Feasibility of using kenaf chemithermomechanical pulp in printing and writing paper

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ABSTRACT: To conserve wood resources, kenaf (Hibiscus cannabinus L.)*, a nonwood-fiber plant, can be substituted for wood in pulping. The objective was to determine if high-yield kenaf mechanical pulp could be used by itself in printing and writing paper. The chemithermomechanical pulps (CTMP) were prepared by injecting various amounts of sodium hydroxide and hydrogen peroxide into the pressurized refiners. Most paper strength properties ranged between those for newsprint and printing and writing papers. Brightness of all but twoCTMPs was low. Opacity and scattering coefficient were high for most CTMPs. Two postbrightened kenaf thermomechanical pulps were prepared but did not achieve the paper properties of kenaf CTMPs. Paper strength and brightness of CTMPs were generally increased, and the energy required to produce CTMP decreased by increasing the amount of applied sodium hydroxide and hydrogen peroxide. Apparently, kenaf CTMP, as prepared in this study, is marginally acceptable by itself in printing and writing paper.*

KEYWORDS: Annual plants, chemithermomechanical pulps, feasibility, kenaf, mechanical pulps, printing papers, writing papers.

Kenaf (*Hibiscus cannabinus* L.) is an annual, nonwood-fiber plant that has been processed by a number of pulping processes familiar to the pulp and paper industry *(1,2)*. Scientists from the USDA Agricultural Research Service (ARS) found that kenaf pulped with kraft, soda, or neutral sulfite chemicals was superior to commercial hardwood pulps and, except for resistance to tear, was comparable to softwood kraft pulps and superior to softwood sulfite pulps *(1)*. Paper machine runs using various kenaf pulps have provided anywhere from a few kilograms up to several tons of specific grades of paper *(3, 4)*. Newsprint has also been successfully produced on a commercial scale using a kenaf peroxide chemithermomechanical pulp (CTMP) *(4)*. The USDA Forest Service, Forest Products Laboratory (FPL), in collaboration with the ARS, the Cooperative States Research Service (CSRS), and an industrial newsprint recycling mill, showed that a pulp blend with 25% kenaf CTMP can be used as a reinforcing pulp in recycled newsprint *(5)*. A more recent cooperative venture between FPL and ARS showed that 30–50% kenaf CTMP (prepared by caustic injection) can be blended with a loblolly pine kraft pulp and made into linerboard with acceptable strength properties. By itself, kenaf CTMP is not suitable for linerboard *(6)*.

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I. Results for 60 g/m² handsheets from Andritz Sprout-Bauer kenaf chemithermomechanical pulp for printing paper[a]

NaOH, %	H_2O_2 %	Total energy, kWh/ o.d.mton	Drainage time, s	Hand-sheet density, kg/m³	Burst index, kPa· m²/g	Tear index, mN· m²/g	Tensile index, N·m/g	Stretch, %	TEA,[b] J/m²	Bright-ness (Elrepho), %	Printing opacity (ISO), %	Scat-tering coeffi-cient, m²/kg	Pulmac shives <0.1 mm, %	Average fiber length[c], mm	Fines analysis[d] <0.2 mm, %
3.0	3.8	1,748	13.5	378	1.6	6.5	37.1	1.57	20.46	71.2	88.6	65.1	0.7	0.75	10.86
2.5	3.0	1,854	12.2	359	1.4	6.4	31.8	1.22	15.44	69.2	90.1	66.4	0.1	0.79	11.26
1.7	2.4	2,423	13.7	341	1.2	5.4	28.6	1.25	13.73	67.6	92.1	70.7	0.1	0.87	10.15

[a]Predicted value at 100 mL Canadian Standard Freeness, obtained from linear regression of original data
[b]Tensile energy absorption
[c]Length weighted average
[d]Analyzed by Kajaani FS-100 at Forest Products Laboratory

For this study, the FPL and the ARS undertook a cooperative project, with the objective of determining if high-yield kenaf mechanical pulp could be used by itself in printing and writing paper. The mechanical pulps used in this study were produced at two locations. An initial experimental pulping trial was conducted at the Andritz Sprout-Bauer Research and Development Laboratory (Springfield, OH) with commercial-sized equipment. All remaining experimental pulping trials were conducted at FPL (Madison, WI) with a 305-mm pressurized refiner. The particle size of the kenaf materials as received had to be reduced at both locations prior to pulping trials (see "Experimental"). Results from both locations are presented and discussed.

