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# Effect of cooking conditions and oxygen-delignification on *Bambusa tulda* kraft pulping

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Bamboo is a fast growing non-wood plant with long and thin fibers. Therefore, it has potential as a raw material for pulping and papermaking. In this work, the effects of alkali charge and sulfidity on the kappa number, yield and viscosity were investigated in a bamboo kraft pulping process before and after $O_2$-delignification. The results indicated that higher alkali charge can get higher residual alkali and lower yield, kappa number and viscosity. Higher sulfidity can conclude higher viscosity and lower yield, residual alkali and kappa number.

**Keywords**: Sulfidity, Active alkali, Kraft pulping, $O_2$-delignification

Bamboo is an important fibrous raw material used in pulp and paper industry. It is widely distributed in the tropical and sub-tropical regions of continents except Europe. Bamboo has very high biomass and is well established as an excellent fiber raw material for the production of pulp and paper. Bamboo can be considered as a long and thin fiber source. It has a wide range of fiber characteristics, from fibers similar to hardwood, to fiber similar to softwoods. Bamboo grows much faster than hardwood and softwood. A three years bamboo can reach the diameter of 20 cm and the height of 20 meters[1]. In India, bamboo pulp is blended with shorter fiber pulps for making packaging paper and fine papers. High-grade bamboo pulp is used in its pure form for making coated and uncoated book and magazine papers. Due to the high length to diameter ratio of bamboo fiber, it can be used for more versatile paper products better than the majority of other non-wood pulps[2]. Since bamboo has high silica content, it is usually pulped using the kraft process, in order to separate the fibers by removing lignin. Also, bamboo is similar to wood for material handling process and can replace some part of the feedstock without any system modification[3].

Kraft pulping is an alkaline chemical pulping method using sodium hydroxide (NaOH) and sodium sulfide ($Na_2S$) to separate fiber by dissolving lignin[4]. It gives a high strength of pulp and has an acceptable yield and chemical recovery cycle. In order to improve the properties of pulp, modifications of kraft pulping is an important method. Cooking conditions affect pulping properties such as yield, screen rejects, kappa number, residual alkali and viscosity including white liquor charge, liquor to bamboo chips ratio, H-factor (related to time of reaction rate and temperature) and sulfidity. In practice, sulfidity is often determined by chemical balance of the mill: higher in closed cycle mills; lower in open mills. Typical sulfidity ranges are usually around 25% to 40%. However, the optimum sulfidity also depends on several factors, such as wood species, alkali charge, cooking temperature and properties desired in the final product. Higher sulfidity means higher delignification rate, better selectivity and improved pulp strength and slightly higher yield. However, when the higher sulfidity are used, the active alkali charge has to be increased to keep the effective alkali constant.

Also O2-delignification process is very flexible, and is best viewed as a bridging strategy between cooking and final bleaching. The important parameters used to control and optimize an $O_2$-delignification stage in a commercial industrial setting are temperature, reaction time, chemical application rate, *p*H, reactor pressure, and pulp consistency[5]. Vu *et al.*[6] in a study on *Bambusa procera* reported that a suitable pulp could be produced by conventional kraft pulping followed by ODL (oxygen delignification). They observed that the high sulfidity (35-45%) with lower effective alkali (14-16%) resulted in both high yield and high pulp viscosity compared with low sulfidity and high effective alkali at the same degree of delignification. Also the response of kraft pulp of *Melocanna baccifera* (Muli Bamboo) in different conditions of oxygen delignification was investigated by Thomas *et al*[7]. In this work, oxygen delignification process reduced the kappa number of pulp up to 40-75%. In order to increase pulping characteristics, optimization of kraft pulping process is an important necessity. The experimental cooking conditions in pulping process include white liquor charge, sulfidity, liquor to bamboo chips ratio, H-factor such as relation reaction time and temperature, which must be treated. Variations of these experimental conditions strongly affect the yield, viscosity, kappa number, screen rejects, and residual alkali. In the present investigations, effects of alkali charge and sulfidity on the yield, kappa number and viscosity were investigated in bamboo kraft pulping. It was also found that bamboo kraft pulp was easily delignified by oxygen up to a low kappa number (11) without any significant loss in yield. In $O_2$-delignification, pulp of higher kappa number consumes more chemicals to reduce its lower kappa number. It is more difficult to remove residual lignin from pulp of higher kappa number in cooking.

