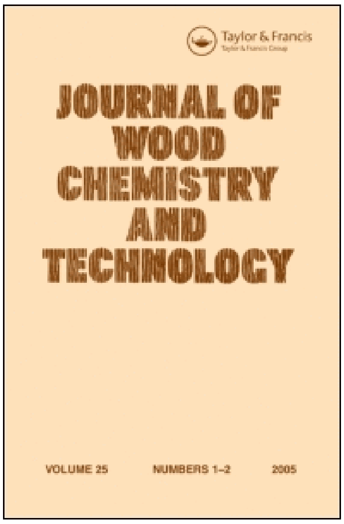

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Steam Explosion Pulping of Kenaf: A Preliminary Study on Pulp Characteristics and a Comparison with Simulated CMP and CTMP of Kenaf

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STEAM EXPLOSION PULPING OF KENAF: A PRELIMINARY STUDY ON PULP CHARACTERISTICS AND A COMPARISON WITH SIMULATED CMP AND CTMP OF KENAF.

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ABSTRACT

The use of kenaf as a raw material for the preparation of ultra-high-yield pulp by applying conventional (CMP and CTMP) and non-conventional (explosion pulping) process conditions, has been investigated. Explosion pulping conditions used for kenaf pulping are actually the optimum conditions for aspen pulping. The effects of impregnation chemicals on explosion pulp properties are examined while the cooking time and temperature are kept constant at optimum level. Breaking length of kenaf explosion pulp is undoubtedly higher than that of simulated CMP and CTMP, even in the case of lower ionic content. Tear values of explosion pulp, CMP and CTMP are similar when the impregnation chemicals contain 1% NaOH in addition to 8% Na_2SO_3. The relative specific refining energy requirements of explosion pulp, CMP and CTMP are greatly influenced by impregnation chemicals. Sulfonate content of explosion pulp depends on the chemical charge. Pulp yield, brightness and opacity decrease with the rise of the sulfonate content of pulp achieved by increasing the chemical charge or by adding NaOH along with Na_2SO_3. The kenaf explosion pulp can be bleached to 77% from an initial 57% level by using 3 to 4% H_2O_2 in a peroxide bleaching process.

INTRODUCTION

Although wood constitutes the major part of global pulp and paper as well as papermaking materials, non-wood plant fibers remain an important source of raw materials in many countries where pulpwood samples are limited, or non-existant. Bagasse, bamboo, straw and reeds are the dominant raw materials among non-wood fibers used in the production of pulp, paper and boards.

Kenaf fibers represent a potential source of raw materials for pulp and paper making in many parts of the world. Kenaf is in fact being used to this effect on a limited scale, mainly in South and South-East Asia. Kenaf is a plant which grows to 4-5 m during a 5-7 month growth cycle. It consists of two basic fiber components, the bark and the core fibers, which possess different pulp and paper making characteristics. The bark fibers are 3-4 mm long and slender, whereas the core fibers are very short 0.5 -0.7 mm. Because of the different nature and structure of the two kenaf fibers, the best quality results are obtained if they are pulped separately and then mixed in different proportions. The pulp derived from whole stalks tends to be slow in drainage characteristics and limits the paper machine speed. However, kenaf bark fibers produce pulp with excellent strength characteristics which can be used as a long fiber substitute.

The kenaf fibers can be processed into chemical pulp using most conventional pulping processes. Kenaf pulps prepared according to sulfate, soda or soda-AQ processes provide the best quality and yield results[1]. Clark et al.[2] prepared kenaf pulps of favorable strength properties by applying the soda, kraft or sulfate and neutral sulfite processes. Kenaf fibers have certain characteristics which may make them suitable for pulping in some new experimental processes - such as alcohol pulping and explosion pulping. So far, Papermaking properties of kenaf thermomechanical pulps were evaluated by Touzinsky et al.[15] They prepared handsheets with strength properties equivalent to commercial newsprint from blends of bleached kenaf thermomechanical pulp containing 15% kenaf soda pulp. The unbleached thermomechanical pulps were not suitable for such an end-use due to its weak bonding properties.

This paper presents the characteristics of kenaf pulp prepared by simulated CTMP and CMP processes and non-conventional steam explosion processes. The steam explosion pulping process consists of the chemical impregnation of chips, short time saturated steam cooking at temperatures varying from 180 to 210°C, pressure release, refining and bleaching.[3,4]

EXPERIMENTAL

Materials

Kenaf Everglades #41, grown at Muskogee, Oklahoma, USA, and harvested on Nov. 25, 1988, was supplied by Kenaf of North America Inc., Tulsa. The samples of kenaf stalk base, lower middle, upper middle, lower top and top were chopped manually to 2.5 cm in length. The levels of sample discoloration were moderate to high. In order to obtain representative samples for pulping, samples were mixed to get composition of that of whole stalk. Samples of whole stalks were also provided for comparison.

Chemical Pre-treatment

110 g of chips (50% moisture) were mixed in a plastic bag along with 110 ml of solution containing either 8% Na_2SO_3 or 16% Na_2SO_3 or 8% Na_2SO_3 + 1% NaOH. The time of impregnation was 24 hours at 60°C. The cooking liquor was absorbed completely by the chips after impregnation.

Steam Cooking

The experiment was carried out in a laboratory batch reactor designed and manufactured by Stake Technology Limited. The cooking temperature and time were 190°C and 240 s respectively. Each cooking stage was preceded by 1 min steam flushing at atmospheric pressure, and, after cooking, the pressure was immediately released. Chips which exploded into the release vessel were washed and cooled with tap water, and subsequently refined after being stored in a cold room. Cooking conditions i.e. temperature 190°C and time 4 min were chosen according to previous studies on aspen.[4,5] As for CTMP, cooking temperature was 128°C and time 10 min, and for CMP, cooking temperature reached 150°C and time 30 min. Cooking yield was measured after exploded fibers were defibrated for 3 min in a laboratory blender Osterizer B-8614 at a consistency level of 2%. The O.D. weight of thoroughly washed and dried pulp was related to initial O.D. chip weight.

