# Determining the Minimum Conditions for Soda-AQ Pulping of Kenaf Bast, Core, and Whole Stalk Fibers

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## Abstract

Chemical pulping of kenaf fiber is comparatively new. In this study, bast, core, and whole stalk kenaf fibers were pulped using a soda-AQ pulping process and various pulping conditions. Handsheets were evaluated for density, Canadian standard freeness, brightness, opacity, smoothness, and tensile, burst, and tear indexes and strength. The results indicate that commercially viable pulp can be produced from kenaf using 12% NaOH, 0.15 AQ, and 2 h of cooking at 160°C.

## Introduction

Over the past 100 years, soft- and hardwood pulping processes have been refined, wood pulping chemistry has been thoroughly studied, and commercial processes have been optimized to produce high quality papers at low prices. Changes in the wood resource have prompted researchers to explore whether fibers other than wood could be used for papermaking. Kenaf *(Hibiscus cannabinus* L.) is an annual row crop identified by the U.S. Department of Agriculture as a viable replacement for trees in the pulp and papermaking process. While the cultivation of kenaf is still in its infancy, kenaf is attracting much interest because of its apparent environmental and economic benefits.

The increased commercial interest in using kenaf as a raw material for pulp and paper has led to the identification of its potential benefits. Two major benefits identified to date are high yield and low lignin content. The low lignin content of kenaf is reflected in lower pulping chemical and energy consumption and lower bleaching requirements. These

characteristics have been documented and quantified in both mechanical and chemical pulping processes (Atchison 1987, Horn et al. 1992).

In this paper, we present the second in a series of studies on kenaf pulping. The first study focused on kraft pulping of kenaf (Han et al. 1997). The purpose of the second study was to establish certain baseline data for minimum soda-AQ chemistry on kenaf bast, core, and whole stalk fibers. Soda-AQ pulping chemistry was used because of its potentially lower environmental impact when compared to kraft pulping chemistry. Nonwood fiber soda pulps have been shown to have good yields and properties. In our experiment, the pulps were not bleached.

## Methods

Pulping was carried out in stainless steel pulping bombs with dimensions of 64 mm in diameter and 360 mm in height (approximately 1,100 cc of volume). Purity of the core and bast fibers was 90% to 95%, rather than l00%, to simulate commercial pulping. The bast fiber bundles were chopped to about 25 mm long and the core fibers were reduced to pass through a 10-mm screen.

Treatment was the same for bast, core, and whole stalk fibers. Three bomb reactors (one reactor each for bast, core, and whole stalk fibers) were placed inside a rotating digester to heat them and to keep the liquor in contact with the fibers during cooking. The ratio of cooking liquor to solids was 6:1. Pulping conditions are shown in Table 1. The cooking temperature was ramped to 150°C or 160°C in 30 min and maintained for 1.5 to 2 h of cooking. When cooking was finished, warm water was slowly introduced through the digester to lower the digester temperature. Black liquor was collected by filtering through a 20-mesh screen. All cooked fibers were washed thoroughly and disintegrated at 7,000 rpm. Pulp was then washed through filtration. Six different sets of experiments were carried out in various pulping conditions (Figure 1).

## Results and Discussion

Pulps were made into handsheets at the Forest Products Laboratory. Data on percent yield, percentage of clumps, and kappa number are shown in Table 2. Data on optical and physical properties of handsheets are shown in Table 3 and summarized in Table 4. Table 4 shows data for only pulping condition 5 (12% NaOH, 0.15% AQ, and 2 h cooking at 160°C). Table 5 compares soda-AQ pulping results for kenaf to results of our previous kraft pulping study (Han et al. 1997).

For all pulping conditions, core fibers absorbed more cooking liquor than did bast and whole stalk fibers. Kenaf could not be cooked if the active alkali was less than 12%, even when the temperature was raised from 150°C to 160°C. Two different sets of experiments using 10% active alkali were conducted for 2 h at different temperatures. These experiments showed that cooking with 10% active alkali is not suitable for kenaf soda pulping.

Cooking for 2 h using 12% active alkali with 0.15% AQ and raising the temperature to 160°C yielded good quality pulp from kenaf bast fiber. Pulp obtained from core and stalk fibers showed bundles of fibers, indicating that cooking was incomplete. Two sets of experiments were conducted at 160°C using 0.15% AQ, 12% active alkali for bast fiber, and 15% active alkali for core and stalk fibers. Cooking time was reduced from 2 to 1.5 h. These conditions yielded good quality pulp and required less time and less chemicals even though the temperature was increased by 10°C. In all experimental conditions, much foam was produced during fiber disintegration. Less foam was produced during disintegration of stalk fiber than core fiber. Disintegration of bast fiber did not produce foam. The results indicate that the minimum soda-AQ pulping condition for kenaf pulping is 12% NaOH, 0.15% AQ, and 2 h cooking time at 160°C (condition 5).