Results and discussion

Andritz Sprout-Bauer and FPL pulping trials

Pulping trials conducted at both locations included injection of solutions of sodium hydroxide, hydrogen peroxide, and chelating chemicals into the eye of a primary refiner as the steamed kenaf materials were conveyed from digester to refiner. Chemical applications were slightly different at the two locations and are listed in **Tables I and II.**

Mechanical pulps must be fiberized and refined to very low freenesses to reduce or eliminate shives and develop strength properties *(7)*. As each pulp was refined to the lower freenesses, shive content decreased, length-weighted average fiber length shortened, fines content increased, and all paper strength properties increased, except for tear index of FPL prepared pulps. Brightness, opacity, and scattering coefficient of the Andritz Sprout-Bauer pulps increased with additional refining. For FPL-prepared pulps, brightness remained stable or decreased, opacity increased, and scattering coefficient either increased or decreased in response to the additional refining. To facilitate comparisons between the different pulps, a linear regression was performed on the paper properties for each pulp and a property predicted at 100 mL Canadian Standard Freeness (CSF) (Tables I and II). Generally, chemical application used in the CTMP preparation apparently played a major role in the pulp and paper properties.

At both locations, energy consumed to reach 100 mL CSF decreased as chemical application increased. Energy consumption at the two locations was different, probably because of refiner size and differences in disc peripheral speeds. The commercial-sized equipment at Andritz Sprout-Bauer lowered pulp freeness with fewer passes and consumed less electrical energy than did the laboratory-sized equipment at FPL, which required more passes to reach the same pulp freeness.

The same basis weight (60 g/m²) handsheets were prepared at both locations for testing. Densities of the

Andritz Sprout-Bauer handsheets were all low, indicating a bulky paper that is desirable for printing papers. The FPL handsheets had higher densities, but were within the desired range for printing and writing paper. Because most strength properties are density dependent, these differences in density might affect strength properties.

Handsheets prepared and tested at Andritz Sprout-Bauer and FPL had burst indices that were below the unpublished range for printing and writing papers. When compared to burst indices for paper made from other pulps, burst indices for kenaf CTMP were lower than or similar to those for aspen CTMP, and similar to mixed pine CTMP *(7)*.

There was a big difference in tear index between kenaf CTMP prepared at Andritz Sprout-Bauer and that prepared at FPL. Pulps prepared at the Andritz Sprout-Bauer pilot plant were fiberized at a higher operating pressure than those prepared at FPL, which can yield significantly higher tear indices. The FPL pulps were also refined at lower consistencies, which cuts fibers and shortens fiber length. This is why CTMPs prepared at FPL had lower tear indices than did Andritz Sprout-Bauer pulps. All Andritz Sprout-Bauer pulps had tear indices that were within the desired range for printing and writing papers; they were about the same as those for aspen CTMP but lower than those for mixed pine CTMP *(7)*. The FPL-prepared kenaf CTMP had tear indices much lower than desired for printing and writing and lower than those for aspen and mixed pine CTMPs *(7)*.

There was also a difference in tensile index between kenaf CTMP prepared at Andritz Sprout-Bauer and that prepared at FPL; FPL-prepared pulps had higher values. Pulps prepared at Andritz Sprout-Bauer had tensile indices similar to those for mixed pine CTMP, and lower than aspen CTMP. The FPL-prepared kenaf CTMPs had one tensile index value that fell within the desired printing and writing paper range, and all others fell below that range. The FPL-prepared pulps had higher tensile values than those of loblolly pine TMP and within the range of those for mixed pine CTMP and aspen CTMP *(7)*.

Brightness values for pulps prepared at Andritz Sprout-Bauer were higher than those from FPL, and except for 2.4% H_2O_2 application, the Andritz Sprout-Bauer pulps achieved levels desired for North American No. 5 lightweight coated paper *(8)*. The kenaf CTMP pulps prepared at FPL had brightness similar to mixed pine CTMP and aspen CTMP *(7)*, depending on the charge of alkaline peroxide liquor applied.

Printing opacity for kenaf CTMPs prepared at FPL exceeded the desired values for printing and writing papers *(8)*, and some CTMPs achieved extremely high opacity levels. These high values are important, because printing opacity is an essential requirement for printing

II. Results for 60 g/m² handsheets from Forest Products Laboratory kenaf chemithermomechanical pulp for printing paper[a]

