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Alkaline Pulping and Bleaching of *Acacia auriculiformis* Grown in Bangladesh

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Abstract: The physical, chemical, and morphological characteristics of *Acacia auriculiformis* were evaluated in terms of its suitability for papermaking. The fiber length (1.1 mm) of *A. auriculiformis* in this study was within the range of tropical hardwoods. The lignin content in *A. auriculiformis* was 19.4% and α-cellulose 44.1%, which was within the range of other acacias, but that of extractives was higher. Soda, soda-AQ, and kraft processes were studied in pulping. Screened pulp yield was increased with increasing active alkali. Acceptable pulp yield (43%-44%) and kappa number (22-24) were obtained at 20% alkali and 2.5 h of cooking in soda, 16% alkali and 2.5 h of cooking in soda-AQ, and 18% alkali in 2 h of cooking in kraft process. Soda-AQ pulp showed better strength properties than soda and kraft pulp. Soda, soda-AQ, and kraft pulps were bleached in DEpD and DEpDEpD (where D denotes Chlorine dioxide, E denotes peroxide reinforced alkaline extraction) bleaching in different kappa factors. In DEpD bleaching, kraft pulp showed better bleachability as compared to soda and soda-AQ pulp. However, in case of DEpDEpD bleaching, all pulps exhibited almost the same brightness. At the same kappa factor, final brightness of pulp increased from 72%-75% to 85%-86% with splitting DEpD and DEpDEpD sequences, respectively.

Key Words: *Acacia auriculiformis*, pulp yield, kappa number, strength properties, bleachability, viscosity

Introduction

An ever-increasing demand for paper combined with a declining fiber supply from the forests of the world is forcing the pulp and paper industry to find technically and economically viable fiber sources to supplement forest-based resources. Today a large amount of paper is produced from various annual plants (nonwood fibers) in developing countries where forest resources are limited, but wood pulp is still needed for technically and economically feasible pulp processing. Forestland in Bangladesh is only 10.2% (FAO, 2005). Population density of the country is very high. Therefore, forestland for industry is decreasing because of the competition with other land uses. So, it is hard to supply pulpwood from the forests to keep the growth of the paper industry. On the other hand, environmentalists are keeping pressure on the industry to preserve forests. To overcome this issue, plantation of fast growing species must be established to compensate the declining supply from natural forests. Fast wood plantation can produce 1.5-2 times more wood per hectare per year, and reach maturity 2-3 times faster than longer-rotation softwood plantations (Cossalter and Smith, 2003). So we can say that restricted access to natural forests attracts short rotation woods as a source of fiber.

Acacia species have been studied and used for pulpwood in many countries like Australia, Brazil, South Africa, Indonesia, Vietnam, and Malaysia (Logan and Balodis, 1982). Pulping properties of acacia are generally good, but their log properties are not excellent. Acacia species occur in all continents except Europe and Antarctica. They are particularly well developed in Africa and Australia. There are more than 1200 published species, of which about 700 occur in Australia (Kokima, 2001). Acacias have received attention in recent years because they are proved suitable for reforestation projects in the tropics. Since they are nitrogen fixing trees, many acacia species adapt well to poor soils. Many

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acacia species are used in various ways, such as erosion control, plantation and community forestry, production of fuel wood, pulp for papermaking, construction and furniture timber, and as tannin for leather making. Acacia is a relatively new in the short-fiber pulp market that is ranked close to eucalyptus for applications in fine papers (Paavilainen, 2000; Hillman, 2003). The small fiber dimensions of the acacia pulp make it very useful for printing papers. *Acacia auriculiformis* shows the best species in the environment of Bangladesh.

Acacia auriculiformis is an evergreen tree that grows between 15 and 30 m tall, with a trunk up to 12 m long and 50 cm in diameter (World Agroforestry Centre, 2005). It has dense foliage with an open, spreading crown. Roots are shallow and spreading. Natural stands of *A. auriculiformis* are found in Australia, southwestern Papua New Guinea, and Indonesia. It is planted widely in tropical Asia with extensive plantings in China and India. In western Malaysia it has also become naturalized. In Bangladesh it has achieved good growth (Davidson, 1985) and can be used as a pulping raw material (Akhtaruzzaman et al., 1987). Thus, because of its potentiality as a fibrous raw material, a study on the pulping by soda, soda-anthraquinone (AQ), and kraft processes and their bleaching potentiality was carried out by elemental chlorine free (ECF) bleaching sequences.

Materials and Methods

Material

The *A. auriculiformis* was collected from the Gazipur Forest Station, which is 10-year-old. Three trees were selected for this experiment. Sixty-cm-portions from the top and bottom and branches of these trees were discarded and remaining portion was debarked and chipped to $0.5 \times 0.5 \times 2$ cm size. The chips were ground in a Wiley mill and 40-60 mesh size was used for chemical analysis.

