BIOMECHANICAL PULPING OF KENAF

Aziz Ahmed[1]
Masood Akhtar[2]
Gary C. Myers[1]
Gary M. Scott[3]

[1]USDA Forest Service
Forest Products Laboratory
One Gifford Pinchot Drive
Madison, WI 53705–2398

[2]Biopulping International Inc.
P.O. Box 5463
Madison, WI 53705

[3]Faculty of Paper Science and Engineering
College of Environmental Science and Forestry
State University of New York
One Forestry Drive
Syracuse, NY 13210

ABSTRACT

The objective of this study was to investigate the effect of fungal pretreatment of whole kenaf prior to refining on refiner electrical energy consumption, paper strength, and optical properties. We also explored the suitability of whole kenaf biomechanical pulp for making newsprint in terms of ISO brightness and strength properties. Kenaf was sterilized by autoclaving and treated with the white-rot fungus *Ceriporiopsis subvermispora*. Control and fungus-treated kenaf fiber was pulped by refiner mechanical pulping (RMP) and chemirefiner mechanical pulping (CRMP) processes. Pulps were then compared in terms of refiner electrical energy consumption, physical and optical properties of paper, and response to post hydrogen peroxide (H_2O_2) bleaching conditions. Fungal treatment of kenaf fiber saved up to 38% electrical energy consumption during preparation of RMP and CRMP compared to energy used for the control. Handsheet properties of treated (biomechanical) RMP pulp improved 60% to 80% in burst index, 40% to 45% in tear index, and 58% to 65% in tensile index compared to the control. RMP biomechanical pulp also showed a 15% to 20% decrease in brightness compared to that of control RMP. However, brightness could be raised to 62% ISO with a single-stage application of 2.5% H_2O_2 compared to 1% H_2O_2 for control pulp. Applying multistage hydrogen peroxide and hydrosulfite bleaching processes could raise the brightness level of biomechanical pulp even further. The higher strength of biomechanical kenaf pulp could eventually reduce the percentage of costly kraft pulp needed in newsprint and coated paper based on kenaf pulps.

INTRODUCTION

Kenaf is a rapidly grown renewable annual plant that can be used as an alternative to wood-based fiber for pulp and paper products. Kenaf, which is primarily a fibrous stalk, consists of 60% to 65% core and 35% to 40% bast fibers (weight basis). The bast fibers are roughly equivalent in length and width to softwood fibers, and the core fibers are roughly equivalent to hardwood fibers. Kenaf is the potential alternative source of good fiber in many countries where wood pulp is not available locally [1]. Extensive research at the USDA Midwestern National Center for Agricultural Utilization Research and the Forest Products Laboratory led to the conclusion that most conventional pulping processes (e.g., kraft, soda, neutral sulfite, thermomechanical pulping (TMP), chemithermomechanical pulping (CTMP), and chemimechanical pulping (CMP)) are suitable for kenaf pulping [2–4]. A blend of 82% to 95% kenaf CTMP with 5% to 18% kraft pulp has been reported to produce commercial-grade newsprint [5]. A blend of 25% kenaf CTMP with 75% commercial deinked recycled pulp also produces newsprint of acceptable quality [6].

The effect of fungi on wood, especially white-rot fungi, has been known for a long time. The benefits of fungal treatment of chips prior to TMP pulping was first reported by Eriksson et al. [7]. Bar-Lev et al. [8] reported that fungal treated TMP coarse fiber required less energy in secondary refining compared to untreated coarse fiber. These results were verified and strengthened by work at other laboratories [9–16]. Fungal treatment of wood chips saved electrical energy during fiberization and refining, and improved burst and tensile indexes of handsheets [13–15].

The use of fungi for non-woody plants prior to mechanical pulping has recently received attention. The white-rot fungus *Panus conchatus* was able to release 24.7% of water-soluble modified lignin from wheat straw in only 3 days after inoculation [17]. Selective delignification of wheat straw by *Pleurotus eryngii* has also been reported [18]. The white-rot fungus *Ceriporiopsis subvermispora* apparently modifies the cell wall and middle lamella of kenaf bast fibers; it resulted in about 40% refiner energy savings and substantially enhanced the pulp strength properties [19]. Benefits of enzymatic treatments of non-woody plants prior to mechanical pulping in terms of energy savings and paper strength improvements were recently reported [20], although the non-woody fibers suffered significant loss in cellulose and hemicellulose contents with virtually no effects in lignin content. Energy consumption in refiner mechanical pulping of untreated, fungal-treated, and alkali-treated jute was investigated [21]. Fungal-treated bast jute required about 33% less refining energy and showed significant improvement in handsheet strength properties. Alkali treatment of jute also increased handsheet strength properties significantly.

