch related problems.

- The acacia wood has high values of both the basic density and the bulk density of chips that should result in a higher amount of pulp produced per digester.

Response to pulping and bleaching

After a few trial cooks, we observed that an active alkali dose of 17% (expressed as Na_2O) on oven dry wood basis gave satisfactory yield and brightness levels for the bleached pulp. The pulps obtained from three batches cooked under identical conditions were reproducible with kappa number 18.6±0.1 and unbleached yield 54.3±0.2%.

As shown in Table 2, active alkali charged for pulping were slightly different for different raw materials as we attempted to select pulping conditions that gave high value of pulp yield and high brightness of bleached pulp. Alkali charge influences pulping economics, but not as much as pulp yield or pulpwood productivity and even large variations in alkali requirement do not greatly affect the overall cost per tonne of pulp (19). The acacia pulp had a lower kappa number than the kappa number of other pulps, yet it gave slightly higher unbleached yield than the yields for eucalyptus and bamboo.

Pulpwood productivity is defined as the mass of oven dry pulp produced from a cubic meter of green wood. It is the product of the basic density of wood and the pulp yield. Pulp productivity of acacia mearnsii wood is considerably higher than the productivity of other raw materials. Screen rejects, expressed as a percentage of the total

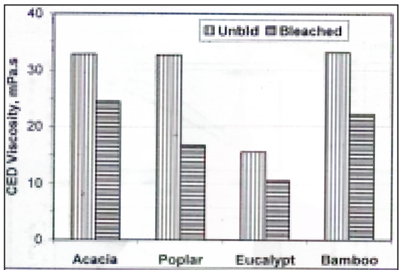

Fig.2 Cupriethylenediamine (CED) viscosity of unbleached and bleached pulps

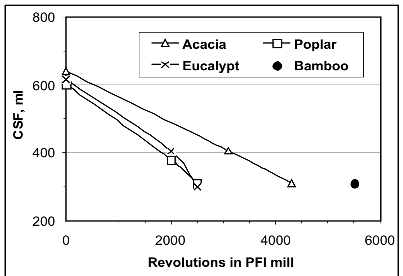

Fig.3 Response of pulps to refining.

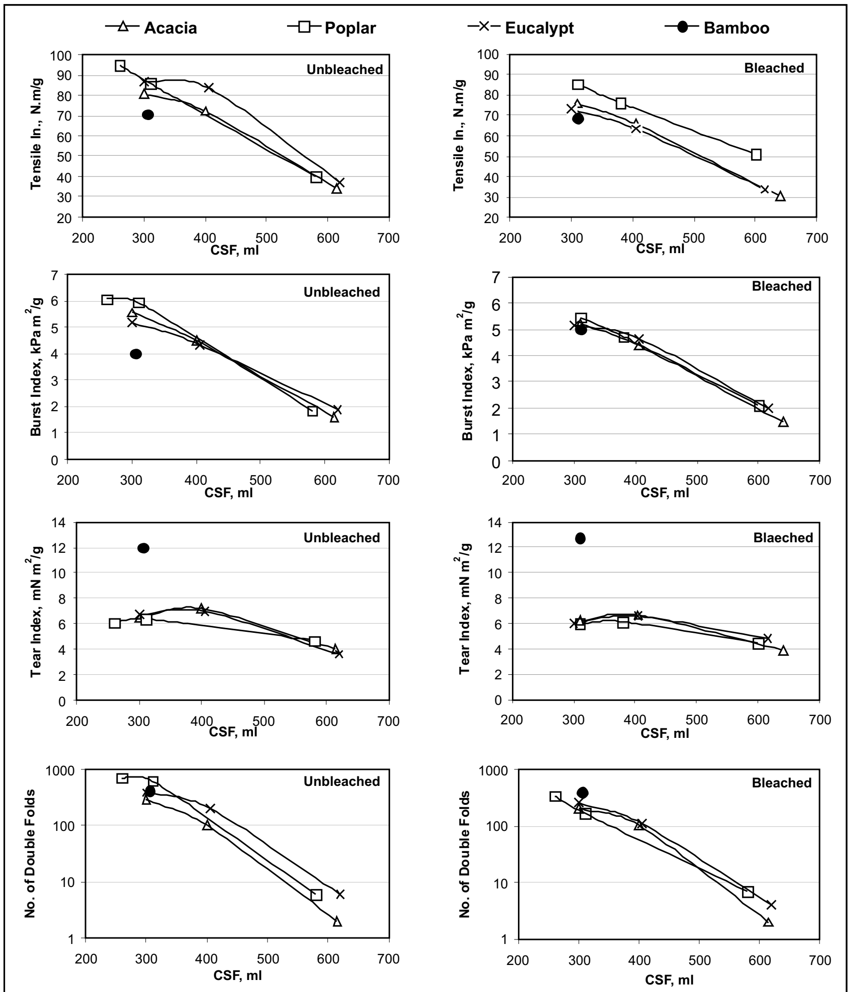

Fig.4 Strength properties of unbleached and bleached pulps at different levels of refining

amount of wood put through the digester, are slightly greater for acacia than for the other woods and bamboo.

