

# Refiner mechanical pulp from kenaf for newsprint manufacture

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**ABSTRACT:** Kenaf (*Hibiscus cannabinus*) is an annual, non-wood cellulosic plant fiber. Kenaf is being promoted as a potential fibrous raw material for the pulp and paper industry in the countries experiencing shortage of wood raw material. The objective of this study was to optimize the process of refiner mechanical pulping (RMP) from kenaf for newsprint production. RMP was produced from whole kenaf (mixture of separated core and bark in 65 and 35 ratio), and whole stems (cut into 25-38 mm length) using a Sprout-Bauer 300-mm refiner. Water-soaked raw materials were refined to a targeted CSF of 100-125 ml in several passes to simulate the refining actions experienced by a fiber in commercial refining. It was observed that spacing of refiner plates and numbers of passes were important parameters in determining the quality of pulp in a 300 mm Sprout-Bauer refiner. Results indicate that kenaf RMP is not only suitable for newsprint manufacture but it also improves various mechanical properties. Its usage in de-inked pulp from old newsprint for newsprint production will also improve pulp quality.

**Application:** Kenaf refiner mechanical pulp (RMP) could be used to make newsprint. Supplementing the de-inked pulp (DIP) from old newsprint (ONP) with 20%-30% of bleached kenaf RMP, strength and optical properties of the newsprint will improve significantly.

Kenaf (*Hibiscus cannabinus*) is a promising raw material for pulp and paper manufacture. It can be grown widely in North America and in countries such as Australia, Thailand, China, and India [1]. Kenaf has been promoted on the strength of its environmental appeal, and as an alternative fiber source for papermaking [2].

In recent years, considerable efforts have been made to improve and optimize chemical and mechanical pulping processes for kenaf. Kenaf is a blend of two fibers: long fibers (35% by weight) are similar to those of softwood fibers, while short fibers (65% by weight) are similar to those from hardwood. Thus, kenaf provides an excellent fiber for pulp and paper manufacture in countries having wood in short supply.

In earlier efforts to produce whole kenaf thermomechanical pulp (TMP), researchers [3, 4] at the U.S. Department of Agriculture had problems with the large number of fiber bundles and broken fibers appearing in the sheet, which affected the strength properties. The cause of fiber bundles and broken fibers appearing in the sheet were not fully analyzed. The authors of the present work realized that more work was needed to optimize the refining process for the most promising raw material, kenaf. The aim of this study was to produce refiner mechanical pulp (RMP) from whole kenaf (a 65:35 mix of core and bark) and from

kenaf stems cut into 25.4 mm pieces with improved pulp quality. Researchers also focused on reducing “fiber bundles” and improving strength and surface properties for RMP pulp.

We screened the crushed whole kenaf on a vibrating screen to remove foreign matter, including soil (approximately 3%-5%), and to separate core and bark. Longer bark pieces were cut manually into 25-38 mm fibers and screened on a 4.7 mm mesh screen to remove any bark fiber smaller than 15.0 mm. Separated core containing approximately 7% to 8% bark fibers after screening was rescreened to remove 98%-99% of remaining bark fibers. For refining, whole kenaf (referred to as *kenaf*) represented a mixture of bark and core in a ratio of 35(±1):65(±1). Kenaf stems (referred to as *stem*) having approximately the same core and bark ratio as in kenaf were cut into 25-38 mm long pieces with a guillotine cutter. The different raw materials were washed with warm water to remove any remaining soil and sand and then soaked in water for 4 hours before refining.

Kenaf and stem were refined in a 300 mm single disc Sprout-Bauer (Model 12 LAB) open discharge pilot scale refiner equipped with a type C 2976A plate pattern (Fig. 1) originally designed for softwood refining. The available refiner could only operate at a single speed (1800 rpm).