## Experimental Procedure

### Pulping and Screening

Bamboo chips (*Bambusa tulda*) used were obtained from Thailand. For pulping, these chips were screened in a laboratory chip classifier as described in SCAN–CM 40:94 standard by using the screen plates having from the top to down 45 mm holes, 8 mm slot, 7 mm round holes and 3 mm holes. The chips between 8 mm slots and 7 mm holes were collected by screening. Then dirty bamboo chips were washed. Screened chips were air-dried and stored in the cold room. Dry matter content (DMC) of the bamboo chips was measured according to the standard test method of SCAN–CM 39:94.

Cooking liquor including sodium hydroxide and sodium sulfide were prepared from Merck products (Germany). Concentrations of cooking liquor were analyzed according to SCAN–N 2:88 standard. Then, on the basis of concentration of cooking liquor and the ratio of liquor to bamboo chips weight (L/W), the volume of white liquor and water were calculated. Finally, these liquors were mixed evenly before charging. Bamboo chips were cooked in the CRS reactor Engineering Digester equipped with six autoclaves each 2.5 L volume air-heated digester. The cooking method is kraft process in which effect of the two variables of alkali charge and sulfidity were investigated. After each cooking, the autoclaves were cooled by spraying cold water on autoclaves for 5 min. Then black liquor was taken out and residual alkali for each cooking liquid based was measured on the standard scan of Tappi (T625 cm-85). The cooking conditions are shown in Table 1. The cooked pulps were washed with about 8 L of tap water in a diffuser vessel equipped with wire cloth. This washing procedure was repeated 5 times. After washing, all the pulps were centrifuged for 5 min and homogenized for 10 min. Then DMC of pulp was measured (SCAN–C 3:78) and cooking yield was calculated. After calculating yield, each pulp was defibrated in defibrator chamber and then screened on a flat screen using a 0.2 mm slot screen. The amount of screen reject was determined to obtain the percentage of pulp reject and the screened yield. Screened pulp was centrifuged for 5 min and homogenized for 10 min. The DMC of the pulp (SCAN–C 3:78), kappa number (SCAN–C 1.77) and viscosity (SCAN–CM 15:88) were determined.

### Oxygen delignification

The oxygen delignification was carried out in bleaching reactor. Pulp and distilled water before bleaching were preheated in microwave oven. The oxygen delignification conditions have been summarized in Table 2. The temperature of stock was raised from room temperature to 95°C as fast as possible. The oxygen pressure was adjusted to 6 bars at 95°C. Then the temperature of 95°C was maintained for 60 min. The *p*H was determined at the end of $O_2$-delignification at room temperature. After $O_2$-delignification, the pulp was washed with deionized water using suction bottle in three stages. At the first stage, the pulp was diluted to a 3-3.5% consistency in a Buchner funnel and then carefully dewatered by pressing. In the second and third stage, the pulp was diluted to 10 and 3% consistency respectively with deionized water and this mixture was then dewatered by pressing. Prior to analysis, the

Table 1—Cooking conditions for *Bambusa tulda*

| | |
|---|---|
| Cooking method | Kraft |
| Amount of bamboo chips (oven dry, o.d.) | 400 g |
| Liquor to bamboo chip ratio (L/W) | 4:1 |
| Cooking temperature (°C) | 165 |
| Pulping time from 80°C to maximum temperature (min) | 90 |
| Active alkali, on o.d. bamboo (as NaOH) (%) | 18, 20, 22, 24 |
| Sulfidity (%) | 0, 5, 10, 15, 30 |

