# Acacia An Emerging Raw Material For Pulp

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### ABSTRACT

*Acacia mangium* is a fast growing and nitrogen-fixing tree with good annual wood yield. It is an excellent source of short fibre for papermaking. Its short and thin walled fibre is suitable to produce low bulk, high opacity and smooth sheet. However, its extractive content is quite high. Now the efficient methods are available to reduce/eliminate the pitch problems associated with high extractives. *Acacia* species have been studied and used for pulpwood in many countries like Australia, Brazil, South Africa, Indonesia, Vietnam, and Malaysia. Indonesia is the largest supplier of *Acacia* fibre. The interesting properties of *Acacia mangium* fibres together with its easy adaptation to tropical humid climates suggest that extensive *Acacia mangium* plantations soon will spread to other regions of the world such as South America, competing seriously with other tropical hardwood fibre sources.

## Introduction

*Acacia* is a well-known nitrogen-fixing tree species, being used for land rehabilitation, particularly in eroded and nitrogen-deficient soils. It is a fast-growing tree, native to northern Australia and Southeast Asia [1], where it has been planted because of its high silvicultural performance and its ability to grow in degraded soils. The basic density of 8 years old *Acacia mangium* plantation is 409 $kg/m^3$, which yields an annual wood production of 4 to 12 tons/ha/year [2]. Tree form is relatively good, but there is a tendency for persistent branching which affects wood quality if pruning is not done at an early age. When grown for pulp logs on a rotation of 5 to 7 years, pruning and thinning are not necessary. *Acacia mangium* forms a symbiotic relationship with bacteria *Rhizobium* that fixes nitrogen to enhance the tree growth [3]. The fertilization costs for *Eucalyptus deglupta* were found to be generally higher than for *Acacia mangium*, i.e. 13-32 % and 9-16 % of overall investment costs, respectively as per study conducted in Indonesia [4]. Those range covered from low-, medium- to high-impact management, which depended on nutrient losses due to burning of residual phytomass, leaching below root deep, erosion and harvesting techniques. The soil pH in this area was 4.5-4.8 and characterized by sand, silt and clay sediment. In another study on the growth of different *Acacia* species in acidic soil of Hawai showed that *Acacia mangium* ranked the best in the growth rate among the others at both low and high soil fertility level. The species under the study were *A. mangium, A.crassicarpa, A.cincinnate, A. leiocalyx, A. leptocarpa, A. auriculiformis, A. orites, A. implexa, A. angustissima, A. polystachya,* and *A. koa.*

In recent years, this hardwood species has been recognized as an excellent source of short cellulose fibers for papermaking [5-8]. Extensive plantations are now growing in Southeast Asia, particularly Indonesia, supplying wood to the pulp and paper industry [9]. In Indonesia, *Acacia mangium* has become the dominating plantation pulpwood during the last decade because *Eucalyptus* plantations have not been successful. Many large-scale pulp mills have been built in Indonesia based on *Acacia* plantations. *Acacia* pulp is very interesting from a quality point of view and fairly similar to *Eucalyptus camadulensis* in terms of fibre morphology. Environmentally *Acacia* species are attractive because of their ability to fix nitrogen from air to improve soil fertility. *Acacia* species have been studied and used for pulpwood in many countries like Australia, Brazil, South Africa, Indonesia, Vietnam, and Malaysia. The interesting properties of *Acacia*

**Table 1.** Chemical composition of *Acacia mangium* wood

| Component | % on dry wood[a] |
|---|---|
| Ashes | 0.22 |
| Extractives | |
| - Ethanol/ Toluene | 4.46 |
| - Dichloromethane | 1.32 |
| - Methanol/water | 4.05 |
| Lignin | |
| - Klason lignin | 27.10 |
| - Acid soluble lignin | 0.54 |
| Holocellulose | 70.9 |
| Cellulose (Kurschner-Hoffer) | 46.5 [b] |
| Pentosans | 13.30 |
| Neutral monosaccharides [c] | |
| - Rhamnose | 0.3 |
| - Arabinose | 0.2 |
| - Xylose | 10.9 |
| - Mannose | 1.0 |
| - Galactose | 0.6 |
| - Glucose | 48.0 |
| Uronic acids | 7.6 |

[a] Extractive-free wood, except for extractive content, [b] Corrected for pentosans content, [c] Determined as anhydrous monosaccharide.

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## Chemical Coposition

Table 1 summarizes the general chemical composition of *Acacia mangium* wood, used in the pulp and paper industry [10]. The lignin content of *Acacia mangium* wood was found to be 27.6 %, a value above the range of lignin contents typically found in hardwoods (20-26 %), and was found similar to *Eucalyptus urograndis* (Table 2) [11,12]. This can be explained, at least partially, by the presence of polyphenolic extractives that were not removed by ethanol/toluene extraction of wood.

