Biobleaching of kenaf bast fiber, soda–AQ pulp using white-rot fungus

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ABSTRACT

Soda–AQ pulps were made from two types of kenaf bast fibers, one from China and one from Japan. The pulp from China was retted bast fiber. After a six-day treatment with the white-rot fungus Phanerochaete chrysosporium, *the kappa number decreased by 67% for the pulp from Japan and by 33% for the pulp from China. The biobleaching process, which combined a fungal treatment and EP bleaching, compared favorably with a conventional CEH process in terms of brightness, opacity, yield, and strength for both pulps.*

Application: *Kenaf is a nonwood fibrous plant grown in many parts of the world. Its pulp can be bleached without chlorine in a treatment with white-rot fungus.*

THE SEARCH IS ON FOR NEW sources of fibrous materials to replace forest-based resources, and the effort to reduce the environmental impact of pulp mill effluents is in full swing (*1–4*). In Japan, the utilization of nonwood plants for pulp and paper is only 0.1%, and the demand for feasible nonwood resources is increasing. Over the last decade, kenaf has attracted attention as a potential resource for papermaking.

Kenaf (*Hibiscus cannabis L.*) is a fast-growing, warm-season, annual plant of the *Malvaceae* family. Kenaf has been pulped by the kraft method on a commercial scale, making use of the whole stalk. Most of the conventional processes of chemical pulping have been practiced, although some nonconventional methods have also been used (*5–8*). When bast and core fibers have been cooked separately, soda–AQ pulping of bast fiber has yielded satisfactory results (*9*).

Growing public concern about the environment is giving rise to technological changes in the bleaching processes. The effluent from the conventional bleaching process contains some chlorinated organic compounds that have shown mutagenic activity. One of the new and developing techniques is the replacement of chlorine-based bleaching stages with biobleaching using ligninolytic white-rot fungi (*10–13*).

The white-rot fungi, including *Phanerochaete chrysosporium* and *Trametes versicolor*, are effective microorganisms for degrading lignin (*14–15*). There are numerous studies regarding the use of white-rot fungus for biobleaching of different kinds of wood and nonwood pulps. However, there are few reports on the biotreatment of kenaf fiber pulp with a white rot fungus.

Therefore, we applied the fungus *P. chrysosporium* to the delignification and brightening of unbleached soda–AQ pulps of kenaf bast fibers. After the fungal treatment, the pulps were bleached by a chlorine-free EP sequence (alkaline extraction and hydrogen peroxide). The pulp and the pulp's handsheet properties were compared with pulp bleached by the conventional CEH process (chlorine, alkaline extraction, and hypochlorite).

MATERIALS AND METHODS

Kenaf fibers used and pulp preparation

Two types of kenaf bast fibers were selected for this study. Some of their properties are given in **Table I**. One is a commercial kenaf bast fiber that is harvested and retted in China, and the other is a kenaf bast fiber harvested in Japan.

Laboratory-scale pulping trials were made on both kenaf bast fibers using the soda–AQ process. The following conditions were used:

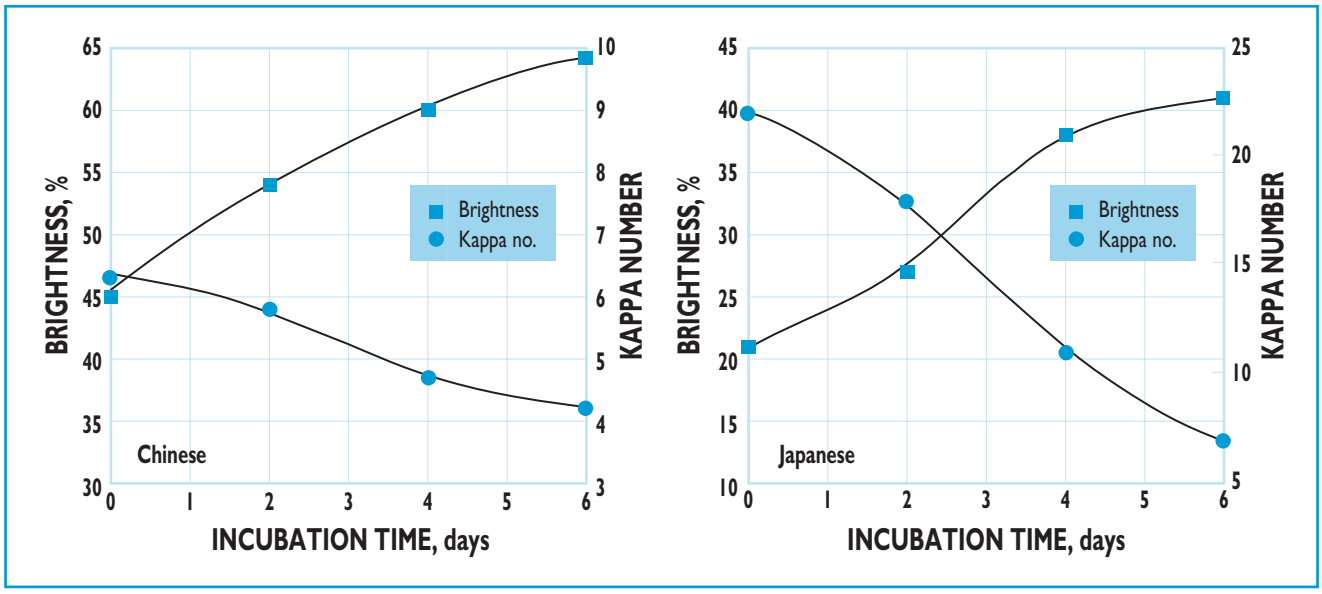
- Liquor-to-solids ratio of 5 L/kg
- Cooking temperature of 170°C
- Cooking duration of 2 h
- Anthraquinone charge of 0.2%
- NaOH charge of 13%, Chinese NaOH charge of 16%, Japanese.

For the unbleached soda–AQ pulps, the yields were 63% and 48% with kappa numbers of 6.3 and 21 for the Chinese and Japanese pulps, respectively.

Biobleaching of soda–AQ pulps

P. chrysosporium ME-446 was used in this study. The fungus was maintained on potato dextrose agar (Difco Laboratories). The agar plate was inoculated with the fungus and was incubated for five days at 30°C. Five disks punched from the grown edge of mycelium were homogenized for 30 s with 50 mL of a medium consisting of 3.0% glucose, 1.0% peptone, 1.0% malt extract, and 0.4% yeast extract. A 500-mL Erlenmeyer flask with 150 mL of this medium was shaken at 200 rpm to give a mycelium suspension culture.

After three days, 50 mL of the culture was homogenized once again. The homogenized culture was precultured in a 500-mL Erlenmeyer flask with 250 mL of the medium on a rotary shaker (200 rpm) for five



1. Kappa number and brightness of soda–AQ pulps of kenaf bast fibers from China and Japan as a function of incubation time with **P. chrysosporium.**

	China	Japan
Extractives, %	1.2	4.3
Klason lignin, %	8.0	12.5
Ash, %	4.0	4.2
Holocellulose, %	76	73
Pentosans, %	23	21
Basic density, g/cm³	0.33	0.31

1. Comparison of properties for kenaf bast fibers from China and Japan

days at 30°C. The precultured mycelium of the fungus was separated from the medium and was aseptically added to a 300-mL Erlenmeyer flask. This flask already contained a mixture of unbleached pulp (10 g) and a culture medium (40 mL). In regard to its composition, this culture medium contained the following in one liter of distilled water at pH 4.5:

- 20.0 g of glucose
- 0.2 g of ammonium tartrate
- 1.0 g of KH_2PO_4
- 0.2 g of NaH_2PO_4
- 0.5 g of $MgSO_4 \cdot 7H_2O$
- 1.46 g of dimethyl succinate
- 100 µg of thiamine hydrochlorite
- 100 µg of $CaCl_2$
- 100 µg of $FeSO_4 \cdot 7H_2O$
- 10 µg of $ZnSO_4 \cdot 7H_2O$
- 20 µg of $CuSO_4 \cdot 5H_2O$
- 10 µg of $MnSO_4 \cdot 4H_2O$.

With this system, the pulp consistency corresponded to about 20%. The pulps were incubated statically at 30°C.

Samples were collected during the second, fourth, and sixth days of incubation. These samples were washed thoroughly with deionized water, dewatered by filtration on a fine filter paper, and stored in a refrigerator.