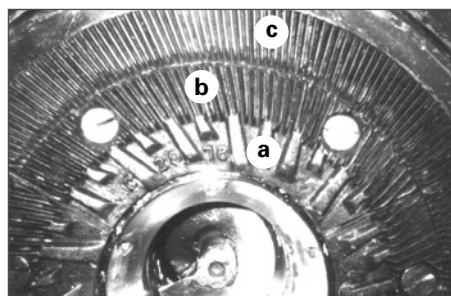
To vary the refining intensity, we changed the inlet pulp consistency and plate gap while keeping refiner speed and plate pattern the same. The change in consistency and plate gap brought about the change in the residence time of fiber in the refiner and thus, the number of impacts experienced by each fiber. Refining experiments for kenaf and stem were carried out at consistencies of 15% and 22%. The consistency was maintained at 15% or 22% for each pass (except for the first pass, which was carried out at 35±1% consistency). For all the raw materials, refining was carried out in several passes to obtain a typical newsprint level Canadian Standard Freeness (CSF) between 100-125 mL. For refining in each subsequent pass, plate gap was reduced gently and maintained, as shown in Table I. Pulp after final stage refining were hot disintegrated before screening. Handsheets formed from the screened pulps were analyzed as per TAPPI standards.

## RESULTS AND DISCUSSION

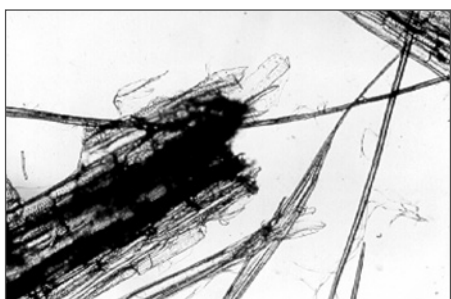
### Number of passes, and specific energy consumption in a 300 mm Sprout-Bauer refiner

Small refiners, such as the one used in this study, require much energy to refine kenaf and stem to a CSF of 100-125 mL typical of mechanical pulp for newsprint production, compared to a larger refiner[5]. Plate pattern, as shown in Fig. 1,

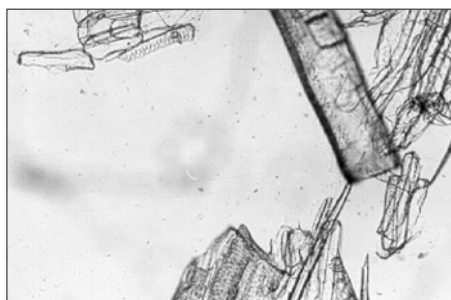
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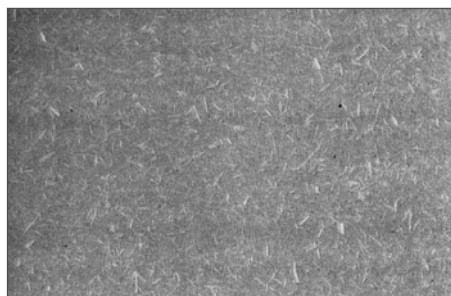
**1. Design of plate pattern (C 2976A) as used in a 300 mm Sprout Bauer atmospheric discharge refiner to refine kenaf and stem at 15% and 22% consistencies. Refining zones: a-coarse, b-medium, c-fine.**



**2. The above figure indicates that shives content from whole kenaf and stem RMP contain fiber bundles.**



**3. Tissues of shives show the presence of vessels and paranchyma cells indicating that shives constitute a considerable core amount.**



**4. Surface of a hand sheet prepared from whole kenaf RMP shows the presence of shives like core bundles.**

| Pass number   | 1    | 2    | 3    | 4    | 5    | 6    | 7     | 8     |
|---------------|------|------|------|------|------|------|-------|-------|
| Plate gap, mm | 1.52 | 1.27 | 1.02 | 0.76 | 0.51 | 0.38 | 0.254 | 0.127 |

