Characteristics of Flax straw pulps obtained by steam explosion pulping

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ABSTRACT

The adhesion properties such as burst and breaking length of explosion flax pulps are superior to those of equivalent RMP (refiner mechanical pulp) and CTMP flax pulps when 8% Na_2SO_3 and 1% NaOH are used during impregnation stage. Flax #1 samples (without outer shell present) give stronger and brighter pulp than that of flax #2 samples containing fragments of outer shell The brightness of flax #1 pulp (51 to 54%) and flax #2 (45 to 48%) would increase to 70% level (flax #1) and 65% level (flax #2) by a single stage bleaching with 4% H_2O_2. Paper properties especially tear values are improved tremendously through bleaching process. The pulp yield of flax is around 75% level.

Introduction

Although wood constitutes the major part of the world paper making materials, non-wood plant fibers remain the important source of paper making materials in many countries where wood forests are limited or nonexistant. To fulfil the growing demands of paper consumption, countries possessing less or no forest resources, have paid great attention in recent years for the development of non-wood fibers for paper making. Flax straw is an important source of non-wood fibers among the growing list of non-wood fibers.

Flax *(Linum usitatissimum)* is a herbaceous annual plant grown for fiber used in the production of linen and for seed used in the production of linseed oil. The plant stem grows to a height of about 0 9-1 2 m and have a diameter of 0.25-0.5 cm. The stems of the flax plant have a woody core with a hollow center. The woody core (shive) that constitutes 70% of the stem, has very short fibers. The long fibers used for the production of linen and for paper making are located in the bark The ultimate flax bast fibers are long and slender The fiber length ranges from 10 to 55 mm and diameter ranges from 12 to 30 μm. The total amount of fiber in the bark is about 20% of the total weight of stems. The raw flax straw cannot be used for the production of high quality pulp because of the shive content that yields a pulp equivalent to a very weak hardwood pulp. The flax straw destined for pulping is decorticated by mechanical means to remove as much shive as economically feasible. For pulping, caustic soda is the most common chemical although sometimes sodium sulfite or a small amount of elemental sulfur may be added to the caustic soda. It is obvious that pulp produced from decorticated flax straw will contain a substantial fraction of short fiber from the shive content, whereas pulp from textile flax too consists of bark fiber only, will contain very little short fiber. As a result, paper produced from bast fiber pulp will be stronger and more durable and resistant to production of thin strong papers, such as cigarette papers: airmail papers, bible papers and light weight bond papers as well as currency papers.

In this paper, we have presented the characteristics of flax pulp prepared by non-conventional steam explosion pulping process. The explosion pulping process consists of chemical impregnation of chips, short duration saturated steam cooking at high temperature varying from 180 to 210°C, rapid pressure

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release, refining and bleaching (1,2). We have used this process previously for pulping various non-wood plant materials such as bagasse (3) and kenaf (4) obtaining pulp of good quality,

Experimental

Flax samples were provided by Crown Management Board of Saskatchewan. Sample flax$\neq$1 represent chopped flax fibers with outer shell removed. Sample flax $\neq$2 represent long flax fibers with darker outer shell present and was manually cut to a length of about 2 inches.

Chemical pretreatment of flax

150 g of flax at about 50% of moisture content were mixed in a plastic bag either with 150 g of solution (liquor/chips=3) or with 300 g of solution (liquor/chips=5). Solutions were made either of 8% Na_2SO_3 or 8% Na_2SO_3+1% NaOH. The time of impregnation was 24 h at 60°C.

Steam cooking

Cooking was done in a laboratory batch reactor built by Stake Technology Limited, Canada. The temperature was 190°C and time 4 min. Cooking was preceded by 1min steam flushing at atmospheric pressure. After cooking, the pressure was insantaneously released and chips which exploded into the release vessel were washed and cooled with 1 L of tap water and subsequently refined after being stored in a cold room. Cooking conditions were chosen based on previous studies (5). In case of CTMP of flax, cooking temperature was 128°C and cooking time was 10 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. RMP was prepared by refining the original flax which was not chemically pretreated. Defibration and refining of exploded fibers were done using a laboratory blender Osterizer B 8614 at a consistency level of 2%. It was shown that paper properties obtained by blender refining of mechanical (6) and explosion (2) pulps correspond well to that obtained with pulps refined industrially or semi-industrially.