Refining

Defibration and refining of exploded fibers were carried out using a laboratory blender Osterizer B 8614 at a consistency level of 2%. Total refining and blending energy were measured using a Hioki model 3181-01 powermeter. Specific refining energy was calculated by subtracting the blending energy of water-beaten fiber suspension from total refining energy. Paper properties obtained by blender refining of mechanical[6] and explosion[4] pulps corresponded well to those obtained from pulps refined industrially or semi-industrially.

Property Evaluation

Paper sheets were prepared and tested according to CPPA testing methods, and the properties were evaluated under dry conditions.

Levels of sulfonation and carboxylation reached after cooking and defibration (see Table 1, 2 and 3) were determined by using a method described by Katz and al.[7]

Brightness (Elrepho) was measured on 1.2 g or 3 g sheets made with demineralized water. One-stage hydrogen peroxide bleaching conditions reported previously[8] and described in Table 4 were applied in this study.

RESULTS AND DISCUSSION

Our study on kenaf pulping is of a preliminary nature. The experimental conditions used for the explosion pulping process had already been optimized for aspen. Cooking time and temperature for explosion pulping of aspen were optimized in order to achieve maximum chip softening without causing serious hydrolytic and oxidative degradation responsible for brightness and yield loss. Considering the resulting pulp properties, brightness and yield, optimum steam cooking conditions were set at 190°C for 4 min.[5,9] Good pretreatment of chips with pulping chemicals is an essential part of the whole explosion pulping process. During high temperature cooking in this process, the uniform distribution of chemicals in the chips helps create ionic groups on the fiber surface, greater inter fiber-bonding, as well as a softer fiber resulting in decreased refining energy and increased physical properties.[4,10,11]

Characteristics of explosion pulp, CMP and CTMP prepared from kenaf impregnated with 8% Na_2SO_3, 16% Na_2SO_3 and 8% Na_2SO_3 + 1% NaOH are presented in Tables 1, 2 and 3 respectively.

Caustic and sulfite are known to greatly influence pulp yield, refining energy, pulp strength and brightness of ultra-high-yield chemimechanical pulps. We also compared the properties of explosion pulp of kenaf with those of simulated CTMP and CMP of kenaf, all prepared with an identical chemical charge applied during the pretreatment of chips.

TABLE 1

Characteristics of Explosion Pulp, CMP and CTMP Prepared from Kenaf (Pretreatment Solution: 8% Na_2SO_3, Liquor/Chips ratio = 3)

Pulp	**Explosion**	**CMP**	**CTMP**
CSF, mL	118	80	96
Relative specific Refining energy, MJ/kg	1.65	6.12	4.48
Breaking length, km	5.81	4.44	3.24
Burst index, KPa.m^2/g	2.84	1.81	1.28
Tear index, mN.m^2/g	10.38	4.06	5.56
Stretch, %	1.99	1.83	1.7
Bulk, cm/g	2.89	2.89	3.85
Brightness, % (1.2g sheet	61.4	66.6	73.2
Brightness, % (3g sheet)	63.2	68.1	73.7
Opacity, %	94	95	93
Light scattering Coefficient, cm^2/kg	534	652	659
Porosity, mL/min	182	206	685
Drainage time, sec	7.7	10.8	7.2
Yield, %	73	76	83
Sulfonate content, mmol/kg	47	40	34
Carboxylate content, mmol/kg	170	162	132
S - Factor, mL	655	652	672
Bauer McNett classification			
M14, %	4.2	1.3	0.2
M28, %	11.5	10.4	9.8
M48, %	16.4	12.5	9.8
M100, %	31.25	27.3	21.33
M200, %	17.1	19.6	21.1
P200, %	19.55	28.9	37.8

TABLE 2

Characteristics of Explosion Pulp, CMP and CTMP Prepared from Kenaf (Pretreatment Solution: 16% Na_2SO_3, Liquor/Chips ratio = 3)

Pulp	**Explosion**	**CMP**	**CTMP**
CSF, mL	97	100	100
Relative specific refining energy, MJ/kg	0.87	1.65	2.5
Breaking length, km	8.83	6.8	3.5
Burst index, KPa.m^2/g	5.5	3.75	1.40
Tear index, mN.m^2/g	7.87	10.4	5.9
Bulk, cm/g	1.78	2.0	3.35
Brightness, % (1.2g sheet)	55	60	69
Opacity, %	87	92	93
Light scattering coefficient, cm^2/kg	292	425	640
Porosity, mL/min	5.5	110	560
Drainage time, s	22.7	7.7	6.5
Yield, %	67	71	78
Sulfonate content, mmol/kg	85.5	81.5	63
Carboxylate content, mmol/kg	168	216	255
S - Factor, mL	592	675	685
Bauer McNett classification			
M14, %	3.46	2.70	0.7
M28, %	10.72	15.7	8.5
M48, %	19.75	19.0	9.0
M100, %	28.44	26.0	26.0
M200, %	14.56	14.0	23.8
P200, %	23.07	22.7	32.0

TABLE 3

Characteristics of Explosion Pulp, CMP and CTMP Prepared from Kenaf (Pretreatment Solution: 8% Na_2SO_3 + 1% NaOH, Liquor/Chips ratio = 3)

Pulp	**Explosion**	**CMP**	**CTMP**
CSF, mL	103	100	94
Relative specific refining energy, MJ/kg	0.57	0.26	0.55
Breaking length, km	8.74	7.95	4.50
Burst index, KPa.m^2/g	5.22	4.5	2.08
Tear index, mN.m^2/g	7.15	7.5	6.57
Bulk, cm/g	1.82	2.25	3.46
Brightness, % (1.2g sheet)	55	58	66.5
Opacity, %	86	87	92
Light scattering coefficient, cm^2/kg	290	320	479
Porosity, mL/min	3	10	77
Drainage time, s	25	15	12.8
Yield, %	66	74	76
Sulfonate content, mmol/kg	81	81	66
Carboxylate content, mmol/kg	181	215	140
Bauer McNett classification			
M14, %	6.5	10.0	12.3
M28, %	10.8	14.0	12.8
M48, %	17.8	21.0	19
M100, %	27.9	25.0	21.6
M200, %	14.9	14.5	16.3
P200, %	22.1	15.5	18.0

TABLE 4

Bleaching Conditions, Brightness and Brightness Stability of Kenaf Explosion Pulp (Chips Impregnation Solution: 8% Na_2SO_3 + 1% NaOH).