Biomechanical pulping [9,21,22] draws attention as a result of the substantial energy savings realized during refining, for both woody and non-woody lignocellulosic materials. Energy consumption when using refiner mechanical pulp from fungus-treated wood chips is 30% to 35% lower than with similar control pulp [14]. Chemirefiner mechanical pulping is also influenced by type and level of chemical pretreatments applied.

We recently investigated the biokraft process (fungus-treated lignocellulosic material pulped by kraft process) for both whole and bast kenaf [23]. Mechanical properties of kraft pulp produced from fungus-treated kenaf and control kenaf were similar. The bleaching response of biokraft kenaf pulp to conventional bleaching chemical was better than that of kenaf kraft pulp. The brightness of whole kenaf biokraft pulp was raised to 86% ISO brightness by applying DED stages and to 88% ISO brightness by applying DEDP stages. Brightness of whole kenaf kraft pulp was raised to 80% ISO brightness by using a similar bleaching condition. The objective of this study was to investigate the effect of fungal pretreatment of whole kenaf prior to refining on refiner electrical energy consumption, paper strength, and optical properties. We also explored the suitability of whole kenaf biomechanical pulp for making newsprint in terms of ISO brightness and strength properties.

EXPERIMENTAL

Raw Material

All pulping trials used kenaf grown in Mississippi. The freshly cut kenaf was dried, cut into pieces 15 to 20 cm long, packed in a 0.08 by 0.08 by 0.17 m^3 box, and delivered to the USDA Forest Service, Forest Products Laboratory. The whole kenaf was chopped into 1- to 4-cm-long pieces before further processing. The chopped kenaf stem was dispersed and washed with warm water to remove dirt, dust, and fine noncellulosic material. The washed kenaf was dewatered to a solids content of 40% to 45%. A portion of the washed kenaf was autoclaved for 90 min and used as a control. Another portion of the washed kenaf was used for fungal pretreatment.

Fungal Treatment

Preparation of fungal inoculum has been described elsewhere [24]. A sample consisting of about 300 g (o.d. basis) washed whole kenaf was placed in a bioreactor [22] and autoclaved for 90 min. The flask-grown white-rot fungus (*Ceriporiopsis subvermispora* L-14807-SS-3) was initially diluted to 50 mL (A). One gram of (A) was further diluted to 100 mL (B); 5.0 mL of (B) was finally diluted with 300 mL of water plus 3 g of unsterilized corn steep liquor (CSL) and mixed with the autoclaved kenaf in the bioreactor. The kenaf remained in the bioreactor for 2 wk at 27°C. Bioreactor temperature was maintained using humidified air.

Sample	Chemical pretreatment		Pulp CSF (ml)	Energy consumption (W·h/kg)	Energy savings	
	Na_2SO_3 (%)	NaOH (%)			Fungus treatment[b] (%)	Chemical treatment[c] (%)
RMP control	0.0	0.0	170	2344	-	
RMP treated	0.0	0.0	180	1501	36	
C_1, control	8	0	171	1931	-	18
C_2, control	4	0	158	2006	-	14
C_3, control	2	0	170	2177	-	7
C_4, control	8	1	157	1460	-	38
C_5, control	4	1	159	1795	-	23
C_6, control	2	1	155	1965	-	16
T_1, treated	8	0	172	1199	38	20
T_2, treated	4	0	175	1521	24	-
T_3, treated	2	0	165	1702	22	-
T_4, treated	8	1	165	931	36	-
T_5, treated	4	1	170	1195	33	-
T_6, treated	2	1	165	1535	22	-

[a]Note: C= control kenaf CRMP, T= fungus-treated kenaf CRMP.
[b]Based on respective control.
[c]Based on respective RMP.

Table 1. Pretreatment chemicals and energy consumption of control and fungus-treated kenaf RMP and CRMP

Chemical Treatment Prior to Refining

Prior to refining, washed whole kenaf and fungus-treated whole kenaf were treated with Na_2SO_3 at 2% to 8% (o.d. weight basis), with and without 1% NaOH, in a polyethylene bag for about 24 h at 60°C for better chemical absorption. The ratio of solution to kenaf was maintained at 6 to 1. The control whole kenaf and treated whole kenaf with or without chemical treatment were refined in a Sprout-Waldron 305-mm single disk refiner at atmospheric pressure. The pulp was refined at 20% consistency level at a feeding rate of 265 g/min. The refining was done in four stages with intermediate washing and shredding to arrive at target CSF level.

