Feasibility of Sodium Carbonate Pulping of Kenaf for Corrugating Medium

Jennifer A. Lechlitner
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Feasibility of Sodium Carbonate Pulping of Kenaf for Corrugating Medium

by

Jennifer A. Lechlitner

A Thesis submitted in partial fulfillment of the course requirements for The Bachelor of Science and Engineering Degree

Western Michigan University
Kalamazoo, MI
April, 1997
ABSTRACT

The pulp and paper industry is showing an increasing amount of interest in the use of nonwood fiber sources for the production of paper. Research is being performed that involves the use of kenaf which is a nonwood fiber source that is grown in warm climates. The outer portion of kenaf, the bast, consists of long fibers similar to softwood fibers and the inner portion, the core, consists of short fibers similar to hardwood fibers. Paper properties that result by the use of kenaf pulp are similar to those of softwood and hardwood.

Once fiber is continuously reused as recycling becomes more popular, its quality is reduced which affects grades such as corrugating medium that contain this fiber in large percentages. Stronger virgin fiber may be needed as a replacement for hardwood, which is typically mixed with secondary fiber, in corrugating medium. Kenaf fiber could serve this purpose.

In this experiment, a mixture of 20% kenaf core and 80% bast fiber was pulped using sodium carbonate. The pulps were then refined to 300 mL CSF. Handsheets were made from this fiber and tested for strength properties. The strongest pulps were mixed with OCC different ratios and handsheets were then made from these mixtures. It has been determined that the addition of kenaf increases corrugating medium strength properties.
ACKNOWLEDGMENTS

Through the course of this study, several individuals have assisted my efforts. Dr. Raja Aravamuthan, my thesis advisor, has guided me through the obstacles of this experiment and has helped me understand any unfamiliar concepts related to my work. The Lee Honors College has helped me financially by awarding me a research grant to assist with any costs related to this project. Valuable information about the corrugating medium industry and some necessary materials for this project were given to me by Menasha Corporation. Individuals at Menasha who assisted me were David Merkle, Cris Croteau, Mike Schreiter, and Bill Youtze. Valuable information about kenaf was learned through correspondence with several individuals, especially James Han, at the United States Department of Agriculture Forrest Products Laboratory. They also provided the kenaf fiber used in this experiment. Special thanks go out to my roommates and fellow paper students for their support during the frustrating moments of this thesis.
# TABLE OF CONTENTS

ACKNOWLEDGMENTS ................................................................. ii

LIST OF TABLES ........................................................................... v

LIST OF FIGURES .......................................................................... vi

INTRODUCTION .............................................................................. 1

BACKGROUND AND THEORITICAL ............................................. 2
  Kenaf Fiber ................................................................................. 2
  Sodium Carbonate Pulping ......................................................... 4
  Kenaf Pulping ............................................................................. 5
  Technological Considerations ................................................. 9
  Economic Considerations ......................................................... 9
  Important Corrugating Medium Properties ............................. 10

EXPERIMENTAL ............................................................................ 11
  Materials .................................................................................. 11
  Equipment ............................................................................... 11
  Kenaf Cooking Schematic ...................................................... 13
  Papermaking and Testing ....................................................... 14

RESULTS AND DISCUSSION ...................................................... 13
  Pulping Data ............................................................................ 16
    Pulp Yield ............................................................................. 17
    Hypo Number ......................................................................... 18
# Table of Contents—Continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Liquor Analysis</td>
<td>19</td>
</tr>
<tr>
<td>Refining Energy</td>
<td>23</td>
</tr>
<tr>
<td>Kenaf Handsheet Testing</td>
<td>24</td>
</tr>
<tr>
<td>Ring Crush</td>
<td>24</td>
</tr>
<tr>
<td>CFC</td>
<td>25</td>
</tr>
<tr>
<td>CMT</td>
<td>26</td>
</tr>
<tr>
<td>STFI</td>
<td>27</td>
</tr>
<tr>
<td>Tensile Index</td>
<td>28</td>
</tr>
<tr>
<td>Handsheets Made from Kenaf and OCC</td>
<td>31</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>36</td>
</tr>
<tr>
<td>RECOMMENDATIONS</td>
<td>39</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>40</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>42</td>
</tr>
<tr>
<td>I. Formulas Used for Statistical Analysis</td>
<td>42</td>
</tr>
<tr>
<td>II. Kenaf Handsheet Testing Data</td>
<td>44</td>
</tr>
<tr>
<td>III. Kenaf Handsheet Testing Data</td>
<td>46</td>
</tr>
<tr>
<td>IV. Kenaf / OCC Handsheet Testing Data</td>
<td>48</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

2. Physical Properties of 2-ply Handsheets Produced from 75% Southern Pine Kraft Pulp and 25% Kenaf Bark and Core .................. 6
3. Cost Comparison of Kenaf to Wood ............................................................... 10
4. Conditions for Kenaf Pulping ............................................................... 16
5. Strength Property Percent Increases Resulting from Kenaf Added to OCC at Different Ratios .................................................. 32
## LIST OF FIGURES