NaOH, %	H_2O_2, %	Total energy, Wh/ o.d. kg	Drainage time, s	Hand-sheet density, kg/m³	Burst index, kPa·m²/g	Tear index, mN·m²/g	Tensile index, N·m/g	Stretch, %	TEA[b], J/m²	Brightness (Elrepho), %	Printing opacity (ISO), %	Scattering coefficient, m²/kg	Pulmac shives <0.1 mm, %	Average fiber length[c], mm	Fines analysis[d] <0.2 mm, %
0.13	0.18	4153	19.5	458	1.1	2.9	33.0	1.70	0.205	52.7	99.2	84.0	1.6	0.91	11.56
0.17	0.24	3621	16.5	448	1.1	2.8	32.1	1.51	0.180	56.6	98.3	78.5	1.7	0.76	11.45
0.9	1.1	3223	15.9	516	1.7	2.5	38.9	1.57	0.247	59.5	97.3	65.9	0.7	0.68	13.42
1.4	2.0	3234	16.6	512	1.6	3.6	40.0	1.81	0.297	61.7	96.0	72.0	1.0	0.82	11.16
1.6	2.1	3005	21.5	560	2.1	2.9	47.4	1.75	0.391	60.3	96.6	61.9	1.2	0.74	12.48
2.0	2.5	3496	14.3	497	1.6	3.6	36.1	1.71	0.237	57.2	98.1	69.4	4.9	0.90	10.89
2.6	3.7	3052	17.4	538	1.7	3.2	44.3	1.86	0.346	60.5	96.0	67.9	1.9	0.68	13.42
3.4	4.1	2596	18.8	626	2.4	2.7	51.0	1.82	0.437	61.1	94.4	55.0	2.6	0.70	12.82
3.5	4.4	2010	22.7	616	2.4	3.0	49.9	1.91	0.478	63.0	93.4	51.9	3.4	0.74	12.84

[a]Predicted value at 100 mL Canadian Standard Freeness, obtained from linear regression of original data
[b]Tensile energy absorption
[c]Length weighted average
[d]Analyzed by Kajaani FS-100

paper *(9)*. Two Andritz Sprout-Bauer kenaf CTMPs failed to achieve the desired opacity levels; the pulp with 2.4% H_2O_2 application was the only exception.

Scattering coefficient for kenaf CTMPs prepared at both locations exceeded the values desired for printing and writing papers. Pulps prepared at both locations exceeded the scattering coefficient values for aspen CTMP and mixed pine CTMP *(7)*.

Postbrightened kenaf thermomechanical pulp

Brightness properties. Two FPL-prepared kenaf thermomechanical pulps (TMPs) were brightened with two levels of sodium hydroxide/hydrogen peroxide, for comparison with kenaf CTMPs (Tables I and II). Test results for 60-g/m^2 handsheets made from the postbrightened kenaf TMPs are presented in **Table III**. Both kenaf TMPs responded very well to the two single-stage caustic-peroxide brightening treatments, which reduced pulp freeness and increased drainage time to a maximum of 22 s. Handsheet density increased slightly, primarily after the more severe caustic-peroxide treatment. Burst, tear, and tensile indices all increased with treatment. Brightness of the TMPs increased by 14 and 20.8 points, respectively, but still fell short of brightness levels desired for printing and writing papers. Brightness did fall within a range of published values for peroxide bleached aspen TMP *(7)*. Both brightening treatments reduced printing opacity and light-scattering coefficient.

When compared with properties of the high caustic-peroxide treated CTMPs made at Andritz Sprout-Bauer and FPL, the properties of the postbrightened kenaf TMP pulps are not very encouraging. First, more electrical energy was needed to produce a kenaf TMP compared with that needed for CTMP, based on unpublished measurements taken at FPL. Second, nearly all strength properties of postbrightened kenaf TMPs were nearly equal to or less than those of the kenaf CTMPs. Caustic addition in the CTMP process softened the fibers, which lowered refiner energy consumption, reduced fiber cutting and damage, and improved fiber conformability and bonding. On the positive side, the postbrightened TMPs did have equal or better brightness, printing opacity, and scattering coefficient. This raises a question about the benefits of postbrightening a kenaf TMP instead of making a caustic-peroxide treated CTMP, because extra processing steps are required to perform a postbrightening procedure. Adding sufficient hydrogen peroxide to the refiner in an alkaline-peroxide mechanical pulping process achieved 60–64% brightness.

Brightness reversion. Brightness loss, or reversion, is a concern with most mechanical pulps. This characteristic was evaluated for the postbrightened kenaf TMPs, but not for the kenaf CTMPs, by exposing paper samples to intense ultraviolet (UV) light for 4 h. The paper samples were removed each hour, and brightness was measured. The most rapid reversion occurred during the first hour, and then the rate of decline became less steep (**Table IV**). All samples showed nearly parallel results in brightness loss, and after 4 h of exposure, samples were 4.9 and 6.9 percentage points higher compared with prebleached brightness. After 4 h of exposure, only 1.5 percentage points of brightness separated the two chemical levels used for postbrightening.