Property evaluation

Paper sheets were prepared and tested according to the Canadian Pulp & paper Association (CPPA) testing methods and the properties were evaluated under dry conditions. The brightness (Elrepho) was measured on 1.2 g sheets made by using demineralized water.

Results and Discussion

Our study on flax pulping is a preliminary one. The experimental conditions used for explosion pulping process were optimized previously for aspen wood. The 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 reactions responsible for brightness and yield loss. Judging the resulting pulp properties, yield and brightness, the optimum steam cooking condition was set at 190°C for 4 min (5,7). A good impregnation of chips with pulping chemical is an essential part of the whole explosion pulping process. During high temperature cooking in explosion pulping process, the uniform distribution of chemicals during impregnation of chips helps to create ionic groups on the fiber surface and uniform interfiber bonding, as well as softens the fiber leading to decrease in refining energy and increase in physical properties (2, 8, 9).

Caustic and sulfite are known to influence greatly the pulp yield, refining energy, pulp strength and brightness of ultra high-yield chemi-mechanical pulps (10). Types of pretreatment solution and characteristics of flax explosion pulp at 200 mL level have been presented in Table 1. The influence of NaOH concentration in pretreatment solution on mechanical and optical properties of both types of flax pulp is also shown in Table 1. Burst index, breaking length and tear index of flax$\neq$1 explosion pulp are plotted in Figure 1 as a function of CSF. Flax $\neq$1 explosion pulp obtained with pretreatment solution containing 1% NaOH in addition to 8% Na_2SO_3 shows superior paper properties than that obtained with 8% Na_2SO_3 only. Both the opacity and brightness of Flax $\neq$1 explosion pulps obtained with pretreatment solution containing NaOH or not are similar. Similar to Flax $\neq$1 explosion pulp, flax $\neq$2 explosion pulp obtained with pretreatment solution containing 1% NaOH in addition to 8% N_2SO_3 shows superior paper properties than that obtained with 8% Na_2SO_3 only (see Figure2). The opacity of flax ≠2 explosion pulp corresponding to pretreatment solution 8% Na_2SO_3+1% NaOH is lower than that obtained with 8% Na_2SO_3 solution, although the brightness of both pulps are similar,

The influence of liquor/chips ratio applied during the pretreatment of flax ≠1 cuttings on explosion pulp properties is shown in Figure 3. The higher liquor/chips ratio raises the tear values of the pulp at all CSF level and reduces the breaking length values especially at lower CSF levels. In case of flax ≠2, both breaking length and tear index values of the pulp are increased at all CSF levels with the rise of liquor/chips ratio during pretreatment with 8% Na_2SO_3.

Comparison of breaking length and tear index values of flax ≠1 and flax ≠2 explosion pulps obtained with 8% Na_2SO_3 pretreatment solution is presented in Figure 4 as a function of CSF levels, breaking length and tear values of flax ≠1 are higher than those of flax ≠2 explosion pulp. Brightness of flax ≠1 explosion pulp shows higher values than that of flax ≠2 pulp (see Table 1). Flax ÷1 yield pulp of superior quality in comparison to flax ±2, when the pretreatment solution consisting of 8% Na_2SO_3+1% NaOH. The inferior properties of flax ±2 pulp is probably due to the presence of fragments of outer shell which contain short fiber and inherent low bonding strength.

