Black spruce pulping : A comparison of explosion and conventional chemi-mechanical pulping processes

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ABSTRACT

Explosion pulping of sodium-sulfite treated Black Spruce produces fibers which are easier to refine and superior in strength compared with chips discharged at atmospheric or low pressure. This process results in pulps of higher strength and lower specific refining energy as opposed to conventional CMP and "CTMP" processes. Explosion pulp of the same yield and freeness level as that of conventional CMP can require up to 60% less refining energy while its tear can be up to 20% superior for similar breaking length. The usual trade-off of strength for brightness is also observed for Explosion Black Spruce pulp.

KEYWORDS

Steam Explosion Pulping, Black Spruce, CMP/CTMP, Explosive, Atmospheric, Discharge.

INTRODUCTION:—

Recently, a pulping process entitled "Process for Preparing Pulp for Paper Making" (1,2,3) referred to as "Steam Explosion High Yield Pulping process" or "S-Pulping" has been proposed both for softwoods and hardwoods.

The steam explosion pulping process consists of the chemical impregnation of chips, short duration saturated steam cooking at *temperatures varying from 180°C to 210°C*, pressure release, refining and bleaching.

It has been shown (4) that paper properties of explosion pulp from a softwood mixture of spruce, fir and aspen compare to those of conventional CMP or CTMP properties. However, they are obtained with considerably less refining energy. In the case of hardwood the explosion pulping process produces pulps with remarkable strength accompained by appreciably less refining energy than the conventional CMP and CTMP processes (4,5). Results of semi-industrial trials have shown that Explosion Aspen pulps can require 50% or less refining energy while their strength can be increased by as much as 90% compared to conventional CMP/CTMP processes(5) Brightness of Explosion Aspen pulp was better than that of conventional CMP/CTMP pulps, and their bleachability as well as brightness stability were excellent (4,6,7). Compared at similar CSF levels (250), Explosion Aspen pulps bleached at a 85% brightness level provide stronger paper properties than commercial low—yield bleached hardwood pulps (7).

Law et al. (8) recently claimed in their work on *Black Spruce* that :

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— explosion pulping produces pulps with mechanical properties similar to those of conventional CMP pulps;

— fibers exploded below 200 °C are more difficult to refine and are inferior in strength and optical characteristics compared with fibers (chips) discharged at atmospheric or low pressure; and

— the sudden decompression may be advantageous only if high steaming pressure and long reaction time are used, but this inevitably leads to lower pulp yield and brightness.

The objective of the present paper is:

(i) to examine explosion pulping of Black Spruce using optimum process conditions (4,7) in comparison with conventional CMP/CTMP processes; ii) to compare paper properties and specific refining energy for high temperature steam cooked chips discharged suddenly (explosively) along with a slow pressure release.

EXPERIMENTAL .

Newly-grown Black Spruce trees (Picea mariana) were debarked, chipped and screened at La Station Forestiere Duchesnay, Quebec. Average chip size, after screening, was as follows : length 2.5 to 3.75 cm; width : 1 to 2 cm; thickness : 1 to 9 mm, with an average thickness of 5 mm. Chips, used in the present study were 8 weeks old.

Impregnation

150 g of chips (50% moisture content) were mixed in plastic bags with 150 g of a 16% solution of Na_2SO_3 providing a concentration of sodium sulfite in solution equal to 106 g/l. Liquor to chip ratio was 3. The total amount of Na_2SO_3 present in the solution was 31.8%, based on the O.D. weight of wood. Soak impregnation at atmospheric pressure of 60° C lasted 24 hours.

Cooking

All the cooking was carried out in vapour phase using a laboratory batch reactor (volume of 300 ml), built by Stake Technology Company. Previously impregnated and drained chips were cooked as follows:
"CTMP" mode : 128° C for 10 minutes
CMP mode : 150° C for 30 minutes;
EXPLOSION mode : 190° C for 4 minutes.

Steam flushing at atmospheric pressure for one minute preceeded the cooking. Afterwards, pressure was instantaneously released, and chips, which exploded into the release vessel, were washed and cooled down with one liter of tap water.

In the case of Explosion pulping with slow pressure release, once the chips were cooked at 190° C for 4 minutes, the pressure was gradually released at 2 minute interval and the chips were mechanically discharged. *Cooking yield* was measured as follows : Exploded chips (75 g O.D.) were washed with 1 l. of tap water, and subsequently defibrated for 3 minutes in a laboratory domestic blender Osterizer B- 8614 at a con istency level of 2%. The weight (O.D) of thoroughly washed and dried pulps was related to initial chip weight.

Total refining and blending energy were measured using a HIOKI model 3181-01 powermeter with an integrator while *specific refining energy* was calculated by subs racting the *blending* energy of waterbeated fiber suspension from the *total refining and blending energy* (4)

SPECIFIC REFINING ENERGY = TOTAL REFINING AND BLENDING ENERGY — BLENDING ENERGY OF BEATED PULP SUSPENSION

Property evaluation

Paper sheets were prepared and tested according to standard CPPA teste methods on 1.2 g sheets.

All measurements were made at 23° C and at a 50% level of relative humidity. Optical properties were measured with the Zeiss Elrepho photometer. Brightness was evaluated on 3 g sheets prepared with distilled water. Ion content (sulphonate and carboxylate ions) was determined by means of conductometric titration (9).

RESULTS AND DISCUSSION

Steam Explosion Pulping is a generic name used to describe short duration, high temperature (180°-210°C) saturated steam cooking. In order to

obtain fibers suitable for pulping, the time-temperature of steam cooking at high pressure levels must be sufficiently long to lead to the softening and partial defibration of the chips without producing excessive yield loss due to a hydrolytic reaction. Furthermore, the presence of hydrophylic and antioxydant agents such as Na_2SO_3 leads to an improvement in the resulting paper properties by the formation of hydrophylic surface groups while brightness is preserved (or brightness loss is limited) (7).

In general, optimum paper properties and yield above or equal to 90% were obtained in a laboratory when K constant, defined as a multiple of temperature in °C and time in minutes, reached 760 (7).

Therefore, most of our published work was done at 190° C with 4 minutes of cooking time. Cooking conditions characterized with K above 1000 led to paper property improvement at the expense of sharp yield and brightness loss. We thus chose, for explosion purposes, a cooking time of 4 minutes and a temperature level of 190° C.

Explosion versus slow pressure release

We previously postulated (4, 7) that the advantage of the Explosion Pulping process is due to high temperature-pressure steam cooking leading to chip softening and to the use of a lower amount of specific energy during refining (4, 5, 7). At identical CSF levels, explosion pulps refined with a lower amount of energy also have higher contents of long fiber fractions and provide superior paper properties when compared to conventional CMP/"CTMP" processes.

There may be some beneficial effect on resulting Explosion pulp properties due to explosion pressure release. It was reported that in the case of aspen at low K constant (270), adhesion properties such as breaking length are about 25% higher for sudden pressure release compared to a slow atmospheric discharge. Similar behavior was also observed in the case of softwood mixtures of 75% of Black Spruce, 20% Balsam Fir and 5% hardwoods (3).

In Table 1, experimental conditions used in the present study compared with those of Law et al. (8).

