Ultra-high-yield explosion pulping of Aspen

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ABSTRACT

The effects of the variation of chemical charge during impregnation on the resulting explosion pulp properties are studied. Physical properties of the explosion pulp increase with the increase of chemical charge in the form of liquor/chips ratio from 3 to 6, when the impregnation solution contains 8% Na_2SO_3 only. The liquor/chips ratio above 4 has little positive effect on the physical properties of the resulting explosion pulp in comparison to the level of reduction in pulp yield and brightness The breaking length of the explosion pulp is directly proportional to the ionic content of the pulp Higher chemical charge reduces the ionic content and so the breaking length, when the impregnation solution contains 1% NaOH in addition to 8% Na_2SO_3. The explosion pulps show superior physical properties but inferior optical properties in comparison to those of CTMP. However, the refining energy of the explosion pulp is much lower than that of CTMP.

INTRODUCTION

In recent years, a substantial effort in pulp and paper research is directed towards three objectives : 1) to maximize the utilization of forest resource by using the hardwood species due to worldwide continuous depletion of softwood species traditionally used for pulp and paper making. 2) to obtain ultra-high-yield pulp with reasonable optical and physical properties to maintain continuous supply of raw materials in near future. 3) to reduce the application of chemical charge and improve the chemical recovery system to follow the strict regulation program of the Government.

Aspen (Populus termuloides), a hardwood species, grows favourably and is available in many parts of Canada. The inherent high brightness and opacity makes aspen more attractive for paper making. A number of ultra-high-yield conventional pulping processes such as RMP (refiner mechanical pulping), TMP (thermomechanical pulping), CMP (chemi-mechanical pulping) and CTMP (chemi-thermomechanical pulping) is at present in operation. Aspen pulp of good opacity and brightness but of relatively weak mechanical properties can be produced by RMP or TMP process (1-3). The mechanical properties of the pulp can be improved by pretreating the wood chips with a mixture of sulfite and caustic before cooking either in CTMP or CMP process (4-14). In both processes, the pretreatment step consists of presteaming, compression and chemical impregnation of wood chips. The impregnation solution can be reused by adding make-up chemicals that ultimately reduces the quantity of chemical in paper mill effluent.

A new ultra-high-yield explosion pulping process has recently been proposed by Kokta et al (15-19) to pulp, both hardwood and softwood. The process consists of the following steps : 1) impregnation with chemicals, b) cooking in a high pressure reactor under saturated steam at temperatures varying between (180 to 210 °C) explosive decompression d) washing and refinining of exploded chips to produce pulp suitable for paper making. It is claimed that exploded hardwood pulps give considerably stronger papers when compared to equivalent CMP/CTMP and also substan-

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cially lower refining energy (20,21). Comparison of the properties of steam explosion aspen pulps with that of CTMP / CMP both obtained in parallel semi-industrial trials confirm the laboratory results (20,21). The purpose of the present study was to investigate the effects of chemical charge by varying the liquor/chips ratio during impregnation on the properties of aspen explosion pulp. This study will also include the comparison of the properties of CTMP prepared in sunds defibrator and explosion pulp.

EXPERIMENTAL CONDITION

The wood chips were classified mechanically to separate the undesirable size and also then separate manually the chips containing bark. The wood chips (50% siccity) weighing 75g on oven dry basis were brought in contact with impregnation solution in a plastic bag. The liquor/chips ratio used in impregnation was 3/1, 4/1 and 6/1. The impregnation was performed in a temperature controlled water bath at 60°C for 24 hours. This is the optimum conditions of impregnation in laboratory. The liquor/chips ratio below 3:1 is not adequate for well impregnation of chips. However, in semi-industrial trial or industrial practice where compression impregnation is generally used, the liquor/chips ratio 2:1 or 3:1 can be used for well impregnation.

The wood chips separated from the excess impregnated liquor were submitted to a presteaming stage in vapor in the temperature range 100-120°C for 1 minute before steam cooking for 4 minutes in saturated steam at 190°C corresponds to a pressure of 12 atmospheres. The wood chips were then exploded as a consequence of sudden drop of pressures from 12 to 1 atmosphere. The explosion creates partial defibration of wood chips resulting the reduction of energy consumption during refining.

