A New Look Towards High Temperature Vapour Phase Short Time Pulping of Indian Bagasse

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ABSTRACT

Preimpregnated sugarcane bagasse of Indian origin was cooked at 463 K (1.26 MPa saturated steam pressure) in a batch reactor developed by M/s Stake Technology, canade with different chemical charges, with different nature of chemicals and with or without the presence of some additional swelling agents. For the sake of comparison sodium hydroxide and sodium sulphite has been considered as primary chemicals and sodium carbonate, bicarbonate as secondary chemicals. From the detailed experimental investigations it is found that bagasse can produce good quality of pulp conforming to any grade including newsprint. Varying of chemicals concentration and other parameters like time temperature at the impregnation stage can help to achieve the above objectives.

INTRODUCTION

In countries like India importance of renewalable nonwood fibre like bagasse has been recognized as a papermaking material. Bagasse availability is large in India (1,2) and there is a need to ensure their proper utilization.

Saturated vapour phase pulping has been evolved out specifically with an aim to produce high yield pulp or ultra high yield pulp with comparatively less energy usage, reduced pollution load compatible with pulp qualities acceptable for especially newsprint grade pulp. In overwhelmingly majority of the cases the saturated steam is employed as a cooking fluid. Explosion pulping is one of such processes which appears to be promising to meet the above objectives. There are some other conventional processes working in vapour phase such as Chemi-mechanical pulping (CMP), chemithermo- mechanical pulping (CTMP) processes which have the same goal as the explosion pulping. Explosion pulping is principally composed of three steps; Impregnation with proper chemicals at a desired temperature, and time, extracting the liquor by pressure, steam purging and steam cooking also at preferred temperatures (443K-483K), time (0.5-7 min) at medium pressure range (1.1-1.9 MPa), rapid steam release/decompression and finally refining. Work on steam explosion pulping has mostly been on Hardwood and Softwoods. Only limited data are available on vapour phase explosion pulping with Australian and Hawaiian bagasse (12,15,17) and on Bamboo, Rice straw & Bagase of Indian origin by present investigators (8,14). Mason has originally developed Explosion pulping technique (17) using steam as the working fluid at 6.9 MPa and 558 K on wood without any pretreatment of chemicals. Patent

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is also available (11,13) for conversion of wood into biomass by Delong. Ray et al.has made extensive review (12) of the literature. Mamers etal. (3-5), first attempted to produce explosion pulp in SIRO pulper from kenaf, kenaf bark, rice straw, wheat straw and bagasse of Australian origin in laboratory and pilot plant at 3.4-13.8 MP a pressure in presence of Nitrogen gas (saturation steam pressure 0.54-1.55 MPa) with the impregnating chemicals like sodium sulphite, kraft mixtures, caustic soda, ammonium hydroxide, ammonium bi-sulphite and urea to manufacture low yield chemical grade pulp. Attempts are also made (6,9,10,15,16) to apply these chemicals on woody and nonwoody raw materials at a milder pressure conditions (1.1-1.9 MPa) but at the same range of temperature 170 C -210 C) and lower time (1-7min.) with or without the presence of Nitrogen gas pressure. Kokta et al (6,9,10) produced newsprint grade high yield/ultra high yield pulp from impregnated woods and nonwoods in a digester a batch reactor made by M/s Stake Technology of Canada for the first time, Sodium sulphite with or without additional chemicals like caustic soda, sodium carbonate, sodium bicarbonate were mainly cooking chemicals in all these experiments either in laboratory, pilot plant or semi -commercial plant. Law and Valade (7) and Heitner et al. (17) also published some results on explosion pulping of woods like Aspen. More recent trials are made on nonwood fibres (18-20). In this present investigation, an attempt has been made to compare the properties of pulps from bagasse with different principal chemical charges of sulphite or soda with the presence of other secondary (swelling agent) chemicals at a fixed conditions of impregnation and pulping times. Comparison is also made on similar processes expected to produce similar quality pulp. Previous experiments show that though extensive sulphonation leads to increase flexibility, conformability, sheet density and strength properties of paper in steam explosion cooking, is no really true in case of non wood fibres, atleast in case of bagasse. It is wellknown that the main factors for newsprintquality paper are low caliper, high printing opacity (90%), scattering coefficient (40m^2/kg) with moderate brightness (45%), tear index, breaking length and high yield. Attempts are also made first to prepare newsprint grade pulp based on only sulphite preimpregnating chemicals and then to extend to other varieties after subjecting to other additional chemicals and change of system parameters. To obtain pulp conforming to the newsprint grade pulp a good refiner is essential which can consume less electrical energy. Table-1 indicates the comparison of different blender/defibrator. Reliability of tests through laboratory blender is thus justified.