1. Kenaf Plant .......................................................... 2
2. Experimental Design for Kenaf Cooking ....................... 13
3. Effect of Kenaf Cooking Conditions on Pulp Yield ............ 17
4. Effect of Cooking Conditions on Hypo Number for Kenaf Pulps ... 18
5. Relationship Between Yield and Hypo Number for Kenaf Pulps .... 19
6. Effect of Kenaf Cooking Conditions on Black Liquor Percent Solids. 20
7. Effect of Kenaf Cooking Conditions on Black Liquor Solids by Weight .......................................................... 20
8. Relationship Between Black Liquor Percent Solids and Pulp Yield for Kenaf Cooking .................................................. 21
9. Effect of Kenaf Cooking Conditions on Sodium Carbonate Content in Black Liquor .................................................. 22
10. Relationship Between Yield and Sodium Carbonate Consumption During Kenaf Pulping At Different Conditions .................. 22
11. Effect of Cooking Conditions on Refining Energy Needed to Achieve 300 mL CSF .................................................. 23
12. Effect of Cooking Conditions on Ring Crush for Kenaf Pulps ...... 24
13. Effect of Cooking Conditions on CFC for Kenaf Pulp ............ 26
14. Effect of Cooking Conditions on CMT for Kenaf Pulp ............ 27
15. Effect of Cooking Conditions on STFI for Kenaf Pulps ............ 28
16. Effect of Cooking Conditions on Tensile Index for Kenaf Pulps .... 29
List of Figures---Continued

17. Relationship Between Ring Crush and CMT for Kenaf Handsheets 30
18. Relationship Between CFC and Ring Crush for Kenaf Handsheets 30
19. Relationship Between CMT and CFC for Kenaf Handsheets 31
20. Effect of Kenaf Mixed with OCC at Different Ratios on Ring Crush 33
21. Effect of Kenaf Mixed with OCC at Different Ratios on CFC 33
22. Effect of Kenaf Mixed with OCC at Different Ratios on CMT 34
23. Effect of Kenaf Mixed with OCC at Different Ratios on STFI 35
24. Effect of Kenaf Mixed with OCC at Different Ratios on Tensile Index 35
INTRODUCTION

Methods of pulping nonwood fibers are necessary to reduce the need for wood fiber in the pulp and paper industry. World pulp production from nonwood plant fibers is increasing mainly because of insufficient forest and wood pulp resources. The need to identify fast growing fiber sources domestically and high interest within the U.S. to replace surplus agricultural crops with more valuable crops to landowners and farmers has also been motivation to research nonwood fiber use (1). If strength properties of nonwood fiber are similar or better than those of wood fiber, it could be a substitute for wood fiber in grades such as corrugating medium. Several studies have proven that a nonwood fiber source, kenaf, meets the standards of a variety of paper grades. Several corrugating medium mills cook hardwood chips with a sodium carbonate process and mix the pulp with waste paper. In this study, kenaf will be cooked using this process to determine if it can be a hardwood substitute to increase strength and reduce costs by reducing chemical usage and mechanical energy requirements. The optimal ratio of kenaf, and waste paper that produces the highest strength properties will also be investigated.
BACKGROUND

Kenaf Fiber

Kenaf, Hibiscus cannabinus L., is an annual plant that grows a straight stem to a height of up to six meters on a 5 to 7 month growth cycle in suitable temperate and tropical climatic conditions (2,3). Figure 1 is a picture of a kenaf plant. It has

![Kenaf Plant](image)

Figure 1: Kenaf Plant

been traditionally been a source of bast fiber for the production of cordage and coarse yarns in countries such as India, China, Iran, Nigeria, and El Salvador (4). It is grown
in the southern United States in Mississippi, California, Texas, Georgia, New Mexico, Arkansas, Florida, Hawaii, and Louisiana (5,1). In 1993, these states accounted for a total of 4,375 growth acres (1). Table 1 shows the contribution from each state. Herbicides and pesticides are used at a minimum since kenaf is not susceptible to diseases under normal growing conditions. Yields as high as 10.2 tons per year have been achieved through growth rate studies (4). The plant contains two distinct fiber components. The outer portion is called the bast and the inner portion is called the core. The bast fibers, which constitute 35-40% by weight, are 3 to 4 mm long and have properties similar to softwood fibers. The core fibers, which constitute 60-65% by weight are 0.5 to 0.7 mm long and have properties similar to those of hardwood fibers (2,3). Bast fiber contains 5-10% Klason lignin and the core portion contains 18-20%. For a comparison, hardwood typically contains 20-28% lignin while softwood contains 26-32% (6).

### Table 1

<table>
<thead>
<tr>
<th>State</th>
<th>Growth Acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>560</td>
</tr>
<tr>
<td>Georgia</td>
<td>130</td>
</tr>
<tr>
<td>Louisiana</td>
<td>260</td>
</tr>
<tr>
<td>Mississippi</td>
<td>2,000</td>
</tr>
<tr>
<td>New Mexico</td>
<td>205</td>
</tr>
<tr>
<td>Texas</td>
<td>1,200</td>
</tr>
<tr>
<td>Arkansas, Florida, Hawaii</td>
<td>20</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4,375</strong></td>
</tr>
</tbody>
</table>
In the past, kenaf has not been used successfully because there was no process available to separate the bast from the core (1). The separation of these two portions is possible with the development of the Ankal Separation Technology which is capable of producing bast fiber of 94-99% purity by weight and a core fiber with limited residual bast content (3,7). Kenaf is one of the highest quality nonwood fiber sources that can be grown in most areas of the world and plantations can be set up within only a few years (3). The use of kenaf fibers in the place of wood fibers provides several advantages. Some of these are lower refining energy, smaller scale mills, higher pulp yields, twice the yield per acre per year as that of softwood, and 85 to 90% of the total cost of softwood pulping operations (3).