Conclusions

Increasing the chemical application in the pulps tested reduced energy consumption during fiberizing and refining. Increasing the chemical application also increased paper strength properties and brightness but lowered printing opacity and scattering coefficients.

Postbrightening of kenaf thermomechanical pulp (TMP) does not appear to be a viable alternative to producing kenaf chemithermomechanical pulp (CTMP) because of the extra processing required to produce a slightly inferior pulp. Bleached kenaf TMP suffered brightness reversion after 4 h of intense UV light exposure. Response appears similar to earlier observations of other mechanical pulps evaluated at FPL.

Kenaf CTMP appears to be about the same quality as aspen CTMP and should be marginally acceptable by itself in printing and writing paper.

Experimental

Raw material, particle size reduction, and material wash

Kenaf grown in Louisiana and Texas was used in all Andritz Sprout-Bauer and FPL pulping trials. The particle size of the chopped, whole-stem kenaf varied from dust to approximately 25-cm long strips of predominantly bark fibers. Attempts to use the as-received raw materials failed because the long particles quickly became entangled on any rotating shaft, for example, stirrers and feed screws of pressurized refiners. Thus, additional particle size reduction was required before processing and was accomplished by hammermilling. Andritz Sprout-Bauer used a 25-mm grate opening and FPL used a 38-mm grate opening in their respective hammermills.

At both locations, kenaf materials were slurried in a pulper, at about 3% consistency, to hydrate the raw material and loosen dirt from the kenaf. The loosened dirt particles were flushed away, and the kenaf was drained on a Hydrasieve.[2] Andritz Sprout-Bauer had 0.51-mm slot openings and FPL had 0.76-mm slot openings in their respective Hydrasieves. Effluent from the Hydrasieve was sewered. Some drained kenaf was further dewatered

III. Results for 60 g/m[2] handsheets made from hydrogen peroxide brightened kenaf thermomechanical pulps made, brightened, and tested at Forest Products Laboratory

NaOH, %	*H_2O_2, %*	*CSF,[a] mL*	*Drainage time, s*	*Handsheet density, kg/m³*	*Burst index, kPa·m²/g*	*Tear index, mN·m²/g*	*Tensile index, N·m/g*	*Brightness (ISO), %*	*Printing opacity (ISO), %*	*Scattering coefficient (ISO), m²/kg*
TMP		102	17.2	459	0.9	2.4	29.6	45.3	99.7	84.9
1.5	2.5	69	19.0	446	0.9	2.5	30.7	57.8	97.9	82.5
3.0	5.0	54	22.0	541	1.3	2.6	40.5	64.7	94.7	70.9
TMP		93	13.8	444	0.8	2.5	27.2	44.9	99.7	82.0
1.5	2.5	79	16.4	457	1.0	2.8	30.6	60.3	97.0	79.4
3.0	5.0	77	18.4	535	1.4	3.0	41.0	67.0	92.8	66.9

[a]Canadian Standard Freeness.

on a vacuum pan at Andritz Sprout-Bauer. All drained kenaf was press dewatered at FPL. Andritz Sprout-Bauer stored the washed kenaf particles at ambient temperature, and FPL stored the dewatered kenaf at 3°C, until needed for pulping trials.

Injection process

A positive displacement metering pump delivered the solutions composed of sodium hydroxide, hydrogen peroxide, and chelating chemicals to the eye of the pressurized refiner at Andritz Sprout-Bauer and to the horizontal feed screw housing at a point approximately 18 cm before the eye of the pressurized refiner at FPL. Chemical solution delivery and kenaf material delivery to the pressurized refiners were simultaneous. Actual amount of application to the kenaf materials was calculated upon completion of the run, based upon solution volume used and ovendry (o.d.) weight of the kenaf processed. These amounts are reported as percentage chemical applied in Tables I and II.

Fiberizing and refining process

At Andritz Sprout-Bauer, the kenaf was fiberized in a Model 418 pressurized double disc refiner, with plate pattern 36104 installed on both discs, rotating in a counterclockwise (CCW) direction. The material was presteamed and fiberized at 207 kPa of steam pressure. Dwell time varied between 1.5 and 3.0 min. Raw material feed rate and clearance between the refiner plates varied. The fiberized material was refined in a model 401 atmospheric double disc refiner, with plate pattern 36104 installed on both discs, rotating in a CCW direction. A constant volume of shredded pulp was delivered to the refiner inlet by a series of constant-speed belt conveyors. Clearance between the refiner plates was variable, and the dilution water entering with the shredded pulp was adjusted to approximately 22% consistency in the refining zone. Two or three passes were necessary to reach desired pulp freeness. Energy consumed during fiberizing and refining was determined by measuring the motor load in brake kilowatts and actual feed rate of raw material to the refiner. These values were used to compute and report energy consumption as kilowatt hours per o.d. metric ton.