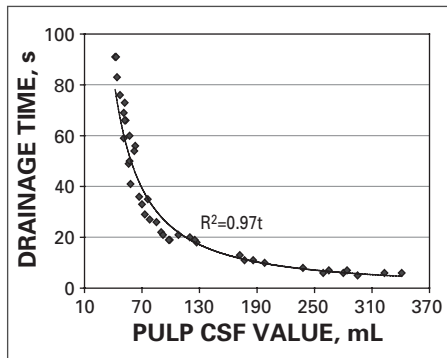
**1. Plate gaps (mm) maintained for each pass of refining at 15% and 22% consistency to achieve a CSF typical of newsprint.**

influenced the quality of pulp and specific energy required for refining of fibers [6]. Plate pattern has an effect on the fiber residence time if refiner speed, plate gap, refining consistency, and the feed rate are maintained the same. The final stage in two-stage refining requires a refiner equipped with plates of higher bar density. Thus, fibers experience an increased residence time, ensuring a higher number of bar impacts. Under the same process parameters, the refiner plate size will play a vital role in determining the residence time of fiber in a refiner. Fiber residence time will be at least six times longer in a 600 mm refiner equipped with high bar density plates than in the 300 mm refiner used in this study.

The kenaf and stem had to be refined in several passes to get a required CSF that resulted in higher energy consumption. Medium (Section b) and coarse (Section a) bar zones covered more than 65% of the plate pattern used in this experiment (Fig. 1). After defiberization of kenaf and stem, the researchers needed to separate small fiber bundles into individual fibers by refining them in the plate's high-density (Section c) bar zone. Hence, coarse and medium sections will be of little importance in kenaf fiber development. Moreover, the core fibers were stuck in the bar grooves, particularly in the coarse and medium zones. The grooves were wider than the core fibers, which left a substantial portion of the core fibers unrefined. Because of the bark's strand-like structure, it was not defiberized in the coarse refining zone. Thus, the coarse refining zone consumed a significant portion of the energy applied in transporting the bark material to a section of the plate with higher bar density. On occasions, the fibers became embedded between refiner plates because of fiber bundling. Bark fibers, in particular, became bundled in the coarse refining zone after 3-4 passes, causing serious problems in the flow of material to be refined.

The viscoelastic nature of the fiber resulted in repeated compressive and shearing actions during refining. Consequently, much of the electrical energy of the refiner was converted into thermal energy through hysteresis losses. West [7] also claimed that most of the electrical energy is converted to heat during refining. In this experiment, the temperature of the material discharged from the refiner rose to 85°-95°C after refining, which indicates that a substantial amount of energy was dissipated as heat in each pass.

The bark and core fiber matrix, which is different from that of wood fiber [2, 8], will also affect refining energy consumption. Bark fibers having thick cell walls need more intensive refining. They require higher specific energy to produce a pulp with the desired CSF and fiber flexibility. On the other hand, we expected that core fibers having thin cell walls would refine easily under the compressive refining action and contribute to the pulp quality. We observed during this experimental work, however, that core fibers escaped refining actions in the presence of long and thick cell walled bark. Thus, core fibers neither produced an expected fibrillation during refining to improve pulp quality nor contributed to the pulp CSF. The reason is that thin-walled fibers are more flexible than thick-walled fibers, so they absorb a substantial amount of energy during fibrillation [9]. Moreover, the specific energy consumption would be higher for the refining of thin-walled fibers, because 1 metric ton would have more thin-walled fibers (core) relative to thick-walled fibers (bark) in 1 metric ton. Therefore, the total number of bar impacts (or specific refining energy) will be more for 1 ton of thin-walled core fibers compared to 1 ton of thick-walled bark fibers. Because kenaf and stem contain approximately 65% thin-walled core fibers, the specific energy consumption will be greater to refine kenaf and stem to a CSF of 100-125 mL. Thus, the fiber matrix of bark and core fibers contribute equally to higher energy requirement during kenaf and stem refining.



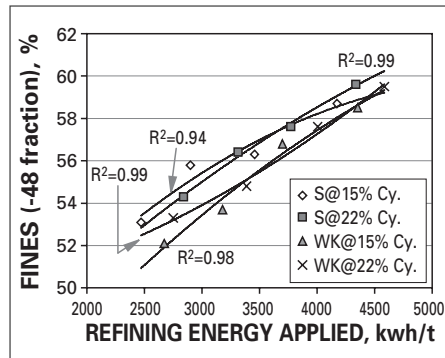
5. This figure shows that the fines content of different pulps increases with increased refining.