The exploded wood chips were then refined for 1 minute in a domestic blender., OSTERIZER B 8614 at 2% consistency level and then washed in centrifugor to remove excess chemicals and to have uniform siccity. The washed and partially refined fiber was then further refined at 2% consistancy to the desired CSF value. The refining energy consumption was measured by means of a EW 604 wattmeter. Defibration and refining energy was calculated by subtracting the blending energy of fully beaten pulp from the total energy needed to blend the fiber suspension. The pulp properties have been evaluated following the CPPA standard methods.

Preparation of CTMP: Aspen chips soaked in water were pretreared with steam at atmospheric pressure for about 10 minutes. Then the chips were compressed (2:1) before releasing to impregnation solution A) 8% Na_2SO_3 and 1% NaOH or B) 5% Na_2SO_3 and 5% NaOH. The liquor/ chips ratio was 3:1. This is the optimum impregnation condition for CTMP. The impregnated chips were then cooked in sunds reactor at 128°C for 10 minutes. The cooked chips were refined in sunds defibrator.

Yield was measured as follows: exploded chips (75g O.D basis) were washed with 1 liter of tap water and subsequently defibrated for 90 seconds in a laboratory blender at a 2% consistency level. The resulting pulp was washed once again with 1 liter of water, dried at 105°C to constant weight and compared to the initial O.D. weight of chips.

RESULTS AND DISCUSSION

The influence of operating conditions on the resulting paper properties of steam explosion aspen pulp has been shown earlier (19,21). The cooking time and temperature were optimized previously in order to achieve maximum chip softening without causing serious hydrolytic and oxidative degradations responsible for brightness and yield loss. Considering the resulting pulp properties, brightness and yield, the optimum steam cooking conditions was set at 190°C for 4 minutes (19,21). A good pretreatment of wood chips with pulping chemicals is an essential part of the whole explosion pulping process. The laboratory pretreatment conditions were also optimized previously (19,21). Pretreatment softened the chips by diffusing the chemicals in deep inside the porous structure. During steam cooking, the uniform distribution of chemicals in the chips helps to create ionic groups on the fiber surface and inter fiber bonding more uniformly, as well as softens the fiber leading to decrease in refining energy and increase in physical properties (13,14,18).

Tables 1 and 2 represent the properties of aspen explosion pulp obtained from the chips impregnated respectively with chemicals 8% Na_2SO_3 + 0% NaOH

TABLE - 1

Experimental conditions and properties of explosion

Chemicals			
Na_2SO_3 (%)	8	8	8
NaOH (%)	0	0	0
Liquor/chips	3	4	6
Impregnation			
Time , hours	24	24	24
Temperatures, °C	60	60	60
Cooking Time, min	4	4	4
Cooking Temperatures°C,	190	190	190
Total SO2			
Initial (%)	4.1	4.1	4.1
After impregnation (%)	2.6	3.1	3.4
Yield (%)	88.8	88	86.8
Sulfonation , m mol/kg	52.08	56.89	61.5
Carboxylation , m mol/kg	118.8	121.97	126.65
CSF , ml	100	100	100
Brightness (%)	60.4	58.8	58.6
Opacity (%)	89.5	88.5	85.4
Bulk , cm3 /g	2.05	1.87	1.8
Porosity (%)	100	40	40
Burst index, kPa. m^2/g	2.6	3.15	4.05
Tear index, mN. m^2/g	5.95	6.35	6.35
Breaking length , km	5.6	6.8	8.05
Stress (%)	1.8	2.1	2.2
Bauer McNett Classification			
R 14 (%)	0.1	0.15	0.6
R 28 (%)	6.6	9.5	13
R 48 (%)	52.1	51.5	52.5
R 100 (%)	16.2	15.3	14
R 200 (%)	9.2	7.75	6.25
P 200 (%)	16.2	15.5	13.5

1. Experimental conditions and properties of explosion pulp obtained from aspen chips pretreated with Na_2SO_3 + 0% NaOH.

TABLE—2

Experimental conditions and properties of explosion pulp.