Flax pulps (explosion, CTMP and RMP) give extraordinarily high tear values. Explosion flax ±1 pulp with (8+1) chemical pretreatment gives the highest tear values among the pulps that have been studied here (Figure 5). Both CTMP and explosion flax ±1 pulp corresponding to pretreatment solution (8+0) show similar tear values but slightly higher than that of RMP of flax ±1. When the impregnation solution contains 1% NaOH in addition to 8% Na_2SO_3, tear values of both CTMP and explosion flax pulp increased substantially. The incorporation of NaOH in flax during pretreatment helps to soften the fiber more at explosion pulping conditions than in CTMP conditions where low temperature was maintained during cooking. Moreover, the explosive pressure release contributes in defibration and fiber flexibility of flax without damaging fiber length that contributes to the ultimate tear values of the pulp. This study reveals that Na_2SO_3 alone in pretreatment solution is not sufficient to soften the flax fiber that differ from aspen fiber characteristics.

In absence of caustic in pretreatment solution (8+0), explosion and CTMP of flax ÷1 shows similar tear-breaking length relationship (see Figure 6). RMP of flax that is not subject to pretreatment shows considerably lower tear and breaking length values. Explosion process is not effective in absence of swelling agent such as NaOH in pretreatment solution. Tear values of explosion flax pulp increase substantially through H_2O_2 bleaching.

The relationship between tear index and breaking length (see Figure 7) shows the advantage of explosion pulp over CTMP when the pretreatment solution contains 1% NaOH in addition to 8% Na_2SO_3. In this pretreatment condition, explosion flax ÷1 pulp shows substantially high tear and breaking length values in comparison to that of CTMP flax ±1 pulp.

Bleaching conditions and brightness bleached pulps are presented in Table 2. The unbleached brightness of flax ÷1 explosion pulp varying from 51 to 54 are higher than that found for flax ÷2 explosion pulp The dark outer shells present in flax ÷2 cuttings are fully responsible for the reduction in unbleached brightness of flax 2 ÷explosion pulp. The brightness of flax ÷1 explosion pulp would increase to 73% level and that of flax ÷2 explosion pulp to 66% level when bleached with one stage H_2O_2 (see Table 2).

Conclusions

The test sheets of RMP, CTMP and explosion pulp of flax ÷1 show extraordinarily high tear values and relatively low bonding related properties such as tensile and burst strength. The presence of caustic in pretreatment solution along with Na_2SO_3 substantially improve the physical properties of flax pulp. Flax ≠1 samples without outer shell yield brighter and stronger paper than that obtained from flax ≠2 samples containing fragments of outer shell. Explosion flax pulp with yield 75% can be bleached to 70% level in one stage with 4% H_2O_2. The best explosion flax ≠1 pulps prepared with impregnation solution containing 8%

$Na_2SO_3 + 1\%$ NaOH give papers with properties considerably superior when compared to that of RMP or CTMP flax pulps.