**Table 2.** Compositions of hardwoods and unbleached kraft pulp

| Species | *E. globulus* | *E. urograndis* | *E. grandis* | *B. pendula* | *A. mangium* |
|---|---|---|---|---|---|
| Wood Composition (%) | | | | | |
| Lignin (Klason)* | 22.1 | 27.9 | 26.7 | 21.5 | 27.6 |
| Glucomanan | 53.4 | 52.1 | 50.9 | 44.5 | 51.6 |
| Xylan | 14.2 | 11.4 | 12.4 | 23.6 | 11.9 |
| Rhamnose | 0.3 | 0.2 | 0.3 | 0.8 | 0.3 |
| Arabinose | 0.4 | 0.4 | 0.4 | 0.7 | 0.2 |
| Mannose | 1.1 | 0.7 | 0.7 | 2.1 | 1.0 |
| Galactomanan | 1.5 | 1.2 | 1.0 | 0.8 | 0.6 |
| Unbleached pulp composition (%wood basis) | | | | | |
| Lignin (Klason)* | 1.3 | 1.0 | 1.2 | 1.3 | 1.2 |
| Glucomanan | 45.0 | 40.2 | 40.5 | 38.8 | 42.2 |
| Xylan | 10.6 | 6.8 | 6.6 | 12.4 | 6.7 |
| Rhamnose | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 |
| Arabinose | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 |
| Mannose | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 |
| Galactomanan | 0.4 | 0.1 | 0.1 | 0.1 | 0.0 |

* Uncorrected for polyphenolics content

The high lignin/polyphenolic extractives content of *Acacia mangium* wood contributes to the high chemical consumption required to chemically delignify this wood and to the low pulp yield, when compared to those of other hardwoods [13]. Hardwood lignin is a complex macromolecule composed of dehydropolymerized units derived from syringylpropane (S) guaiacylpropane (G), and p-hydrophenylpropane (H). The relative proportions of S, G, and H units and the nature and relative abundance of linkages between them are highly variable, influencing the reactivity of lignin during pulping and bleaching processes [14].

*Acacia mangium* had the highest surface coverage (24%) of extractives compared to those of *Betula pendula*, *Eucalyptus globulus*, *Eucalyptus urograndis* and *Eucalyptus grandis* that had 10, 7, 6 and 5 %, respectively [15]. The main component of the extractive was saturated fatty acids (docosanoic, tetracosanoic, hexacosanoic and octacosanoic acids) that were quite stable under the condition of ECF bleaching [16].

The proximate analysis of Malaysian *A. mangium* in Indian laboratory also indicates holocellulose 75.5% (with high content of hemicellulose 26.8%), 24% Klason lignin and 7.4% total extractives with 1.7% DCM extractives (unpublished results).

## Pulping Characteristics

*Acacia mangium* can be readily pulped by either the kraft or NSSC (neutral sulfite semi-chemical) process to produce good quality pulp for fine papers or packaging materials respectively. Test of *Acacia mangium* cooking has shown that yields of screened pulp of over 50% can be obtained by the kraft process and as high as 75% by the neutral sulphite process. Tests conducted by CSIRO have shown that kraft pulping and papermaking properties of *Acacia mangium* compared very favorably with those of plantation-grown *Gmelina arborea* and *Eucalyptus deglupta*. *Acacia dealbata* and *Acacia melanoxylon* were also reported to exhibit better kraft pulping performance than *Eucalyptus globules* [17]. An added advantage is the higher basic density of *Acacia mangium* wood. Due to chemical composition and structure of lignin and extractive, *Acacia mangium* required different pulping conditions to get a similar Kappa number and also consumed *a* little higher amount of chlorine dioxide during bleaching stages to get a similar brightness compared to those other four hardwoods studied as shown in Table 3.

**Table 3.** Kraft pulping conditions[@], a pulp yield, and $ClO_2$ consumption during bleaching by a chlorine dioxide based sequence (DEDED)[#]

| Wood species | Active alkali (% $Na_2O$/wood) | Unbleached pulp Kappa number | Unbleached pulp yield (%/wood) | $ClO_2$ consumption (%/pulp) |
|---|---|---|---|---|
| *E. globules* | 16 | 18.9 | 55.6 | 4.4 |
| *E. urograndis* | 20 | 18.4 | 49.6 | 5.3 |
| *E. grandis* | 19 | 16.1 | 50.6 | 5.4 |
| *B. pendula* | 18 | 18.5 | 49.8 | 7.2 |
| *A. mangium* | 24 | 16.0 | 51.1 | 7.4 |