Chemicals			
Na_2SO_3 (%)	8	8	8
NaOH (%)	1	1	1
Liquor/chips ratio	3	4	6
Impregnation			
Time , hours	24	24	24
Temperatures	60	60	60
Cooking time, min.	4	4	4
Cooking temperature, °C	190	190	190
Total SO_2			
Initial (%)	4	4	4
After impregnation (%)	2.6	3.1	3.6
Yield (%)	85.8	85.3	84 2
Sulfonation, m.mole/kg	61.2	70.62	61.59
carboxylation, m.mole/kg	122.91	131.32	121.76
CSF, ml	100	100	100
Brightness (%)	51.5	48.5	42
Opacity (%)	87.5	83	84.5
Bulk, cm^3/g	1.8	1.6	1.6
Porosity (%)	25	4	10
Burst index, $kPa.m^2/g$	4.05	4.75	5.05
Tear index, $mN.m^2/g$	6.25	6.05	6 35
Breaking length, km	8.15	9.2	8.75
Stress (%)	2.2	2.55	2.65
Bauer McNett Classifications			
R 14 (%)	1.5	1.5	0.5
R 28 (%)	16.5	16	10
R 48 (%)	48.5	52	57.7
R 100 (%)	14.5	14	14 5
R 200 (%)	6.6	4.5	3.9
P 200 (%)	11.6	11.5	13.6

2. Experimental conditions and properties of explosion pulp obtained from aspen chips pretreated with 8% Na_2SO_3 + 1% NaOH.

and 8% Na_2SO_3 +1% NaOH. In these explosion pulping process, the cooking conditions are kept constant and in the pretreatment step, only the liquor/chips ratio was varied from 3 to 6 keeping impregnation time and temperature constant. As seen in Tables 1 and 2, the pulp yield decreased with the increase of chemical charge in the form of liquor/chips ratio. The higher liquor/chips ratio facilitates the uniformity of impregnation through diffusion process.

Breaking lengths versus CSF are plotted in Figures 1 and 2 respectively for the impregnation solution containing 8% Na_2SO_3 + 0% NaOH and 8% Na_2SO_3 +1% NaOH. Breaking length of the explosion pulp increased at all CSF level with the increase of liquor/chips ratio from 3 to 6 when the impregnation solution contains 8% Na_2SO_3 + 0% NaOH (Figure 1). But when the impregnation solution contains 8% Na_2SO_3 +1% NaOH, breaking length of the resulting explosion pulp increased at all CSF level with the increase of liquor/chips ratio from 3 to 4. Breaking length of the explosion pulp corresponding to liquor/chips ratio of 6 increased up to the CSF level 300 and then decreased with further decrease of CSF (Figure 2).

In Figure 3, tear index is plotted as a function of CSF. Tear index of the explosion pulp increases with the increase of liquor/chips ratio from 3 to 4 and drops with further rise of liquor/chips to 6, when the impregnation solution contains only 8% Na_2SO_3. This indicates the adverse effect of higher chemical charge in pulping. When the impregnation solution contains 8% Na_2SO_3 + 1% NaOH, the tear values of pulp having CSF 400 and above rise with the increase of liquor/chips ratio from 3 to 4 but drop with further increase of liquor/chips ratio to 6. At lower CSF level, the variation of liquor/chips ratio has little effect on pulp tear values. The large variation in tear values of pulp obtained with various chemical charge is minimized through refining of pulp to low CSF value.