Physical, morphological and chemical properties

The basic wood density of *A. auriculiformis* was determined according to PAPTAC Standard A. 8P. For the measurements of fiber length, the sample was macerated in a solution containing 1:1 HNO_3 and $KClO_3$. A drop of macerated sample was taken in a slide and fiber length was measured under a profile projector (Nikon V-12, Japan). The fiber diameter was measured in an image analyzer.

The extractive (T204 om88), 1% alkali solubility (T 212 om98), water solubility (T207 cm99), Klason lignin (T211 om83), and ash content (T211 os76) were determined in accordance with Tappi Test Methods. Holocellulose was determined by treating the extractive free wood meal with $NaClO_2$ solution. The pH of the solution was maintained at 4 by adding CH3COOH-CH3COONa buffer and α-cellulose was determined by treating holocellulose with 17.5% NaOH.

Pulping

Pulping was carried out in a thermostatically controlled electrically heated digester. The capacity of the digester was 20 l. The normal charge was 1 kg oven dried (o.d.) *A. auriculiformis*. Pulping conditions of kraft, soda, and soda-anthraquinone (AQ) are as follows:

- Active alkali was 14%, 16%, 18%, and 20% on o.d. raw material as Na_2O cooking time was 2, 2.5, and 3 h at maximum temperature (170 °C). 90 min was required to reach the maximum temperature (170 °C) from room temperature.
- Liquor to material ratio was 4.
- AQ charge was 0.1% on o.d. raw material in soda-AQ process.
- Sulphidity was 25% for kraft process.

After digestion, the pulp was washed till it is free from residual chemicals, and it is screened by a flat vibratory screener (Yasuda, Japan). The screened pulp yield, total pulp yield, and screened reject were determined gravimetrically as percentage of o.d. raw material. The kappa number (T 236 om-99) of the resulting pulp was determined in accordance with Tappi Test Methods. Three replicates of all experiments were done and an average reading was taken. The standard deviations were analyzed using MS Excel.

Evaluation of pulps

Soda, soda-anthraquinone (AQ), and kraft pulps were beaten in a valley beater at different times to different freeness (°SR) and hand sheets of about 60 g m^{-2} were made in a Rapid Kothen Sheet Making Machine. The sheets were tested for tensile (T 494 om-96), burst (T 403 om-97), tear strength (T 414 om-98), folding endurance (T 511 om 96), and brightness (T525 om 92) according to TAPPI Standard Test Methods.

DEpD and DEpDEpD bleaching

The soda, soda-anthraquinone (AQ), and kraft pulps were bleached by DoEpD$_1$ bleaching sequences (where D represents chlorine dioxide and Ep represents peroxide reinforced alkaline extraction). The kappa factor was 0.22-0.30 in the first stage of DoEpD$_1$ bleaching sequences. The temperature was 70 °C in Do stage for 60 min. Pulp consistency was 5%. The pH was adjusted to 2.5 by adding dilute H_2SO_4. In alkaline extraction stage, temperature was 70 °C for 60 min in a water solution of 2% NaOH and 0.5% H_2O_2 (on o.d. pulp). Pulp consistency was 5%. In the final D$_1$ stage, pH was adjusted to 4 by adding dilute H_2SO_4. The ClO_2 charge in the D$_1$ stage was half of the first stage. In case of 5-stage bleaching, the same amount of ClO_2 was splitted to last 2-stage ClO_2 charge. The brightness and viscosity (T 230 om-99) of the bleached pulp were determined in accordance with Tappi Test Methods. The physical properties of 5-stage bleached soda, soda-AQ, and kraft pulps were determined after 3000 revolution in PFI mill. The Standard deviation was analyzed using MS Excel.

Results

Physical, morphological and chemical properties

Table 1 shows the properties of *A. auriculiformis* and compares the data of *A. mangium* with the literature. The basic density of *A. auriculiformis* was 0.568 g.cm^{-3}, which was better than *A. mangium* (Table 1). The fiber length of *A. auriculiformis* in this study was 1.1 mm, which was in the range of tropical hardwoods (0.7-1.5 mm) and considered as short fiber (Hale, 1959). The fiber width was within medium range (20.6 mm).

The lignin content in *A. auriculiformis* was 19.4%, which was lower than the other acacias (Malinen et al., 2006) and similar to *Eucalyptus globules* (Santos et al., 2006). *A. mangium* also had lower lignin (Table 1). The acetone extract and 1% alkali solubility of this species were higher than the normal range of acacias. This difference may be due to the difference of region. This high extractive content can be explained with the high content of polyphenols in this wood (Pirtarinen et al., 2005). High 1% alkali solubility may be attributed by

Table 1. Physical, morphological, and chemical properties of *A. auriculiformis*.