DTPA, %	0.5	0.5
$MgSO_4$, %	0.05	0.05
Na_2SiO_3, %	5.0	7.0
NaOH, %	2.0	3.0
H_2O_2, %	3.0	4.0
Bleaching temp., °C	80	80
Bleaching time, min	180	180
pH (initial)	10.9	11.2
pH (final)	9.8	10.3
H_2O_2 (residual), %	0.46	0.25
Original pulp brightness, % (1.2g handsheet)	57.6	57.6
Original pulp brightness, % (3g handsheet)	57.6	57.6
Original reverted brightness (3.0 g sheet), %	57.1	57.1
Bleached pulp brightness, % (1.2g handsheet)	75.6	77.0
Bleached pulp brightness, % (3.0g handsheet)	76.5	77.4
Brightness after reversion, % (3.0g handsheet)	74.5	74.9
Opacity (original), %	87.3	87.3
Opacity (bleached), %	69.5	68.2
Light scattering coef., cm^2/g (before bleaching)	326	326
Light Scattering coef., cm^2/g (after bleaching)	230	221
Bleaching yield, %	88	89.64

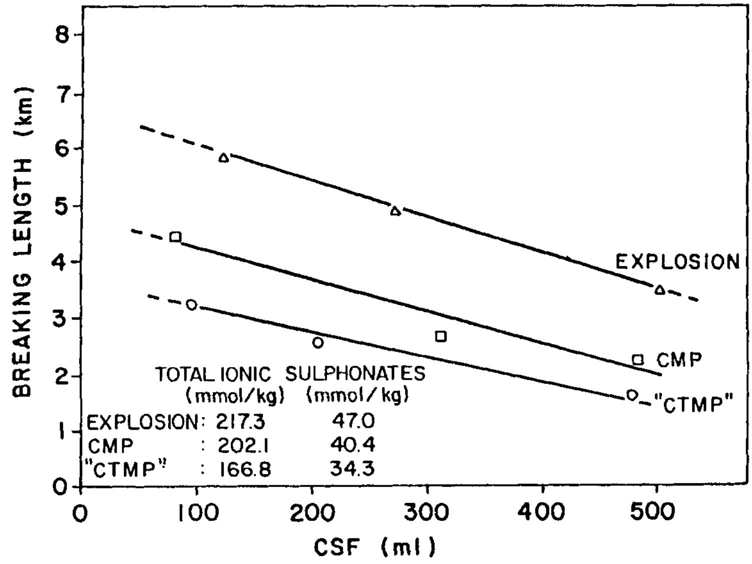

FIGURE 1. Breaking lengths of explosion pulp, CMP and CTMP at various CSF levels (impregnation solution: 8% Na_2SO_3).

Breaking lengths versus CSF are plotted in Figures 1, 2 and 3 respectively. The pretreatment solution consists of 8% Na_2SO_3, 16% Na_2SO_3 and 8% Na_2SO_3 + 1% NaOH. Total ionic (carboxylate + sulfonate groups) and sulfonate groups of the resulting pulps are also indicated in these Figures. Breaking lengths of explosion kenaf pulps are higher at all CSF levels when compared to CTMP and CMP. It is well known that bonding-related properties such as breaking length, burst index, etc. can be correlate well with total ionic content, specifically with sulfonate content of ultra-high-yield chemi-mechanical pulp.[12] The pulps corresponding to a pretreatment solution of 8% or 16% Na_2SO_3 indicate that explosion pulps contain a higher quantity of sulfonate groups, closely followed by CMP. As for pretreatment solution 8% Na_2SO_3 + 1% NaOH (Figure 3), both explosion pulp and CMP have identical sulfonate groups, but CMP exibits higher total ionic group than explosion pulp. This indicates that the higher breaking length of

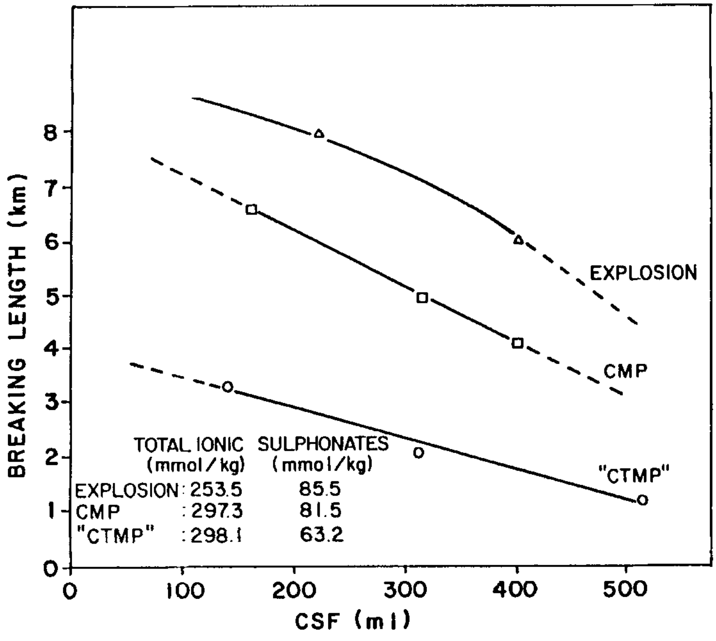

FIGURE 2. Breaking lengths of explosion pulp, CMP and CTMP at various CSF levels (impregnation solution: 16% Na_2SO_3).

explosion pulp depends not only on sulfonate or total ionic content but also on other bonding strength-related properties such as specific surface area, crystallinity, etc.[13]