EXPERIMENTAL

RAW MATERIAL

The details of the raw material preparation for bagasse and its quality are described comprehensively by Ray et al. (12,17) for pulp production.

EQUIPMENT AND ACCESSORIES

The equipments used are:

The constant Temperature Impregnation Trough

The Liquor Squeezing Device

The Cylindrical Batch Reactor

The Cyclone

The Collection Vessel

The details of the batch reactor designed by M/s Stake Technology Limited, Ontario Canada is depicted in schematic diagram (Fig.1.) The design

Table-1 Design and Operational Parameters

Design Parameters		Values	Operational Parameters	Values
Eff. Volume:	ml	300	Degassing time, min	1
Feed spout,	mm	53	Pressure, kg/cm^2(g)	13.8
Tot. L, reactor Tube,	mm	685	Temperature, K	Varying
Dia., exit,	mm	38	Cooking	--
L/D of receiving tank		2	Time to temp., s	15-20
Dia.,	mm	450	Time at temp., min	2-8

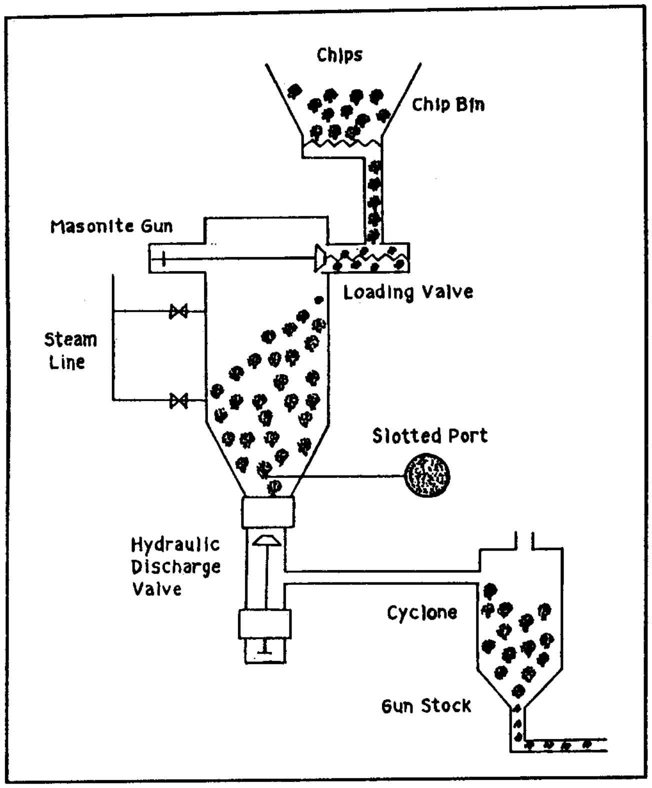

Fig. -1 Schematic diagram of explosion pulping unit (M/s. Stake Technology, Canada)

operational parameters are shown in Table-1.

EXPERIMENTAL PROCEDURE

The experimental procedures include the following step by step sequence:

- Depithing of bagasse
- Impregnation with chemicals as demanded to produce different grades of pulp (bathratio=1:6) (from newsprint to chemical grade)
- Expulsion of the residual liquor
- Charging in the reactor
- Sealing the reactor
- Presteaming
- Steam Cooking
- Sudden Decompression of the reactor
- Explosive Discharge of Biomass and Release of Steam
- Screening of the pulp (200 mesh)
- Thorough Washing
- Refining at 2-3% consistency in Osterizer blender (if required) for 90 seconds
- Evaluation of pulp yield and McNett Bauer Classification
- Sheet making
- Properties evaluation according to the CPPA standard
- Determination of liquor characteristics