**Sodium Carbonate Cooking**

Over the past 25 years, there has been great interest in non-sulfur cooking processes. In several mills that manufacture corrugating medium, the neutral sulfite semi-chemical (NSSC) cooking process has been replaced by a soda cook consisting of sodium carbonate. Sodium hydroxide is also used with the sodium carbonate in some mills. Hardwood chips are frequently cooked with this process and the resulting pulp is added to secondary fiber at different percentages. Old corrugated container (OCC), old newsprint (ONP), and mixed office waste (MOW) are typical sources of secondary fiber with OCC being the most common one. The mill used as a background to this project cooks its hardwood chips using a semi-chemical process. The chips are impregnated with sodium carbonate in a continuous digester. The
cooking temperature is 345 °F at a pH of 11. Mechanical energy is then applied through a defibrator. The black liquor from the digester is sent through an evaporator and incinerated.

A previous experiment involved the use of a carbonate-caustic cook performed to pulp wheat straw, a nonwood fiber source, with the objective of strength improvement in corrugated medium. The chemical charges used were from 5.5 to 8.0% sodium carbonate as sodium oxide combined with levels of sodium hydroxide between 15-50% of the total chemical charge. Sodium hydroxide is a more active chemical agent than sodium carbonate. Pulps prepared with sodium hydroxide were softer and easier to refine, resulting in higher strength pulp and lower energy costs (8).

Since there are a number of corrugating medium mills that already use a soda cook for wood chips, cooking kenaf by this method, would make the easier. Using sodium hydroxide along with the sodium carbonate could be considered, if necessary, when pulping kenaf.

Kenaf Pulping

Most pulping processes familiar to the pulp and paper industry can handle kenaf. Kenaf pulped with kraft, soda, or neutral sulfite chemicals were found superior to commercial hardwood pulps and softwood sulfite pulps and comparable to softwood kraft pulps (9). Batch digesters are used for kenaf cooking with some
advantages such as more flexible cooking time which is important since the development of the kenaf pulping industry is in its early stages (3).

Several studies have been conducted to prove that kenaf can be used successfully in paper making. For example, the soda-AQ process was used to produce pulp from kenaf core fibers. The kenaf core was then substituted for hardwood in the top layer of linerboard. The resulting unscreened yields were between 35 and 40%. Refining the kenaf was not found necessary. A comparison of the results is listed in Table 2. Properties of the linerboard made with 75% softwood kraft and 25% of either kenaf core or hardwood were compared. The kenaf produced similar burst, higher breaking length and smoothness, but lower tear and bulk (1).

Table 2

Physical Properties of 2-ply Handsheets Produced From 75% Southern Pine Kraft Pulp and 25% Kenaf Bark and Core Pulp (1)

<table>
<thead>
<tr>
<th>Property</th>
<th>25% Top Hardwood</th>
<th>25% Top Kenaf Core</th>
<th>25% Top Kenaf Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis Weight (g/m²)</td>
<td>144.5</td>
<td>146.5</td>
<td>148.8</td>
</tr>
<tr>
<td>Caliper (mm)</td>
<td>0.255</td>
<td>0.238</td>
<td>0.254</td>
</tr>
<tr>
<td>Bulk (cc/g)</td>
<td>1.76</td>
<td>1.62</td>
<td>1.75</td>
</tr>
<tr>
<td>Burst Index (kPa m²/g)</td>
<td>3.85</td>
<td>3.65</td>
<td>3.86</td>
</tr>
<tr>
<td>Ring Crush (kN/m)</td>
<td>1.51</td>
<td>1.74</td>
<td>1.66</td>
</tr>
<tr>
<td>STFI (kN/m)</td>
<td>2.8</td>
<td>3.14</td>
<td>2.93</td>
</tr>
<tr>
<td>Smoothness (Sheffield)</td>
<td>424</td>
<td>385</td>
<td>424</td>
</tr>
</tbody>
</table>
Another study showed that kenaf CTMP produced pulp of the same quality as aspen CTMP pulp and is acceptable by itself in printing and writing paper. The addition of Kenaf increased strength properties, but decreased opacity and density (10).

A comparison of kenaf, a typical newsprint sample from the West Coast, and newsprint from southern pine was performed. The kenaf was cooked using the chemi-thermo mechanical pulping process. Kenaf newsprint was produced with strength properties better than those obtained with southern pine and had excellent printing properties (1).

Biomechanical pulping of kenaf bast fibers produced properties between mechanical and chemical pulps with energy savings of 27% compared to kenaf not fungal-treated and 39.7% compared to fungal-treated aspen (11).

An experiment to determine if kenaf CTMP could be used as a reinforcement pulp in newsprint to substitute semi-bleached softwood kraft combined with deinked recycled newsprint was performed. The kenaf was cooked using sodium hydroxide and sodium peroxide. An acceptable newsprint was obtained by using approximately 25% virgin kenaf in place of semi-bleached virgin softwood kraft pulp (12).

In another experiment, whole stem kenaf CTMP pulp was produced using a hammermill to reduce its size, then refined with sodium hydroxide. Blends of 30-50% kenaf CTMP with 70-50% loblolly pine kraft pulp, produced handsheets with compression strength that equaled or exceeded reported values for commercial linerboard. A blend of 25% kenaf and 75% loblolly pine produced a tensile index of
78 Nm/g and a compression strength of 5 kN/m. Because of slow drainage, the freeness of the kenaf should exceed 140 mL CSF (9).

Cooking different ratios of core and bast fiber together has also been studied. A sodium hydroxide charge of between 5 and 15% on dry fiber, maximum cooking temperature of 90 minutes, and liquor to fiber ratio of 7:1 was used. At a 60% yield, and a 50° SR freeness, the tensile index for the 80% bast to 20% core ratio was 92 Nm/g, burst index was 5.9 kPam^2/g, tear index of 9 mNm^2/g, and density of 0.71 g/cm^3. These properties decreased with an increased amount of core except for density, which increased (13).