Table 2—$O_2$-delignification conditions for kraft pulp from *Bambusa tulda*

| | |
|---|---|
| Amount of pulp (g as o.d.) | 150 |
| NaOH charge (%) | 2.5 |
| Oxygen pressure (bar) | 6 |
| $MgSO_4.7H_2O$ (%) | 0.4 |
| Temperature (°C) | 95 |
| Treatment time (min) | 60 |
| Consistency (%) | 8 |

Table 3—Data of cooking results for *Bambusa tulda*

| Experiments AA (%) | Experiments S (%) | Residual alkali (g/L) | Cooking yield (%) | Screen rejects (%) | Screened yield (%) | Kappa number | Viscosity (mL/g) |
|---|---|---|---|---|---|---|---|
| 18 | 0 | 1.2 | 53.5 | 10.4 | 48.9 | 36.5 | 987 |
| | 5 | 1.2 | 53.2 | 9.3 | 48.0 | 32.4 | 997 |
| | 10 | 1.2 | 52.1 | 8.4 | 48.0 | 32.6 | 1040 |
| | 15 | 1.2 | 51.2 | 6.8 | 47.0 | 30.8 | 1086 |
| | 30 | 0.8 | 49.8 | 2.9 | 48.6 | 29.9 | 1190 |
| 20 | 0 | 4.1 | 50.2 | 7.9 | 47.8 | 33.4 | 812 |
| | 5 | 3.0 | 50.1 | 6.7 | 44.5 | 30.2 | 964 |
| | 10 | 2.9 | 49.6 | 6.0 | 44.2 | 30.1 | 987 |
| | 15 | 2.9 | 47.3 | 4.3 | 43.5 | 30.1 | 986 |
| | 30 | 1.7 | 50.3 | 2.8 | 49.0 | 27.0 | 1030 |
| 22 | 0 | 11.6 | 49.9 | 5.7 | 45.3 | 29.7 | 692 |
| | 5 | 10.7 | 49.1 | 5.4 | 42.4 | 27.5 | 864 |
| | 10 | 10.3 | 49.0 | 4.4 | 43.0 | 24.2 | 972 |
| | 15 | 9.5 | 49.0 | 3.5 | 44.7 | 24.6 | 1005 |
| | 30 | 8.7 | 49.5 | 2.6 | 46.7 | 22.9 | 1050 |
| 24 | 0 | 15.7 | 48.8 | 4.7 | 43.1 | 29.0 | 807 |
| | 5 | 14.4 | 48.7 | 4.4 | 43.3 | 26.2 | 842 |
| | 10 | 14.0 | 48.5 | 4.2 | 44.1 | 24.0 | 923 |
| | 15 | 14.0 | 48.2 | 3.5 | 44.7 | 22.6 | 964 |
| | 30 | 12.8 | 49.0 | 2.1 | 46.4 | 21.8 | 1001 |

washed $O_2$-delignified pulp was centrifuged for 5 min and homogenized for 10 min. The yield, kappa number and viscosity of pulps were determined according to the same standard test methods as used for the cooked pulps.

## Results and Discussion

### Effect of AA and sulfidity

The effects of active alkali and sulfidity on properties of the pulps are shown in Table 3. These results show that both active alkali charge and sulfidity have reverse effect on kappa number. Therefore, either an increase in AA at a constant sulfidity or, on the other hand, an increase in sulfidity at a constant AA resulted in a clear reduction in kappa number. The benefical effect of sulfur addition (e.g. addition of hydrogen sulfide ions) was also easily observed from these cook series. Without sulfur addition (at a sulfidity level of 0%), it was difficult to delignify bamboo to a desired kappa number even though high AA charges were used. In particular, in the case of non-sulfur cooks, an intensive alkali-catalyzed degradation of carbohydrates occurred, as indicated by the low viscosity values (<1000 ml/g) (Table 3). On the contrary, at the lowest AA (18%) and the highest sulfidity (30%), it was possible to delignify bamboo to a kappa number close to 30. These conditions also resulted in a higher pulp viscosity (with desired yield) than those obtained under the conditions of high AA (22-24%) and high sulfidity. From these results, it could be concluded that the selective action of hydrogen sulfide ions in bamboo pulping is similar to that observed in wood pulping[8]. Also Table 3 indicates that, even at very low kappa numbers (21-22), bamboo gave adequate cook yields (48-49).