At FPL, the kenaf was fiberized in an Andritz Sprout-Bauer model 12-1CP laboratory-sized pressurized refiner, with plate pattern D2B505 installed in both stationary and rotating positions. The kenaf was presteamed and fiberized at 68.9 kPa of steam pressure. Feed screw rotational speed and clearance between the refiner plates varied. The fiberized material was refined in a Sprout-Waldron model 105-A laboratory-sized atmospheric refiner, with plate pattern D2B505 installed in both stationary and rotating positions. A constant volume of shredded pulp was delivered to the refiner inlet by a constant-speed conveyor. Clearance between the refiner plates was variable, and the dilution water entering with the shredded pulp was adjusted to approximately 15% consistency in the refining zone. Three to five passes were necessary to reduce pulp CSF to 100 mL or less. Energy consumed during fiberizing and refining was measured using an Ohio Semitronic model WH 30-11195 integrating watt hour meter (Columbus, OH) attached to the power-supply side of the 44.8-kW electric motor. Energy consumption values for fiberizing and refining are reported as watt hours per kilogram (o.d. weight basis), with the idling energy subtracted. Latency was removed from the pulp after fiberizing and after each refining stage by slurrying the pulp in 88°C water in a large container for 30 min with frequent stirring.

Kenaf CTMP was produced at both locations without pulp screening and separate reject refining.

[2]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Dept. of Agriculture of any product or service.

IV. Brightness reversion after UV exposure of hydrogen peroxide bleached thermomechanical pulp made, brightened, and tested at Forest Products Laboratory

NaOH	*H_2O_2*	*ISO brightness (%) after exposure times of* 0 h	1 h	2 h	3 h	4 h
1.5	2.5	57.6	54.5	52.4	50.3	49.0
1.5	2.5	60.0	56.2	54.1	52.3	51.0
3.0	5.0	64.0	58.7	56.0	53.8	52.0
3.0	5.0	66.5	58.5	56.7	53.8	52.0

Testing of pulp and forming and testing of handsheets

At FPL, CSF was measured after each fiberizing and refining operation according to TAPPI Test Method T 227. Shive contents of the pulps were determined with a Pulmac shive analyzer, using a disc with 0.102-mm slot openings. Fiber analysis was performed using a Kajaani FS-100 analyzer.

At FPL, handsheets weighing 60 g/m^2 were made according to TAPPI Test Method T 205. Drainage time was measured according to TAPPI Test Method T 221 as the pulps were formed into handsheets. Burst and tear indices were measured according to TAPPI Test Methods T 403 and T 414, respectively. Tensile properties were measured according to a procedure described by Setterholm and Kuenzi *(10)*. Brightness, printing opacity, and light scattering coefficient were measured with a Technidyne Corp. Technibrite Model TB-1 diffuse brightness apparatus (New Albany, IN) according to TAPPI Test Method T 525.

At Andritz Sprout-Bauer, pulps were made into handsheets weighing 60 g/m^2 and were tested in the laboratory, according to TAPPI methods. A disc with 0.10-mm slot openings was used for shive content determination. Fiber analysis was performed at FPL using a Kajaani FS-100 analyzer.

Postbrightening of kenaf TMP

Kenaf TMP samples were brightened with hydrogen peroxide solutions. All pulps were treated with 0.5% diethylenetriamine-pentoacetic acid (DPTA) to chelate any metal ions present before treating with hydrogen peroxide solution. The peroxide solutions consisted of 1.5% NaOH and 2.5% H_2O_2, and 3% NaOH and 5% H_2O_2, with 0.05% $MgSO_4$ and 4.0% Na_2SiO_3 added to both solutions. A sample of pulp was placed in a plastic bag and mixed with bleaching liquor until a 12.5% consistency was achieved. Then, the bag was submerged in a 60°C to 65°C water bath for 1 h. Pulp was neutralized and washed after reaction time was completed.

Brightness reversion

Bleached paper samples were exposed to 254-nm UV light in a Rayonet Photochemical Reactor. Samples were removed after each hour of exposure, and brightness was measured in the Technibrite apparatus. Samples were immediately returned to the photochemical reactor for additional exposure, for a total of 4 h. TJ

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