Spaceboard has also been made successfully out of kenaf fibers. An experiment was performed to compare blends of OCC, ONP, and kenaf. The goal was to produce spaceboard panels that would have the strength of corrugated boxboard. The kenaf was hammermilled and pulped with a 2% sodium hydroxide charge that was added to the eye of a refiner. Four compositions were compared-100% OCC, 100% kenaf, 50% OCC with 50% kenaf, and 50% kenaf with 25% of both OCC and ONP. The panels made with 100% kenaf could sustain stresses 50% higher than the panels made with 100% OCC. Bending tests showed that modulus of elasticity values from 5 GPa for 100% OCC panels to 6 GPa for 100% kenaf resulted. For these same panels, the modulus of rupture values were 20 and 35 MPa respectively (14).

Core and bast fibers have been pulped separately using sodium hydroxide at a charge on the raw fiber of 16.2% for the bast and 25% for the core. A liquor to raw
A fiber ratio of 7:1, a time of 90 minutes to maximum temperature of 338 degrees Fahrenheit, and a time of 90 minutes at maximum temperature were the cooking conditions used for both the core and bast fibers (1).

Through these experiments, it has been determined that kenaf is a useful material in the pulp and paper industry and may be used as a replacement for both hardwood and softwood in a variety of applications including corrugated medium. Since non-sulfur cooks have been successfully used for pulping other non-wood fibers, kenaf could likely be pulped using the same procedures.

**Technological Considerations**

In the past, the fading away of nonwood materials in favor of wood was due to techno-economic problems related to the use of these materials. The success of continuing to secure a place for nonwood materials in the pulp and paper industry depends on how related obstacles are overcome (16). The commercial development of a kenaf based pulp and paper industry depends on confirming the feasibility of the following: 1. Agricultural production and fiber processing. 2. Pulping of the kenaf fiber. 3. Development of a range of pulp and paper products. 4. Market development for the product range. Through research projects involving the cultivation of kenaf and an increasing number of plantations being created, item 1 listed above has been accomplished (17, 13). Through the pulping experiments listed above and the procedures of this experiment, items 2 and 3 are continuously being accomplished. Item 4 still has not been fully developed at this time.
Economic Considerations

Farmers are trying to find a method to produce kenaf at a cost that mills are prepared to pay in comparison to wood fiber. The harvesting, collecting, bundling, and storage of kenaf is labor intensive compared to wood. Estimated fiber costs in 1997 are located in Table 3. These figures do not include transportation costs.

Table 3
Cost Comparison of Kenaf to Wood

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood Chips</td>
<td>$100 - $200/ton</td>
</tr>
<tr>
<td>Softwood Chips</td>
<td>$60/ton</td>
</tr>
<tr>
<td>Kenaf Bast</td>
<td>$300/ton</td>
</tr>
<tr>
<td>Kenaf Core</td>
<td>$100/ton</td>
</tr>
</tbody>
</table>

The lower lignin content of kenaf compared to wood results in higher yields. Lower amounts of refining energy also reduces costs. Higher production rates because of lower cooking times and lower amounts of chemicals are being considered to off-set the higher cost of the fiber source.

Important Corrugating Medium Properties

There are certain paper properties that are important to the corrugating medium industry. Ring Crush, Concora Medium Test (CMT), Concora Fluted Crush (CFC), Short Span Compression Test (STFI), and Tensile are of most importance. Concora refers to the crushing resistance of a laboratory fluted strip of paper. A key
characteristic of a corrugated board is the rigidity of the fluted structure. This test predicts the flat crush resistance of combined board. Low Conccora mediums result in a combined board with susceptibility to crushing of the fluted structure. Deterioration from the effects of rider rolls, feed rolls, pull rolls, and other downstream processing forces is more likely to occur. Ring Crush and compression are important because if specified minimums are not met, boxes will not meet stacking strength expectations. Tensile strength affects the ability of medium to withstand the stresses of flute formation and resist tearing and breaking from acceleration and tension forces as the web follows its path through the machines. Low tensile leads to web breaks, and fractured flutes.
EXPERIMENTAL

Materials

This project required the following materials: kenaf fiber, OCC, sodium carbonate, and the chemicals to perform hypo number on the kenaf pulps and sodium carbonate content of the black liquor from each cook.

Equipment

The following equipment were used to perform this experiment: M & K batch digester, PFI mill, Noble and Wood handsheet maker, and various paper testing equipment.

Kenaf Cooking Schematic

Figure 2 shows the experimental design for kenaf pulping. A kenaf blend of 80% bast and 20% core was cooked in the M & K digester to a maximum temperature of 300 or 340 °F. The corresponding heating times were between 40 and 45 minutes and between 55 and 60 minutes respectively. The fiber was heated to this temperature and cooked for one of three times at maximum temperature. These times were 0, 15, or 30 minutes. The liquor to kenaf ratio remained constant at 10:1. The charge of sodium carbonate on the kenaf dry fiber was either 12 or 15%. After rinsing the pulp with water, it was defibered using a Waring blender for 4 minutes. Screening was not possible because the fibers became tangled as they were too long.
Figure 2: Experimental Design for Kenaf Cooking

M & K Digester
Waring Blender
Wash
Liquor, Kenaf Ratio: 10:1

Kenaf
80% Bast, 20% Core

Time @ Max. Temp. (min.)