Tear index of explosion pulp is plotted in Figure 4 as a function of breaking length. When the impregnation solutions contain only 8% Na_2SO_3, the pulps of breaking length 6 km and higher obtained by using liquor/chips ratio of 6, also showed higher tear values in comparison to that obtained by using lower liquor/chips ratio such as 3 and 4 But at lower breaking length the pulp corresponding to liquor/chips 6 showed lower tear values than that corresponds to liquor/chips ratio 4. However, the effect of liquor/chips ratio is different when the impregnation solution contains NaOH in addition to Na_2SO_3. The tear index decreases with the increase of breaking length for all the pulps obtained with various liquor/chips ratio Explosion pulps obtained from chips impregnated with 8% Na_2SO_3 and 1% NaOH gives higher breaking length but similar tear index when compared with the pulps obtained from the chips impregnated with 8% Na_2SO_3 at the liquor/chips ratio of 4 and 6. Figures 1 to 4 indicate that high chemical charge i e. Liquor/chips ratio 6 show positive effect on breaking length but negative effect on tear values of the pulp when the impregnation solution contains only 8% Na_2SO_3. Both breaking length and tear values of the pulp obtained corresponding to liquor/chips ratio 6 are adversely effected by the presence of NaOH in liquor along with Na_2SO_3. The reason of this unusual behavior is explained as follows: in presence of high concentration ef chemicals during high temperature cooking, the chips become soft and the fiber surface is affected through hydrolytic and oxidative reaction. The explosive pres ure release and the mechanical impact the chips received against the wall of the reservoir caused some fiber damage and resulted in lower paper strength. A similar situation was found in the case of softwood kraft pulping where a sudden pressure release resulted in weaker paper (22). We have observed in another studies (23) that the steam explosion pulping under the same conditions, but without explosive pressure release, showed property improvement with an increase in liquor/chips ratio.

In Figure 5, fiber length as factor "L" [(R14 + R28 + R48)] is plotted as a function of breaking length. Both the long fiber fraction of the pulp and breaking length increase systematically with the increase of liquor/chips ratio during impregnation. The higher breaking length of the pulp corresponding to Na_2SO_3 + NaOH impregnation results from better defibration and surface bonding property of the pulp developed through refining Pulps obtained from the chips impregnated with solution containing 8% Na_2SO_3 and 1% NaOH conserve the long fiber fraction and show higher breaking length in comparison to the pulp obtained from

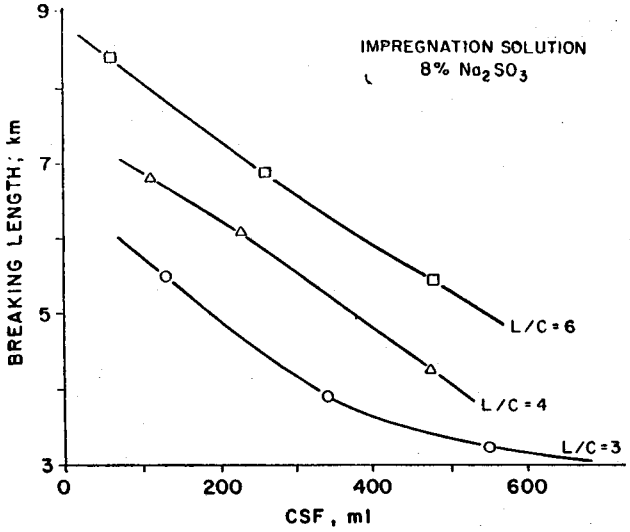


Figure 1. Variation of breaking length as a function of CSF of the pulp obtained from aspen chips impregnated with 8% Na_2SO_3 at various liquor/chips ratio.

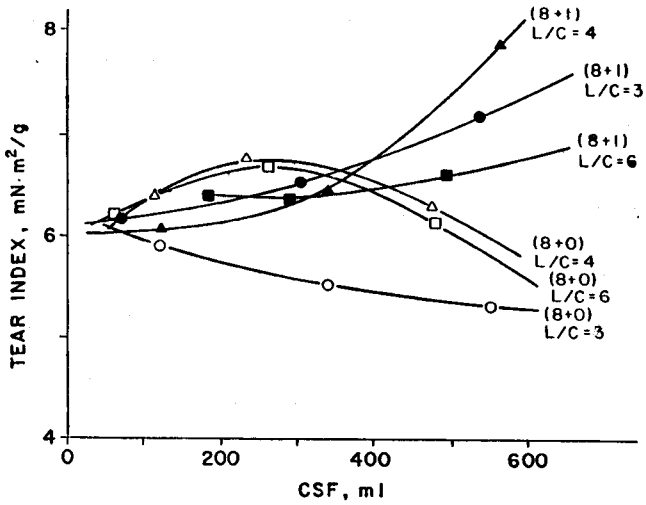


Figure 3. Variation of tear index as a function of CSF of the pulp obtained from aspen chips impregnated with chemicals (8+0) or (8+1) at various liquor/chips ratio.