Acknowledgement

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List of Figures

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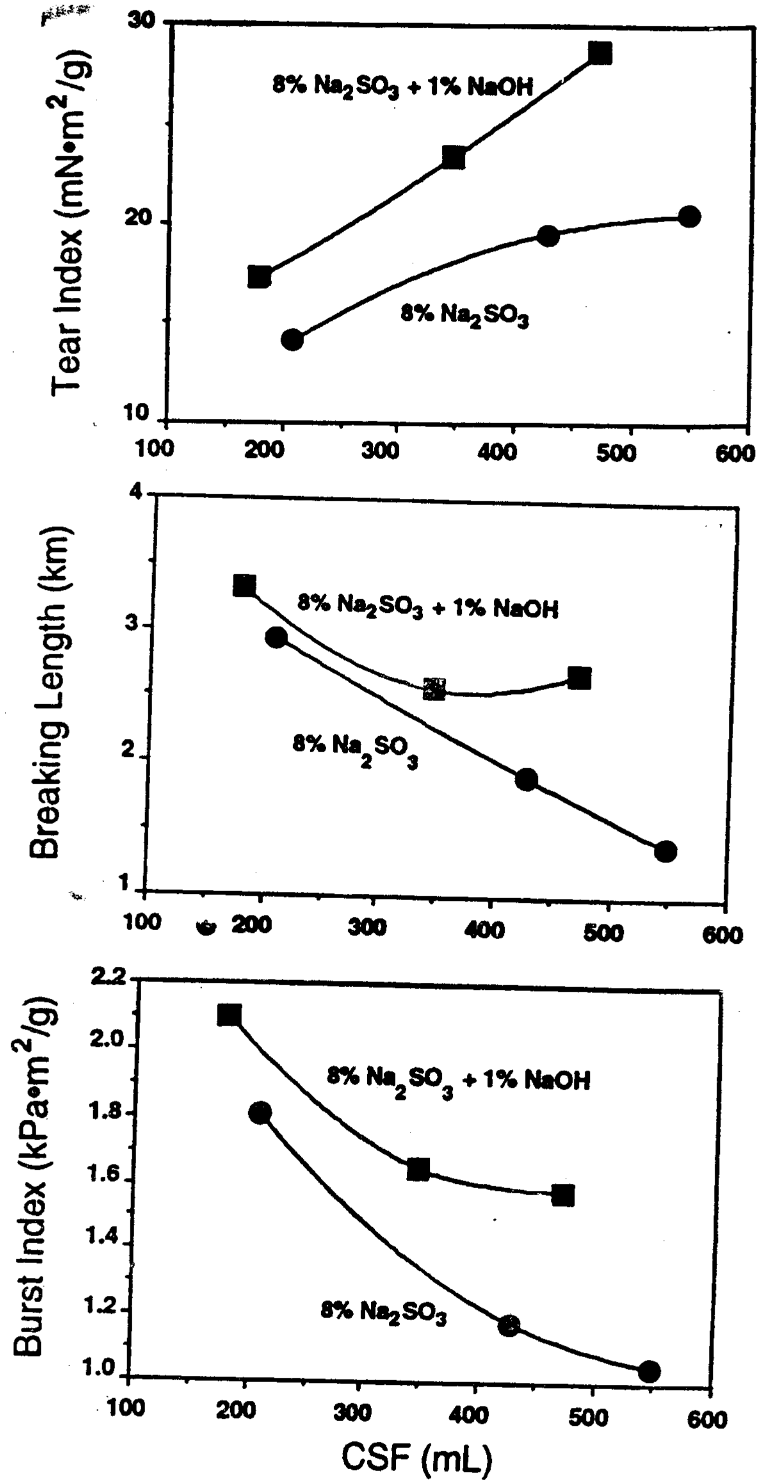

Fig. 1

2. Influence of NaOH in pretreatment solution (L/C =3) on the mechanical properties of resulting flax ≠2 pulp at various CSF levels.