Pulp bleaching procedure

The unbleached soda–AQ pulps of both types of bast fibers were bleached by a three-stage sequence. A six-day fungal treatment (F) was followed by alkaline extraction (E) and hydrogen peroxide bleaching (P). During the alkaline-extraction stage, the pulps at 10% consistency were extracted with 1.5% NaOH for 1 h at 50°C. The hydrogen peroxide bleaching was carried out with charges of 2% H_2O_2 for the China bast and 4.5% for the bast from Japan. The NaOH charge was 1% at 10% consistency for 3 h at 70°C.

To compare the results with a conventional bleaching method, we bleached the soda–AQ pulps by a CEH sequence as well. The active chlorine charges in the C stage were 4% and 6.5% for the Chinese and Japanese pulps, respectively. In the E stage, the NaOH charge was 1.5%. In the hypochlorite stage (H), the amounts of active chlorine charge were 1% and 2% for the Chinese and Japanese pulps, respectively.

Analytical methods

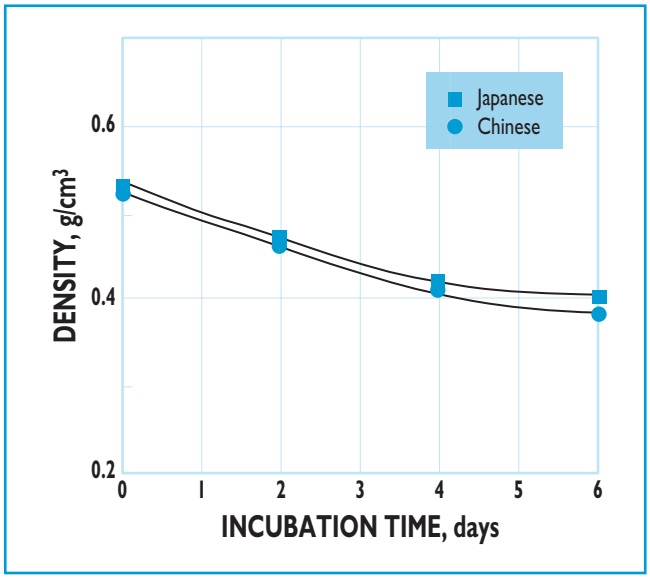
TAPPI Test Method T 452 was used to determine the kappa number and prepare the handsheets. The brightness and opacity values of the handsheets were determined with a Hunter-type reflectometer, according to TAPPI T 452 om-87 and Japanese Industrial Standard (JIS) Test Method P 8138. Handsheet strength properties were measured according to TAPPI Test Method T 220, and their densities were calculated according to JIS C 2111.

RESULTS AND DISCUSSION

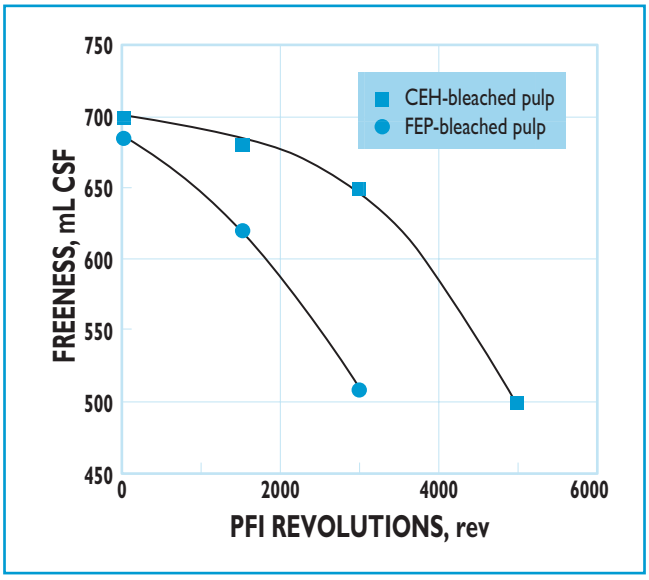
Fungal treatment of kenaf soda–AQ pulps

Figure 1 shows the effects of fungal treatment on the kappa numbers and brightnesses of the kenaf soda–AQ pulps. For each pulp, the kappa number decreased, and the brightness increased proportionally, indicating that the fungal treatment readily removed residual lignin in the pulp.