In Figures 4 to 6, tear indexes are plotted as a function of CSF of pulps prepared from kenaf pretreated with 8% Na_2SO_3, 16% Na_2SO_3 and 8% Na_2SO_3 + 1% NaOH, respectively. For the paper sheet of the same grammage, the most important factors controlling tear values are fiber length as well as number and strength of fiber to fiber bonds. As shown in Table 1, explosion pulp corresponding to a 8% Na_2SO_3 contains more long fiber fraction and shows higher bond-dependent properties in comparison to simulated CMP and CTMP. In these pretreatment conditions, wood matrixes are not soft enough for CMP and CTMP processes. But in an explosion process, high temperature and

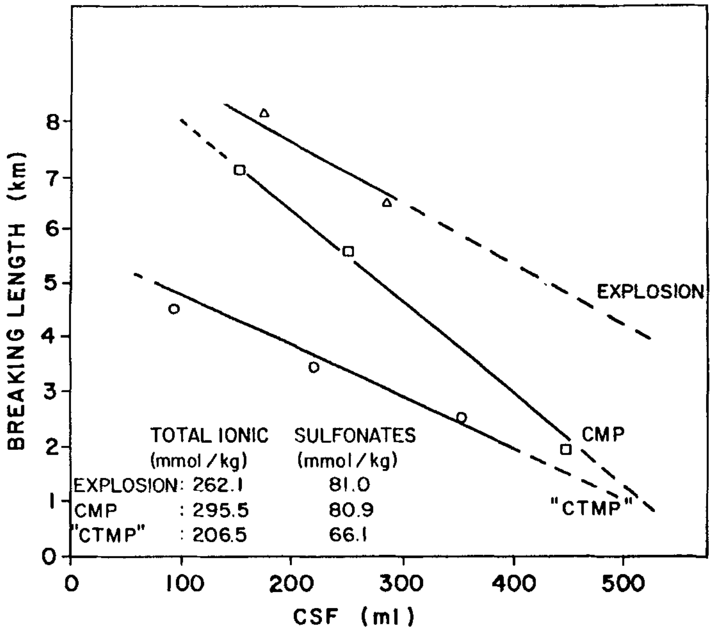

FIGURE 3. Breaking lengths of pulps at various CSF levels (impregnation solution: 8% Na_2SO_3 + 1% NaOH).

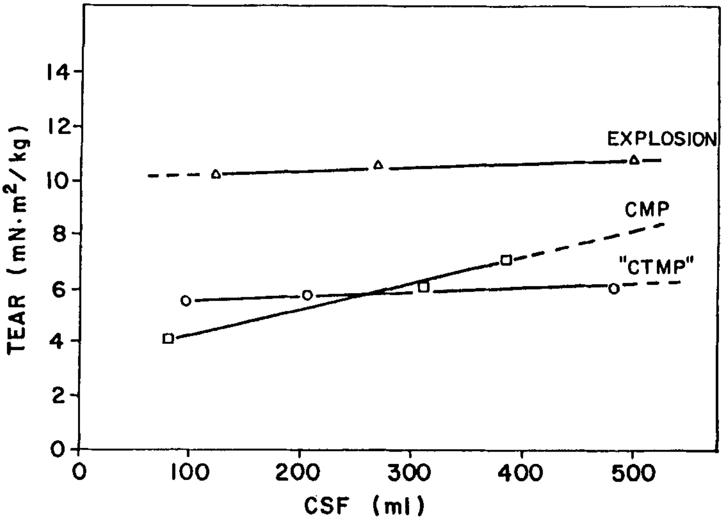

FIGURE 4. Tear values of pulps at various CSF levels (impregnation solution: 8% Na_2SO_3).

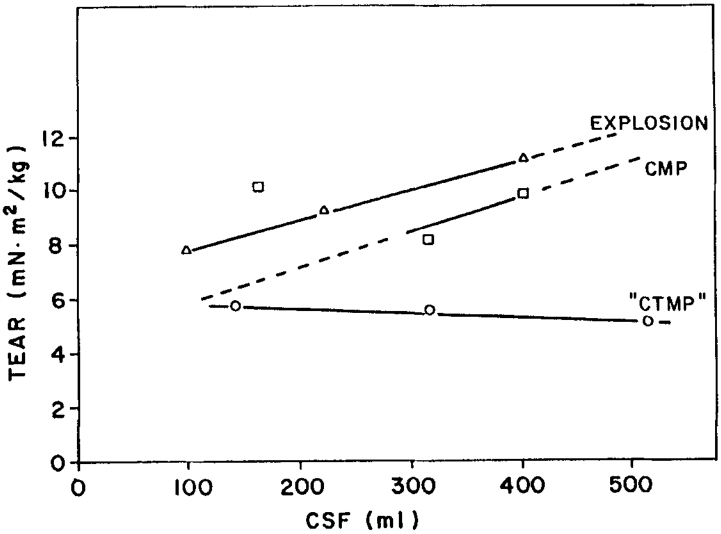

FIGURE 5. Tear values of pulps at various CSF levels (impregnation solution: 16% Na_2SO_3).

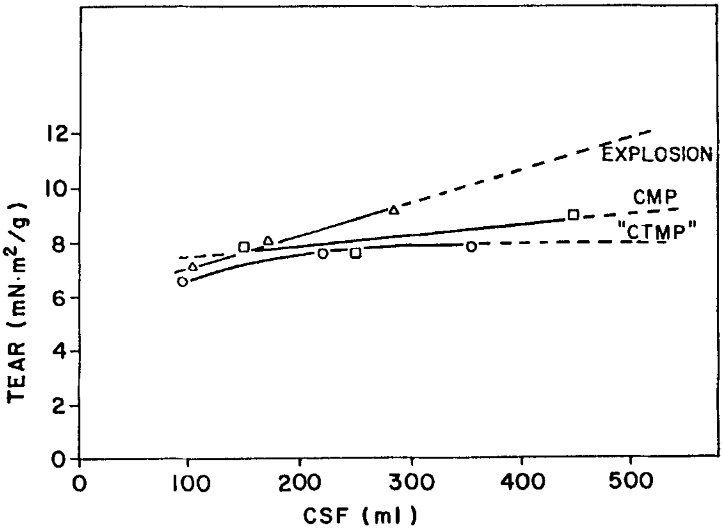

FIGURE 6. Tear values of pulps at various CSF levels (impregnation solution: 8% Na_2SO_3 + 1% NaOH).