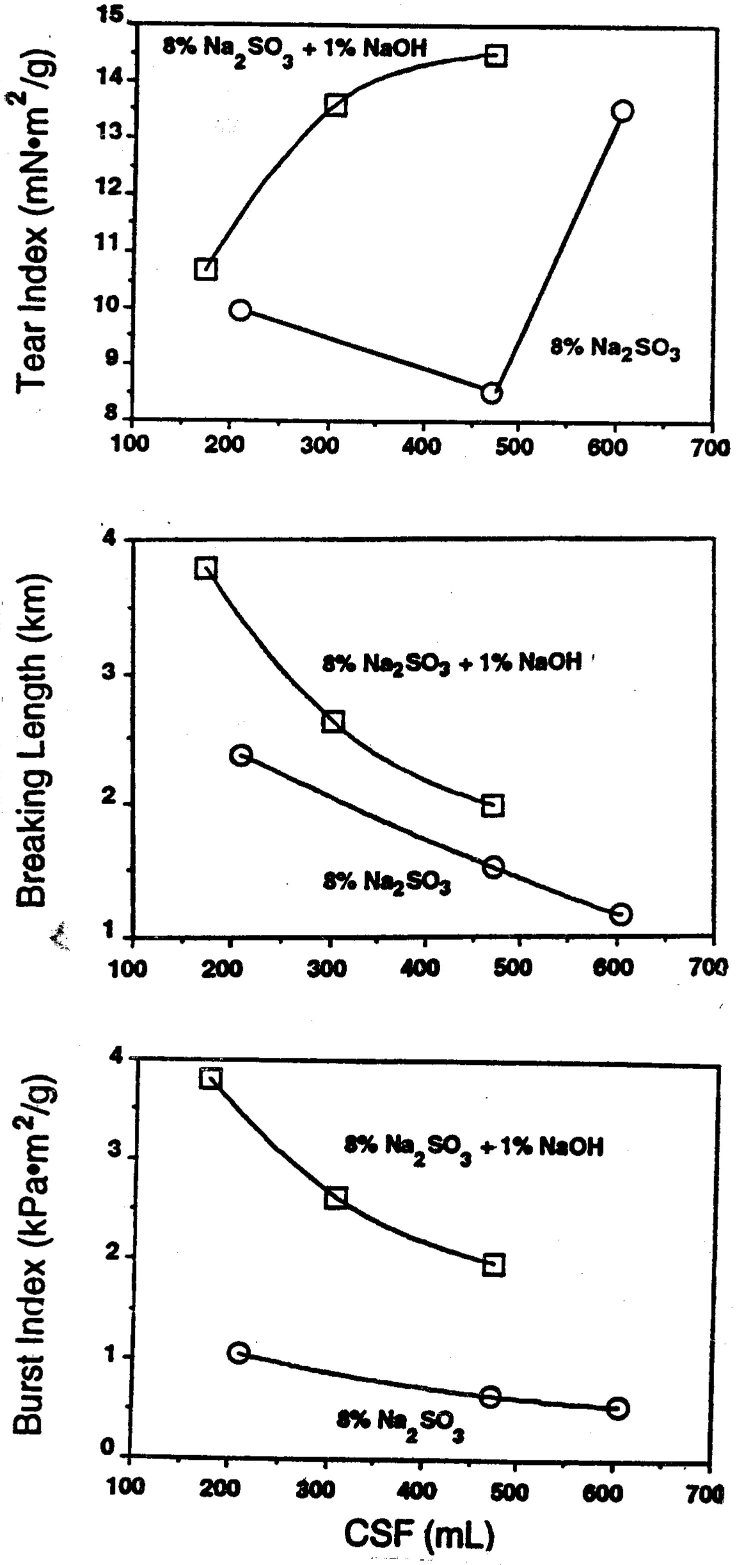

Fig. 2

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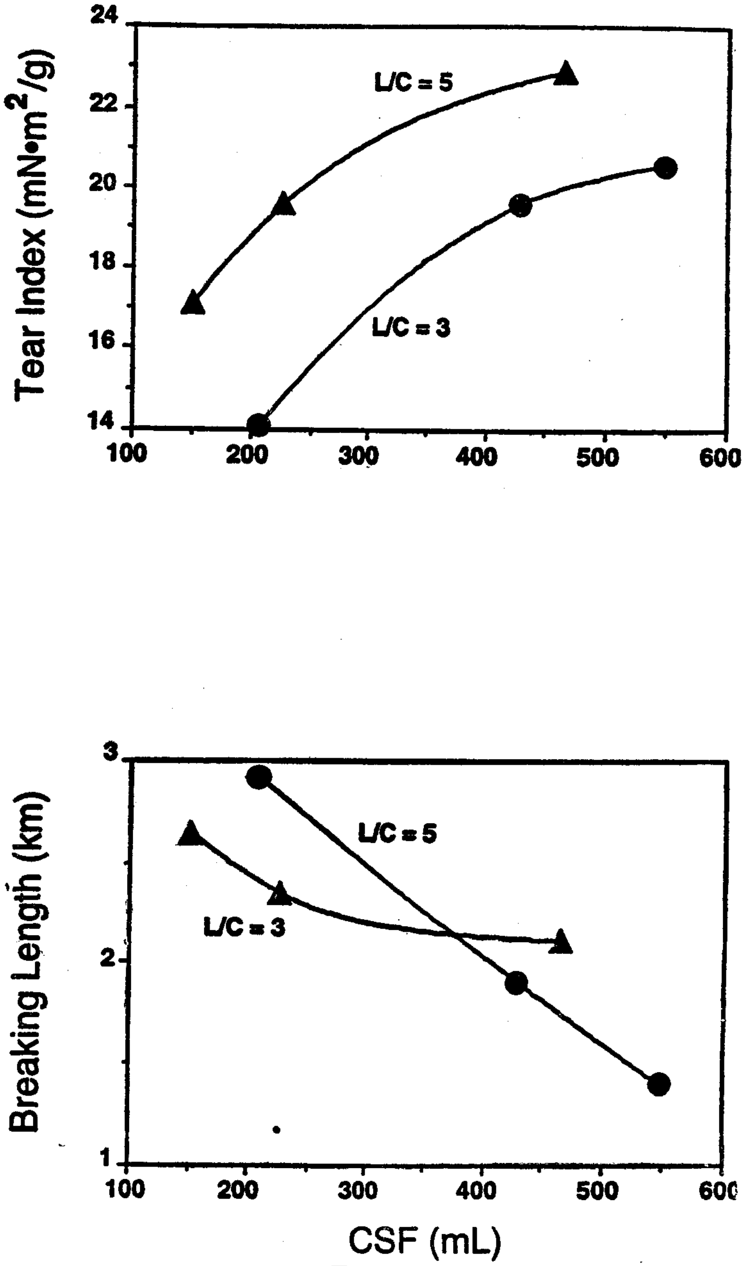

Fig. 3

4. Comparison of the breaking length and tear index values of flax ╪1 and flax ╪2 explosion pulp at various CSF levels (pretreatment solution: 8% Na_2SO_3, L/C=3).