	Acacia auriculiformis	*Acacia mangium* (Law and Daum, 2000; Siregar, 2001)
Basic density, g/cc	0.568 ± 0.081	0.43
Fiber length, mm	1.1 ± 0.12	0.9
Fiber width, mm	20.6 ± 1.9	22.3
Lignin, %	19.4 ± 1.6	25.6
Holocellulose, %	76.1 ± 3.1	71.5
a-cellulose, %	44.1 ± 2.1	50.8
Pentosan, %	17.5 ± 0.9	17.4
Solubles in		
Acetone, %	10.0 ± 1.1	-
1% NaOH, %	27.9 ± 1.7	16.4
Hot water, %	4.8 ± 0.5	4.8
Cold water, %	3.2 ± 0.2	3.9
Ash, %	0.6 ± 0.07	0.5

higher amount of wood decay and/or low molecular weight polysaccharides. The holocellulose and α-cellulose of *A. auriculiformis* were 74.1% and 44.1%, respectively, which was lower than the other hardwood grown in Bangladesh (Jahan and Mun, 2004). The α-cellulose in *A. auriculiformis* was lower than *A. mangium* (Table 1). The lower α-cellulose in *A. auriculiformis* in this investigation may be the basis of lower pulp yield. The pentosan content was 17.5%, which was similar to *A. mangium*. The ash content (0.6%) was much lower than usual for tropical species (1%-3%) (Kristova et al., 1997).

Pulping and pulp properties

A. auriculiformis was pulped in soda, soda-AQ, and kraft processes (Table 2). We have presented a few cooking data from our experiment. The target kappa number was about 25. Targeted kappa number was selected on the basis of its delignification ability in alkaline cooking. In soda-AQ process, the kappa number of pulp obtained in 2 h of cooking was very high (47-32). If cooking time increase to 2.5 h, kappa number decreased to 20-24 depending on alkali charge. At the same time screened pulp yield decreased to 42.9% from 44.8% with increasing cooking time (to 2.5 h from 2 h in 16% alkali). If alkali charge is increased to 20% from 16%, screened pulp yield decreased rapidly to 36.6% from 42.9% with 4.2 point reduction of kappa number. In 3 h of cooking, pulp yield obtained was 33.7%-41.4% with kappa number 17.0-20.4. The screened reject in 2.5 and 3 h of cooking was zero. The highest screened yield (45.4%) was obtained in 20% alkali charge and 2 h of cooking, but kappa number was still high (32.3).

Table 2. Pulp properties of *A. auriculiformis* during soda, soda-AQ, and kraft pulping.

	T	Alk	SY	R	TY	KN	SR	TI	BI	Tear	D	DFN
Soda-AQ	2.0	16	44.8	4.8	49.6	47.0	15	22.0	0.8	5.0	0.40	2
	2.0	18	45.1	3.8	48.9	40.8	17	23.8	1.5	6.7	0.42	8
	2.0	20	45.4	0.5	45.9	32.3	17	26.3	1.3	7.1	0.42	3
	2.5	16	42.9	0	42.9	24.0	17	21.5	0.8	5.4	0.44	2
	2.5	18	40.7	0	40.7	22.8	17	22.2	1.0	4.3	0.38	2
	2.5	20	36.6	0	36.6	19.8	14	22.9	0.8	4.8	0.40	2
	3.0	16	41.4	0	41.4	20.4	14	19.6	0.9	3.7	0.41	1
	3.0	18	40.7	0	40.7	17.7	17	20.0	1.1	4.2	0.41	2
	3.0	20	33.7	17.0	16	17.9	16	17.9	0.8	3.8	0.37	1
Soda	2.5	16	31.0	20.0	51.0	43.1	15	20.4	1.2	4.7	0.39	2
	2.5	18	42.0	2.1	44.1	39.3	16	21.3	1.5	4.9	0.41	1
	2.5	20	42.5	0.1	42.6	22.0	15	22.9	1.6	5.1	0.44	2
Kraft	2	14	41.7	3.6	45.3	39.8	15	23.5	1.7	6.1	0.46	3
	2	16	43.3	1.1	44.4	27.8	14	23.4	1.8	5.9	0.47	7
	2	18	42.8	0.8	43.6	22.0	16	23.9	1.8	6.3	0.49	9

T-Time, h, SY-Screened yield, %, R- Reject, %, TY- Total yield, %, KN- Kappa number, SR-drainage rasistance, TI- Tensile index, $N.mg^{-1}$, BI- Burst index $kPa.m^2g^{-1}$, Tear index, $Nm.m^2g^{-1}$, D- Density $g.cm^{-3}$, DFN- Double Fold Number