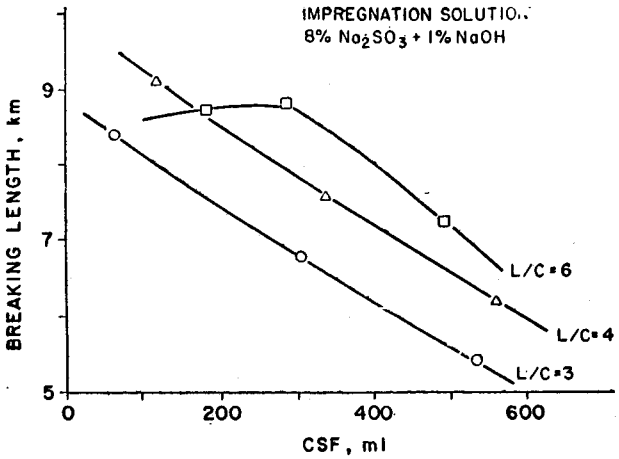


Figure 2. Variation of breaking length as a function of CSF of the pulp obtained from aspen chips impregnated with 8% Na_2SO_3 + 1% NaOH at various liquor/chips ratio.

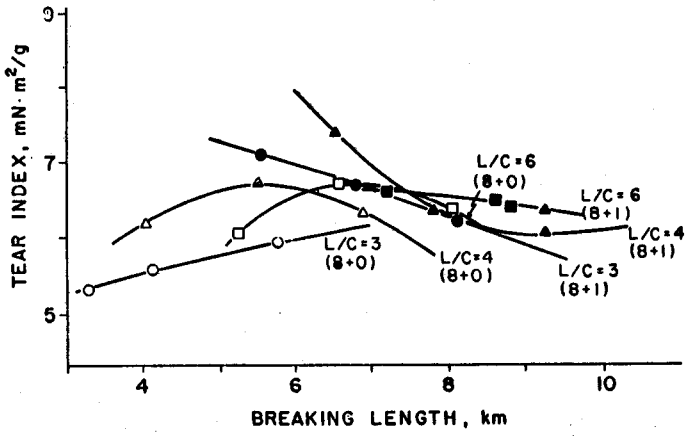


Figure 4. Variation of tear index as a function of breaking length of the explosion pulp obtained from aspen chips impregnated with chemicals (8+0) or (8+1) at various liquor/chips ratio.

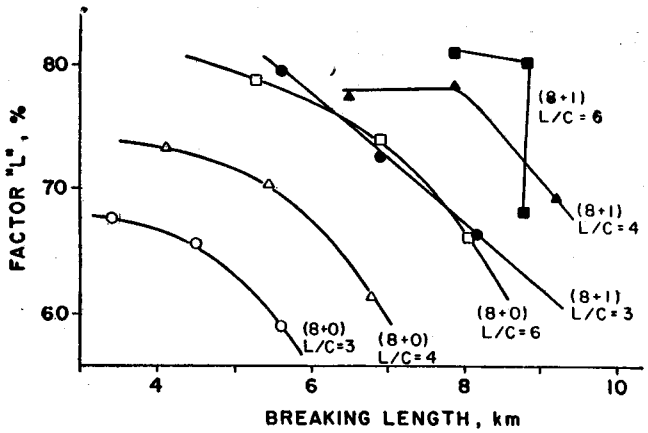


Figure 5. Effect of long fiber fraction (Factor "L") of the pulp obtained from aspen chips, impregnated with chemicals (8+0) or (8+1) at various liquor/chips ratio on the resulting paper breaking length.

the chips impregnated with Na_2SO_3 only. The presence of NaOH in impregnation solution is credited for much of the improvement in pulp breaking length. As a negative effect of NaOH in impregnation, the diminution of pulp yield by 3 to 4% and brightness by 10 to 16% is observed.

Breaking length and tear index of explosion pulp are plotted in Figure 6 as a function of liquor/chips ratio. The effects of the variation of liquor/chips ratio on tear values is not very significant. The breaking length increases linearly from 5.6 to 8 km corresponding to a variation of tear index from 6 to 6.5 mN.m²/g with the increase of liquor/chips ratio from 3 to 6 when the impregnation solution is 8% Na_2SO_3. For the pulp obtained from the chips impregnated with 8% Na_2SO_3 and 1% NaOH, breaking length increases sharply from 8.15 to 9.2 km with an increase of liquor/chips ratio from 3 to 4 and afterwards breaking length decreases to 8 75 km with further increase of liquor/chips ratio to 6, while the tear values vary between 6 and 6.5 mN.m²/g.