TABLE–1
EXPLOSION PULPING OF BLACK SPRUCE

	LAW (8) VACUUM SOAK IMPREGNATION		PRESENT WORK ATMOSPHERIC SOAK IMPREGNATION	
IMPREGNATION				
CONCENTRATION OF Na_2SO_3 (%)	10	*10	10.6	*10.6
LIQUOR/CHIP RATIO	6	6	3	3
(%) Na_2SO_3 IN SOLUTION ON O.D. WOOD (%)	60	60	31.8	31.8
TIME (hours)	12	12	24	24
TEMPERATURE (°C)	25	25	60	60
STEAM COOKING				
TEMPERATURE (°C)	190	190	190	190
TIME (min)	3	3	4	4
SULFONATE CONTENT (mmol/kg)	—	—	162	159
CARBOXYLATE CONTENT (mmol/kg)	—	—	147	132
YIELD (%)	—	—	91.8	90.1
BRIGHTNESS (%)	49.3	53.9	51.8	54.5
OPACITY (%)	—	—	92.7	92.5
SPECIFIC REFINING				
ENERGY (MJ/kg)	—	—	5.3	7.7
CSF (ml)	—	—	100	100

* Slow pressure release.

The major difference lies in the impregnation conditions. In our work, we used *atmospheric* soak impregnation at 60° C for 24 hours because it *correlated* well with results obtained using *Bauer press impregnation* in *recent semi industrial Explosion pulping trials* (7).

Figure 1 contains paper properties of Explosion pulps with sudden and slow pressure releases. Law et al. (8) results, taken from his Figure 6, are plotted on the same scale.

The following conclusion can be drawn from Figure 1 :

...Explosion pressure release results in better paper properties (higher tear for the same breaking length) when compared to slow pressure release.

...Some conclusions can be drawn from Law et al. (8) results.

Law et al. (8) conclusions indicating that sudden explosion for temperatures less than 200°C leads to weaker paper properties are *incorrect* (based both onpresent results as well as Law (8) and Kokta (3) findings).

Furthermore, Blender refining was used in the present study because paper properties of Blender-refined Explosion pulps closely match properties of Explosion pulps refined on a 4500 kg/day Bauer refiner (4).

PFI refining, used in Law's work (8) leads to considerable fiber cutting and tear loss, as demonstrated by Shaw (10) and Kokta (4). Figure 1 indicates that using PFI for ultra-high-yield pulps *is incorrect* because resulting properties cannot be related to those obtained on semi-industrial or industrial scale refiners.

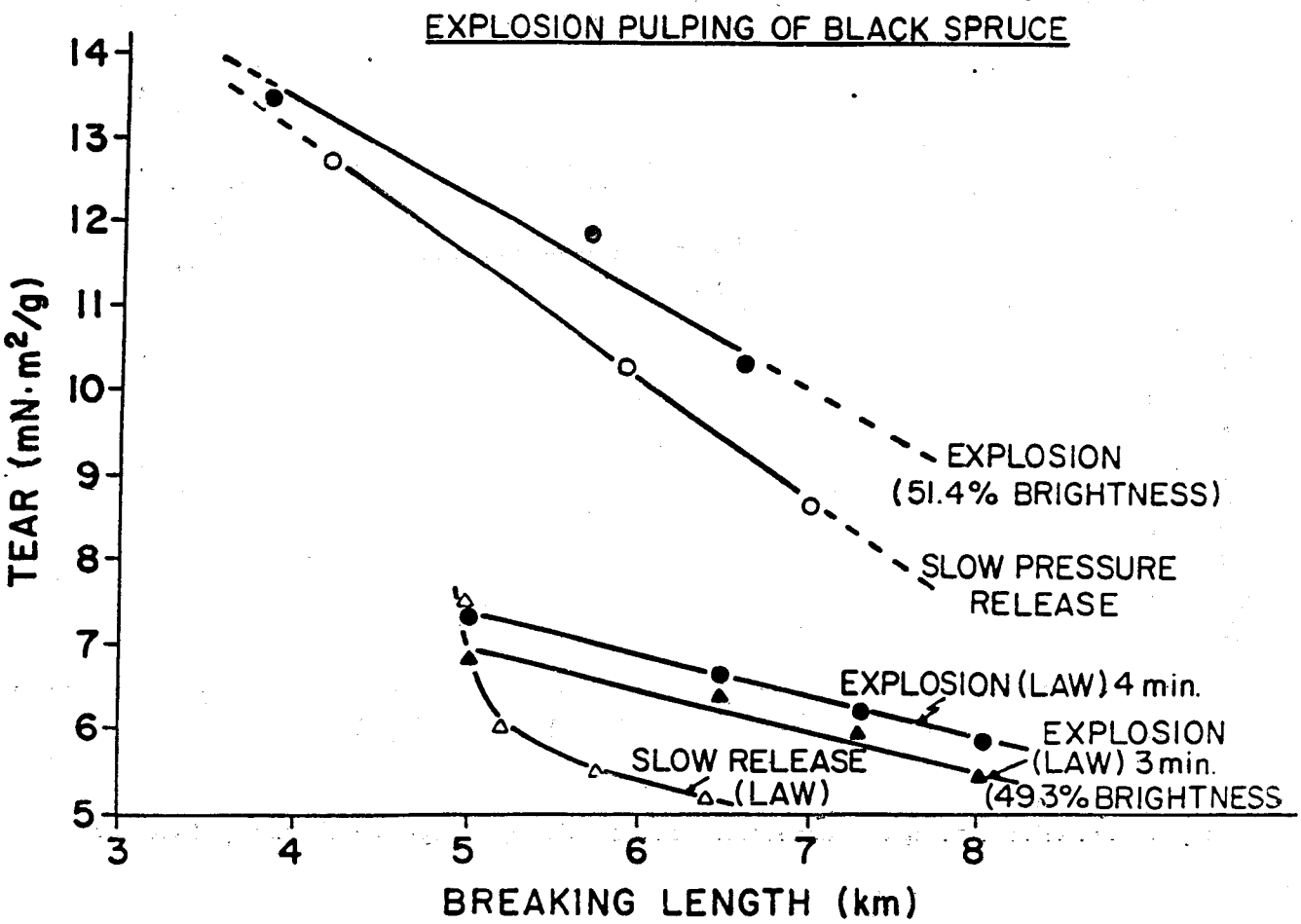

Fig. 1. Explosion pulping of black spruce. Tear Versus breaking length.

In Figure 2, *specific refining energies* for Explosion Black Spruce pulp are plotted as a function of CSF. Specific refining energies of pulps with explosive pressure release are compared to those under slow pressure release.

It is quite clear that sudden pressure release by explosion is beneficial because it results in a 40% to 50% energy decrease compared to a slow (atmospheric) pressure decrease.

Absolute values of specific refining energy obtained in the present work should be within 25% of those obtained using pilot plant Sund Defibrator or Bauer refiner as published by Kokta et al. (4).

We believe that the conclusion reached by Law et al. (8) concerning refining energy cannot be justified based on the results presented in their work for the following reasons :