A comparison of the performance of laboratory blender with CD-300 SUNDS DEFIBRATOR, BAUER PAPRICAN Plant is shown in Table-2. The predictors were energy, brightness and strength properties. Performance of SPROUT WALDRON REFINER, PFI

Table-2 Comparison of Laboratory and Pilot Plant Refiner

Property		Laboratory Blender	CD-300 Sunds Defibrator UQTR Pilot Pl.	Bauer Paprican Pilot Plant
CSF,	ml	704	702	687
Energy,	MJ/kg	3.6	4.0	4.0
Breaking Length,	km	3.7	4.4	3.7
Tear index,	$mn/m^2/g$	14	14	14
Bulk,	cm^2/g	3.5	3.3	2.8
Brightness,	%	47	52	52

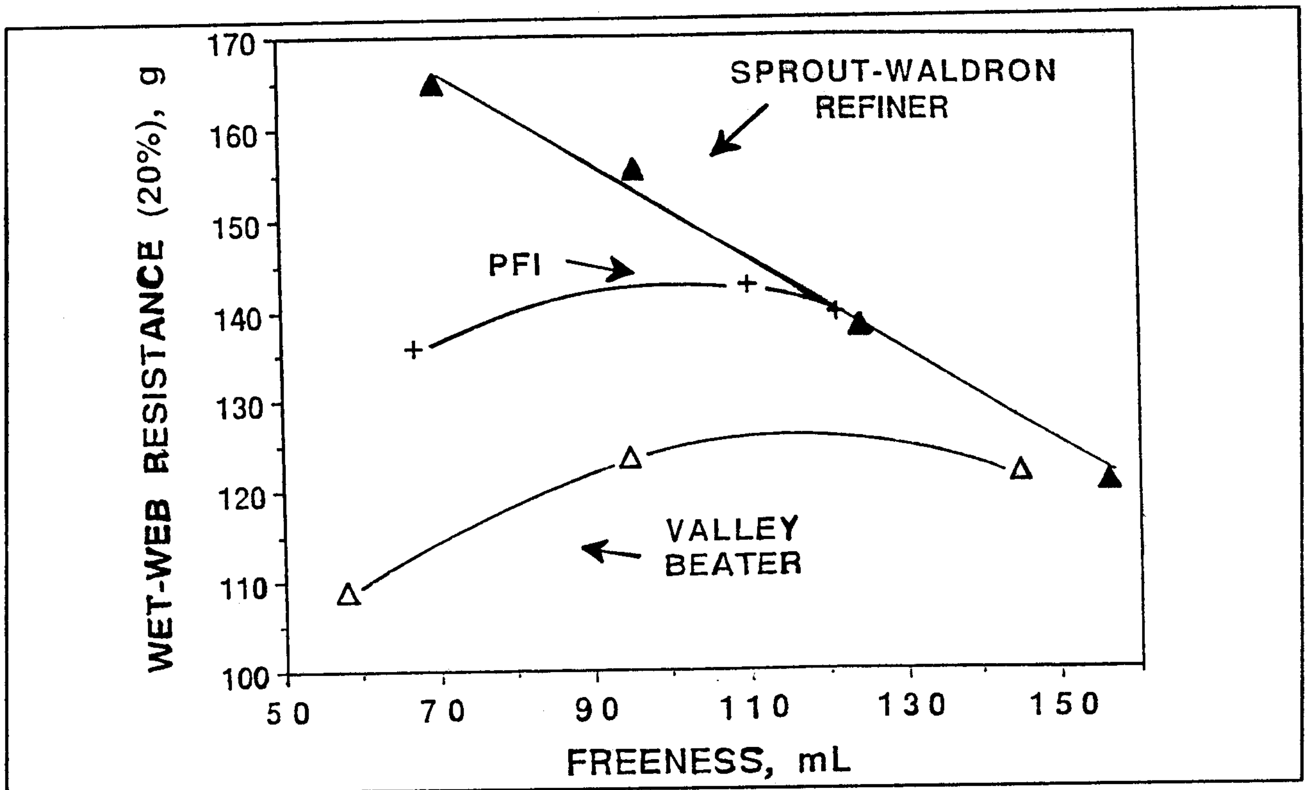

Fig. -2 Comparative performance of different kind of lab. refiners.