In soda process, the screened pulp yield increased continuously with increasing alkali. Screened pulp yield obtained at 16% alkali in 2.5 h of cooking was only 31.0%, which increased to 42.5% with increasing alkali (20%). In a similar condition, kappa number decreased from 43.1 to 22.0. At 16% alkali, screened reject was very high (20.0%). Figure 1 shows the effect of alkali in kraft, soda and, soda-AQ pulping of *A. auriculiformis*. At 18% alkali, kraft and soda-AQ processes produced pulp of almost similar kappa number. In the similar cooking condition, soda-AQ pulp had lower kappa number than soda pulp. At higher alkali charge (20%), kappa number difference between these 2 pulps became narrower. Figure 2 shows the relationship between kappa number and pulp yield of kraft, soda, and soda-AQ processes. It is clearly seen that the kraft process showed its superiority over soda and soda-AQ processes. At kappa number 24, soda and soda-AQ had similar pulp yield (43%), which was 1% lower yield on o.d. raw material compared to kraft process. To reach kappa number 24, soda process also required 30 min more cooking time and 4% higher alkali compared to kraft process.

Physical properties

In the unbeaten state the physical properties of soda, soda-AQ and, kraft pulps are also shown in Table 2. The initial SR value of *A. auriculiformis* pulp was 14 to 17. No direct correlation was observed between SR value and cooking condition. As expected, the strength of acacia pulp was very poor in the unbeaten state. Tensile index was increased slightly with increasing alkali charge (Table 2). Kraft pulp showed slightly better physical properties as compared to soda and soda-AQ processes in the unbeaten state.

Soda, soda-AQ, and kraft pulps from *A. auriculiformis* were beaten in a valley beater and strength properties are given in Figures 3-6. As expected, strength properties were improved with increasing beating degree (SR value). It is clearly seen from the figures that strength properties in soda-AQ pulp were superior to soda and kraft pulp. At about SR number 30, tensile index in soda-AQ pulp was 75 $N \cdot mg^{-1}$, which was 20 $N \cdot mg^{-1}$ higher compared to the soda pulp (Figure 3). Kraft pulp showed slightly better tensile index than the soda pulp. Similarly burst index of soda-AQ pulp was 33% higher than that of soda pulp at SR value 30 (Figure 4). Kraft pulp showed lower burst index as compared to soda and soda-AQ pulps. The tear index development of kraft, soda, and soda-AQ pulps with SR value had a similar nature as shown in Figure 5. Tear index increased with SR value up to 22-24, and then decreased with further increase of SR value. At SR value 30, both soda and soda-AQ pulp showed similar tear index (9.3 $mN \cdot m^2 g^{-1}$). Kraft pulp had higher tear index than soda and soda-AQ pulp at higher beating degree (higher SR value).

Bleaching

Pulp obtained from kraft, soda, and soda-AQ processes (kappa number was 25.0 for kraft, 27.8 for soda-AQ, and 38.3 for soda) was bleached by DEpD sequences in various kappa factors. The brightness improved with kappa factor as shown in Figure 7. Kraft

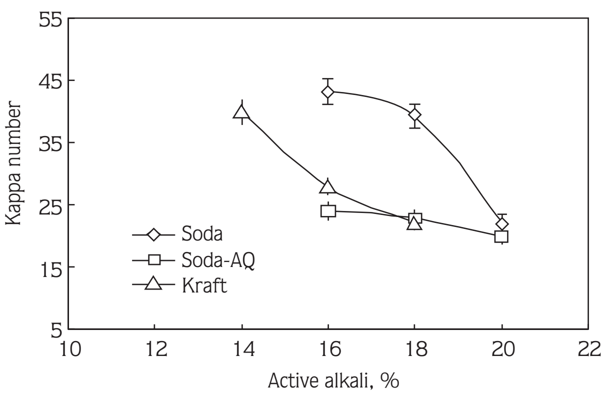

Figure 1. Effect of active alkali on the delignification of *Acacia auriculiformis.*

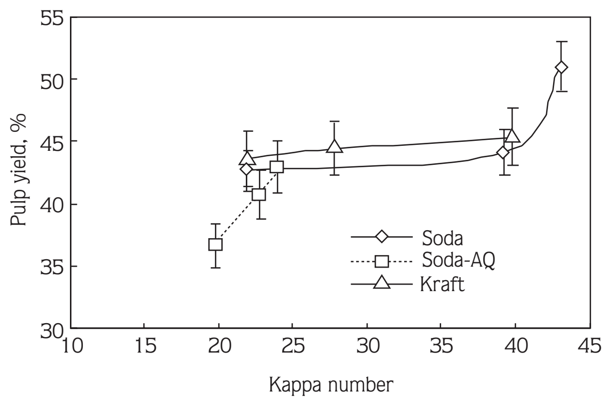

Figure 2. Pulp yield vs kappa number relationship of different processes.