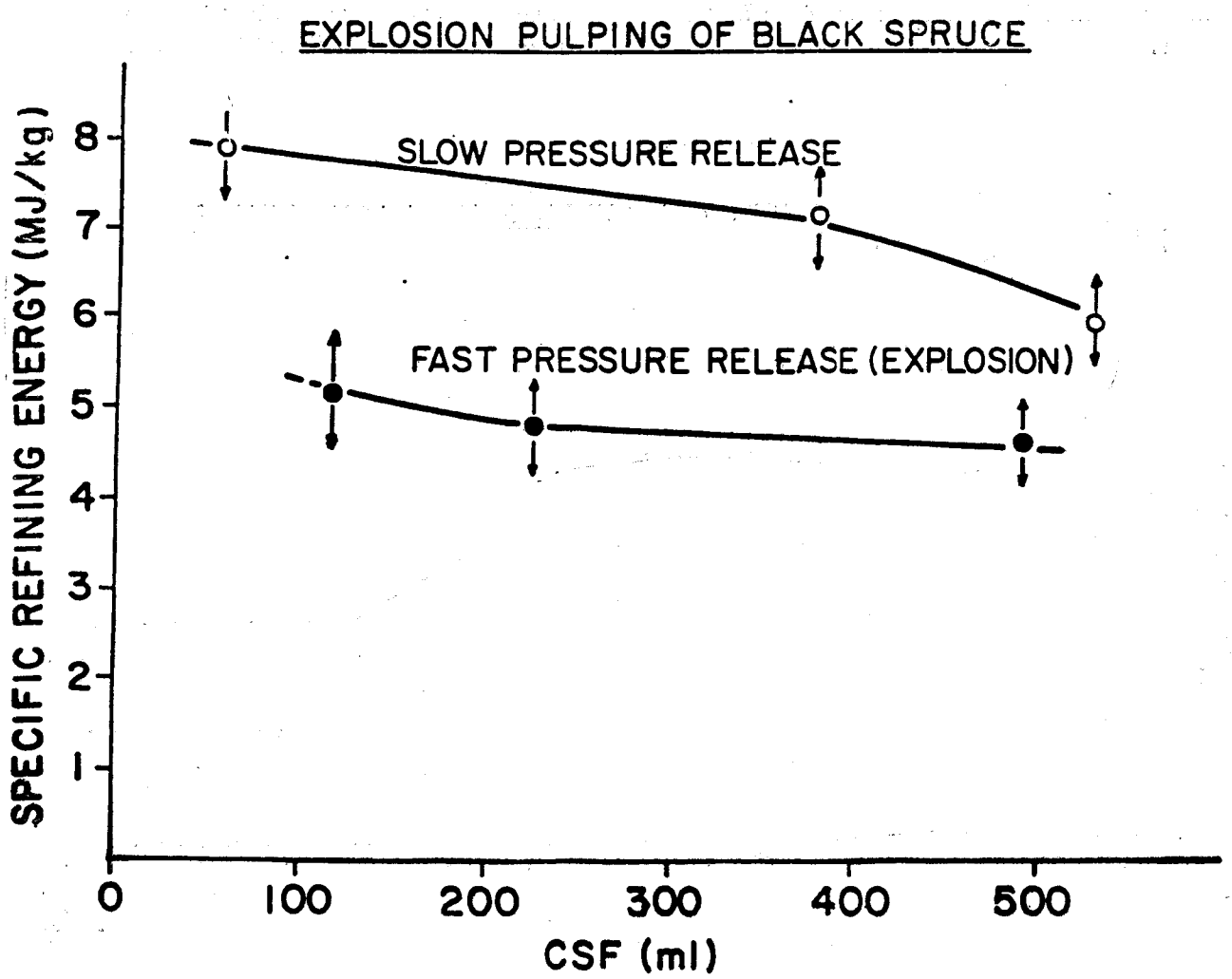

Fig. 2. Explosion pulping of black spruce. Specific refining energy versus drainage factor CSF.

i) Results presented in their work (Fig. 3) do not represent refining energy, but PFI *beating energy* of previously defibrated chips in a laboratory blender.

ii) The only PFI curves presented in the explosion pulping region (180°C—210°C) are those for 200°C and 190°C. In both cases, *PFI beating energy is less than* 200°C or *equal* (190°C) to that *suddenly exploded chips* when *compared to that of obtained with atmospheric discharge.*

iii) Figure 4 represents *beating* energy curves only because :

— refining is done with coarse pulp using previously defibrated cooked chips without considering defibration energy, and

— extremely high energy values (i.e. 20 MJ/kg at CSF 100) indicate that they represent a mixture of *refining and blending energy.* It has been shown (4) that substantial parts of refining energy, (not included in Law et al. work) is consumed in this first stage of defibration of chips on coarse pulp.

iv) Results in the literature indicate (see Table 2) that *there is absolutely no correlation* between beating energy and *industrial refining energy.*

v) Law et al. (8) do not come to any correlation between their beating energy and *industrial refining energy.*

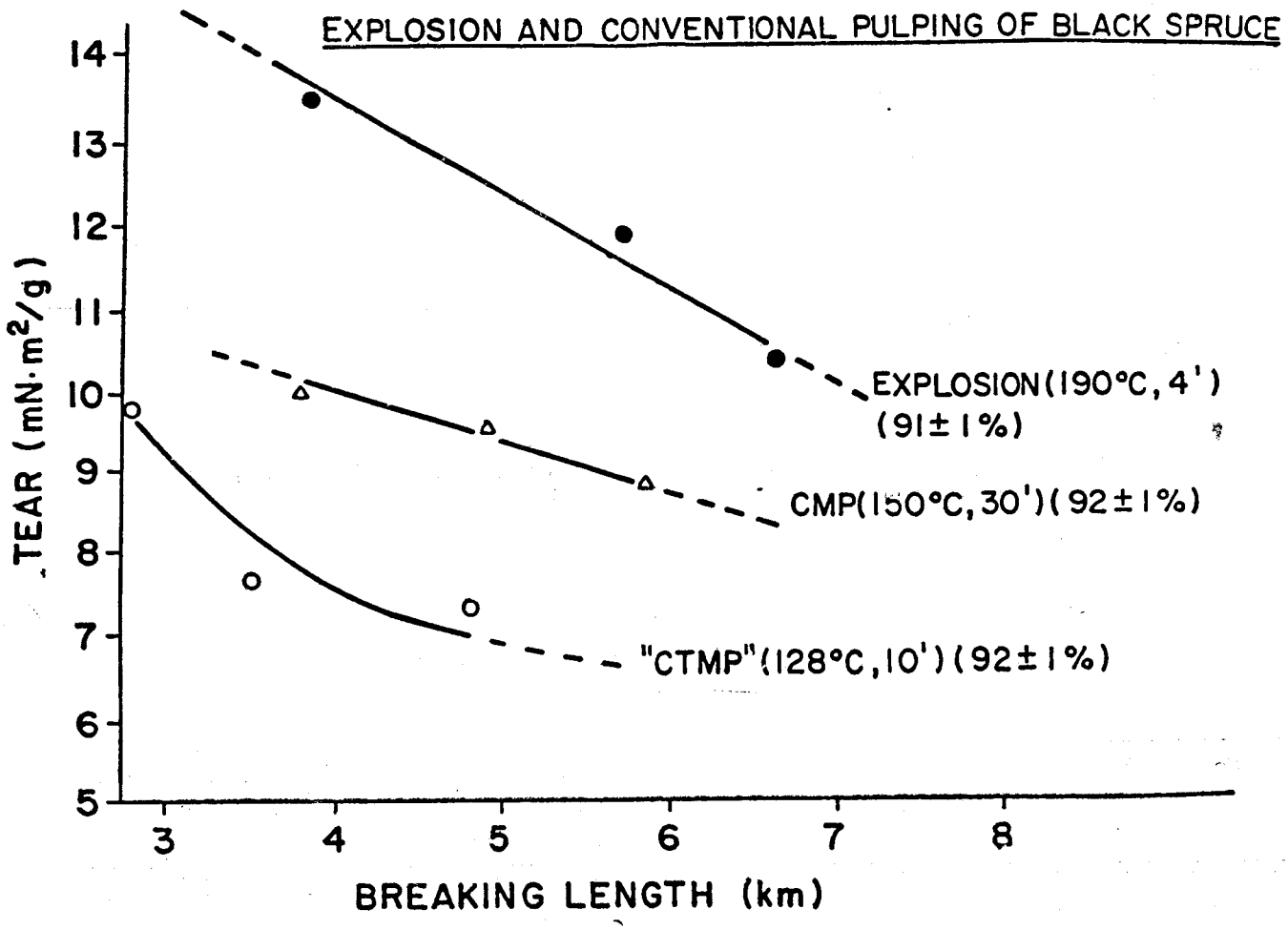

Fig. 3. Explosion and conventional pulping of black spruce. Tear versus breaking length : Explosion, CMP, "CTMP".