decompression facilitate the liberation of fibers from the wood matrix, and thus preserve the fiber length. The high temperature helps to increase the fiber bonding properties through softening. But this advantage diminishes with higher chemical charges and/or by the addition of a swelling agent, such as NaOH in a pretreatment solution. Explosion pulp and simulated CMP and CTMP show similar tear values at a CSF value inferior to 300 ml (Figure 6). As shown in Table 3, both CMP and CTMP pulps contain identical long fiber fractions which are at least 10% greater than those of explosion pulp. However, the bond-related properties of explosion pulp are greater than those of CMP and CTMP. The negative effect of higher short fiber fraction in explosion pulp is compensated by greater bonding strength, as indicated by greater breaking length and burst index values. The tear values of three pulps are similar.

Relative specific refining energy of explosion pulp, CMP and CTMP obtained with the pretreatment solution 8% Na_2SO_3 and 16% Na_2SO_3 is presented as a function of CSF in Figures 7 and 8, respectively. As in the case of tear values, the relative specific refining energy requirement of ultra-high-yield pulp is greatly influenced by the chemical charge in the pretreatment solution. When the pretreatment solution contains 8% Na_2SO_3, explosion pulps need less refining energy while CMP requires more refining energy (Figure 7). High temperature softening and defibration caused by decompression result in lower refining energy, whereas for CMP the moderate temperature treatment increased the stiffness of the pulp more than in the case of CTMP (Figure 7). When the pretreatment solution consists of 16% Na_2SO_3, explosion pulp requires the least amount of specific refining energy followed by CMP and CTMP. At higher chemical charges, aspen chips submitted to CMP conditions are better softened than when they are tested under CTMP conditions. As for explosion pulp, high temperature softening and partial defibration by explosive decompression result in a decrease in specific refining energy (Figure 8). When 1% caustic along with 8% Na_2SO_3 are present in the pretreatment solution, kenaf chips at CMP, CTMP and explosion pulping conditions are sufficiently softened to defibrate easily and require similar refining energy. The effect of

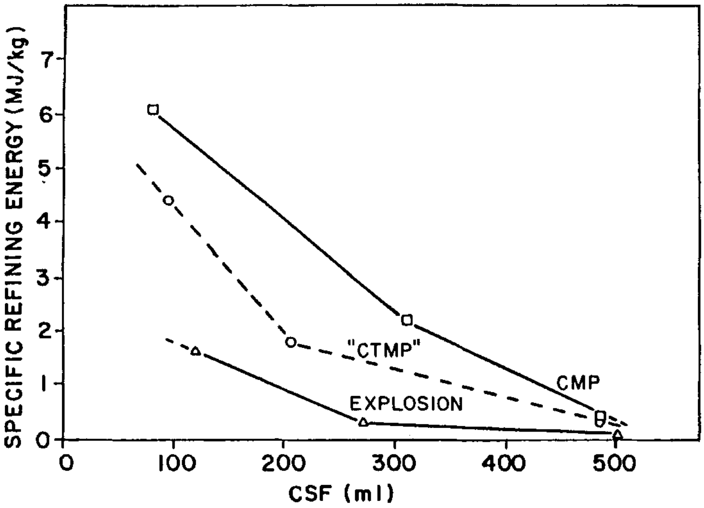

FIGURE 7. Specific refining energy requirements of pulps to obtain various CSF values (impregnation solution: 8% Na_2SO_3).

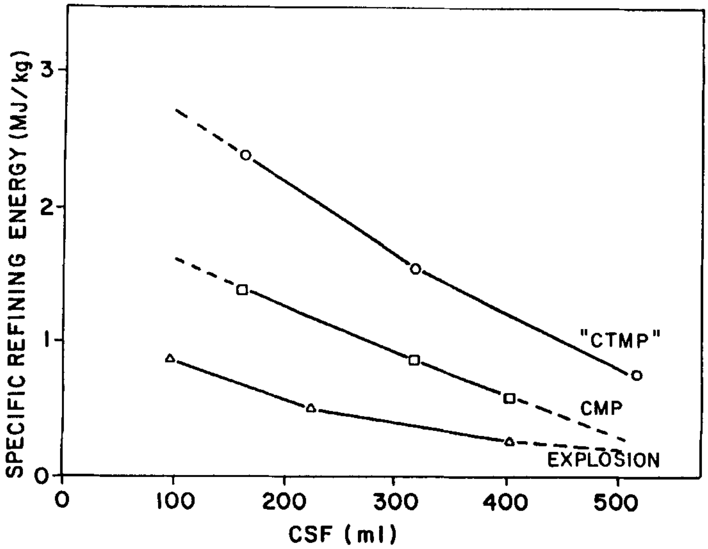

FIGURE 8. Specific refining energy requirements of pulps to obtain various CSF values (impregnation solution: 16% Na_2SO_3).