MILL and VALLEY BEATER compared in terms of Wet web resistance as a function of stock freeness is depicted in Fig.2. Though all the above performances are based on woods, the indicators give enough signals regarding the accuracy of prediction particularly above freeness level of 150.

PULP EVALUATION

The procedure for evaluation of pulp is explained elsewhere. Standard instruments are used for evaluation of pulp properties. Some modern instruments were required for the purpose for accurate determination of strength and optical properties. These are given as under:

Instron 4201	for Breaking Length, Elongation etc.
Parker Print Surface	for Porosity, Rough - ness
Technibrite Micro TB-IC	for Optical Properties
Pulmac Trouble Shooter	for Zero Span Tensile/ B.L.
CDM 83 Conductivity meter	for Ionic species, Ionic conductivity

The details of experimental conditions with the specific objectives are shown in Table. 3.

RESULTS AND DISCUSSIONS

The effect of pH of original liquor on explosion pulp yield, the influence of impregnation time on the formation of ionic groups, effect of chemicals on drainage properties and optical properties, parametric effects on the strength properties and liquor characteristics are already enumerated in earlier communications (12,17). The effect of sodium hydroxide plus additional impregnating chemicals (NaOH, Na_2CO_3, $NaHCO_3$) on yield, drainage characteristics and liquor properties are also reported (17). This paper draws attention for some other properties of the resulting pulp pertaining to bagasse explosion pulp. A set of typical data for all properties of exploded bagasse are shown in Table. 4. This includes many physical, strength, optical and colour properties of pulp.

RELATIONSHIP BETWEEN THE IONIC GROUP AND THE PROPERTIES

It has been observed by Kokta and his co-workers (6, 9, 10) on woods that refining energy and also the breaking length are strong function of the

Table-3 Experimental Conditions and Parameters Studied for Bagasse Explosion Pulp in Batch Reactor (Stake Technology Company, Canada)

Bath ratio: 1:6, Time of steaming: 2 min.; Temperature of cooking: 453K-463K; Pressure of saturated steam: 1.20-1.26 MPa

Pulp	Chemical/Bagasse, %		Impregnation time, h	Parameters studied
	Primary	Secondary		Yield, Liquor Characteristics, Bulk
Temperature, 353 K				Basis Wt., Thickness, Density,
Al	40	2.5	--	TEA, Young Mod
Ml	0	5.0	--	Stiffness, Porosity, Tear Index, Burst Index
Temperature, 363 K				Breaking Length, Elongation
B2	40	0	24	Energy of Rupture, Roughness
B21	40	0	18	Zero Span B.L., Drainage Time
B22	40	0	12	R(X), R(Y), R(Z)
B3	30	0	24	X. Y, Z, L*, a*, b*
B31	30	0	18	Scat. Coeff., Scat. Power
B32	30	0	12	Absorp. Power, Absorp. Coeff., Tap. Opacity, Brightness
B4	20	0	24	CSF, SO_3H, Co_3H, TIC
B41	20	0	18	Ash%, ME
B42	20	0	12	Rupture Force
B1	0	32.0, Sod.met a bi-sulfite	24	All of the above except Drainage time, Zero span B.L., and Stiffness, Refining Cy.
B4	40	5.0, Sod. Bi-carbonate	24	All the above Characteristics,
B3	0	5.0, Sod. Hydroxide	24	Drainage time
B6	40	5.0, Sod. Carbonate	24	Bauer Mc-Nett
B7	40	5.0, Sod. hydrcxide	24	Fibre Classification
B5	40	2.5, Sod. Hydroxide	24	Of refined and unrefined
BK1	0	5.0 Sod. Hydroxide	24	Pulp, Initial Freeness
BM1	0	5.0 Sod. Hydroxide	24	B-Factor.

sulphonate content of the pulp. This is shown in Fig. 3. Similar behaviour though expected also in bagasse explosion pulp with chemical pretreatment could not be obtained. The reasons are probably due to different topochemical characteristics and nature of lignin compared those of wood pulp The effect of impregnation time on total ionic groups formation at various sulphite charges is shown in Fig. 4. The rate of total ionic group formation increases initially at a slower rate, becomes faster with subsequent increase