RESULTS AND DISCUSSION

Energy Savings

As for wood chips, fungus-treated kenaf requires less refiner energy compared to control kenaf. Table 1 shows chemical pretreatments, pulp CSF obtained with subsequent refining, and refiner energy consumption. The fungus-treated RMP required 36% less refining energy than did the control kenaf. Chemical pretreatment of kenaf with or without fungal treatment also reduced refiner energy consumption. Fungal treatment followed by chemical treatment reduced refiner energy consumption from 22% to 38% compared to chemical treatment alone, depending on amount and type of chemical used. It is interesting to note that chemical treatment alone could save 7% to 38% energy consumption compared to energy used for control RMP, depending on the amount and type of chemicals used.

Paper Strength and Optical Properties

Table 2 shows the mechanical and optical properties of control and fungus-treated RMP and CRMP. The 2-week fungus-treated kenaf RMP showed 70%, 36%, and 53% improvement in burst, tear, and tensile indexes, respectively, but ISO brightness values were reduced by 24% compared with those of control RMP. The trend found in treated and control RMP disappeared when chemical pretreatment was applied prior to disk refining. The control

Sample	Density (kg/m^3)	Burst index (kN/g)	Tear index ($mN \cdot m^2/g$)	Tensile index (Nm/g)	Brightness (%)	Opacity (%)	Scattering, coefficient (m^2/kg)
RMP, control	283	0.65	2.85	15.3	46.0	99.0	53.8
RMP, treated	314	1.10	3.89	23.5	35.1	99.0	42.4
C_1, control	397	1.57	4.91	33.8	48.8	97.4	49.3
C_2, control	366	1.44	4.39	27.2	48.4	97.4	49.9
C_3, control	344	1.19	4.28	26.6	49.2	97.4	49.6
C_4, control	387	1.90	5.20	36.7	47.5	97.2	47.8
C_5, control	374	1.59	4.86	32.6	46.2	97.7	50.4
C_6, control	351	1.55	4.44	31.3	47.8	97.7	50.5
T_1, treated	322	1.29	4.09	26.2	40.5	98.5	46.9
T_2, treated	330	1.26	4.28	26.0	39.9	98.4	46.5
T_3, treated	337	1.21	4.03	26.9	39.6	98.8	47.2
T_4, treated	356	1.37	4.28	28.7	40.5	98.3	44.5
T_5, treated	348	1.36	4.09	28.3	40.8	98.2	47.6
T_6, treated	335	1.32	4.0	28.4	40.5	98.1	42.4

Table 2 Properties of unbleached control and treated kenaf RMP and CRMP

CRMP (kenaf pretreated with Na_2SO_3 with or without NaOH before refining) showed improved mechanical properties compared with those of fungus-treated kenaf CRMP. Both burst and tear indexes of control CRMP were superior to those of treated CRMP. Tensile indexes are comparable in all cases. The brightness of control CRMP was 8 to 9 points higher than that of fungus-treated kenaf CRMP. The scattering coefficient was also higher for control CRMP. The fungus-treated CRMP showed a brightness loss of about 8 points compared with control CRMP. In a broad sense, fungus pretreatment enhanced mechanical properties and refiner energy savings at the expense of 10 points ISO brightness loss in the case of RMP. There was some deterioration of mechanical properties when fungus-treated kenaf was pretreated with chemicals and refined. There was some energy saving with an ISO brightness loss of about 8 points compared with control CRMP. The chemical pretreatment of fungus-treated kenaf CRMP shows benefits in terms of mechanical properties, energy savings, and brightness when compared with fungus-treated RMP but not when compared with control CRMP. The RMP and CRMP prepared from fungus-treated kenaf are suitable for newsprint grade papers as far as mechanical properties are concerned.

Bleaching

To optimize the consumption of H_2O_2 and NaOH, a control CRMP prepared from whole kenaf treated with 8% Na_2SO_3 was bleached using a three-level two-factorial design, keeping other conditions the same. Bleaching conditions are shown in Table 3. Single-stage bleaching with 2% H_2O_2 and 2% NaOH raised pulp brightness (initially 48.8% ISO) to 75%; 4% H_2O_2 and 3% NaOH raised ISO brightness to 77%. ISO brightness was raised even higher by multi-stage bleaching.