## Conclusions

The results of this study indicate that good quality pulp can be obtained from kenaf. Thus, kenaf provides a good raw material substitute for wood fiber. The quality of paper from core and bast pulp is quite different. Paper produced from core fibers is thin and dense, whereas paper produced from bast fiber is thicker, lighter, and generally stronger. The kappa number of bast paper is strikingly lower than that of core paper, and bast produces high pulp yields. It is not clear whether core and bast fibers should be pulped together or separately.

## References

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**Table 1. Pulping conditions**

| Parameter | Value |
|---|---|
| Cooking temperature | 150_C or 160_C |
| Cooking time | 1.5 or 2.0 h |
| Caustic charge | 10%, 12%, or 15% |
| AQ charge | 0.15% or 0.30% |

**Table 2. Laboratory pulping results for kenaf fibers**

| Fiber type and pulping condition | NaOH (%) | AQ (%) | Cooking time (h) | Temp (°C) | Yield (%) | Clumps (%) | Kappa number |
|---|---|---|---|---|---|---|---|
| Core | | | | | | | |
| 1 | 15 | 0.30 | 2.0 | 150 | 49.9 | 50.1 | 42 |
| 2 | 10 | 0.30 | 2.0 | 150 | 55.3 | 44.8 | – |
| 3 | 15 | 0.30 | 2.0 | 150 | 51.2 | 48.8 | 50 |
| 4 | 10 | 0.30 | 2.0 | 160 | 61.4 | 38.6 | – |
| 5 | 12 | 0.15 | 2.0 | 160 | 53.3 | 46.7 | 68 |
| 6 | 15 | 0.15 | 1.5 | 160 | 48.8 | 51.3 | 32 |
| 7 | 15 | 0.15 | 1.5 | 160 | 48.8 | 51.2 | – |
| Bast | | | | | | | |
| 1 | 15 | 0.30 | 2.0 | 150 | 77.8 | 22.2 | 16 |
| 2 | 10 | 0.30 | 2.0 | 150 | 68.7 | 31.3 | – |
| 3 | 15 | 0.30 | 2.0 | 150 | 63.4 | 36.6 | 18 |
| 4 | 10 | 0.30 | 2.0 | 160 | 63.7 | 36.3 | – |
| 5 | 12 | 0.15 | 2.0 | 160 | 60.9 | 30.1 | 16 |
| 6 | 12 | 0.15 | 1.5 | 160 | 63.9 | 36.1 | 16 |
| 7 | 12 | 0.15 | 1.5 | 160 | 61.5 | 38.6 | – |
| Stalk | | | | | | | |
| 1 | 15 | 0.30 | 2.0 | 150 | 52.3 | 47.7 | 35 |
| 2 | 10 | 0.30 | 2.0 | 150 | 65.6 | 34.4 | – |
| 3 | 15 | 0.30 | 2.0 | 150 | 52.2 | 47.8 | 39 |
| 4 | 10 | 0.30 | 2.0 | 160 | 67.3 | 32.7 | – |
| 5 | 12 | 0.15 | 2.0 | 160 | 55.4 | 44.6 | 67 |
| 6 | 15 | 0.15 | 1.5 | 160 | 50.2 | 49.8 | 26 |
| 7 | 15 | 0.15 | 1.5 | 160 | 51.1 | 48.9 | – |