Figure 7 shows the variation of ionic content and breaking length of the pulp with the variation of liquor/chips ratio. The total ionic content of the pulp increases from 170 to 188 m mol/kg with the increase of liquor/chips ratio from 3 to 6 when the impregnation solution contains only 8% Na_2SO_3. The breaking length of the pulp shows proportionate increase with total ionic content at different liquor/chips ratio. When the impregnation solution consists of 8% Na_2SO_3 and 1% NaOH, the total ionic content increases from 184 to 201 m mol/kg corresponding to the increase of liquor/chips ratio from 3 to 4, and then the total ionic content decreases to 183 with further increase of liquor/chips ratio to 6. As before, the breaking length of the pulp follows the trend of total ionic content variation of the pulp. The liquor/chips ratio at 6 shows no beneficial effect in term of total ionic content as well as of breaking length. This is probably due to the presence of large amount of NaOH that caused severe hydrolytic and oxidative reactions during impregnation and cooking resulting the diminuation of ionic content and so the breaking length. Explosive pressure release of cooked chips is also partially responsible for the diminution of paper properties.

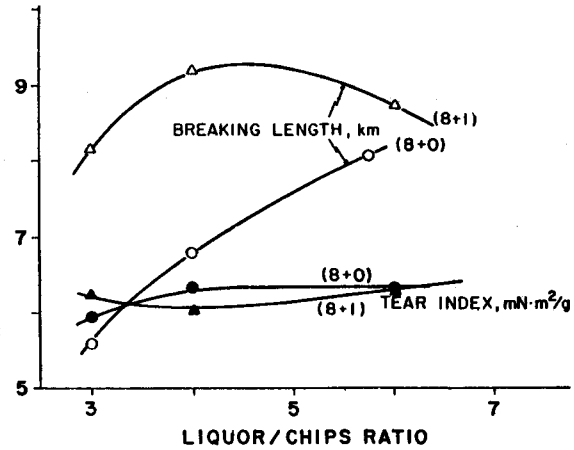


Figure 6. Effect of liquor/chips ratio applied during impregnation of chips with chemicals (8+0) or (8+1) on the resulting paper breaking length and tear index.

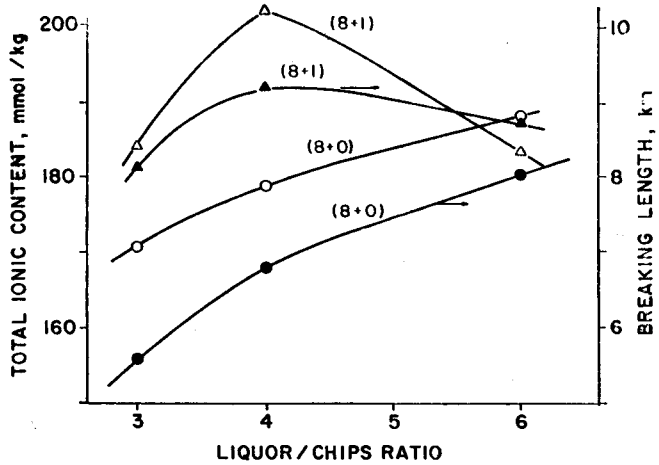


Figure 7. Effect of liquor/chips ratio applied during impregnation of chips with chemicals (8+0) or (8+1) on the total ionic content and breaking length of the resulting explosion pulp.

Brightness shows little or no change with an increase of liquor/chips ratio when the impregnation solution contains only 8% Na_2SO_3 (Table 1). Brightness of the pulp shows rapid decrease from 51 5 to 42% with an increase of liquor/chips ratio from 3 to 6 when the impregnation solution contains 1% NaOH in addition to 8% Na_2SO_3 (Table 2) Normally, NaOH affects the brightness of the pulp through hydrolytic and oxidative degradation during impregnation and cooking of the wood chips. With the increase of liquor/chips ratio, more and more NaOH is responsible for degradation reaction resulting lower and lower brightness. The opacity of the pulp decreases slowly with the increase of liquor/chips ratio.