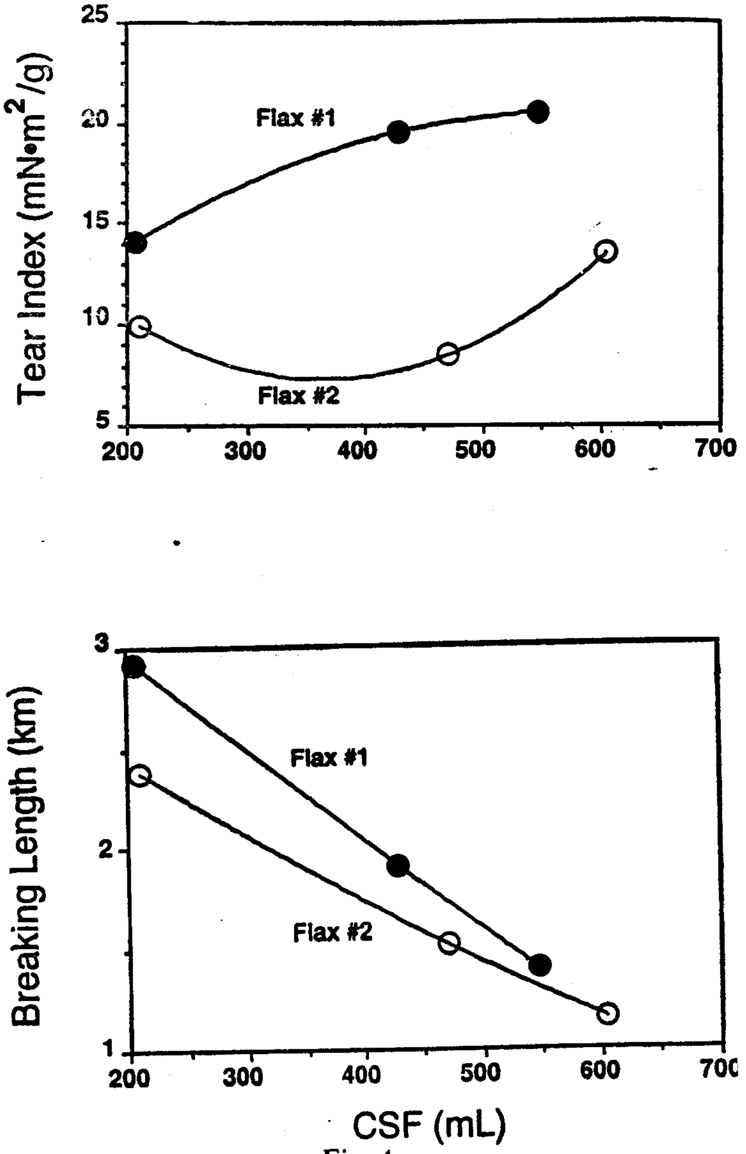

Fig 4

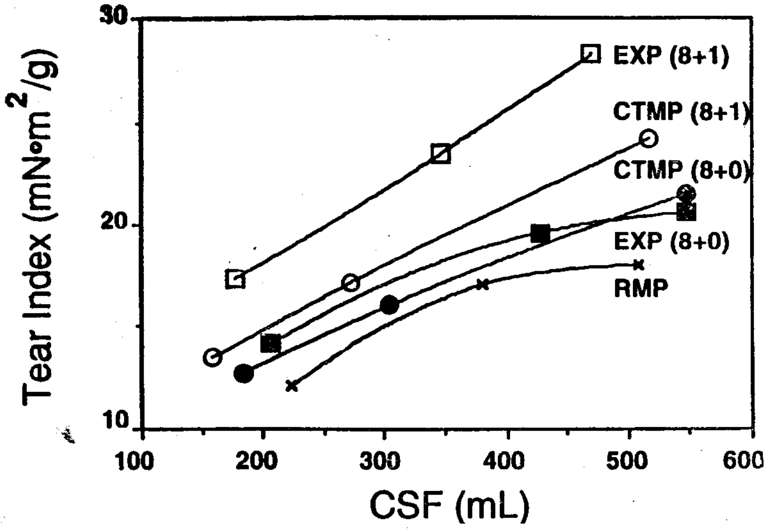

Fig. 5

5. Comparison of the tear values of flax #1 explosion pulp, CTMP and RMP at various CSF levels.

Table 1

Types of pretreatment solutions and characteristics of flax explosion pulps (CSF=200 mL)

Pulp	A	B	C	D	E	F
Flax	1	1	1	2	2	2
Pretreatment solution						
Liquor/chips ratio	5	3	3	3	5	3
Na_2SO_3 (%)	8	8	8	8	8	8
NaOH (%)	0	0	1	0	0	1
Bulk (cm^3/g)	4.6	3.9	3.8	3.4	3.0	2.9
Breaking length (km)	2.4	2.9	3.2	2.4	3.7	3.5
Burst index ($kPa.m^2/g$)	1.8	1.8	2.1	1.1	1.6	1.7
Tear index ($mN.m^2/g$)	18.9	13.9	18.1	10.0	10.9	11.3
Brightness (%)	53.9	50.2	50.3	45.4	49.1	45.0
Opacity (%)	89	91	90	96	91	92
Light scatt. coeff. (cm^2/g)	340	362	341	438	377	380
Sulfonate groups (mmol/kg)	45.8	40.6	41.9	—	—	—
Carboxylate groups (mmol/kg)	218	161	189	—	—	—
Yield (%)	77	75	75	76	76	75