**Table 3. Optical and physical properties of handsheets from kenaf pulp**

| Fiber type, pulping condition | Density (kg/m$^3$) | CSF | EMC (%) | Caliper (mm) | Elong (%) | Tensile strength (kN/m) | Tensile index (kN-m/g) | TEA (J/m$^2$) | ISO bright-ness (%) | Printing opacity (%) | Bursting strength (kPa) | Burst index (kPa-m$^2$/g) | Tear resistance (mN) | Tear index (mN-m$^2$/g) | Smooth-ness (SU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core | | | | | | | | | | | | | | | |
| 1 | 740.0 | 528 | 8.582 | 0.093 | 0.93 | 3.67 | 0.0556 | 20.97 | 17.8 | 95.8 | 111.2 | 1.67 | 260.4 | 3.72 | 405 |
| 2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3 | 664.8 | 536 | 8.771 | 0.103 | 0.85 | 3.26 | 0.0494 | 16.05 | 15.6 | 97.9 | 106.1 | 1.61 | 301.2 | 4.43 | 399 |
| 4 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5 | 572.2 | 597 | 8.734 | 0.118 | 0.62 | 1.90 | 0.0294 | 6.72 | 12.6 | 97.4 | 64.7 | 0.97 | 331.9 | 4.98 | - |
| 6 | 753.9 | 456 | 8.406 | 0.089 | 1.21 | 4.52 | 0.0678 | 35.56 | 18.6 | 98.7 | 179.9 | 2.66 | 311.2 | 4.54 | 262 |
| 7 | 725.3 | 403 | 8.713 | 0.090 | 1.33 | 4.37 | 0.0675 | 37.89 | 17.6 | 98.9 | 158.2 | 2.43 | 238.0 | 3.63 | 193 |
| Bast | | | | | | | | | | | | | | | |
| 1 | 498.4 | 646 | 8.459 | 0.134 | 2.07 | 4.05 | 0.0597 | 55.86 | 21.6 | 98.5 | 231.4 | 3.38 | 1072.9 | 16.13 | 368 |
| 2 | 460.6 | 674 | 8.180 | 0.154 | 1.39 | 2.56 | 0.0376 | 24.76 | 18.9 | 97.7 | 136.7 | 2.04 | 1434.2 | 20.35 | - |
| 3 | 482.2 | 635 | 8.036 | 0.138 | 1.66 | 3.24 | 0.0495 | 36.11 | 24.8 | 98.4 | 166.5 | 2.60 | 879.1 | 13.34 | 396 |
| 4 | 510.6 | 638 | 8.114 | 0.133 | 1.91 | 2.87 | 0.0436 | 38.47 | 18.6 | 98.9 | 164.1 | 2.52 | 923.4 | 13.72 | 414 |
| 5 | 503.0 | 654 | 7.867 | 0.131 | 1.81 | 3.00 | 0.0461 | 37.10 | 25.0 | 98.5 | 166.0 | 2.55 | 942.1 | 14.30 | 385 |
| 6 | 512.3 | 639 | 7.870 | 0.128 | 1.84 | 3.10 | 0.0479 | 39.34 | 24.5 | 98.0 | 169.1 | 2.62 | 903.3 | 13.79 | 386 |
| 7 | 490.2 | 645 | 8.203 | 0.132 | 1.88 | 2.93 | 0.0454 | 37.87 | 22.8 | 98.7 | 150.1 | 2.34 | 853.9 | 13.26 | 398 |
| Stalk | | | | | | | | | | | | | | | |
| 1 | 638.5 | 637 | 8.505 | 0.104 | 1.66 | 3.89 | 0.0578 | 43.83 | 21.8 | 97.3 | 185.6 | 2.72 | 646.7 | 9.73 | 281 |
| 2 | 460.8 | 647 | 8.477 | 0.145 | 0.88 | 1.78 | 0.0274 | 10.24 | 12.3 | 97.7 | 91.0 | 1.42 | 1010.1 | 14.67 | - |
| 3 | 602.6 | 628 | 8.547 | 0.113 | 1.52 | 3.67 | 0.0562 | 37.68 | 22.0 | 97.1 | 171.0 | 2.62 | 643.8 | 9.57 | 298 |
| 4 | 463.4 | 679 | 3.381 | 0.134 | 0.97 | 1.71 | 0.0253 | 11.00 | 11.1 | 98.4 | 83.5 | 1.25 | 663.2 | 10.93 | - |
| 5 | 535.2 | 586 | 8.641 | 0.128 | 1.19 | 2.61 | 0.0392 | 21.03 | 14.6 | 98.6 | 134.4 | 2.01 | 648.6 | 9.38 | 392 |
| 6 | 632.7 | 544 | 8.437 | 0.105 | 1.90 | 4.55 | 0.0700 | 57.55 | 24.9 | 97.7 | 207.8 | 3.21 | 739.4 | 11.19 | 245 |
| 7 | 640.7 | 559 | 8.357 | 0.104 | 1.57 | 3.83 | 0.0581 | 41.09 | 23.1 | 97.9 | 187.8 | 2.77 | 643.1 | 9.74 | 284 |