As shown in **Table II**, the six-day treatment of the Japanese soda–AQ



2. Handsheet density of both unbleached soda–AQ pulps as a function of incubation time with P. chrysosporium.



3. Freeness vs. PFI revolutions for FEP- and CEH-bleached pulps of Chinese bast fiber.

pulp with the fungus *P. chrysosporium* decreased the kappa number by about two-thirds. However, the kappa number of the Chinese pulp decreased by about one-third. At least a portion of the difference in the fungal delignification between the two pulps is attributable to the amount of residual lignin in the pulp. A fair amount of biodegradable lignin in the Chinese pulp had already been removed by the retting and pulping processes. Thus, the fungal treatment of the Chinese pulp did not decrease the kappa number appreciably, compared to the drop in lignin for the Japanese pulp.

The kappa number decrease for the Japanese pulp was comparable to that of other nonwood pulps treated with *P. chrysosporium* in earlier studies. Mehta and coworkers reported that the kappa numbers of wheat straw kraft pulp and bagasse kraft pulp were decreased by 38.5% and 35.9%, respectively, using *P. chrysosporium* (*14*). However, they applied different culture conditions.

Tran and Chambers reported comparatively high lignin degradation (about 33–57%) when an unbleached hardwood kraft pulp was treated with *P. chrysosporium* for ten days in experiments with the pulp consistency at 1.4% and with a glucose–pulp ratio of 33% (*15*).

As shown in Table II, yield losses after the six days of treatment were slight for the two bast fiber pulps. This result shows that selective delignification proceeded readily during treatment with *P. chrysosporium*.

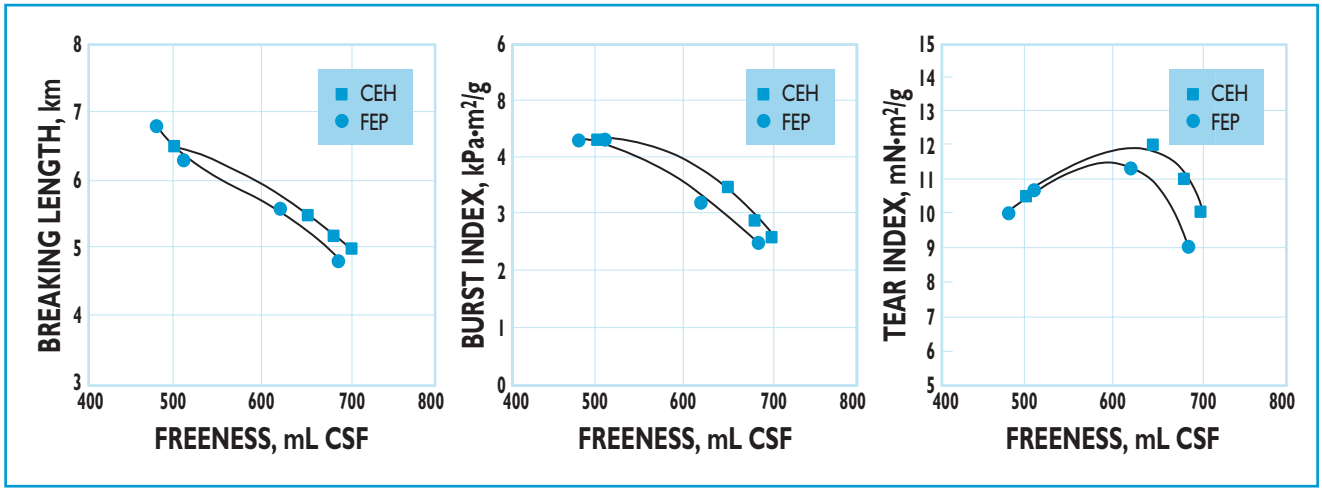
The handsheet density shown in **Fig. 2** was plotted as a function of incubation time. As incubation progressed, the handsheet density decreased for both pulps. Presumably, the porous structure of the individual pulp fibers was influenced by the fungal treatment. The opacity increase caused by the fungal treatment (Table II) supports this consideration.