Table-4 Typical Data of Explosion Pulp Properties

Properties	A	B	C	D	E	F
CSF, ml	330	235	364	336	343	368*
GSM, g/m^2	64.64	63.48	63.1	63.86	57.49	66.63
TEA J/m^2	14.91	21.98	26.32	7.99	6.94	5.898
Mod. El.	467.6	541.6	425.0	736.3	815.2	958.1
Young Mod.	46.39	60.41	61.22	117.5	100.6	111.6
Rupture, kg	4.223	4.52	5.329	2.106	-	-
Elog. (Rup), %	0.917	1.207	1.231	0.972	-	-
R (X) 8.27	59.01	57.98	59.62	63.72	50.39	52.62
R (Y)	54.74	53.59	55.45	59.50	44.86	47.19
R (Z)	36.78	34.94	37.83	40.86	29.52	31.57
X	53.48	52.31	54.16	57.98	45.29	47.45
Y	54.74	53.59	55.45	59.50	44.86	47.19
Z	43.48	41.31	44.73	48.31	34.90	37.32
L*	78.89	78.22	79.30	81.56	72.80	74.31
a*	-0.51	-0.65	-0.55	-0.90	3.72	3.24
b*	20.31	21.59	19.66	19.80	19.94	19.54
Scattering Power	1.04	1.24	1.19	2.10	1.45	1.51
Absorption Power	0.20	0.25	0.21	0.29	0.49	0.45
Tappi Opacity	66.35	73.58	70.91	87.27	85.72	85.32
B, %	59.01	57.98	59.62	41.62	--	--

A: 40% Na_2SO_3+5% NaOH; B: 40% Na_2SO_3+5% $NaHCO_3$; C: 40% Na_2SO_3+5% Na_2CO_3;
D: 40% Na_2SO_3; E: 5% NaOH+0% Na_2SO_3; F: 2.5% NaOH+0% Na_2SO_3
*Temperature = 353K, 2min.

of impregnation time. The interrelationship between the tear index and breaking length as a function of total ionic groups for 40% sodium sulphite treatment is shown in Fig.5. It is evident from the data that higher the chemical charges, higher are the values of strength properties. Average breaking length and tear index values exceed 4.3 km and 5.2 km respectively at 100 CSF for 40% sod. Sulphite impregnation charge. Higher values of breaking length or tear index could not be obtained even after protracted time of impregnation. The effect of time of impregnation does not exhibit coherent behaviour. These may be attributed to many factors including the redeposition of bagasse lignin, especially the acid soluble part. This fact is described in detail elsewhere (12,17).

The variation of scattering coefficient as a function of breaking length and ionic content is presented in Fig. 6. As expected it displays reverse trend. Ionic content has apparently no distinct relationship. Various pulp properties such as bulk,