**Table 4. Pulping results for core, bast, and whole stalk fibers**

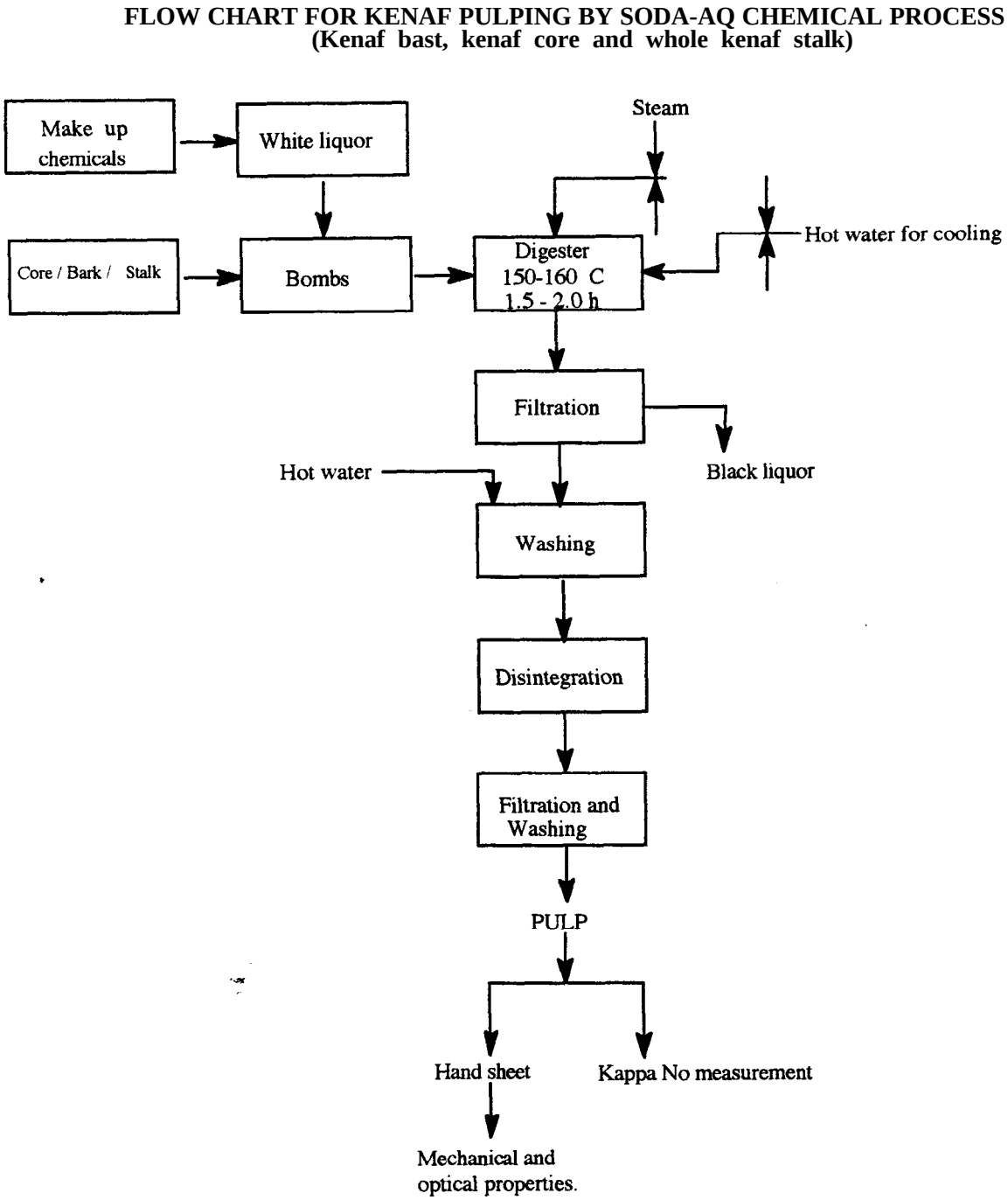
| Property | Core | Bast | Whole stalk |
|---|---|---|---|
| Density, $kg/m^2$ | 572.2 | 503.0 | 535.2 |
| Caliper, mm | 0.118 | 0.131 | 0.128 |
| Elongation, % | 0.62 | 1.81 | 1.19 |
| Tensile strength, kN-m/g | 1.90 | 3.00 | 2.61 |
| ISO brightness | 12.6 | 25.0 | 14.6 |
| Bursting strength, kPa | 64.7 | 166.0 | 134.4 |
| Tear resistance, mN | 331.9 | 942.1 | 648.6 |
| % yield | 53.3 | 60.9 | 55.4 |
| Clumps, % | 46.7 | 30.1 | 44.6 |
| Kappa number | 68 | 16 | 67 |

**Table 5. Properties of paper from soda-AQ and kraft pulping[1]**

| | Soda-AQ 12% NaOH, 0.l5%AQ | | Kraft 20% $Na_2S$, 16% NaOH | |
|---|---|---|---|---|
| Property | Core | Bast | Core | Bast |
| Density, kg/m | 572.2 | 503.0 | 914.8 | 565.8 |
| Caliper, mm | 0.118 | 0.131 | 0.074 | 0.122 |
| Elongation, % | 0.62 | 1.81 | 2.45 | 2.29 |
| Tensile strength, kN-m/g | 1.90 | 3.00 | 7.38 | 5.09 |
| ISO brightness | 12.6 | 25.0 | 20.8 | 24.6 |
| Bursting strength, kPa | 64.7 | 166.0 | 384.9 | 322.2 |
| Tear resistance, mN | 331.9 | 942.1 | 227.3 | 1385.2 |

[1]Kraft data from Han et al. 1997.

Figure 1. Flowchart for kenaf pulping by soda-AQ chemical process.



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