Thermal softening of lignin and hemicellulose during refining is another reason for higher specific energy consumption. Goring [10] reported that the lignin softening temperature decreases considerably in the presence of water. Kano and coworkers [11] also reported that energy consumption was greater in RMP due to the thermal softening of hemicellulose and lignin during refining. The simple lignin structures of kenaf and bark [12] may allow for greater lignin thermal softening.

### Shives content of kenaf and stem RMP

The amount of shives decreases with an increase in specific energy for all the raw materials refined at 15% and 22% consistencies. The analyses of shives for kenaf and stem RMP at different energy levels indicate that the percentage of bark fibers in shives decreases with refining. The average shives content for the pulps at a CSF level of 100-125 mL is approximately 2.5%-4%. Tissue analysis of shives indicates that shives at times consisted mainly of bundles of core fibers (Fig. 2). Figure 3 illustrates the presence of paranchyma cells, vessels, and short fibers, indicating that the shives mainly come from the core of kenaf raw material. We conclude that the shives are mainly bundles of core fibers, which, being short, escape the impact of the refiner bar plates and are flung outward through the bar grooves. The other reason for higher shives content is that the plate pattern used for these experiments was originally designed for long fibers.

Some small and broken bundles of core fibers passed through the screen and appear in the handsheets (Fig. 4).



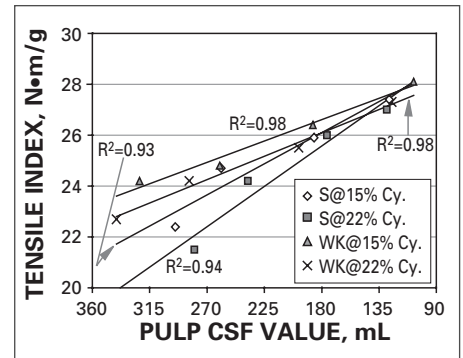
6. Pulps CSF value decreases with increasing refining. However, there is no statistically significant difference in the CSF of various pulps.

The presence of fiber bundles has a negative effect on sheet strength, surface, and optical properties.

### Fiber-fine ratio of kenaf and stem RMP

The fines content of the mechanical pulps contribute significantly to the mechanical properties [13, 14] and the optical properties [15]. It also affects the drainage characteristics. White water, which had a high fines content, was recycled during handsheet formation from kenaf and stem RMP to retain them in the fiber network. We discarded the first five handsheets to stabilize the quality of white water to be recycled. The drainage time, calculated by TAPPI standard T 221 om-93, was almost constant after five sheets. The drainage time increases significantly after the first white water circulation. Figure 5 gives the drainage times of various pulps having different CSF values. We note that drainage time increases considerably with a decrease in pulp CSF and further white water recycling because more fines are present in the pulp.

The quality and quantity of fines generated during refining depend on the morphological nature of fibers. Chemical analyses of various fractions of kenaf and bark22 RMP show that lignin removal was slower for the core fibers than for bark fibers [16]. That could be because the thin-walled core fibers are more flexible than the thick-walled bark fibers. The kenaf and stem RMP analyzed for fiber (+48 fraction) and fines (-48 fraction) per weight by Bauer-McNett classifier indicated that the fiber-to-fine ratio decreases with an increase in the refining energy (Fig. 6).



7. Tensile index for all the pulps increased linearly with decreasing pulp CSF value.

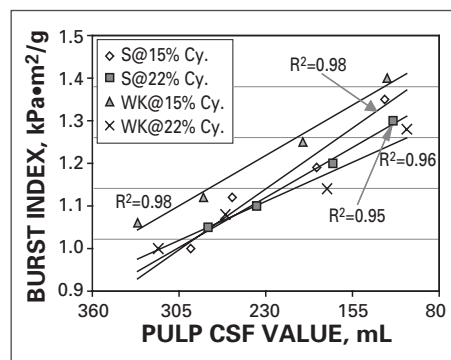
The raw materials refined at 22% consistency produce slightly more fines compared to those refined at 15% consistency. Increased fiber-to-fiber interaction at 22% will peel off more material from the fiber surface, which contributes to increased fines content.