In Figure 8, Percentage of long fiber fraction (R14+R28+R48), medium fiber fraction (R100) and short fiber fraction (R200+P200) are plotted as a function of liquor/chips ratio When the impregnation solution contains only 8% Na_2SO_3, the long fiber fractions increase linearly, medium fiber fractions decrease slightly and the short fiber fractions decrease linearly with the increase of liquor/chips ratio. This indicates the effect of softening of chips in presence of more chemical charge resulting better defibration during refining without damaging the fiber. The case is different when the impregnation solution contains NaOH in addition to Na_2SO_3. The long fiber fraction increases and short fiber fraction decreases with the increase of liquor chips ratio from 3 to 4, and at liquor/chips ratio 6, the long fiber fraction decreases and short fiber fraction increases, whereas the medium fiber fraction remains nearly constant in all liquor/chips ratio, more NaOH charge damages partially the fiber through hydrolytic and oxidative reaction. The fiber is further damaged due to explosive discharge of cooked chips All these effects are believed to be responsible for the diminuation of long fiber fraction.

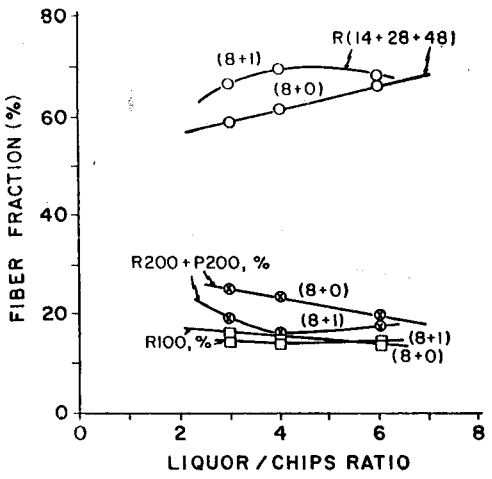
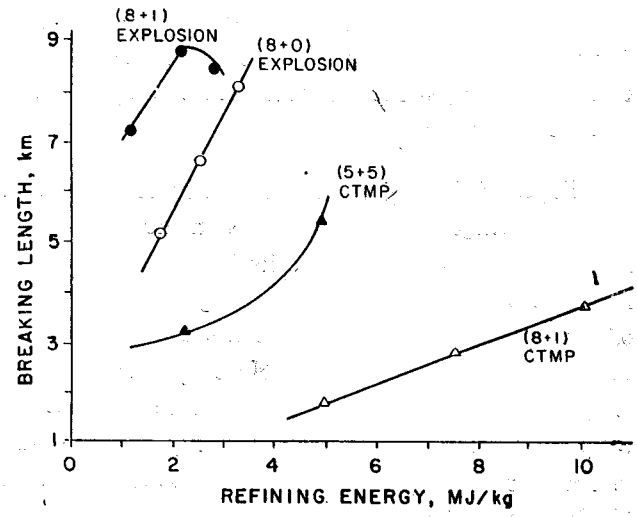


Figure 8. Effect of liquor/chips ratio applied during impregnation of chips with chemicals (8+0) or (8+1) on the different fiber fraction of the resulting explosion pulp.

Figure 9. Variation of breaking length as a function of refining energy for explosion pulp and CTMP.

Table 3 shows the comparison of the properties of aspen CTMP prepared and refined in sunds defibrator, and explosion pulp prepared in Stake tech. reactor and refined in laboratory blender. We have used the best existing conditions such as compression impregnation, liquor/chips ratio 3, cooking temperature 128°C and time 10 min for the preparation of CTMP in sunds reactor. In explosion pulping process, the impregnation of wood chips with solution containing hydrophilic (Na_2SO_3) and swelling (NaOH) agent weakens the internal bond and makes the whole fiberous structure less strong and thus facilitates the separation of fibers. High temperature steam cooking further accelerates the former effects of impregnation in addition to the chemical modification of the fiber responsible for superior paper properties. The explosive discharge of the cooked chips causes partial defibration and internal defibrillation leading to softened and flexible fibers which in turn would demand lower amount of energy for subsequent refining for the development of superior paper properties. Figure 9, where breaking length is plotted as a function of refining energy, clearly demonstrates the superiority of the explosion pulp over the conventiontional CTMP. The explosion pulp requires less refining energy to develop superior physical properties in comparison to CTMP.