The brightness of the pulp as it passes through different stages of bleaching is shown in Fig.1. Acacia pulp could be bleached to a brightness of 88% with slightly lower consumption of bleach chemicals than that required for bleaching of poplar, eucalyptus or bamboo. Low bleach chemical consumption should be beneficial from environmental point of view as the resulting COD, color and AOX levels in bleach effluent would be low.

Fig.2 shows the cupriethylenediamine (CED) viscosity for the unbleached and bleached pulp. The reduction in pulp viscosity due to bleaching is low for acacia suggesting a low degradation of cellulose during bleaching. At equal brightness, the viscosity of bleached pulp was the highest for acacia amongst all the raw materials under study.

Fiber dimensions and fiber classification

Fiber classification (Table 4) shows that the dimensions of acacia fibers were in the same range as of poplar and eucalyptus fibers. However, all the wood fibers were significantly shorter than the bamboo fibers. Although the +30 mesh fraction was much greater for bamboo than for other woods, the fines fraction was in the same range for all the raw materials. There appears a reduction in fines content on bleaching of all the pulps, perhaps due to loss of some fines during repeated washing between bleaching stages.

Strength properties of pulps

The acacia pulp requires a larger number of revolutions in a PFI mill than do the poplar and eucalyptus for achieving the same freeness level of 300 CSF of refined pulp (Fig.3). However, this is less than that required for refining of bamboo pulp.

Fig. 4 shows various strength properties of unbleached and bleached pulps as function of pulp freeness. The tensile strength, burst strength, and folding endurance of unbleached and bleached pulps of acacia were comparable with those of poplar, eucalyptus, and bamboo pulps. When comparing pulps refined to about 300 ml CSF, slightly lower values of tensile and burst strength of bleached pulps than those of unbleached pulps were due, perhaps, to the loss of some fines during bleaching as noted earlier. The acacia pulp had nearly the same tear strength as poplar or eucalyptus pulps had for both unbleached and bleached types. Off course, the long fibered bamboo pulp showed significantly greater tear strength than the other pulps. Fig.5 shows that the acacia pulp resembles with the poplar and eucalyptus pulps in bulk and air resistance (by Gurley method).

CONCLUDING REMARKS

Acacia Mearnsii is a good fibrous raw material comparable with the other conventional hardwoods used for papermaking in India. It has relatively low lignin content and high basic as well as bulk density. It gives high unbleached-pulp yield at low kappa number. It can be easily bleached to brightness levels of about 88% with low bleach chemical consumption, high bleached-pulp yield, and high strength properties.

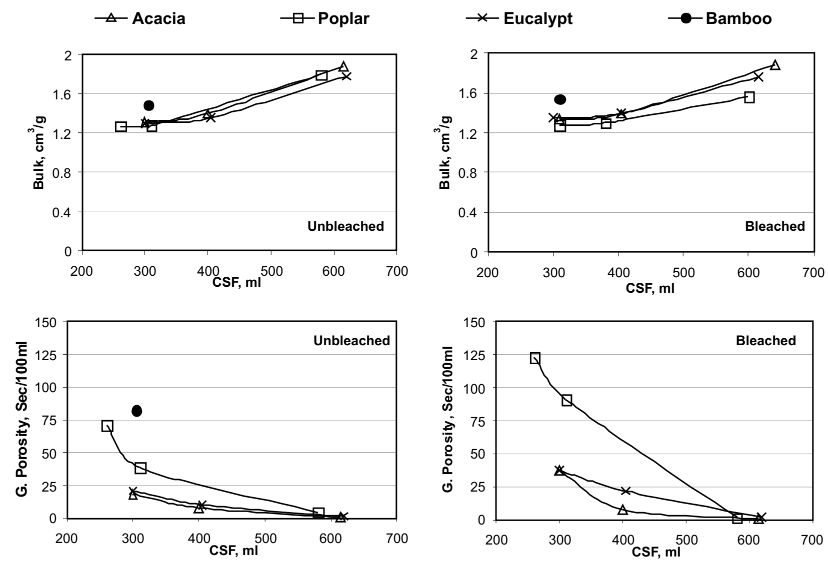

Fig. 5: Bulk and Gurley porosity of pulps at different freeness levels.

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