The white water circulation for handsheet making increases the drainage time because the fines block the passage of water through the void space in fiber-fine network. Fines occupying the void space in a long fiber network behave as small fibers or filler during drainage, depending on their size. This increases sheet consolidation and enhances sheet strength. The fiber compactness in a sheet improves with white water circulation compared to handsheets prepared without white water circulation. During this experiment, we noticed that strength properties improved 5%-10% with the recycling of white water during handsheet formation. White water circulation increases the drainage time, possibly through enhanced mobilization of fines during sheet formation. Because of this mobilization, certain strength and optical properties improved through an increase in fiber bonding or more fiber-to-fiber interaction.

### Properties of the mechanical pulps

CSF decreases with an increase in refining energy and can be reflected from the fines content of the pulp and the stiffness of fiber bundles. As the refining continues, bark fibers develop considerable papermaking potential (i.e. produce more flexible fibrillar and ribbon-like material). However with an increased input of specific refining energy to kenaf

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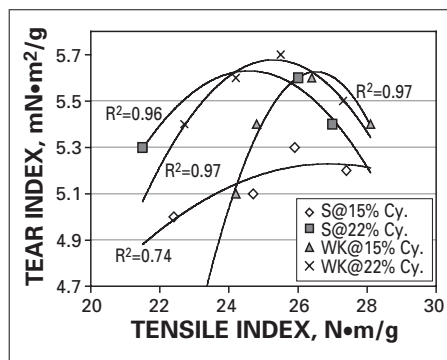


**8. Burst index with respect to pulp CSF for different raw material at various refining consistencies.**

and stem, more fines generation and fiber fibrillation is achieved but they may not necessarily be prerequisite to improve strength properties of mechanical pulp. Individual fiber strength and other morphological properties are equally important in determining the structure and strength properties of a sheet. Newsprint should be reasonably strong to run on fast printing machines, therefore the long fibers (35% by weight) from bark would certainly play a vital role in achieving required newsprint properties.

Figures 7-9 show a trend of tensile index, burst index, and tear index for kenaf and stem refined at 15% and 22% consistency with respect to the specific energy consumption. Kenaf and stem refining at 15% and 22% produce almost the same results for tensile, burst, and tear (Figs. 7-9 and Table II). That could be because an increase in refining consistency did not significantly affect fiber residence time. Higher rotational speeds, such as the 1800 rpm used in our study, have more significant control over residence time than does the refining consistency. Tensile index and burst indices continue to increase as fiber fibrillation is enhanced with refining.

The tear index for raw materials refined at 15% and 22% increases initially with refining energy, but drops with more energy input. Tear index is dependent on fiber length, fibers participating in rupture (intrinsic fiber strength), and the fiber-fiber bonding. During a tear test, the work involved is either against the pulling of fibers from the fiber network, against fiber rupturing, or both [17]. As seen from Fig. 7, tensile index increases

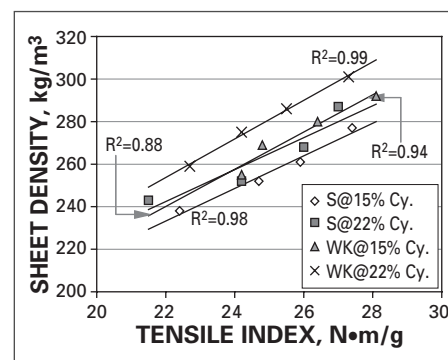


**9. Tear index of different refiner mechanical pulps from whole kenaf and stem initially increases with an increase in tensile index, however decreases with continuous increase in tensile index.**

linearly for all the pulps with refining, indicating an increase in interfiber bonding with refining. Thus, work done in pulling the fibers from a sheet of fiber network increases with an increase in refining energy. With more refining, however, interfiber bonding is further enhanced, but tear strength starts to drop, possibly because of fiber length and degree of bonding exceeding the critical value, as mentioned in the literature [18].