In Figrue 10, tear index of the explosion pulp and CTMP is plotted as a function of breaking length. The explosion pulps posses the superior breaking length in comparison to that of the CTMP. CTMP obtained from the chips impregnated with solution (8+1) as done in case of explosion pulp, shows inferior tear index in comparison to that of explosion pulp. However, CTMP prepared from the chips impregnated with chemicals (5+5) shows similar tear values as explosion pulp.

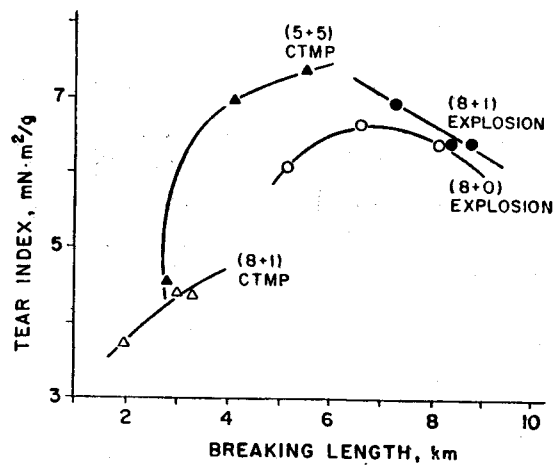


Figure 10 Variation of tear index as a function of breaking length for explosion pulp and CTMP

TABLE-3

Comparison of the propertions of aspen CTMP and explosion pulp.

Chemicals				
Na_2SO_3 (%)	8	5	8	8
NaOH (%)	1	5	0	1
Liquor/chips ratio	3	3	6	6
Presteaming time, min.	20	20	1	1
Impregnation time. hrs.	–	–	24	24
Impregnation temp °C	–	–	60	60
Cooking time, min.	10	10	4	4
Cooking temperatures	128	128	190	190
CSF, ml	100	100	100	100
Specific refining energy, MJ/kg	10.1	4.95	3.3	2.85
Bulk, cm3/g	2.4	1.85	1.8	1.6
Brightness (%)	62	53	58.5	42
Burst index, kPa m²/g	1.6	2.95	4.05	5.05
Tear index, mN m²/g	4.15	7.3	6.35	6.35
Breaking length, km	3.75	5.4	8.05	8.75
Stress (%)	1 6	2.15	2 2	2.65
Bauer McNett Classifications—				
R 14 (%)	0.1	0.2	0 6	0.5
R 28 (%)	3.25	4.6	13	10
R 48 (%)	39	42	52.5	57.7
R 100 (%)	32	23.5	14	14.5
R 200 (%)	11.55	10.85	6.25	3.9
P 200 (%)	14.1	18.15	13.5	13.6

3. Comparison of the properties of asren CTMP and explosion pulp.

CONCLUSIONS

The effects of chemical charge in the form of liquor/chips ratio during impregnation have been correlated to the resulting pulp and paper properties at different CSF levels. Physical properties of aspen explosion pulp increase with the increase of liquor/chips ratio from 3 to 6 when the impregnation solution contains only 8% Na_2SO_3, When the impregnation solution contains 1% NaOH in addition to 8% Na_2SO_3, the liquor/chips ratio above 4 has less beneficial effect in comparison to the reduction in yield and brightness. The breaking length of the explosion pulp is directly proportional to the ionic content of the pulp. The proportion of the long fiber fraction, partly responsible for superior physical properties of the explosion pulp, increases with the increase of liquor/chips ratio from 3 to 6, when the impregnation solution contains 8% Na_2SO_3. Impreganation solution containing 1% NaOH in addition to Na_2SO_3 causes reduction in the proportion of long fiber fraction at liquor/chips ratio higher than 4. The explosion pulps posses superior physical properties but inferior optical properties in comparison to those of CTMP. However, the refining energy of the explosion pulp is much lower than that of CTMP.

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