Table 2

H_2O_2 bleaching of flax #1 and flax #2 explosion pulp

Pulp	Flax #1						Flax #2					
Sample	A_1	A_1	B_1	B_1	C_1	C_1	A_2	A_2	B_2	B_2	C_2	C_3
H_2O_2 (%)	2	4	2	4	2	4	2	4	2	4	2	4
Sample CSF (mL)	428	428	228	228	346	346	470	470	415	415	305	305
Initial brightness (%)	52.8	52.8	54.1	54.1	50.7	50.7	45.3	45.3	48.5	48.5	45.3	45.3
Bleached brightness (%)	64.1	72.8	63.5	73.6	57.2	61.0	58.9	63.3	48	66.5	51.5	63.2
Gain (%)	21.4	37.8	17.4	36	12.8	20	30	39.7	—	37	12	39.5

Note :—The bleaching conditions and concentration of chemicals other than H_2O_2 were hold constant in all cases, consistency of pulp : 25%, bleaching temperature : 80°C, bleaching time: 4 hours, bleaching chemicals: DTPA=0.5%, $MgSO_4$=0.05%, Na_2SiO_3=5% and NaOH=3%.

6. Tear index and breaking length relationship of RMP, CTMP and explosion pulp of flax≠1 (pretreatment solution : 8% Na_2SO_3).

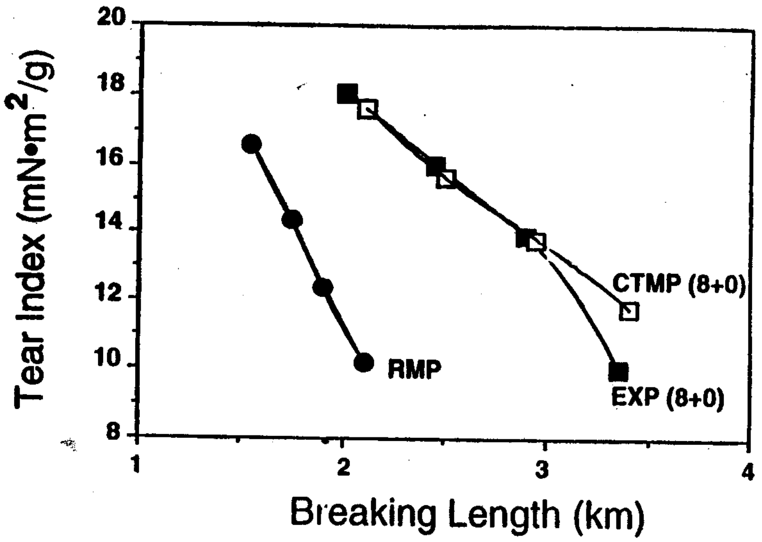

Fig. 6

7. Tear and breaking length reletionship of RMP, CTMP and explosion pulp of flax ≠1 (pretreatment solution : 8% Na_2SO_3 + 1% NaOH).

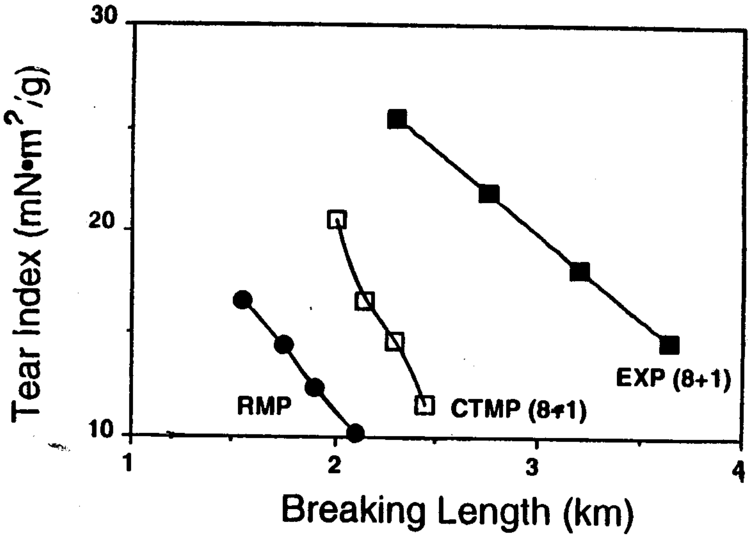

Fig. 7