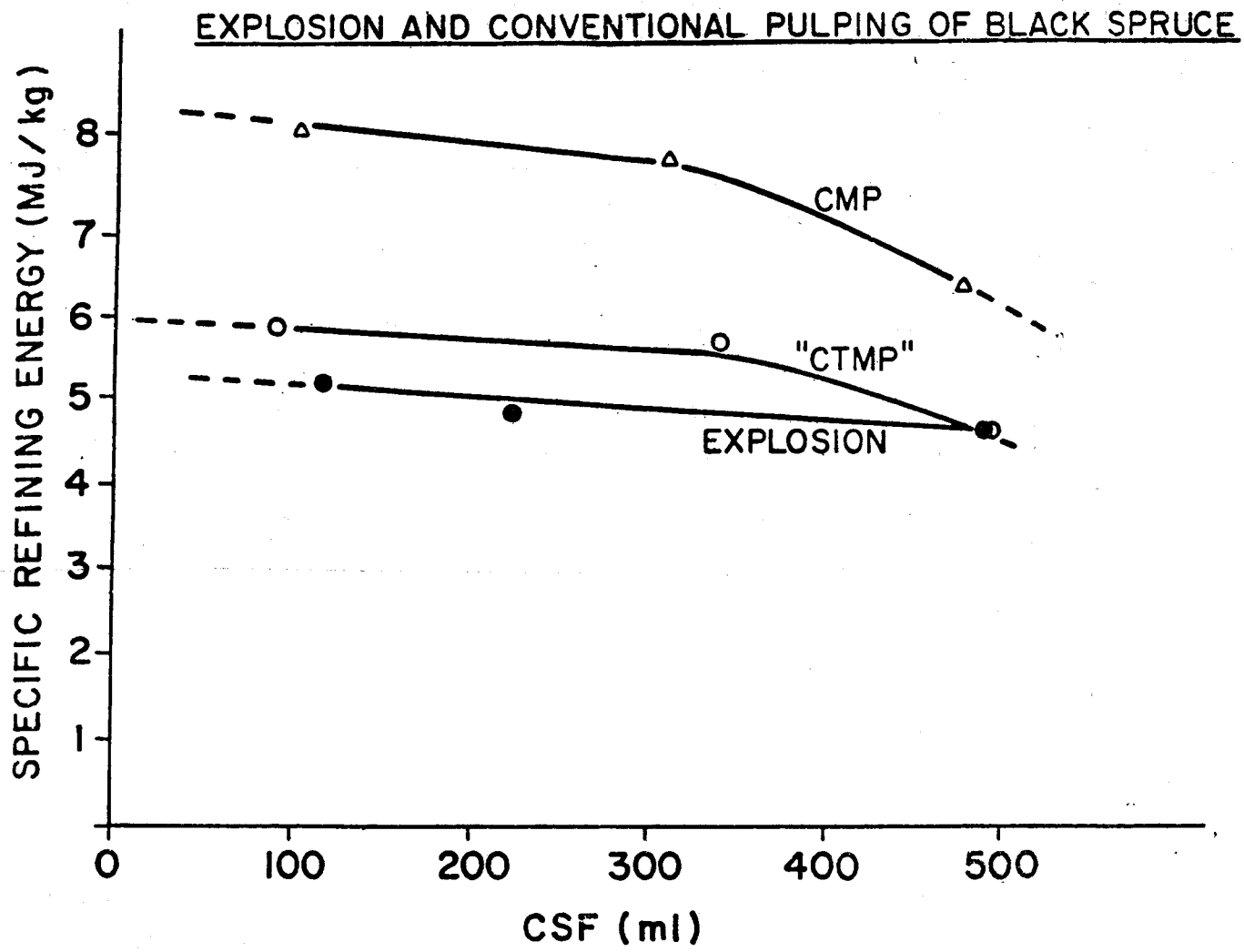

Fig. 4. Explosion and convention pulping of black spruce. Specific refining energy versus drainage : Explosion, CMP, "CTMP".

Table — 2

CORRELATION BETWEEN BEATING AND REFINING ENERGIES
(COMPARISON AT CSF500)

TYPE OF PULP	YIELD	BEATING ENERGY (12) IN PFI (REVOLUTIONS)	INDUSTRIAL REFINING (13) ENERGY (MJ/kg)
BISULFITE (HSO_3^-)	87.3	13 100	3.7 ± 0.5
SULFITE (SO_3^-)	89.0	6 400	$6 \pm 0\,5$
NEUTRAL SULFITE ($HSO_3^- + SO_3^{2-}$)	86.8	22 800	$6 \pm 0\,5$
KRAFT (NaOH, Na_2S)	55.1	16 100	0.6 ± 0.3

The conclusion reached by Law et al. (8) according to which fibers exploding below 200°C are more difficult to refine is incorrect because the authors do not present any acceptable proof to support their claim.

Brightness of Explosion pulp accompained by a sudden pressure release is less than that occurring with slow pressure release (see Table 1) which is in agreement with Law et al. (8). Presently, we do not have any supported explanation for brightness loss due to explosion pressure release.

Better paper properties of Explosion pulp with sudden pressure release (Fig. 1) can be partially explained by slightly higher/longer fiber content (see Table 3) Both Σ M14+M28 as well as Σ M14+M28 +M48 are higher for Explosion pulp: 42 3% versus 40.3%, or 68.2% versus 66.6%. The above-mentioned factor is associated with better paper properties, as shown recently for Explosion Aspen pulp (5,7). A percentage of longer fraction fibers may be a direct consequence of slightly lower fiber cutting during refining, which requires considerably less refining energy for Explosion pulp with sudden pressure release (see Fig. 2). Both S factor and ionic contents are essentially identical (see Table 3).

Comparison of Explosion, CMP and "CTMP"

In order to achieve a credible comparison of different processes, the following methodology was adopted :

Table 3

EXPLOSION AND VAPOUR PHASE CMP/"CTMP" PULPING OF BLACK SPRUCE

PULP	EXPLOSION	*EXPLOSION 2	CMP	"CTMP"
TMPERATURE (°C)	190	190*	150	128
TIME (min)	4	4	30	10
SULFONATES (mmol/kg)	162	159	136	112
SULFONATES (%)	1.32	1.29	1.10	0.91
CARBOXYLATE (mmol/kg)	147	132	147	167
TOTAL IONIC (mmol/kg) CONTENT	309	291	283	279
YIELD (%)	91.8	90.1	92.6	94.0
BRIGHTNESS (%)	51.8	54.5	58.8	65.2
OPACITY (%)	92.7	92.5	92.9	94 0
Σ M14+28 (%)	42.3	40.3	36.5	23.0
M48 (%)	25.4	26.3	24.9	30.1
Σ M14+28+48 (%)	68.2	66 6	61.4	51.6
M100 (%)	13.8	9.8	12.7	15
Σ M200+P200	20.1	23.6	25.9	38
S FACTOR (ml)	560	570	546	648
CSF (ml)	100	100	100	100

* Slow pressure release.

Soak impregnation of regular size chips by 106 g/L sodium sulfite solution at 60 °C; 24 hours; liquor/chip ratio equal 3.

i) same chips were used;

ii) same impregnation procedure was followed in all cases;

iii) vapour phase steam cooking was carried out in the same reactor;

iv) yield was evaluated in the same way;

v) laboratory refining was done using the same blenders, and specific refining energy was evaluated in the same manner;

vi) pulp and paper properties were evaluated using the same techniques as well as the same equipment;

vii) all work was done by the same personnel.