13
0
15
30

Max Temp. (deg. F)

300
340
300
340
300
340

Na2CO3 Charge
12%
15%
12%
15%
12%
15%
12%
15%
12%
15%
12%
15%

PFI Mill To Freeness of 300 mL CSF
to pass through the slots. Hence, the unscreened yield of the pulp was determined.

The pulp was then refined using the PFI mill to a freeness of 300 mL CSF.

The Hypo number of the cooked fiber was determined as per TAPPI T-253 om-92 and the black liquor was tested for solids and sodium carbonate. The test for sodium carbonate that was used was a modification of TAPPI T-625 cm-85.

**Paper Making and Testing**

Seven to ten handsheets weighing 5.24 grams after conditioning were made for each pulp using the Noble and Wood handsheet maker. This weight is equivalent to 26 lb/1000 ft^2 which is a typical weight for corrugating medium. The handsheets were then conditioned in a controlled temperature and humidity (CTH) room and tested for CFC, CMT, ring crush, tensile, and STFI and caliper. Ten determinations were performed, two from each sheet, for each pulp for each handsheet test. The basic error variance of each test was determined to check for the homogeneity of the samples from a single trial. The pooled variance for the average as well as the 2 sigma limits for each test property were found. The formulas for these calculations are shown in Appendix I. This information was used to determine which pulp produces the best strength properties in a statistically significant way. Three kenaf pulps were then mixed with OCC at different ratios to determine if the addition of kenaf would improve the quality of corrugating medium. These pulps were chosen on the basis of their strength properties. The ratios were 100% OCC, 70% OCC and 30% kenaf, 80% OCC and 20% kenaf, and 90% OCC and 10% kenaf. Handsheets
averaging 5.24 grams A.D. were also made from these mixtures. The same tests mentioned earlier were performed on these handsheets in order to evaluate the effects that kenaf have on corrugating medium properties.
RESULTS AND DISCUSSION

Pulping Data

The cooking conditions for each cook are presented in table 4. The total cook time includes the heating period to maximum temperature, the time at maximum temperature, and the time to release the pressure.

Table 4

Conditions for Kenaf Cooking

<table>
<thead>
<tr>
<th>Cook #</th>
<th>Max Temp (°F)</th>
<th>% Na2CO3</th>
<th>Time to Max Temp (min)</th>
<th>Time@Max Temp (min)</th>
<th>Release Pressure</th>
<th>Total Cook Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>340</td>
<td>15</td>
<td>57</td>
<td>0</td>
<td>18</td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td>340</td>
<td>15</td>
<td>55</td>
<td>15</td>
<td>19</td>
<td>89</td>
</tr>
<tr>
<td>3</td>
<td>340</td>
<td>15</td>
<td>52</td>
<td>30</td>
<td>16</td>
<td>98</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
<td>12</td>
<td>41</td>
<td>0</td>
<td>13</td>
<td>54</td>
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<tr>
<td>5</td>
<td>300</td>
<td>12</td>
<td>40</td>
<td>15</td>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td>6</td>
<td>300</td>
<td>12</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>89</td>
</tr>
<tr>
<td>7</td>
<td>300</td>
<td>15</td>
<td>41</td>
<td>0</td>
<td>10</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>300</td>
<td>15</td>
<td>44</td>
<td>15</td>
<td>12</td>
<td>71</td>
</tr>
<tr>
<td>9</td>
<td>300</td>
<td>15</td>
<td>41</td>
<td>30</td>
<td>15</td>
<td>86</td>
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<td>77</td>
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<tr>
<td>12</td>
<td>340</td>
<td>12</td>
<td>56</td>
<td>30</td>
<td>10</td>
<td>96</td>
</tr>
</tbody>
</table>

During this discussion, the time at maximum temperature will be used as the cook time. High temperature corresponds to 340 °F and low temperature to 300 °F.

Similarly, high chemical corresponds to a sodium carbonate charge of 15% and low
chemical means a corresponding charge of 12%. Twelve cooks were performed in this experiment. Appendix II lists the results of each cook.

**Pulp Yield**

Figure 3 shows the effect of cooking conditions on yield for each kenaf pulp.

The yields ranged from 65.8% to 76.5%. As the cooking time increased, the yield decreased for all pulps. The yield values for the low temperature cooks were greater than those from the high temperature cooks. High chemical charge resulted in yields less than those of low chemical charge. High chemical reduced the yield to a lesser extent than low chemical between 0 and 15 minutes of cooking time. It is possible to
achieve yields of 70 to 71% by heating the pulp to high temperature with low chemical instead of using high chemical at high temperature which increases costs.

**Hypo Number**

Figure 4 shows that as cook time increased, the hypo number decreased.

![Figure 4: Effect of Cooking Conditions on Hypo Number for Kenaf Pulps](image)

Delignification was affected to a greater extent by chemical charge than by temperature. The use of high chemical resulted in the most delignification for a given temperature. Figure 5 compares the hypo numbers to the pulp yields. The higher the yield, higher is the hypo number as expected. However, the correlation is not the same for all cooking conditions. For a yield of approximately 71%, a hypo number of 5.51 is possible by cooking at high temperature with high chemical for 15 minutes at maximum temperature. For pulps cooked at high chemical, a more rapid reduction in
lignin content occurred between 0 and 15 minutes at maximum temperature despite the slight decrease in yield.

**Black Liquor Analysis**

![Figure 5: Relationship of Yield and Hypo Number for Kenaf Pulps](attachment:figure5.png)

Figures 6 and 7 show the black liquor percent solids and solids by mass. As expected, an increase in solids occurred as cooking time increased. Temperature had a greater effect than chemical charge on solids. High temperature resulted in greater solids than low temperature. High chemical also resulted in higher solids than low chemical. The amount of recovered black liquor consisted of that which drained out of the bottom of the digester and did not include the residual liquor remaining on the unwashed fiber. With this in mind, the amount of solids in the black liquor measured by mass should
actually be higher. The relationship between black liquor solids and pulp yield is shown.