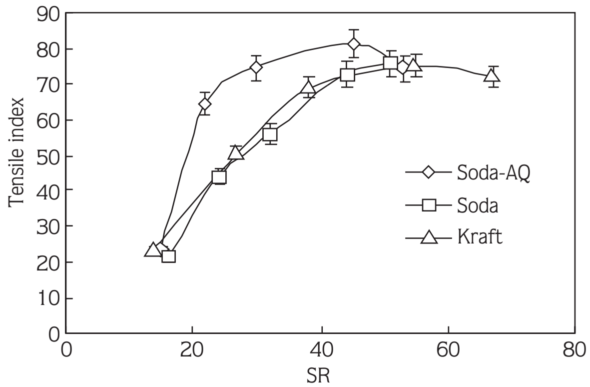

Figure 3. Relationship between SR value vs tensile of *Acacia auriculiformis* pulp from kraft, soda and soda-AQ process.

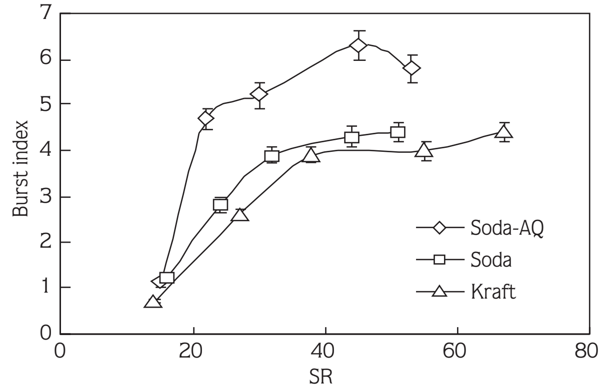

Figure 4. Relationship between SR value vs burst of *Acacia auriculiformis* pulp from kraft, soda and soda-AQ process.

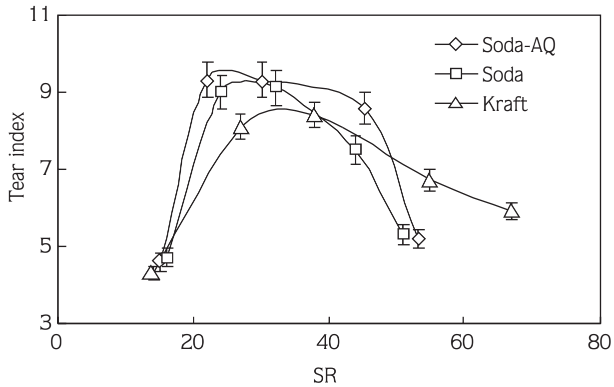

Figure 5. Relationship between SR value vs tear of *Acacia auriculiformis* pulp from kraft, soda and soda-AQ process.

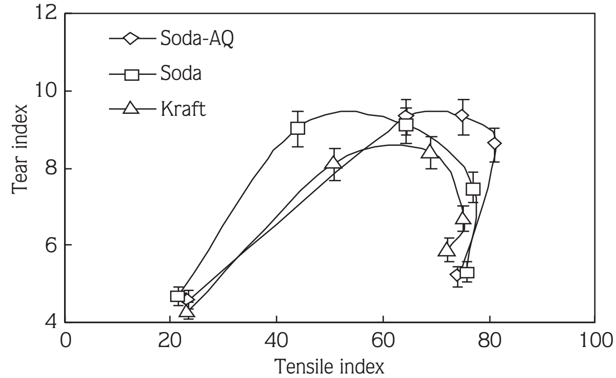

Figure 6. The relationship between tensile and tear of kraft, soda and soda-AQ *Acacia auriculiformis* pulp.

pulp showed the best brightness at any kappa factor. The final brightness of kraft and soda-AQ pulp at kappa factor 0.22 was 73.8% and 67.9%, respectively, which increased to 75.6% and 76% brightness, respectively, with increasing kappa factor (0.30). Soda pulp had very low bleachability. At kappa factor 0.30, soda pulp gave 72.5% brightness. This can be attributed by higher kappa number of brownstock pulp. Bleachability tends to decrease as the kappa number increases (Figure 8).

In the second step, we measured the viscosity of the final pulp as an indication of the effect of kappa factor on the strength of pulp. Soda-AQ pulp showed better viscosity compared to soda and kraft pulp (Figure 9). The viscosity range was 13 to 11 mPa.s for soda-AQ pulp and 11 to 9 mPa.s for soda and kraft pulps.

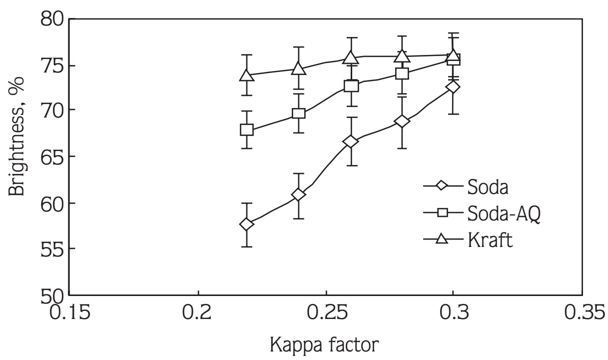

Figure 7. Bleachability of *Acacia auriculiformis* pulp obtained in different processes.