The only difference was in cooking time and temperature :

— 128° C for 10 minures in the case of simulated "CTMP"

— 150° C for 30 minutes in the case of CMP and

— 190° C for 4 minutes in the case of Explosion pulping.

Results of the study are summarized in Table 3 and Figures 3 to 7.

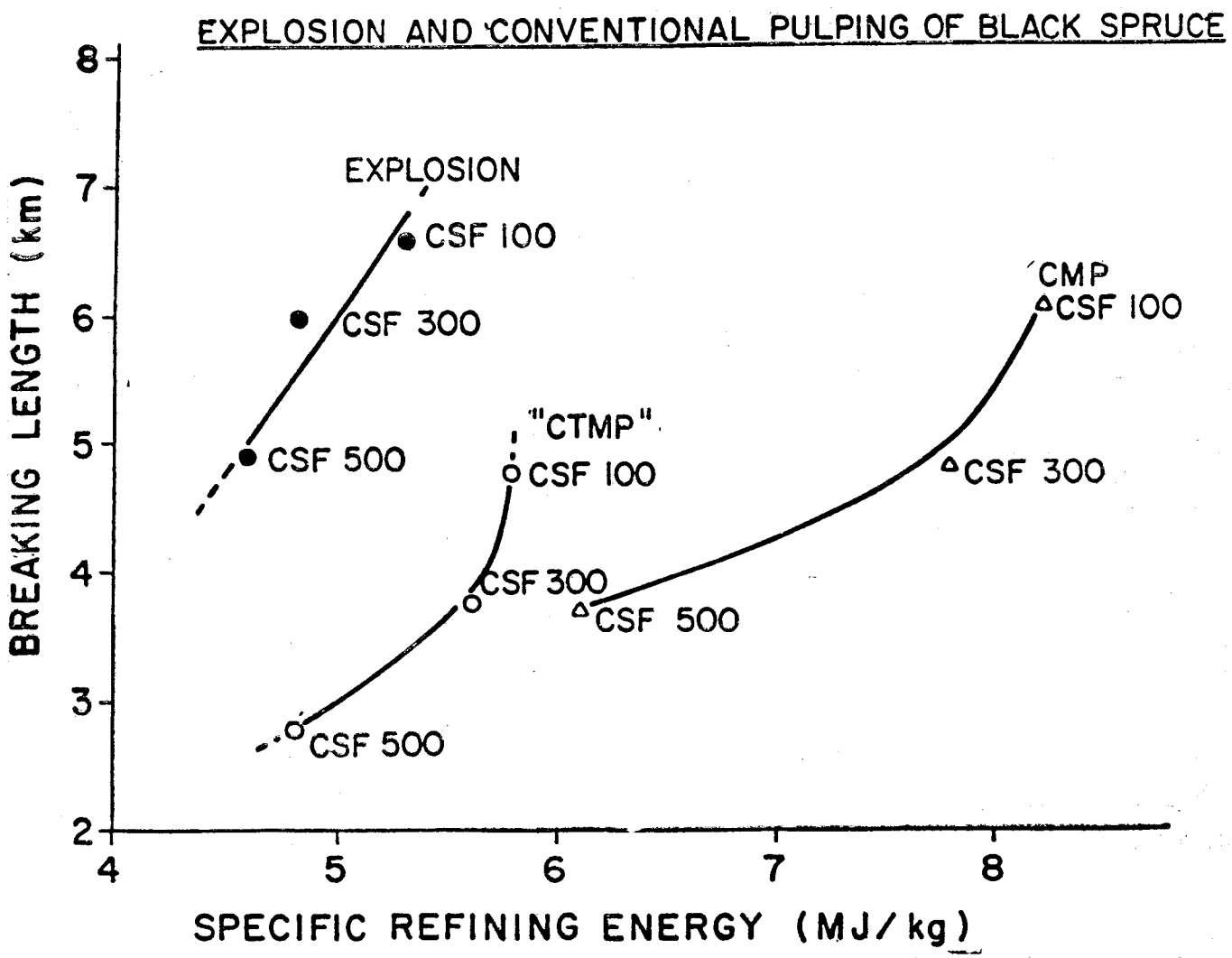

Fig. 5. Explosion and conventional pulping of black Spruce. Specific refining energy versus breaking length : Explosion, CMP, "CTMP".

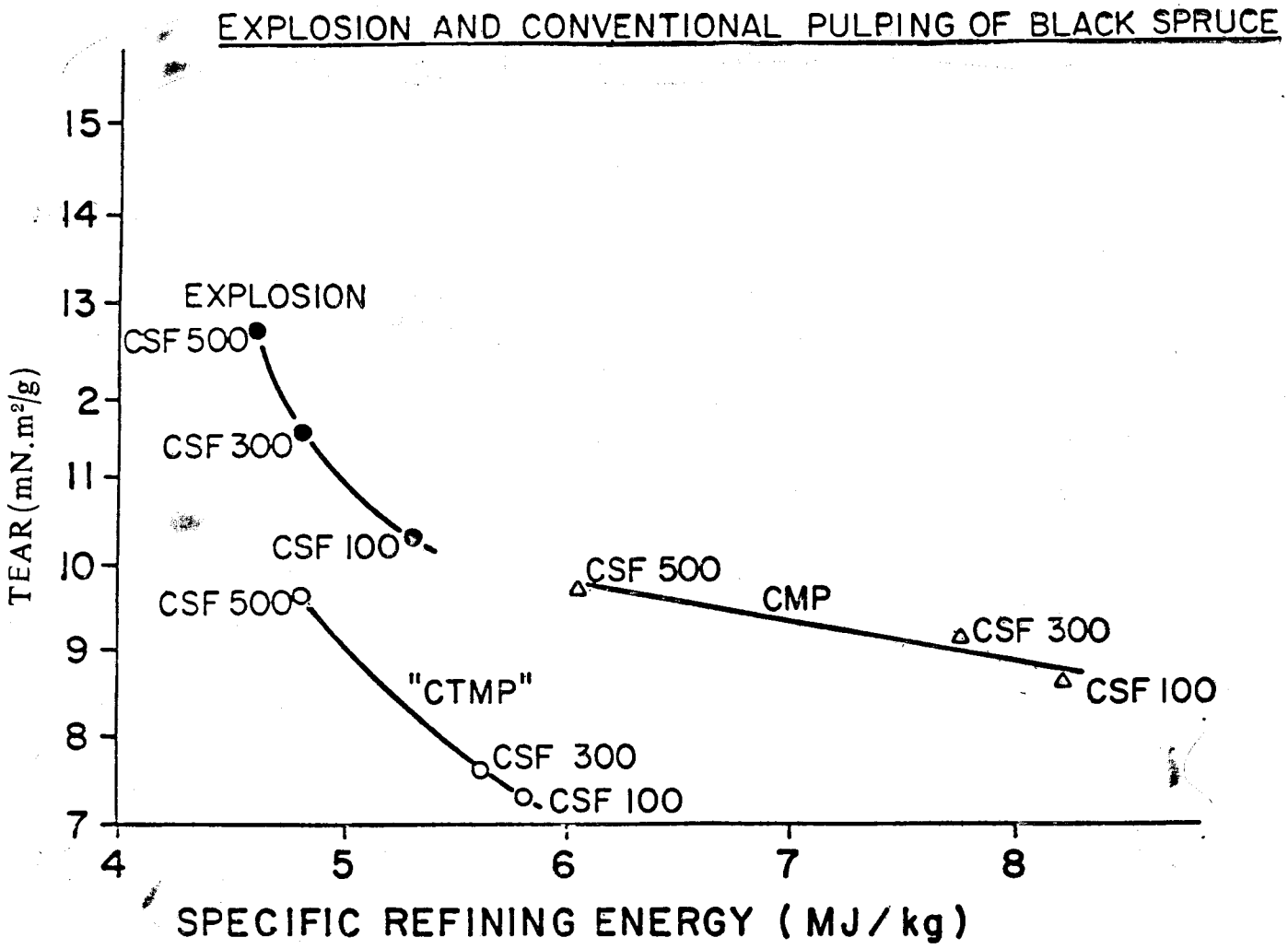

Fig. 6. Explosion and conventional pulping of black spruce. Specific refining energy versus tear factor : Explosion, CMP, "CTMP".