[@] Kappa number 16-19 [#] Final brightness 90 %

A study on the cooking of *Acacia mangium* of different ages from eastern Thailand showed that the yield decreased rapidly when age of wood increases as shown in Table 4 [2]. At Kappa number 20, the pulp yield dropped from 52 to 50 % and the pulp viscosity dropped from 1,200 to 1,000 ml/g along with increasing age. The kraft cooking condition was as follows: sulphidity 35 %, liquor to wood ratio 4, time from room temperature to 80 °C 15 minutes, cooking temperature 165 °C, time from 80 to 165 °C 60 minutes, time at 165 °C 80 minutes, and various effective alkali from 16 to 23 % as NaOH. *Acacia mangium* of seven and eight year old had clearly lower yield,

**Table 4.** Unbleached kraft pulp properties of *Acacia mangium* from eastern Thailand

| Species age (yr) | Effective alkali (%) | Kappa number | Screened yield (%) | Viscosity (ml/g) | HexA (meq/kg) |
|---|---|---|---|---|---|
| 4 | 16 | 24.6 | 53.5 | 1269 | 57.7 |
| | 18 | 18.2 | 51.4 | 1072 | 62.6 |
| | 19 | 18.2 | 52.7 | 1121 | 60.6 |
| | 20 | 16.5 | 51.3 | 955 | 47.8 |
| | 23 | 12.8 | 49.7 | 713 | 24.8 |
| 6 | 16 | 27.3 | 53.3 | 1264 | 64.5 |
| | 18 | 20.3 | 51.9 | 1096 | 64.6 |
| | 20 | 18.6 | 49.9 | 992 | 48.9 |
| | 21 | 16.7 | 50.1 | 965 | 46.8 |
| | 23 | 15.1 | 48.8 | 818 | 34.4 |
| 7 | 16 | 29.0 | 53.3 | 1274 | 57.0 |
| | 18 | 20.1 | 50.9 | 1058 | 60.4 |
| | 19 | 18.2 | 50.4 | 1035 | 58.3 |
| | 20 | 17.3 | 49.5 | 913 | 46.0 |
| | 23 | 16.9 | 48.4 | 878 | 39.9 |
| 8 | 16 | 29.0 | 53.4 | 1218 | - |
| | 18 | 19.7 | 50.2 | 1029 | - |
| | 20 | 19.0 | 48.0 | 928 | - |
| | 22 | 16.3 | 47.5 | 784 | - |
| | 23 | 15.3 | 47.7 | 808 | - |

probably because of heart rot in the wood as indicated by its high 1 % NaOH solubility, 8.2, 13.7, and 16.7 % for four, seven, and eight year old, respectively. The contents of hexenuronic acids (HexA) in unbleached kraft pulps dropped rapidly with lowering kappa number.

A pulping study on seven-year-old *Acacia mangium* was conducted on a pilot scale [18]. The pulps were bleached according to CEHH sequence. The results showed that optimum physical properties of bleached *Acacia mangium* pulp obtained at 15.0 % active alkali, 22.5 % sulphidity, 165 °C, and cooking time for 1.5 + 2.0 hours. The cooking results are shown in Table 5.

**Table 5.** Pilot scale kraft cooking[@] results of *Acacia mangium*

| Active alkali (%) | Max. temp. (°C) | Screened yield (%) | Kappa number |
|---|---|---|---|
| 17.0 | 170 | 41.2 | 11.3 |
| 15.0 | 170 | 48.3 | 14.4 |
| 13.0 | 170 | 44.5 | 17.6 |
| 17.0 | 165 | 47.5 | 12.7 |
| 15.0 | 165 | 42.1 | 15.3 |
| 13.0 | 165 | 41.3 | 21.0 |

[@] Liquor to wood ratio 4, time to reach maximum temperature 1.5 hours, time at maximum temperature 2.0 hours, sulphidity 22.5 %

A kraft cooking study on three different *Acacia* species of six and nine year old was conducted which showed that *Acacia woods* were easily pulped using the conventional kraft process with acceptable pulp yields, i.e. 50 % total yield with Kappa number of 20. The kraft cooking condition was as follows: active alkali 15.0 % (as $Na_2O$ of oven dry chip), wood to liquor ratio of 1:4, sulphidity 25.0 %, maximum temperature 170 °C, and time at temperature 50 minutes. The physical properties of unbleached kraft pulp are shown in Table 6.

**Table 6.** Physical properties of unbleached kraft pulp of three *Acacia* species

| Species | Age (yr) | Tensile index (Nm/g) | Burst index (kPa.m$^2$/g) | Tear index (mN.m$^2$/g) |
|---|---|---|---|---|
| *A. mangium* | 6 | 61.1 | 6.4 | 10.7 |
| | 9 | 63.4 | 6.0 | 8.8 |
| *A. crassicarpa* | 6 | 58.1 | 6.1 | 9.8 |
| | 9 | 62.2 | 5.8 | 8.7 |
| *A. auriculiformis* | 6 | 61.8 | 6.5 | 11.2 |
| | 9 | 62.7 | 6.2 | 10.5 |

In general, the physical properties of six-year-old *Acacia* were better than nine-year-old *Acacia*.