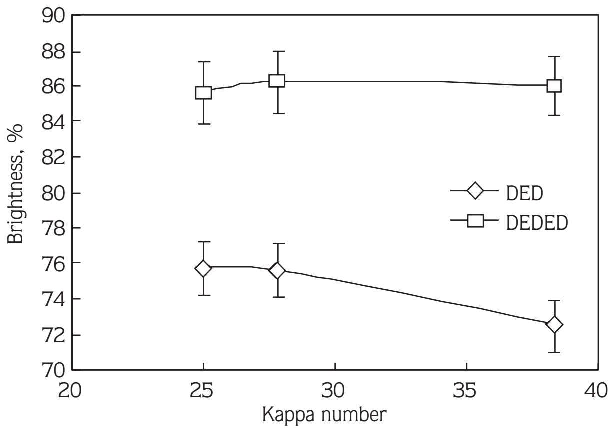

Figure 8. Bleachibility of *A. auriculiformis* pulps of different kappa number.

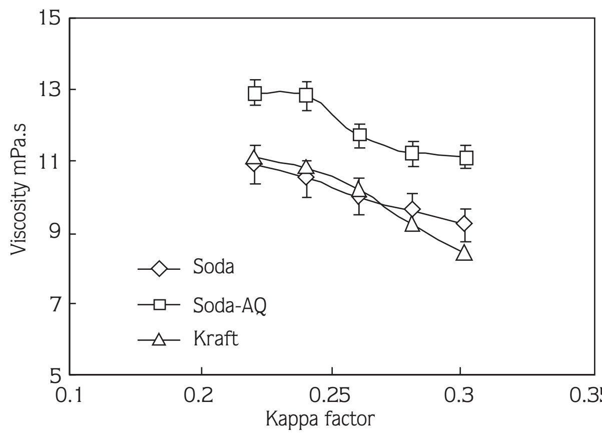

Figure 9. Viscosity of bleached pulp obtained from different processes.

The bleaching stages were divided to more stages using same kappa factor, in which $^1/_2$ of the chlorine dioxide was applied at the last 2 stages with intermediate alkaline peroxide extraction and washing. Brightness reached to above 85% brightness in all pulping processes. The strength properties of soda, soda-AQ, and kraft bleached pulps were measured after beating to 3000 PFI revolution and data presented in Table 3. Similar properties were observed among these 3 pulps. In the unbleached state, pulp was beaten in a valley beater, so bond-depended strength of unbleached pulp was high compared to bleached pulp (PFI mill beaten). But the tear index and viscosity value in the bleached pulp were acceptable. So we can conclude that pulp was not degraded during 5 stage-bleaching. The pulp density of these pulps was 0.517-0.550 g cm^{-3}. The opacity of 5-stage bleached pulp was 82%-84% depending on pulping process. The kraft pulp showed the best opacity, which is consistent with the density data.

Discussion

Physical, morphological and chemical properties

The basic wood density of *A. auriculiformis* was at the upper range of commercial temperate pulpwood (Casey, 1980) and little bit lower than tropical species (Kristova et al., 1997). This value for *A. auriculiformis* is within the usual range reported for the species (Malinen et al., 2006). The basic density of this sample was good for kraft pulping, different from *Eucalyptus camaldulensis* (Pisuttipiched, 2002), which is a suitable fast growing species in Bangladesh. The fiber length of *A. auriculiformis,* compared to other acacias from Thailand, was longer (Malinen et al., 2006). This may be attributed by longer rotation time of *A. auriculiformis* in the present study. The lower lignin indicates easier pulping of *A. auriculiformis*. Higher 1% alkali solubility may result lower pulp yield from *A. auriculiformis* in the present investigation. High extractive contents in wood are undesirable for pulping, bleaching, and papermaking.