Figure 9 shows that with more refining energy, tensile index continues to increase, while tear index starts to drop. That could be because, under the conditions of tightly bonded fibers, more fibers are ruptured through the initial cut, thus giving lower tear strength. Fiber rupture requires less energy than pulling fibers out from the fiber network [17]. Moreover, Seth and Page [19] have shown that for the highly bonded sheets, the tear index is less dependent on the fiber length.

Screening the pulp on a screen with 0.1 mm slots would further improve the tear and tensile indices. That would limit stiff and flat core fiber bundles from coming with the kenaf and stem RMP and appearing in the sheets (Fig. 4). The greater stiffness of these bundles affects the conformity of fibers and consequently the fiber bonding. Under tension, failure in the fiber network would probably occur at a point where these bundles are present, thus lowering tensile strength and tensile energy absorption. The sheet density (Table II) indicates that the fibers



**10. It indicates that the scattering coefficient and tensile index of different pulps are linearly related.**

are coarser, which reflects lower fiber flexibility and reduced interfiber bonding. This is a major drawback with kenaf and stem pulps. It can, however, be addressed by using appropriately designed screening.

Figure 10 shows a linear relationship between the sheet density and tensile index, indicating that interfiber bonding improved with increased refining. We expected that the core fibers having thin cell walls would flex more during refining and produce a sheet of high density. We found, however, that in the presence of unrefined and stiff core fiber bundles in the sheet, the sheet density was lower than that of the bark fibers refined with 22% core fibers [20]. We believe sheet consolidation and strength can be improved further by reducing the amount of stiff core fibers in the pulp.

Table II shows various properties of RMP from kenaf and stem at the same CSF level from their corresponding best-fit curve equations (by regression analysis). This study used a small refiner. Consequently, the overall residence time of the material refined at 15% and 22% consistencies may not be significantly different because the refining is controlled more by the refiner speed. This is one of the reasons that the properties of pulps for kenaf and stem refined at two different consistencies are not significantly different (Table II).

The tear and burst indices of RMP whole kenaf show an improvement over the whole kenaf TMP [3, 4] and are comparable to those of whole kenaf CTMP [21], as reported by the U.S. Department of Agriculture. Thus, we see that kenaf and stem RMP have reasonable proper-

ties for use in newsprint manufacture. Improved plate pattern and control of the shives and unrefined and stiff core fibers will further enhance pulp properties for its possible use in value-added products such as supercalendered and lightweight coated papers. Kenaf RMP usage in de-inked pulp (DIP) from ONP will improve newsprint quality.

## CONCLUSIONS

In our experiments, the specific energy consumption was higher to refine kenaf and stem. We attribute that to using a small refiner and a plate pattern originally designed for softwood. The refining energy is also higher because of the morphological and anatomical characteristics of core and bark fibers. However, there is no significant difference in the energy consumption of kenaf and stem refined at 15% and 22% consistencies, because of the high refiner speed (1800 rpm).

The shives content is higher for kenaf and stem RMP because of the unrefined and stiff core bundles. Some of these bundles also appear in the sheet and affect its surface, optical, and strength properties.

There is no significant difference in the properties of kenaf and stem refined at 15% and 22% consistencies. The refiner speed minimizes the effect of residence time differences for the refining carried out at 15% and 22% consistencies. However, kenaf RMP properties are comparable to those of kenaf TMP reported in the literature. We also determine the following:

- Raw material screening and washing before refining improve pulp brightness, which will save a considerable amount of chemicals during bleaching.
- Kenaf and stem have to be refined in several passes to produce pulp with a reasonable papermaking CSF of 100-125 mL.
- White water recycling retains the fines and improves the strength and optical properties by approximately 5%-10%.
- There is no significant difference in the pulp properties produced from kenaf and stem.
- Appropriate plate patterns need to be designed for kenaf raw material to allow for simultaneous refining of short and long fibers and are suitable to their morphological characteristics.
- Pulp properties will further improve on large-scale refiners equipped with plates specially designed for kenaf raw material. **TJ**