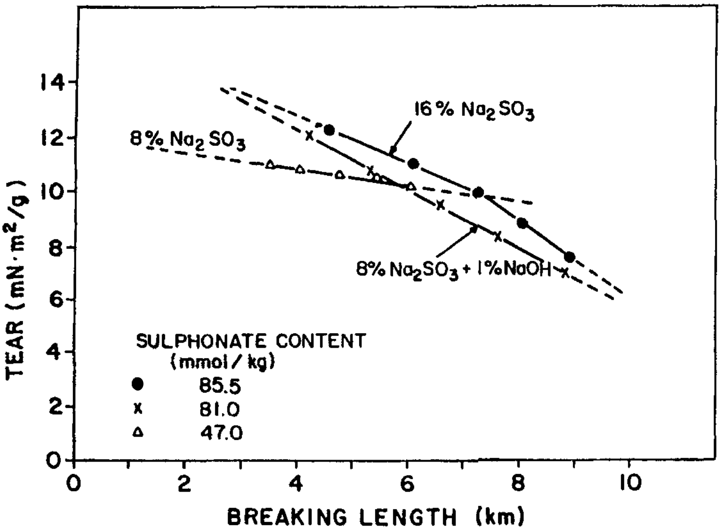

FIGURE 9. Variation of tear values as a function of breaking length of explosion pulps obtained with various impregnation solutions.

explosive decompression on refining energy requirement of highly softened chips is negligible (Table 3). The effect of pretreatment chemicals appears in Figure 9 where tear values of the explosion pulps are presented as a function of breaking length. Pulps corresponding to pretreatment chemicals 8% Na_2SO_3 show tear values of more than 10 mN.m^2/g for a breaking length of 6 km reached at 100 CSF. By increasing the chemical charge from 8% to 16%, or by adding 1% NaOH with 8% Na_2SO_3 in a pretreatment solution, one can obtain a pulp with a breaking length of roughly 9 km and tear values of about 8 mN.m^2/g corresponding to a CSF level of 100 mL. As mentioned earlier, tear values are mainly related to long fiber fraction and bonding properties of the pulp. Pulp obtained with 16% Na_2SO_3 has a higher sulfonate content (85.5 mmol/kg), but lower long fiber fraction in comparison to those of pulp obtained with 8% Na_2SO_3 + 1% NaOH.

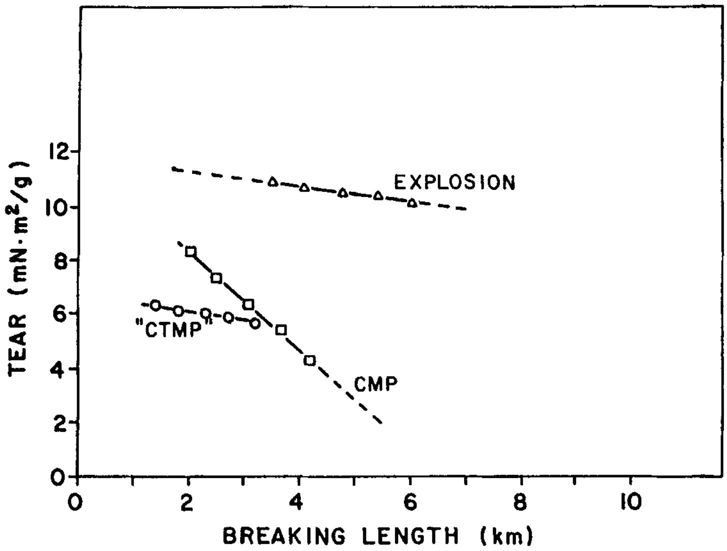

FIGURE 10. Variation of tear values as a function of breaking lengths of pulps (impregnation solution: 8% Na_2SO_3).

Tear index, as a function of breaking length of explosion pulp and of simulated CTMP and CMP, is presented in Figures 10, 11 and 12 for impregnation solutions 8% Na_2SO_3, 16% Na_2SO_3 and 8% Na_2SO_3 + 1% NaOH, respectively. Explosion pulp shows higher tear and breaking length values than those of CMP and CTMP, except for the pulps obtained with a pretreatment solution 8% Na_2SO_3 + 1% NaOH where at 100 CSF level both explosion pulp and CMP show similar tear and breaking length values (Figure 12).

Figure 13 shows the effect of pretreatment chemicals on breaking length and the relative specific refining energy demand of the pulp. An increase in the chemical charge, i.e. from 8% to 16% Na_2SO_3 or the addition of 1% NaOH with 8% Na_2SO_3, reduces the refining energy demand of the pulp accompanied by a simultaneous increase in pulp breaking length. An increase in the chemical charge or the addition of NaOH during pretreatment helps to distribute the chemicals within the

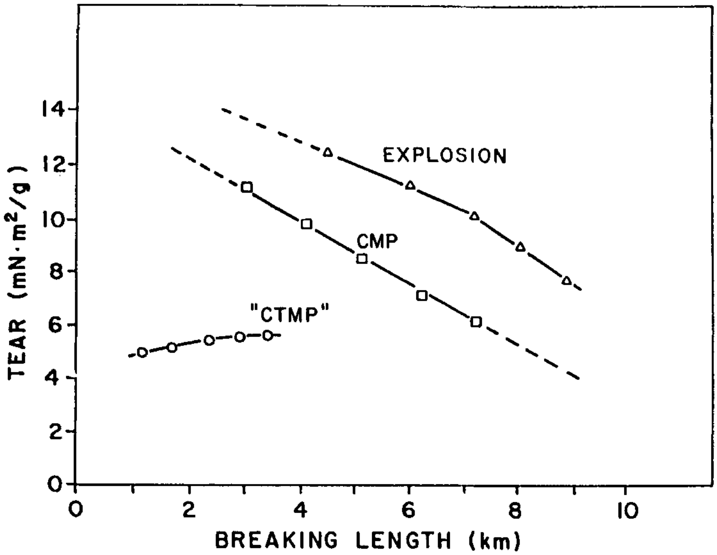

FIGURE 11. Variation of tear values as a function of breaking lengths of pulps (impregnation solution: 16% Na_2SO_3).