Table 3. The physical properties of 5-stage bleached soda, soda-AQ and kraft pulp of *A. auriculiformis.*

Pulp	SR	Tensile index, $N.mg^{-1}$	Burst index, $kPa.m^2g^{-1}$	Tear index, $mN.m^2g^{-1}$	Double fold number	Density, $g.cm^{-3}$	Viscosity mPa.s
Soda	43 ± 2	46.1 ± 3.0	4.5 ± 0.4	11.0 ± 1.0	331 ± 25	0.520 ± 0.10	9.3 ± 1.1
Kraft	44 ± 3	45.4 ± 3.2	4.5 ± 0.3	11.5 ± 1.1	3.64 ± 30	0.550 ± 0.09	8.6 ± 1.0
Soda-AQ	46 ± 3	45.1 ± 3.0	4.4 ± 0.3	11.3 ± 1.0	395 ± 41	0.517 ± 0.08	9.5 ± 1.2

Pulping and pulp properties

As expected, delignification was accelerated by AQ addition in soda liquor (Parthasarathy et al., 1995). Therefore, addition of AQ in soda liquor during *A. auriculiformis* pulping increased selectivity of pulping. The 4% less alkali was needed in the soda-AQ process compared to the soda process to produce similar pulp yield and kappa number. Similar observation was also made in *A. nilotica* pulping (Khristova and Karar, 1999). *A. nilotica* showed similar kappa number (about 25) in the soda and soda-AQ processes, but the yield was higher in soda-AQ pulping. Previously Akhtaruzzaman et al. (1987) observed that an addition of 0.05% AQ in cooking liquor reduced the alkali charge by 3% to reach the same kappa number in *A. auriculiformis* pulping. In that observation, pulp yield was higher and kappa number was lower compared to our present investigation. This may be attributed to different locales of raw material and also the age of tree. The low S:G ratio and high degree of lignin condensation contributes to lower reactivity of acacia during pulping (Pinto et al., 2005). In this investigation, pulp yield in *A. auriculiformis* was lower than *A. nilotica* (Khristova and Karar, 1999). Pulp yield in *A. mangium* was quite compared to the present investigation of *A. auriculiformis* (Miyanishi and Watanabe, 2004). Lower pulp yield in the present investigation may also be explained by low cellulose and high extractive content of wood (Table 1). A high wood density, which causes poor penetration of cooking chemicals, may be another reason of lower pulp yield.

Physical properties

Tensile-tear relationship is one of the most important parameter for papermakers. Figure 6 shows the tear-tensile relationship of kraft, soda, and soda-AQ pulps. At tear index of about 9 $mN{\cdot}m^2g^{-1}$, the tensile index was 75 $N{\cdot}mg^{-1}$ in soda-AQ pulp and 65 $N{\cdot}mg^{-1}$ in soda pulp. But in kraft pulp, maximum tensile index (69 $N{\cdot}mg^{-1}$) was observed at tear index of 8.5 $mN{\cdot}m^2g^{-1}$. A recent study evaluated 3 acacia species, namely *A. crassocrapa, A. aulacocarpa* and *A. mangium* (Malinen et al., 2006). They showed that *A. crassocrapa* had the best tensile-tear relationship and results were similar to our presently investigated *A. aulicuriformis*.

Bleaching

Bleachability tends to decrease as the kappa number increases (Figure 8). As the brownstock kappa number increases, higher doses of bleaching chemicals are required to remove the remaining lignin entering the bleach plant (Rawat and McDonough, 1998). Low kappa number represents low lignin content and easy bleachability of pulps (Gullichsen and Fogelholm, 2000). A lower PhOH concentration in residual lignin was suspected for lower bleachability.

We can conclude that the total amount of chlorine dioxide used had little effect on the final viscosity of pulp. A similar result was observed previously (Hart and Connell, 2006).

No difference in the brightness of different pulps after splitting the bleaching stages was observed (Figure 8). Also brightness reached to above 85% in all pulping processes. The better delignification and higher brightness are likely the result of removing solubilized lignin by-products, which would consume some ClO_2. A similar observation was made by previous researchers (Chirat et al., 2000; Lachenal et al., 2006). The splitting of ClO_2 in 3 stages using the same chemicals also showed higher brightness in cotton stalks soda-AQ pulps (Jahan et al., 2006).

Conclusions

The following conclusions may be drawn from the above results and discussion:

The physical and morphological properties of *A. auriculiformis* were within the range of tropical hardwood species.

The α-cellulose content was lower and extractive content was higher compared to other acacias, which resulted lower pulp yield and higher kappa number in *A. auriculiformis*.

Kraft and soda-AQ processes produced better yield compared to soda process at any kappa number.

Soda-AQ pulp showed better tensile and burst index compared to soda and kraft pulps.

Kraft pulp showed the best bleachability followed by soda-AQ pulp in 3-stage- bleaching. But in the 5-stage-bleaching, all pulps showed similar bleachability. The bleached pulp showed good brightness (>85%) and viscosity (>8 mPa.s).

The pulp produced from *A. auriculiformis* can be used in the production of writing and printing quality paper.

References

Akhtaruzzaman, A.F.M., P. Das and S. K. Bose. 1987. Effect of anthraquinone in alkaline pulping of acacia auriculiformis. Bono Biggyan Patrica. 16: 3-9.