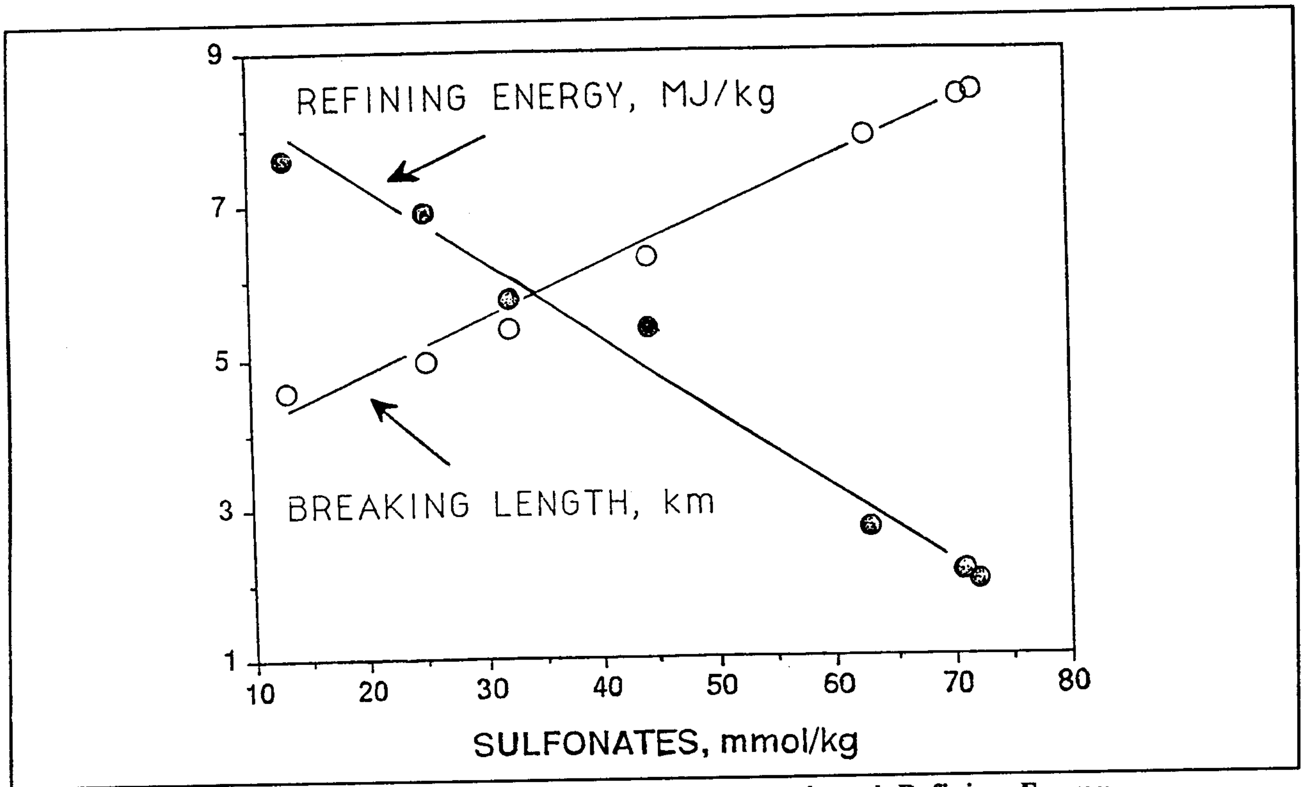

Fig. -3 Effect of Sulfonates on Breaking Length and Refining Energy.

tear index and breaking length as a function of CSF with steeping time as a parameter are shown in Figs. -7 and 8 for 20% sod. sulphite charge. The low values of the above properties are attributed to slow sulphonation of bagasse lignin, p-hydroxy benzyl alcohol in particular. The aforesaid findings are in