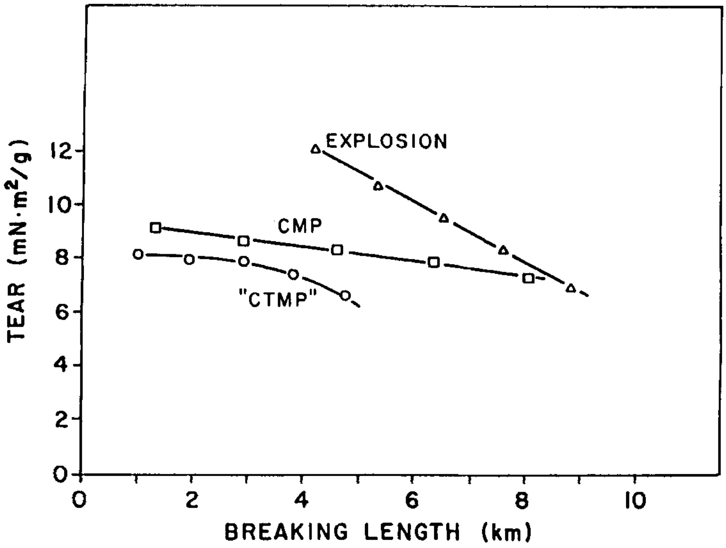

FIGURE 12. Variation of tear values as a function of breaking lengths of pulps (impregnation solution: Na_2SO_3 + 1% NaOH).

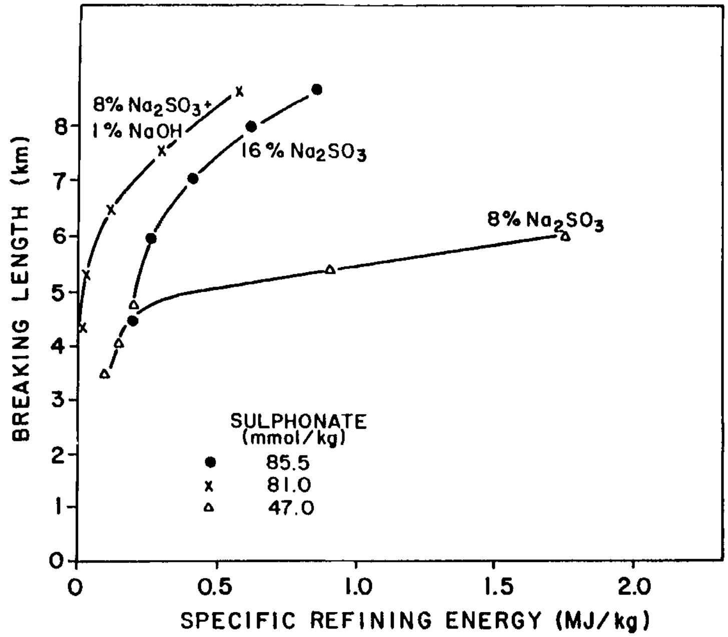

FIGURE 13. Specific refining energy demand of explosion pulp to attain certain breaking length values.

chips uniformly, and to soften them during high temperature cooking. This results in better defibration during the explosion stage and simultaneous creation of bond-forming ionic groups in the pulp.

The relation between breaking length and specific refining energy of explosion pulp, CMP and CTMP prepared with a pretreatment solution consisting in 8% Na_2SO_3 and 16% Na_2SO_3 is presented in Figures 14 and 15 respectively. In almost all cases, explosion pulp develops higher breaking length values by consuming less refining energy. However, when the pretreatment solution contains 1% NaOH, in addition to 8% Na_2SO_3, this creats sufficient softening for easy defibration. Both explosion pulp and CMP then develop similar breaking length values by consuming similar specific refining energy (Table 3).

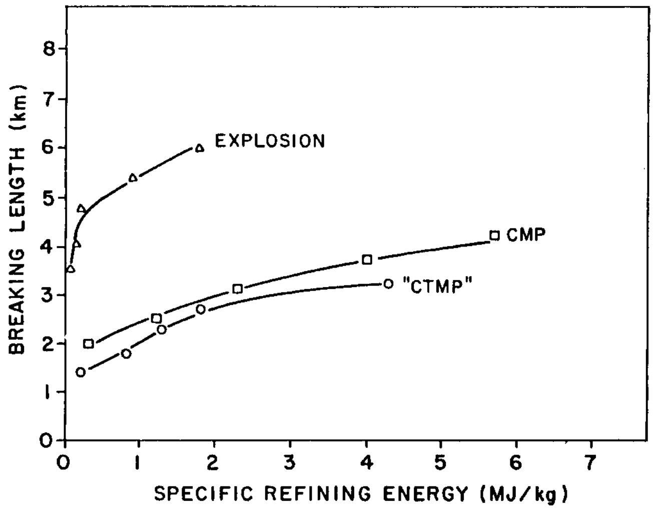

FIGURE 14. Specific refining energy demand of pulps to attain certain breaking length values (impregnation solution 8% Na_2SO_3).

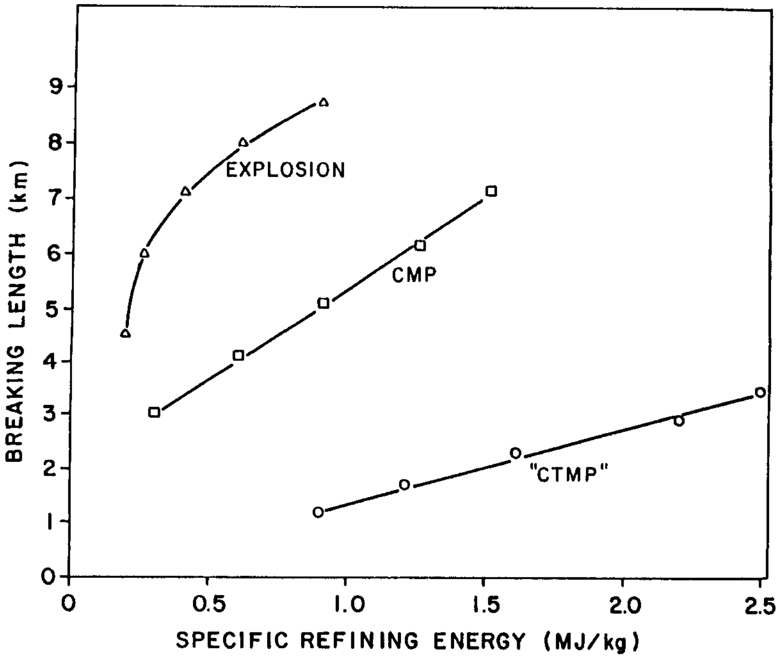

FIGURE 15. Specific refining energy demand of pulps to possess certain breaking length values (impregnation solution: 16% Na_2SO_3).