	Untreated		Treated	
	China	Japan	China	Japan
Initial freeness, mL CSF	689	665	680	648
Kappa number	6.3	21	4.2	7
Yield, %				
Kenaf base	63	48	61.5	46
Soda–AQ pulp base	…	…	97.6	95.8
Brightness, %	45	22	64	41
Opacity, %	83	86	89	92

II. Characteristics of soda—AQ pulps of China and Japan before and after a six-day treatment with P. chrysosporium

	China		Japan	
	FEP	CEH	FEP	CEH
Initial freeness, mL CSF	681	698	635	640
Yield, %	59	51	41	39
Sheet density, g/cm³	0.43	0.52	0.48	0.60
Brightness, %	79.5	78.5	77	78
Opacity, %	78	75.5	79	76

III. Characteristics of FEP- and CEH-bleached soda–AQ pulps of bast fibers from China and Japan



4. Breaking length, burst index, and tear index vs. freeness for FEP- and CEH-bleached pulps of Chinese bast fiber.

Characteristics of the FEP- and CEH-bleached pulps

After alkaline extraction, the fungus-treated pulps were bleached to a brightness of about 77–80% with low amounts of hydrogen peroxide. The initial freeness values of the chlorine-free bleached pulps were slightly lower than those of the conventional CEH-bleached pulps, as shown in **Table III**. However, the difference is thought to be negligible.

Although the handsheet brightnesses were similar for both FEP- and CEH-bleached pulps, the yields of FEP-bleached pulps were greater. The densities of the FEP-bleached pulps were slightly lower, but the opacities of the FEP-bleached pulps were higher than those of the CEH-bleached pulps.

After fungal treatment, the Chinese pulp had higher pulp yields and handsheet brightnesses than the Japanese pulp reached. For the same brightness, it was also easier to bleach the Chinese pulp. We therefore chose the Chinese pulp as the pulp on which to compare strength properties by studying the behaviors of the FEP- and CEH-bleached pulps in PFI refining.

We observed that the relationship between the PFI mill revolutions and freeness of FEP-bleached pulp was different from that of the CEH-bleached pulp. As shown in **Fig. 3**, it took about 5000 rev in the PFI mill to reach a freeness of 500 mL CSF for the CEH-bleached pulp. By contrast, the FEP-bleached pulp needed only about 3000 rev. Thus, fungal treatment reduced the beating energy required by about 40%.

Figure 4 shows the effects of beating on the strength properties of handsheets made from FEP- and CEH-bleached pulps of the bast fiber from China. The strength properties of FEP-bleached pulp during the beating process were almost equal to those of CEH-bleached pulp. As a result of refining to a freeness of about 500 mL, the breaking length was increased by about 42%, and the burst index was increased by about 57%. These results are sufficiently comparable to those of the CEH-bleached pulp, as those two graphs in Fig. 4 show. Furthermore, there was no significant difference in the tear index between the FEP- and CEH-bleached pulps at a freeness of about 500 mL.

KEYWORDS
Anthraquinone, bast fibers, biobleaching, brightness, chlorine-free bleaching, fungi, kappa number, kenaf, multistage process, Phanerochaete chrysosporium, *pretreatment, soda pulping, white rot fungi*

SUMMARY

After a six-day pretreatment with the fungus *P. chrysosporium*, the kappa number of the unbleached China soda–AQ pulp decreased from 6.3 to 4.2. Consequently, the handsheet brightness increased from 45% to 64%. Under the same fungal treatment, the kappa number of the Japanese soda–AQ pulp decreased from 21 to about 7, with an accompanying increase in brightness from 22% to 41%.

The brightnesses for both pulps after chlorine-free bleaching compared favorably with those of the pulps after conventional bleaching. In addition, the yields of both FEP-bleached pulps were greater than those of the conventional method. (This increase was more significant for the pulp made from the bast fiber from China.) The opacity values of the handsheets prepared from the FEP-bleached pulps were somewhat higher than those prepared from the conventional CEH-bleached pulps.

Each of the bleached pulps was processed in a PFI mill to determine the number of revolutions required to obtain a freeness of 500 mL CSF. The CEH-bleached pulp required 5000 revolutions, but the FEP-bleached pulp required only 3000 revolutions. The strength properties of FEP-bleached pulps during the beating process proved to be at least as strong as those of CEH-bleached pulps in all respects. **TJ**

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