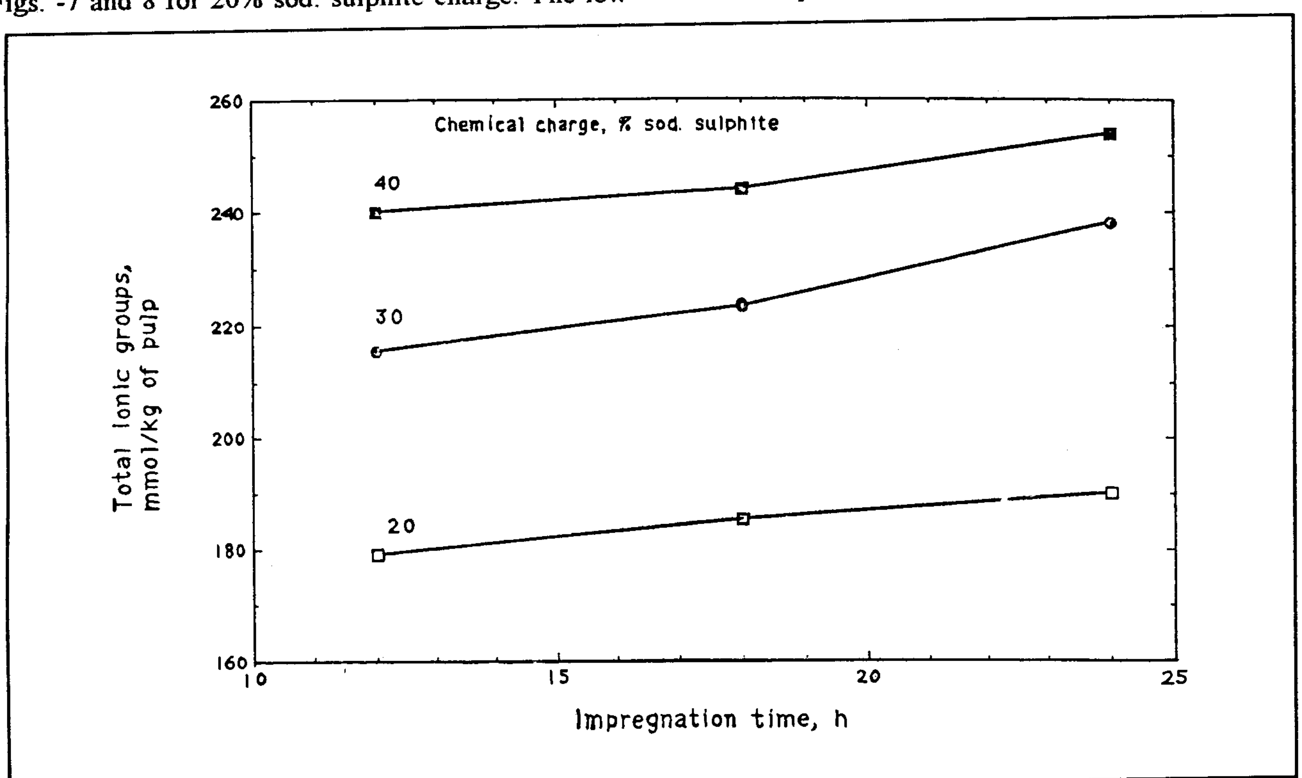

Fig. -4 Variation of total ionic groups as a function of impregnation time with chemical charge as a parameter

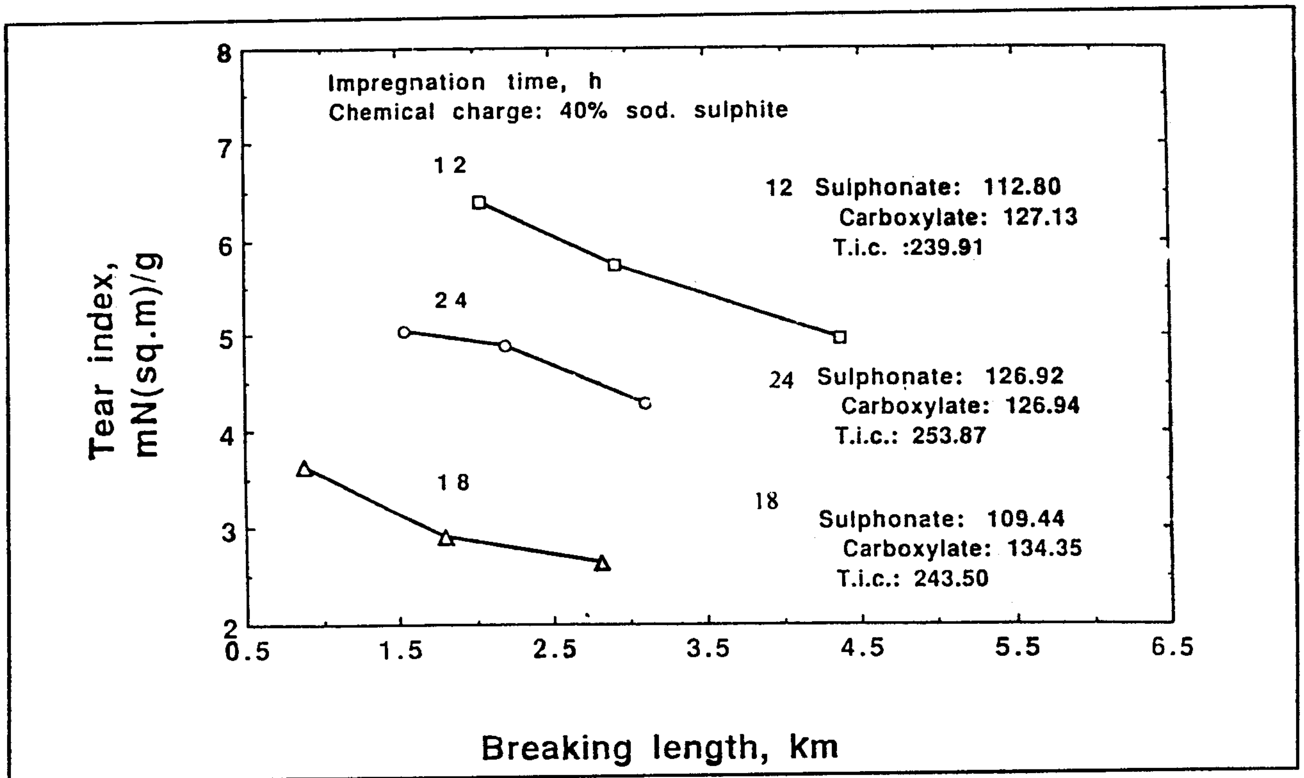

Fig. -5 Tear-index - Breaking Length relationship as a function of ionic groups.