In Figure 3,, breaking length is presented as a function of tear factor. It is obvious that for a similar cooking yield, varying from 91% to 93%, Explosion pulp produces the strongest paper, followed by CMP and "CTMP". This is in complete agreement with results published for aspen (5, 7). The differences can hardly be explained by the ionic content, since all are within a 10% spread (309 mmol/kg. Explosion pulp; 283 mmol/kg. CMP and 279 mmol/kg, "CTMP").

The only clear correlation existing between longer fiber fractions is expressed as Σ M 14+28+48 equal to 68.2%, 61.4% and 51.6% for Explosion pulp, CMP and "CTMP" respectively (see Table 3) or expressed as Σ M 14+28 equal to 42.3%, 36.5% and 30.1% for Explosion pulp, CMP and "CTMP" respectively (see Table 3 and Fig. 7). These results follow a trend identical to that of aspen (5, 7) (see Fig. 10).

In Figures 4, 5 and 6, specific refining energy is plotted as a function of CSF, breaking length and tear respectively. Explosion pulp requires the lowest amount of refining energy, followed by "CTMP" and CMP. For example, CSF 100, CMP pulps consume about 60% more refining energy than explosion pulp (Fig. 4).

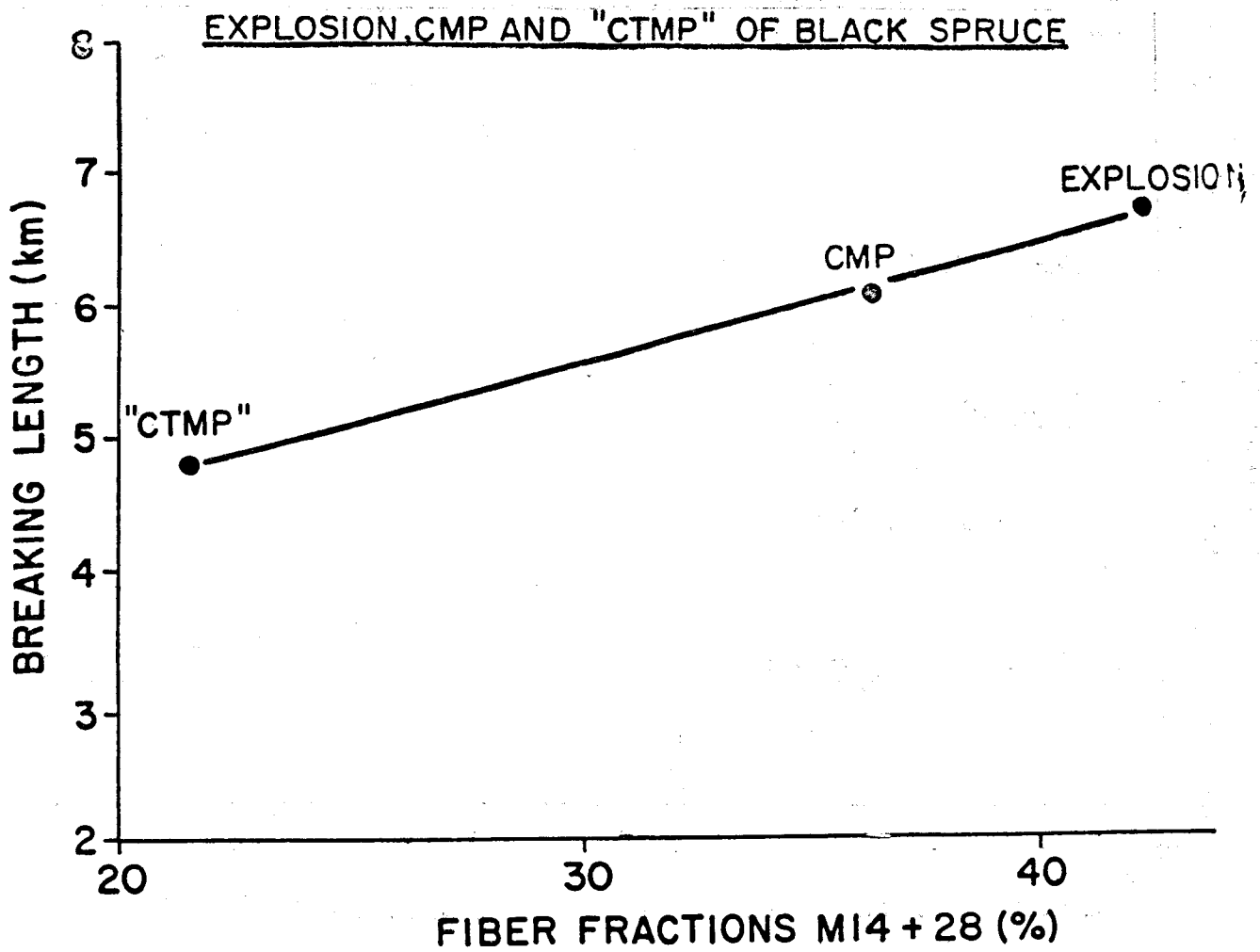

Fig. 7. Explosion, CMP and "CTMP" pulping of black spruce. Breaking versus long fiber fraction M14+M28 (%).

In Figure 5, specific refining energy is presented as a function of breaking length. In general, Explosion pulp is the strongest one and it requires the smallest amount of specific refining energy.

In order to achieve breaking length 5 km, Explosion, "CTMP" and CMP take 4.7 MJ/kg; 5.7 MJ/kg and 7.7 MJ/kg respectively.

To obtain a breaking length of 6 km, Explosion pulp uses 41% less specific refining energy than CMP does. These results follow the same general trend found in the case of semi-industrial explosion and CMP pulping of aspen (7) (see Fig. 8).

A similar correlation exists for tear factor (Fig. 6) Explosion pulp provides the highest tear (12.5) with 4 7 MJ/kg compared to CMP with the least tear (10) obtained with 6 MJ/kg. In the case of the semi-industrial trial of aspen (7) (Figure 9), Explosion pulp prepared with 8% Na_2SO_3 and 1% NaOH (8+1) produced a tear value of 7.75 for specific energy inferior to 1 MJ/kg compared to a 7.5 tear value obtained for CTMP (5+5) with 5 MJ/kg.