**Figure 6: Effect of Kenaf Cooking Conditions on Black Liquor Percent Solids**

**Figure 7: Effect of Kenaf Cooking Conditions on Black Liquor Solids by Weight**
in Figure 8. There was an increase in black liquor solids with a decrease in pulp yield. The exception to this is two cooks completed a maximum temperature of 15 minutes.

**Figure 8: Relationship Between Black Liquor Percent Solids and Pulp Yield for Kenaf Cooking**

![Graph showing relationship between black liquor percent solids and pulp yield for Kenaf cooking](image)

Figure 9 shows that the amount of sodium carbonate remaining in the black liquor ranged between 8.48 and 13.25 g/L. With an increase in cook time, more sodium carbonate was used during the cook as expected. The high chemical cooks resulted in a higher black liquor sodium carbonate concentration than the low chemical cooks. Figure 10 shows that the higher yield cooks resulted in less chemical consumption which was expected. It would be more economical to use low chemical to achieve a particular yield since there will be less chemical to recover from the black liquor.
The low temperature/high chemical cooks would be the least economical in this case.

High temperature/low

Figure 9: Effect of Kenaf Cooking Conditions on Sodium Carbonate Content in Black Liquor

![Graph showing the effect of cooking conditions on sodium carbonate content.]

Figure 10: Relationship Between Yield and Sodium Carbonate Consumption During Kenaf Pulping at Different Conditions

![Graph showing the relationship between yield and sodium carbonate consumption.]

22
chemical pulping would be the best.

**Refining Energy**

The amount of refining necessary to lower the kenaf pulps to a freeness of 300 +/− 15 mL CSF is shown in Figure 11. The required refining energy range, between 5000 and 5450 revolutions, compares to the energy requirements for hardwood pulp and is much lower than that needed for softwood. Softwood typically requires approximately 11,000 revolutions to achieve this freeness. The low temperature/low chemical cooks required the most refining energy which was expected since it was cooked the least. It was unexpected that the high temperature/high chemical cooks required the next to highest refining energy because it experienced the most severe cooking conditions. It is possible that under these...
conditions, more hemicelluloses are getting lost. The lowest amount of refining energy occurred under the conditions of high temperature with low chemical charge.

**Kenaf Handsheet Testing**

The results from testing the handsheets made from each kenaf pulp are listed in Table 8. The variances for each test is located at the bottom of this table.

**Ring Crush**

According to Figure 12, the ring crush values ranged from 1.615 to 2.71

![Figure 12: Effect of Cooking Conditions on Ring Crush for Kenaf Pulps](image)

kN/m. Both cooks performed at high temperature with 0 minutes at maximum temperature, resulted in ring crush values that were statistically the same. They produced the highest ring crush values for this study. It is possible to achieve a ring crush of this value by using lower chemical which is more economical. When
cooking at maximum temperature for 15 minutes, the high temperature/high chemical, high temperature/low chemical cook, and the low temperature/low chemical cooks produced the same values of approximately 1.9 kN/m. It would be most economical to cook at low temperature with low chemical in this case. When cooking at maximum temperature for 30 min., both the low temperature/low chemical and the high temperature/high chemical pulps also statistically fall into this range, but are less economical because of the increased cooking time. Referring back to figure 5, since ring crush decreased as cooking time increased for the high temperature cooks despite the lower lignin content, fiber damage such as cellulose degradation may have occurred. The increase in ring crush with an increase in cook time for the lower temperature cooks indicate that longer cooking time is necessary to develop strength properties.

**Concora Fluted Crush (CFC)**

The results from the CFC test are plotted in Figure 13. The highest CFC value, 3.75 kN/m, occurred when heating the pulp to 340 °F with a sodium carbonate charge of 15%. As for ring crush, CFC decreased as cook time increased when cooking at high temperature. At low temperature, CFC remained statistically the same with an increase in cook time. This was also the case for the high temperature/low chemical cook. If a CFC value of approximately 3.5 kN/m is sufficient, the most economical cooking conditions would be a maximum temperature of 300 °F, sodium carbonate charge of 12%, and a time at maximum temperature of 15 minutes. If a CFC value of 3.1 kN/m is sufficient, heating the pulp to 300 degrees
Fahrenheit with a chemical charge of 12% is most economical.

**Concora Medium Test (CMT)**

As indicated in Figure 14, the CMT values ranged from 321.7 to 363.7 N. In order to reach the highest CFC value of this study, a time at maximum temperature of 30 minutes was necessary and either high temperature/low chemical or low temperature/high chemical. If a CFC value of 350 N is sufficient, heating the pulp to maximum temperature for all pulps except for low temperature/high chemical achieves this. In this case, it is most economical to use low temperature/low chemical.
Figure 14: Effect of Cooking Conditions on Concora Medium Test for Kenaf Pulps

Because the average value of the 10 STFI readings was given by the testing apparatus, the variances could not be determined. According to Figure 15 STFI values ranged from 4.46 to 5.34 kN/m. The common trend between cooks was to decrease and then increase as cooking time increased. When heating to maximum temperature, the highest STFI resulted from the high temperature/high chemical cook. A similar result could be achieved by using less chemical at this temperature and cooking for 15 minutes at maximum temperature. By using high chemical and low temperature while cooking at a maximum temperature for 30 minutes, the highest STFI for this experiment was obtained. This shows that in order to develop strength
Figure 15: Effect of Cooking Conditions on STFI for Kenaf Pulps

![Graph showing effect of cooking conditions on STFI for Kenaf pulps.](image)

from these conditions, a longer cooking time is necessary. The same was true for the temperature.