The initial brightness of biomechanical pulp is limited to 35% to 41% ISO brightness. It is extremely difficult to raise this brightness to that of bleached groundwood and CTMP (70% to 80% ISO brightness) by applying the hydrogen peroxide and/or hydrosulfite bleaching process. We tried to optimize the bleaching process to bleach the biomechanical (fungus-treated) RMP and CRMP to the level of 62% to 65% ISO brightness acceptable for newsprint grades. Five bleaching conditions were used, as shown in Table 4. Both RMP and CRMP controls could be bleached to 62% ISO brightness by applying only 1% H_2O_2, 1% NaOH, and 1% $NaSiO_3$ in a single stage. However, to raise the biomechanical RMP and CRMP to 62% ISO brightness required 2.5% H_2O_2, 2.5% NaOH, and 2.5% $NaSiO_3$ in a single stage bleaching process. The brightness of biomechanical pulp could be raised to 65% by using 3% H_2O_2, 3% NaOH and 3% $NaSiO_3$. Thus, the results showed that more than twice the amounts of bleaching chemicals are required to bleach biomechanical pulp to the brightness level required by newsprint grade. However,

Bleaching condition[a] and brightness	Sample number								
	1	2	3	4	5	6	7	8	9
H_2O_2 (%)	2.0	2.0	2.0	3.0	3.0	3.0	4.0	4.0	4.0
NaOH (%)	2.0	3.0	4.0	2.0	3.0	4.0	2.0	3.0	4.0
Brightness (final)	75.0	73.3	73.6	76.6	76.8	74.6	76.4	77.0	76.0

[a]In all cases; DTPA =0.6%; Na_2SiO_3 =3.0%, $MgSO_4$= 0.05%. DTPA treatment at 60°C for 1 h and pulp washed before H_2O_2 bleaching. Bleaching at 70°C for 3 h and 10% consistency. Initial ISO brightness of pulp was 48.8%.

Table 3 Three-level two-factor design used to optimize H_2O_2 and NaOH consumption in bleaching of control CRMP pulp prepared by pretreating whole kenaf with 8% Na_2SO_3

Bleaching condition[a] and brightness	Sample number				
	1	2	3	4	5
H_2O_2, %	1	2.5	3.0	2.5	3
NaOH, %	1	2.5	3.0	2.0	2.5
Na_2SiO_3, %	1	2.5	3.0	2.5	3.0
$MgSO_4$, %	0.15	0.15	0.15	0.15	0.15
Brightness RMP control, %	61.8 (46)				
Brightness, CRMP control, %	62.9 (48.8)				
Brightness, RMP, 2-wk treatment, %		62.5 (35)	65.1	61.4	63.5
Brightness, CRMP, 2-wk treatment, %		62.4 (40.5)	65.2	62.0	65.1

[a]In all cases; DTPA =0.6%; $MgSO_4$= 0.05%. DTPA treatment at 60°C for 1 h and samples washed before H_2O_2 bleaching. Bleaching at 70°C for 3 h and 10% consistency. Values in parentheses are initial brightness.

Table 4 Bleaching conditions and brightness of RMP and CRMP samples.

the high cost of bleaching can be easily offset by the considerable energy savings (30% to 38%) and strength improvements resulting from the use of biomechanical pulp.

CONCLUSIONS

Whole kenaf biomechanical pulp, like wood biomechanical pulp, requires less energy for refining, results in improved handsheet mechanical properties, and reduces brightness compared with control RMP. Whole kenaf CRMP improves handsheet mechanical properties by 100%, reduces energy consumption by nearly 18%, and improves brightness by 2 to 3 points compared with RMP. Although the CRMP of fungus-treated kenaf results in reduced energy consumption and increased brightness compared with fungi-treated RMP, the resulting mechanical properties were significantly reduced. Control RMP and CRMP can be bleached easily to above 70% ISO brightness with a single-stage H_2O_2 bleaching by using H_2O_2 concentrations as low as 2%. Fungal-treated RMP and CRMP require at least 3% H_2O_2 to reach 65% ISO brightness level. More bleaching chemicals are required for fungal-treated RMP and CRMP to raise the brightness to newsprint grade (about 62% ISO brightness) compared with control RMP or CRMP. Kenaf biomechanical pulp could be used in preparation of newsprint grade paper.

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