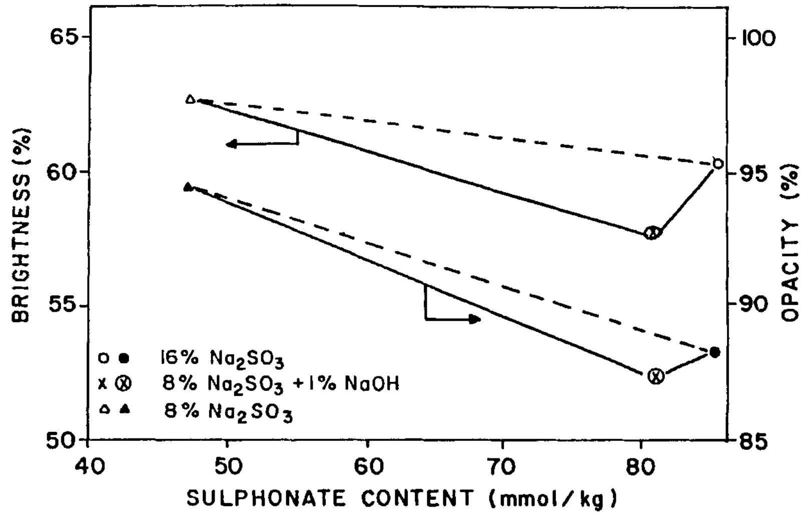

FIGURE 16. Influence of sulfonate content on pulp brightness and opacity.

The sulfonate content of explosion pulp depends on the chemical charge. Figure 16 shows that both brightness and opacity drop with the increase of the sulfonate content in the explosion pulp. However, brightness and opacity are more affected with this increase when the pretreatment solution contains 1% NaOH in addition to 8% Na_2SO_3. NaOH is known for its strengthening effect as well as darkening effect on ultra-high-yield pulp.[14]

The explosion pulp yield dropped with the rise in the sulfonate content achieved by increasing the Na_2SO_3 charge or by adding NaOH along with Na_2SO_3 in the pretreatment solution. Explosion pulp yield is very sensitive to the presence of NaOH in the pretreatment solution due to the hydrolytic action of caustic during cooking at high temperature.[14]

The bleachability of kenaf explosion pulp obtained with 8% Na_2SO_3 + 1% NaOH has been tested by using H_2O_2 bleaching process. Two bleaching conditions (Table 4) were used by varying the percentage

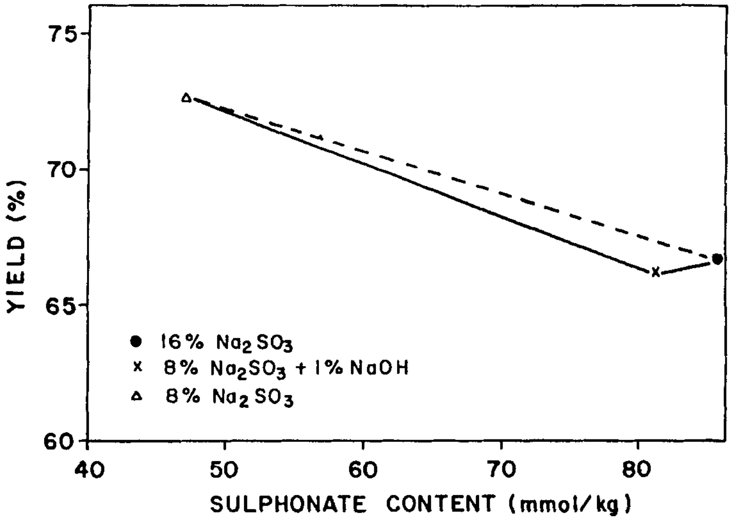

FIGURE 17. Relationship between pulp yield and pulp sulfonate content.

of Na_2SiO_3, NaOH and H_2O_2. The pulp can be bleached up to 76.5% from the initial brightness of 57.6% by using 3% H_2O_2. However, by increasing H_2O_2 to 4% along with an increase in Na_2SiO_3 and NaOH, the pulp can be bleached to 77.4%. The opacity of the pulp decreased from 87.3 to 68%. The light scattering coefficient of the pulp decreased from 326 to 221-230 cm^2/g. The pulp yield after bleaching was 88 to 89%.

The exact pulp end-use depends on pulp mechanical and optical properties which can be controlled by process operating conditions and chemical pretreatment levels. Proper chemical application levels can be chosen to provide a satisfactory compromise among the pulp strength characteristics, light scattering coefficient and opacity as required in newsprint grade. For partial replacement of bleached kraft pulp in various paper grades, kenaf cuttings must be treated in such a manner that improved bonding properties are achieved at higher levels of drainage.

In our studies, we have prepared kenaf pulp at three CSF levels between 100 and 500 mL. These pulps more likely can be used as partial or complete replacement of bleached kraft pulp in various paper grades.

CONCLUSIONS

Kenaf can serve as an important source of raw material for the production of ultra-high-yield pulp. Impregnation chemicals exert a great influence on pulp yield as well as on the mechanical and optical properties of resulting explosion pulp, CTMP and CMP. Breaking length of explosion pulp is superior to that of CMP and CTMP in spite of higher sulfonate content and total ionic content in latter cases. Tear values and specific refining energy demands of the pulp are greatly influenced by the impregnation chemicals. Explosion pulp has an advantage over CMP and CTMP when the impregnation solution contains only Na_2SO_3. Tear values as well as refining energy demands of explosion pulp, CMP and CTMP are similar, when the impregnation solution contains 1% NaOH in addition to 8% Na_2SO_3. Pulp yield, brightness and opacity drop with the rise of the sulfonate content in the pulp. The kenaf explosion pulp can be easily bleached to 77% from an initial brightness level of 57% by applying a hydrogen peroxide bleaching process.

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