**Tensile Index**

Figure 16 shows that the highest tensile index, 81.03 Nm/g, which was obtained when the cook was performed with high chemical, high temperature, and 0 minutes at maximum temperature. As cooking time increased, this value decreased. The range of values was between 55.65 and 81.03 Nm/g. The high temperature/low chemical cook slightly increased and then remained the same with an increase in cooking time showing no economical benefit when cooking at maximum temperature for 30 minutes. Equal tensile indexes occurred when cooking the high temperature/high chemical pulp for 15 minutes at maximum temperature and the low temperature/high chemical pulp for 30 minutes at maximum temperature. The latter
case would provide more economical results because of an overall shorter cook time.

An experiment has been performed to compare CFC, CMT, and Ring Crush to determine if there is a correlation between the three. With an increase in one property, there was an increase in the others. Figures 17, 18, and 19 show that this was not the case for the kenaf handsheets made in this experiment. The lack of trends that these graphs show are representative of all possible strength property comparisons.
Figure 17: Relationship Between Ring Crush and CMT for Kenaf Handsheets

Figure 18: Relationship between CFC and Ring Crush for Kenaf Handsheets
Handsheets Made from Kenaf and OCC Mixtures

Appendix IV lists the testing results from the handsheets made with the kenaf/OCC mixtures. Table 5 lists the percent increases that resulted when adding kenaf to the OCC. Figures 20 through 24 show the results when adding kenaf to the OCC. The horizontal line on each graph represents the results of the handsheets made from a 70% OCC and 30% hardwood mixture. This mixture was a sample taken from the headbox at a corrugating mill. Higher the amount of kenaf in the mixture, higher is the strength achieved. The handsheets made from 100% OCC also showed higher strength properties compared to the hardwood/OCC combination.

Figure 20 shows that when adding kenaf heated to high temperature with high
Table 5

Strength Property Percent Increases Resulting from Kenaf Added to OCC at Different Ratios

<table>
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<tr>
<th>Cooking Conditions</th>
<th>OCC: Kenaf</th>
<th>Ring Crush</th>
<th>CFC</th>
<th>CMT</th>
<th>STFI</th>
<th>Tensile Index</th>
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<tr>
<td>340°F 70:30 15% Na2CO3 0 minutes</td>
<td>28.26 53.75 50.74 28.77</td>
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<td>18.84 32.50 34.13 22.18</td>
<td>36.03</td>
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<tr>
<td>300°F 70:30 15% Na2CO3 0 minutes</td>
<td>8.70 17.50 26.66 19.06</td>
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<td>300°F 80:20 15 minutes</td>
<td>1.45 16.88 25.48 17.67</td>
<td>20.44</td>
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<td>300°F 90:10 15 minutes</td>
<td>-5.80 -16.88 12.99 15.24</td>
<td>7.53</td>
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</table>

chemical to OCC at different ratios, ring crush increased between 18.7 to 28.3% over the 30% hardwood, 70% OCC mixture. Similar increases occurred when adding kenaf cooked for 15 minutes at high temperature and low chemical. When using 10% kenaf pulp that was heated to low temperature at low chemical charge, the ring crush was lower than the hardwood/OCC combination. At 20 and 30% of this kenaf, the ring crush increased by 4.35 and 14.49 respectively.

According to Figure 21, the two kenaf pulps heated to or cooked at higher temperature increased CFC between 17.5 to 53.8%. When adding the low temperature/high chemical kenaf pulp heated to maximum temperature, there
Figure 20: Effect of Kenaf Mixed with OCC at Different Ratios on Ring Crush

Figure 21: Effect of Kenaf Mixed with OCC at Different Ratios on CFC
was a decrease in ring crush at 10 and 20%. There was an increase of 6.35% when the kenaf content was 30%.

Adding kenaf to OCC increased CMT between 13 to 50.8%. This is shown in Figure 22. The greatest increase was caused once again by the addition of the high temperature/high chemical kenaf.

**Figure 22: Effect of Kenaf Mixed with OCC at Different Ratios on CMT**

Figures 23 and 24 also shows that STFI and tensile index exhibit similar increases as CMT. These increases range from 15.2 to 28.9% for STFI and from 7.5 to 48.6 for tensile index.
**Figure 23:** Effect of Kenaf Mixed with OCC at Different Ratios on STFI

**Figure 24:** Effect of Kenaf Mixed with OCC at Different Ratios on Tensile Index
This experiment has proven that sodium carbonate can be used as a cooking chemical for kenaf. The pulp that results from this process is of low lignin content which promotes high strength properties. Expected trends resulted for properties influenced by cooking conditions. For example, higher temperatures produced lower yield and lower hypo number pulps. A decrease in yield resulted in a decrease in hypo number. When cooking for 15 minutes at maximum temperature, there was a drastic decrease in hypo number. Between 15 and 30 minutes, a gradual decrease occurred indicating that if a low hypo number is desired, it may be uneconomical to cook the pulp for long periods of time. As expected, the black liquor solids increased with longer cooking times and with higher temperatures and chemical charges. The amount of sodium carbonate remaining in the black liquor was the lowest for the high temperature/low chemical cooks. These cooks also had the highest percent consumption which reduces the amount of chemical that must be recovered. The amount of refining energy necessary to reach a 300 mL CSF for the kenaf pulps was similar to that needed for hardwood pulps and less than half the energy needed for softwood pulps. The most refining energy was needed for the low temperature/low chemical pulps as expected because the cooking was not as complete as under more rigorous conditions. The least amount of refining necessary was for the pulps cooked to a maximum temperature of 340 °F. These pulps also resulted in higher strength
properties than those pulps cooked to greater times despite the lower hypo numbers. This shows that increasing the severity of cooking conditions may actually damage the fibers. Longer cooking times are necessary to develop the strength properties of the low temperature cooks.