Casey, J. 1980. Pulp and Paper: Chemistry and Chemical Technology Vol. 1 2nd edn. Interscience Publ. New York

Chirat, C., D. Lachenal and G. Mortha. 2000. ClO_2 splitting in chlorine dioxide delignification. 2000 Tappi pulping conf. Proc. TAPPI PRESS Atlanta Ga (CD version).

Cossalter, C. and P.C. Smith. 2003. Fast-Wood Forestry Myths and Realities. CIFOR, Jakarta, Indonesia, pp. 50.

Davidson, J. 1985. Species and sites, Field Document No. 5, UNDP/FAO Project/79 Assistance to the Forestry Sector of Bangladesh, pp. 50.

FAO. 2005. State of the World's Forest. Rome, Italy P135.

Gullichsen, J. and C. Fogelholm. 2000. Papermaking Science and Technology Book Series, 6, Chemical Pulping, TAPPI, B 411, pp. 656-658.

Hillman, D. 2003. All market pulp hardwoods are not interchangeable. Paper Asia 19: 21.

Hale, J.D. 1959. Physical and anatomical characteristics of hardwoods. Tappi J. 42: 670-677.

Hart, P. and D. Connell. 2006. The effect of digester kappa number on the bleachability and yield of EMCC™ softwood pulp. Tappi J. 5: 23-27.

Jahan, M.S. and S.P Mun. 2004. Effect of tree age on the soda-anthraquinone pulping of Nalita wood (*Trema orientalis*) Korean J. Ind. Engg. Chem. 10: 766-771.

Jahan, M. S., D. A. Nasima Chowdhury, M. K. Islam and F. N.Ahmed. 2006. Elemental chlorine free and total chlorine free bleaching of soda-AQ cotton stalks pulps. J. Asiat. Soc. Bangladesh, Sci. 32: 179-186.

Khristova, P., S. Gabbir, S. Bentcheva and S. Dafaala. 1997. Soda-AQ pulping of three Sudanese hardwoods. Tropical Science 37: 176-182.

Khristova, P. and L. Karar. 1999. Soda-anthraquinone pulp from three *Acacia nilotica* subspecies. Bioresource Technology. 68: 209-213.

Kokima, E. 2001. Evolving Technology: Strategies Found in recent Eycalyptus and Acacia tree farms pursuing intensive Agriculture. Japan Tappi Journal. 35: 19.

Lachenal, D., C. Chirat and Y. Hamzeh. 2006. Future challenges in chemical pulp bleaching. ATIP. 60: 6-11.

Logan, A.F. and V. Balodis. 1982. The Malaysian Forester. 42: 217-236.

Law, K.N. and R. W. Daum. 2000. CMP and CTMP of a fast-growing tropical wood: Acacia maingium. Tappi J. 83: 1-7.

Malinen, R.O., S. Pisuttipiched, H. Kohelmainen and F.N. Kusuma. 2006. Potential of Acacia species as pulpwood Appita J. 59: 190-196.

Miyanishi, T. and K. Watanabe. 2004. Kraft pulping of *Acacia mangium*. 2004 Tappi Pulping, Engineering and Environment Conference Proceedings TAPPI PRESS, Atlanta, GA(CD version).

Parthasarathy, V.R., G. C. Smith, G.F. Rudie, A.E. Detty and J.J. Stefy. 1995. Application of anthraquinone in extending the delignification of kraft and polysulfide pulps. Part 1: pulping and bleaching of mixed dense hardwoods. Tappi J. 78:113-125.

Paavilainen, I. 2000. Quality competiveness of Asian short fiber raw materials in different paper grades. Paperi ja puu. 82: 156.

Pinto, P.C., D.V. Evtuguin and C. P. Neto. 2005 Chemical composition and structural features of the macromolecular components of plantation acacia mangium wood. J. Agric. Food Chem. 53: 7856-7862.

Pirtarinen, S. P., S. M. Willfor R.E. Shoholm and B. Holmborn. 2005. Bioactive phenolic substances in important tree species. Part 3. Knots and stemwood of Acacia crassicarpa and acacia mangium Holzforschung. 59: 94-101.

Pisuttipiched, S. 2002. Effect of harvesting age of *Eucalyptus camaldulensis* on bleached kraft pulp manufacture. 69p. Ph.D. Dissertation, AIT, Thailand.

Rawat, N. and T. McDonough. 1998. Pulping Conference Proceedings, TAPPI PRESS, Atlanta, GA p. 201.

Santos, A.J.A, O.M.S. Anjos and R.M.S. Simoes. 2006. Papermaking potential of Acacia dealbata and Acacia Melanoxylon. Appita J. 58: 58-64.

Siregar, D. M. 2001. *Acacia mangium* characteristics of various age, height point and branches for kraft pulping raw material. M. Sc. Thesis, AIT, Bangkok, Thailand.

World Agroforestry Centre 2005: Tree databases: Agroforestree Database 3.0 (CD-version).