It is interesting to note that tear factor *11* at a breaking length of 6 km, obtained in the case of our Explosion pulp at a relatively low level of sulfonation (162 mmol/kg), compares well with results obtained

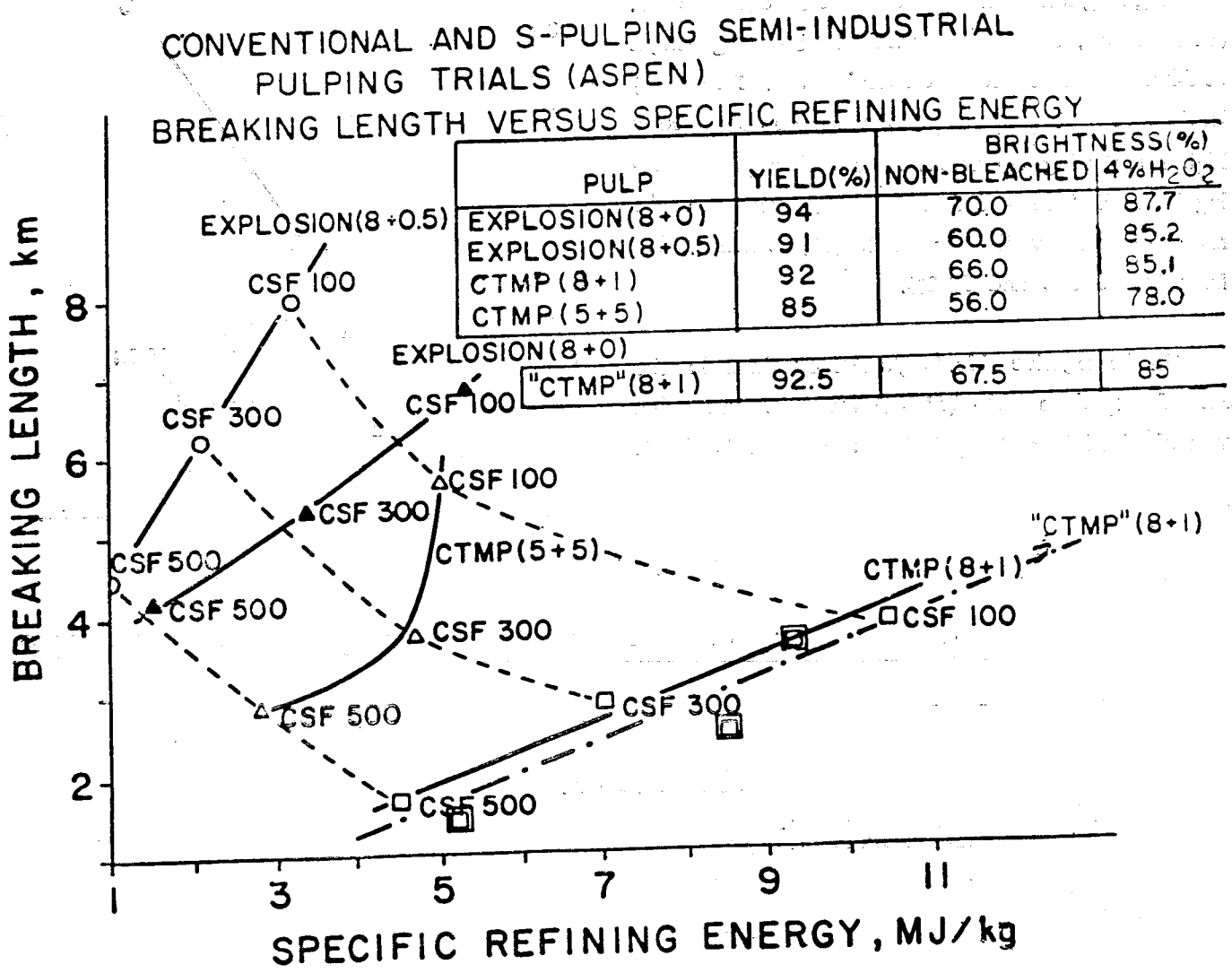

Fig.. 8. *Conventional and **8—pulping semi-industrial pulping trials (aspen). Breaking length versus specific refining energy.

*CTMP : Impregnation with liquor/chip=6 in Sunds Defibrator, 12", UQTR; 8% Na_2SO_3+1% NaOH (8+1) or 5% Na_2SO_3+5% NaOH (5+5); 128°C; 10 min; ((8+1) : 3 Stage refining; (5+5) : 2 stage refining;

**EPLOSION : Impregnation : Bauer, Ohio; 4 : 1 Compression; liquor/chip =3; cooking: Stake Tech II, Sherbrooke, liquor/chip=1; 8% Na_2SO_3 (8+0.5); all expiosion : 1 Stage atmosphere refining in Sunds Defibrator, 12".

CTMP : first stage refining under pressure, other stage atmospheric.
"CTMP" : all stage atmospheric refining.

by Heitner et al. (11) for Black Spruce liquid phase cooked ultra-high-yield sulfite pulp with high level of sulfonation (274 mmol/kg) who got, for the same breaking length a maximum tear factor equal to 7.5. (In our study, the tear factor was at a breaking length of 6 km equal to 6.8 for "CTMP" and 8.9 for CMP.) In the case of Explosion pulp, we also obtained a higher scattering coefficient and a similar yield varying from 393.4 to 465.6 and 91.8% compared to the results reported by Heitner et al. (11) which varied from 280 to 320 and 92.2%.

On the negative side, brightness obtained in the case of Explosion pulp (51.8%) was less than what was obtained for CMP (58.8%) and "CTMP" (65.2%).