Statistically, several of these cooks resulted in equal handsheet testing results. The highest strength properties were achieved by using high temperature/low chemical and high chemical pulps. Because of cost considerations, the high temperature/low chemical pulps should be used. Since these pulps also needed the least refining energy of all the pulps in this study, kenaf pulping can be optimized by using these conditions. When comparing these strength properties to one another, there should have been an increase in one as the other one increased. There was no trend of this nature for the kenaf pulps.

The addition of kenaf to OCC resulted in large strength improvements compared to the strength of a 30% hardwood, 70% OCC combination which is typical for the production of corrugating medium. The addition of a low temperature/high chemical pulp heated to maximum temperature did not result in as large of improvements as the high temperature cooks. This supports the ideas that an increase in cooking time is necessary to promote strength when using a low temperature. CFC was actually lower when 10 or 20% kenaf was added to OCC than for the hardwood/OCC sheets. With the addition of kenaf cooked at high temperature with either a low or high chemical charge, ring crush increased by as much as 28.26%,
CFC by 53.75%, CMT by 50.74%, STFI by 28.77%, and tensile index by 48.64%. Because of these increases, kenaf should be a consideration for corrugating medium.

According to these results, the optimal pulping conditions for this study were a maximum temperature of 340 °F, a sodium carbonate charge of 12%, and a cooking time of 0 to 15 minutes at maximum temperature. These pulps demonstrated high strength properties, good yield and hypo number values, low black liquor sodium carbonate content, and the lowest necessary refining energy of all the pulps.
RECOMMENDATIONS

The following suggestions could be used for continuing work in this area of study:

1. Because the presence of sand in the fiber, it should be washed prior to cooking.

2. The same procedures could be used to cook kenaf whole stalk. Since the material would not have been separated into its core and bast fiber components, a cost savings could result when purchasing the raw material.

3. Sodium carbonate could also be used to pulp pure kenaf bast or core instead of the 80% bast, 20% core mixture.

4. Other ratios of kenaf bast and core could also be pulped.

5. Lower chemical charges could be experimented with to reduce chemical costs.

6. A pilot plant pulp and paper machine trial could be performed using the Sunds Defibrator and the pilot paper machine. This would further indicate the effectiveness that kenaf fiber has when used in corrugating medium.
REFERENCES


\[
\delta^2 = \frac{\sum (n_i - 1) \delta_i^2}{\sum (n_i - 1)}
\]

\[
\delta_{pooled} = \sqrt{\delta^2}
\]

\[
\delta_{average} = \frac{\delta_{pooled}}{\sqrt{10}}
\]

APPENDIX I

Formulas For Statistical Analysis

\[\delta_{pooled} = \text{pooled variance for each test}\]

\[\delta_{average} = \text{average pooled variance for each test}\]

\[n = \text{number of cooks}\]

\[10 = \text{sample size}\]
\[
\begin{align*}
\delta^2 \text{ pooled} &= \sum_{i} (n_i - 1) \delta_i^2 \\
\delta^2 \text{ pooled} &= \frac{\delta^2}{\sum (n_i - 1)} \\
\delta \text{ pooled} &= \sqrt{\delta^2 \text{ pooled}} \\
\delta \text{ average} &= \frac{\delta \text{ pooled}}{\sqrt{10}} \\
2 \text{ sigma} &= \delta \text{ average} \times 2
\end{align*}
\]

\(\delta \text{ pooled} = \) pooled variance for each test
\(\delta \text{ average} = \) average pooled variance for each test
\(i = \) number of cooks
\(10 = \) sample size
# APPENDIX II

Kenaf Cooking Results

| Treatment | Crude Protein | Fiber | Soluble Fiber | Ash | (%)
|-----------|---------------|-------|---------------|-----|-----
| A         | 3.2           | 5.9   | 0.3           | 3.6 | 10.07
| B         | 3.9           | 5.2   | 0.3           | 3.6 | 10.07
| C         | 3.7           | 5.6   | 0.3           | 3.6 | 10.07
| D         | 3.5           | 5.8   | 0.3           | 3.6 | 10.07
| E         | 3.3           | 5.9   | 0.3           | 3.6 | 10.07
| F         | 3.1           | 5.7   | 0.3           | 3.6 | 10.07

44
## Kenaf Cook Results

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<th>Charge Temp</th>
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<th>% Na2CO3</th>
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<th>g/L</th>
<th>g</th>
<th>% Recovery B.L. Solids BL Recovered</th>
<th>B.L. Solids Na2CO3 in BL Na2CO3 in BL Na2CO3 cons.</th>
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APPENDIX III

Kenaf Handsheet Testing Data
Kenaf Handsheet Testing Data

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<tr>
<th>Cook</th>
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<th>Time@V</th>
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Pooled Variance

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Pooled Average Variance

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2 Sigma

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APPENDIX IV

Kenaf / OCC Handsheet Testing Data
### Kenaf / OCC Handsheet Testing Data

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<th>CMT N (avg. std.)</th>
<th>STFI kN/m (avg. std.)</th>
<th>Caliper mm avg. std.</th>
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