Table 3 also indicates that low residual alkali can be obtained at low alkali charge and high sulfidity and it was close to zero at 18% AA level. In these expriments, lower kappa number and higher sulfidity can cause a lower cooking yield (Table 3). It was also noticed that there was lower screen reject at lower kappa number with higher sulfidity.

### Oxygen delignification

The kappa number and yield of the kraft pulps are presented in Table 4 before and after oxygen delignification. It can be seen that the degree of delignification at the same AA was dependent on initial kappa number. The lower the kappa number after cooking, the lower the kappa number after oxygen delignification. It indicates that oxygen delignification process delignifies the selected bamboo kraft pulps to a very low kappa number.

Table 4—Data for $O_2$-delignification of kraft pulp from *Bambusa tulda*

| Experiments | | Kappa number | | Yield (%) | |
|---|---|---|---|---|---|
| AA (%) | Sulfidity (%) | After cooking | After $O_2$-delignification | After cooking | After $O_2$-delignification |
| 18 | 0 | 36.5 | 22.2 | 48.9 | 44.6 |
| | 5 | 32.4 | 20.9 | 48.0 | 44.5 |
| | 10 | 32.6 | 19.1 | 48.0 | 44.0 |
| | 15 | 30.8 | 19.0 | 47.0 | 42.9 |
| | 30 | 29.9 | 15.1 | 50.6 | 47.6 |
| 20 | 0 | 33.4 | 19.6 | 47.8 | 43.6 |
| | 5 | 30.2 | 19.2 | 44.5 | 42.0 |
| | 10 | 30.1 | 17.1 | 44.2 | 41.9 |
| | 15 | 30.1 | 15.8 | 43.5 | 40.6 |
| | 30 | 27.0 | 14.2 | 49.0 | 45.4 |
| 22 | 0 | 29.7 | 17.7 | 45.3 | 41.4 |
| | 5 | 27.5 | 17.1 | 42.4 | 41.8 |
| | 10 | 24.2 | 15.7 | 43.0 | 40.2 |
| | 15 | 24.6 | 14.8 | 44.7 | 40.0 |
| | 30 | 22.9 | 12.2 | 46.7 | 44.2 |
| 24 | 0 | 29.0 | 18.1 | 43.1 | 40.1 |
| | 5 | 26.2 | 17.0 | 43.3 | 39.7 |
| | 10 | 24.0 | 14.6 | 44.1 | 39.5 |
| | 15 | 22.6 | 13.2 | 44.7 | 38.5 |
| | 30 | 21.8 | 11.1 | 46.4 | 39.9 |

## Conclusion

In bamboo kraft cooking, higher alkali charge can increase residual alkali and reduce yield, kappa number and viscosity. Higher sulfidity can result in higher yield and lower kappa number. In $O_2$-delignification, higher kappa number pulp needs more chemical to get lower kappa number. It is more difficult to remove residual lignin from pulp of higher kappa number in cooking. Lower kappa number would give benefits in $O_2$-delignification and bleaching, because of less residual lignin remained in the pulp. Lower residual lignin in pulp content required less amount of bleaching chemicals to obtain the same brightness of bleached pulp. In addition, from final yield, kappa number and viscosity, it is shown that bamboo pulp has very high strength. Though modified pulping and oxygen delignification for lower kappa number may be considered but from the economy aspects long bamboo fibers need to be blended with shorter fiber hardwood pulps in papermaking.

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