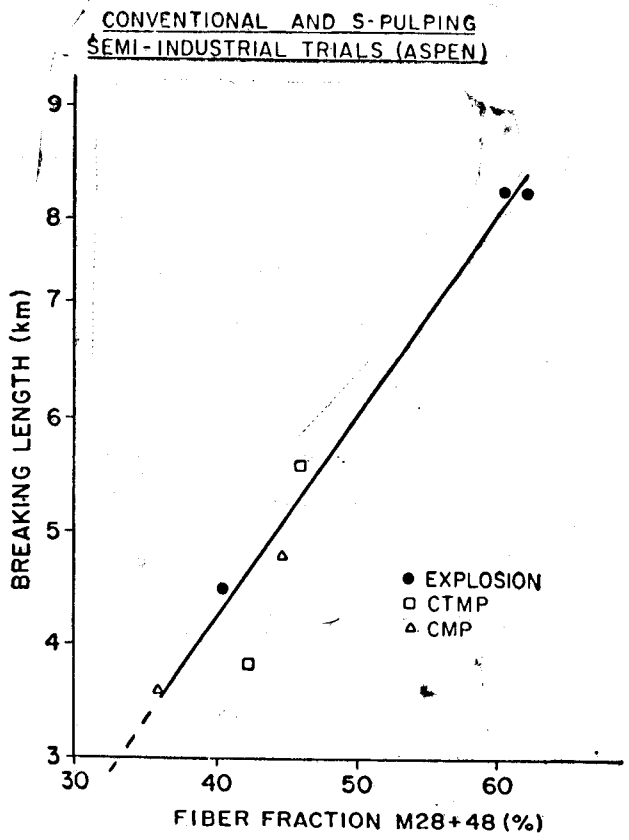

FIG. 8A

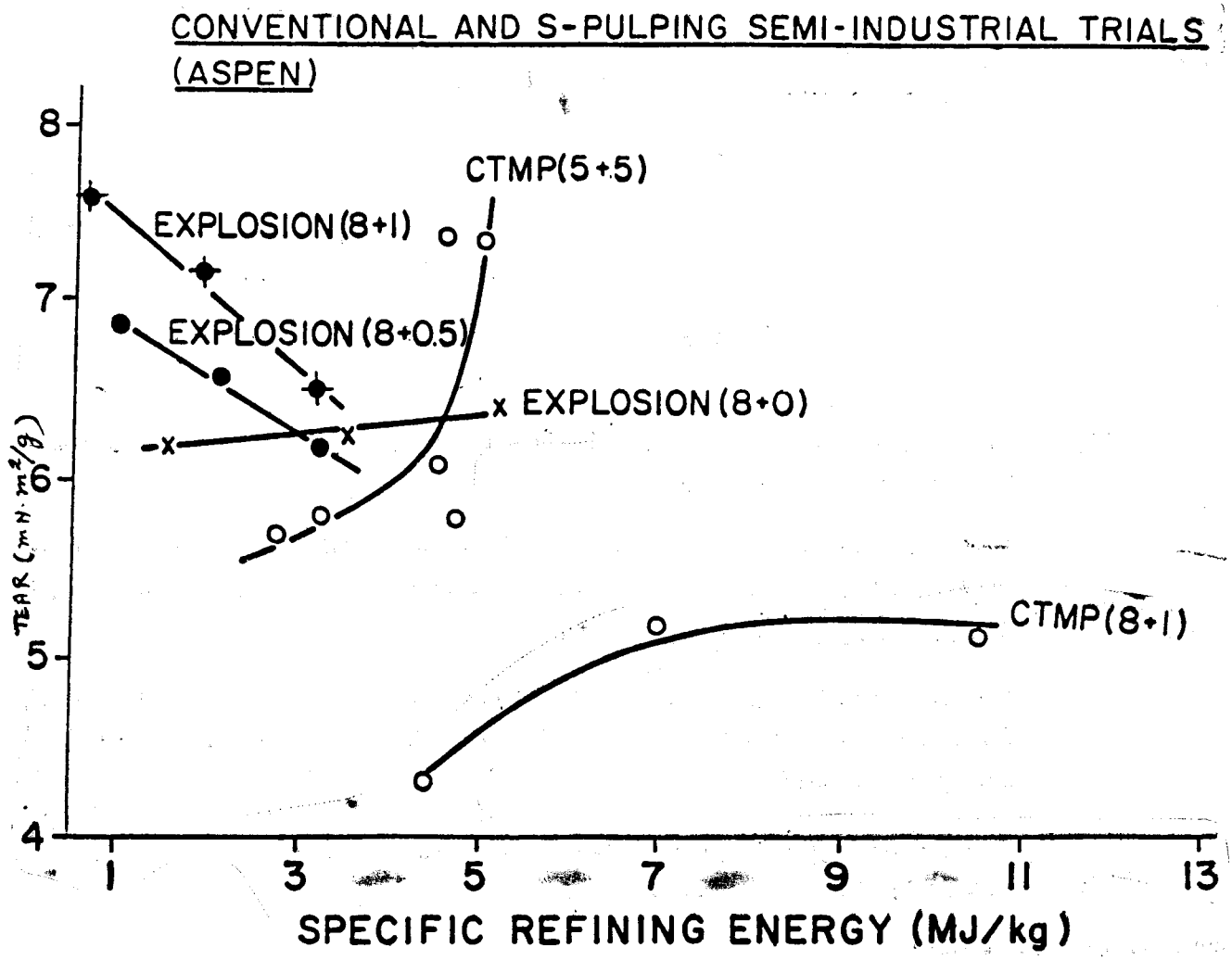

Fig 9. Conventional and S-pulping semi-industrial trials (aspen). Tear versus specific refining energy.

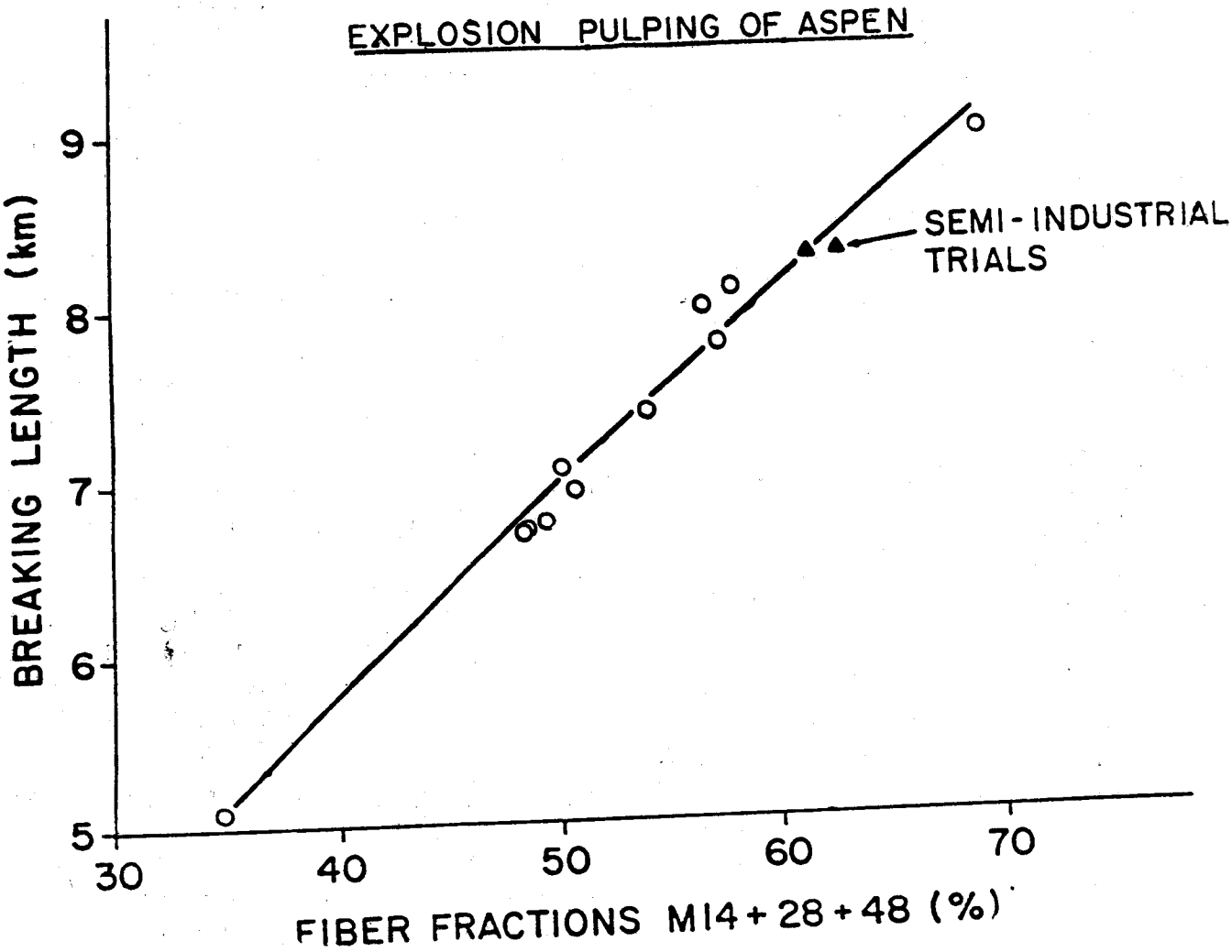

Fig. 10. Explosion pulping of aspen. Breaking leng-h versus long fiber fraction M14+M28+M48.

CONCLUSION

Explosion pulping of Black Spruce provides fibers which are easier to refine and superior in strength compared with chips discharged at atmospheric or low pressure (but with lower brightness).

Explosion pulping with sulfite chemical pretreatment of wood chips produces Black Spruce pulp with greater strength and appreciably less specific refining energy than in conventional chemimechanical (CMP) and chemi-thermomechanical pulping processes ("CTMP").

Explosion pulps of the same yield and freeness level as conventional CMP pulp can require up to 60% less refining energy while their tear can be up to 20% superior for similar breaking length. The usual trade-off of strength for brightness is also observed for Explosion pulp.

More work is needed to optimize explosion pulping conditions in order to improve resulting optical properties as well as to understand the fundamentals of the process.

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