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| Properties                          | Refining at 15% |             | Refining at 22% |             |
|-------------------------------------|-----------------|-------------|-----------------|-------------|
|                                     | Stalk           | Whole kenaf | Stalk           | Whole kenaf |
| Refining energy, kWh/metric ton     | 4320            | 4303        | 4509            | 4760        |
| CSF, mL                             | 108             | 108         | 108             | 108         |
| Shives, %                           | 3.7             | 5.2         | 3.5             | 4.0         |
| Tensile Index, N.m/g                | 28.0            | 28.1        | 28.0            | 28.1        |
| Tear Index, mN.m <sup>2</sup> /g    | 4.8             | 5.5         | 4.7             | 4.9         |
| Burst Index, kPa. m <sup>2</sup> /g | 1.3             | 1.4         | 1.3             | 1.3         |
| Fiber (+48 fraction), %             | 41.7            | 41.5        | 40.7            | 40.8        |
| Fines (-48fraction), %              | 58.3            | 58.5        | 59.3            | 59.2        |

## II. Properties of refiner mechanical pulps from kenaf and stem at same CSF.

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## INSIGHTS FROM THE AUTHORS

Kenaf is a good quality raw material for pulp and paper manufacture. Its distinct advantage over wood is that it grows to maturity in only six months. Moreover, it provides a good blend of two fibers, long (35%) and short (65%), which resemble hardwood and softwood fibers, respectively.

In the literature, I found that most efforts focused on producing chemical pulp from kenaf; very little work tried to prepare a good quality mechanical pulp. After an extensive literature survey and review of available resources, I proposed to my supervisory committee that kenaf would produce a good quality mechanical pulp for newsprint manufacture. The committee accepted the proposal to optimize the process of refiner mechanical pulp for kenaf, which was to be carried out on a pilot scale Sprout-Bauer refiner.

Previous reported efforts to make kenaf mechanical pulp resulted in mediocre pulp. I was sure that a good quality mechanical pulp was possible, provided the refining process was designed properly. It took a little time to optimize the process through trial runs. Once the right parameters—plate gap, refining consistency, and kenaf size—were obtained, the desired objectives were achieved.

Raw material preparation, in particular for bark, was difficult. A vibratory screen did not produce the expected results of removing 3%-5% soil and extraneous matter from the raw material. The bark had to be cut manually to 25-38 mm lengths, which was difficult and sometimes painful. Finally, the cut bark was screened manually to remove soil and extraneous matter. In addition, the whole kenaf mechanical pulp contained a lot of fines (<0.20 mm), making the washing and screening process very slow. Vacuum has to be applied to speed-up the thickening process.

The core (short fiber) and bark (long fiber) of whole kenaf behave differently during refining. Core fibers have thin cell walls. When refined with bark fibers having thick cell walls, the core fibers seem to be protected, possibly because they are more flexible. Hence, it took more energy to refine whole kenaf to a required CSF level as compared to that which was achieved from bark and/or bark with 22% core.

Kenaf refiner mechanical pulp amazingly provides a good quality pulp, which will not only be used in newsprint manufacture, but also provide a good raw material to manufacture value-added papers such as supercalendered paper.

With minor modifications, this research provides an immediate "knowledge transfer" and confidence to potential manufacturers to use this process to make good quality newsprint from kenaf. This research gives excellent opportunities to countries such as India and China and countries not having enough wood resources to manufacture newsprint from kenaf.

Because kenaf contains a significant portion of long fibers, similar to softwood, mechanical pulp produced from it may not need any northern bleached kraft (NBK) pulp to improve strength properties for the newsprint. It is already there!

To my fellow researchers and scientists, if they want to take this research forward, I would suggest the following:

- Design a suitable system for cutting kenaf stalks into an acceptable chip size.
- Design a suitable plate pattern for the refining of whole kenaf to reduce unrefined core fibers to improve upon surface, optical, and strength properties.
- Reduce refining energy consumption to make it an economical process.
- Expand our understanding of the drainage behavior of whole kenaf pulp.

Such efforts will improve the economics of mechanical pulp production for newsprint manufacture on industrial scale.

— Dinesh C. Mohta

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