Pulping characteristics of 14 year old *Acacia mearnsii* (grown in southern part of India) were investigated by Yadav et al. using kraft pulping and C/D-$E_{OP}$-D-D bleaching and the results were compared with those obtained from eucalyptus, poplar and bamboo [19]. *Acacia mearnsii* wood had relatively low lignin content and high basic & bulk densities. It gave high pulp yield at low kappa number and could be easily bleached to around 88% ISO brightness with low bleach chemicals having good strength properties.

In a study of Malaysian *Acacia mangium,* conducted in India, showed 51% total yield of the kraft pulp with 16% alkali ($Na_2O$) at 165 $^oC$ cooking temperature. The pulp of around 20 kappa number could be bleached to 88.4% ISO brightness by ECF bleaching using 45 kg elemental Chlorine & 7.5 kg $ClO_2$ in $C_D$ stage and 7 & 4 kg $ClO_2$ in $D_1$ & $D_2$ stages respectively (unpublished results). In another study on kraft pulping of *Acacia mangium* by Nippon Paper Industries in Japan has reported high pulp yield comparable to *Eucalyptus globules*. A bleached pulp of high brightness, low dirt and high viscosity was obtained which was suitable for producing low bulk, high opacity and smooth paper [20].

It is known that pressing and washing after oxygen delignification stage can reduce the extractives concentration in the pulp. Ultrasonic treatment of kraft pulp and/ or a short mechanical treatment in Quantum mixer at ambient temperature for few seconds before oxygen delignification could almost eliminate the extractives from the pulp (up to 92%), leading to a best solution to the pitch problem [21]. Ultrasonic and mechanical pretreatments did not induce fines formation but reduced curl and kinks. In addition, the selectivity of oxygen delignification improved by applying mechanical pretreatment prior to oxygen delignification reaction by 50%.

## Fibre and Paper Properties

The main difference between the *Acacia* and the *Eucalyptus* bleached kraft pulp was found that the *Acacia* had thinner fibre walls and fewer defects (kink) as shown in Table 7 and Table 8. Similar results on the fibre properties of Malaysian *A. mangium* pulp have also been obtained by an Indian laboratory - average fibre length 0.6 m, average fibre width 16 µm, fibre kinks per fibre 0.20, fibre coarseness 70 µg/m.

**Table 7.** Fibre properties of bleached hardwood kraft pulps

| Pulp | Fibre length (mm) | Fibre width ( m) | Fibre kink (numbers/fibre) | Fibre coarseness ( g/m) |
|---|---|---|---|---|
| *Acacia* | 0.65 | 14.1 | 0.22 | 46 |
| *Eucalyptus* A[a] | 0.74 | 14.9 | 0.53 | 60 |
| *Eucalyptus* B[b] | 0.71 | 15.1 | 0.47 | 59 |

[a]Brazilian origin, [b]Iberian origin

**Table 8.** Microscopic measurement of cross sectional dimensions of unrefined bleached hardwood kraft pulps

| Pulp | Wall thickness (µm) | Wall perimeter (µm) | Lumen diameter (µm) | Wall area ($\mu m^2$) |
|---|---|---|---|---|
| *Acacia* | 2.0 | 38.0 | 23.0 | 53.7 |
| *Eucalyptus* A[a] | 2.7 | 39.4 | 18.0 | 70.4 |
| *Eucalyptus* B[b] | 2.5 | 38.9 | 19.1 | 66.5 |

[a]Brazilian origin, [b]Iberian origin

The energy requirement for refining of *Acacia* pulp is relatively lower as compared to thick walled coarser fibres to achieve the same water retention value (WRV), which is a measure of fibre bonding to develop the strength properties of paper sheet [22]. Due to being short fibre, the number of fibres per unit weight of pulp is very high, giving very good formation of sheet with high opacity & scattering and smoothness. Some of the paper mills are blending small proportion of long fibres to *Acacia* pulp for producing strong & smooth paper sheet with excellent formation index.

**CONCLUSIONS**

*Acacia* is emerging as an important raw material for cellulose fibre. Fast growth due to nitrogen-fixing nature, adaptability to varying climatic conditions and multi-utility nature of its wood make *Acacia* economically important tree. It is an excellent source of short fibre for papermaking. Its short and thin walled fibre is suitable to produce low bulk, high opacity and smooth sheet. Its kraft pulping results have been shown to vary with the variety and age of the tree. Although its wood can be easily pulped & bleached to a good brightness level & yield, the extractives content in *Acacia* wood is quite high. Extractives can be reduced/ eliminated by new techniques of ultrasonic and/ or mechanical treatments in Quantum mixer before oxygen delignification.

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