concurrence of many investigators including Mamers et al. (3-5) and stipulates that more than 12 hours impregnation time is not necessary for sulphite pulping of bagasse but demands more drastic chemical charge. However bulk behaves oppositely and increases with increase of impregnation time.

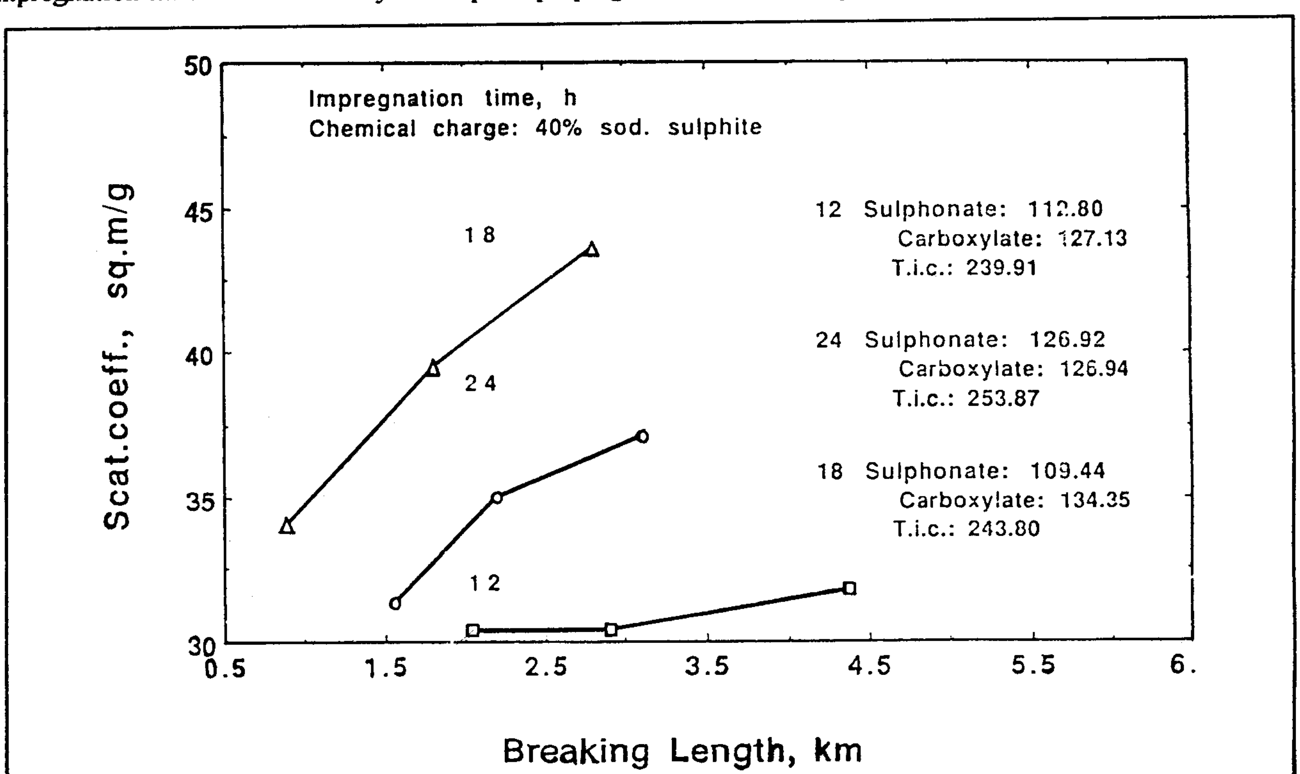

Fig. -6 Scattering Coefficient - Breaking Length relationship with ionic groups and time as parameters.

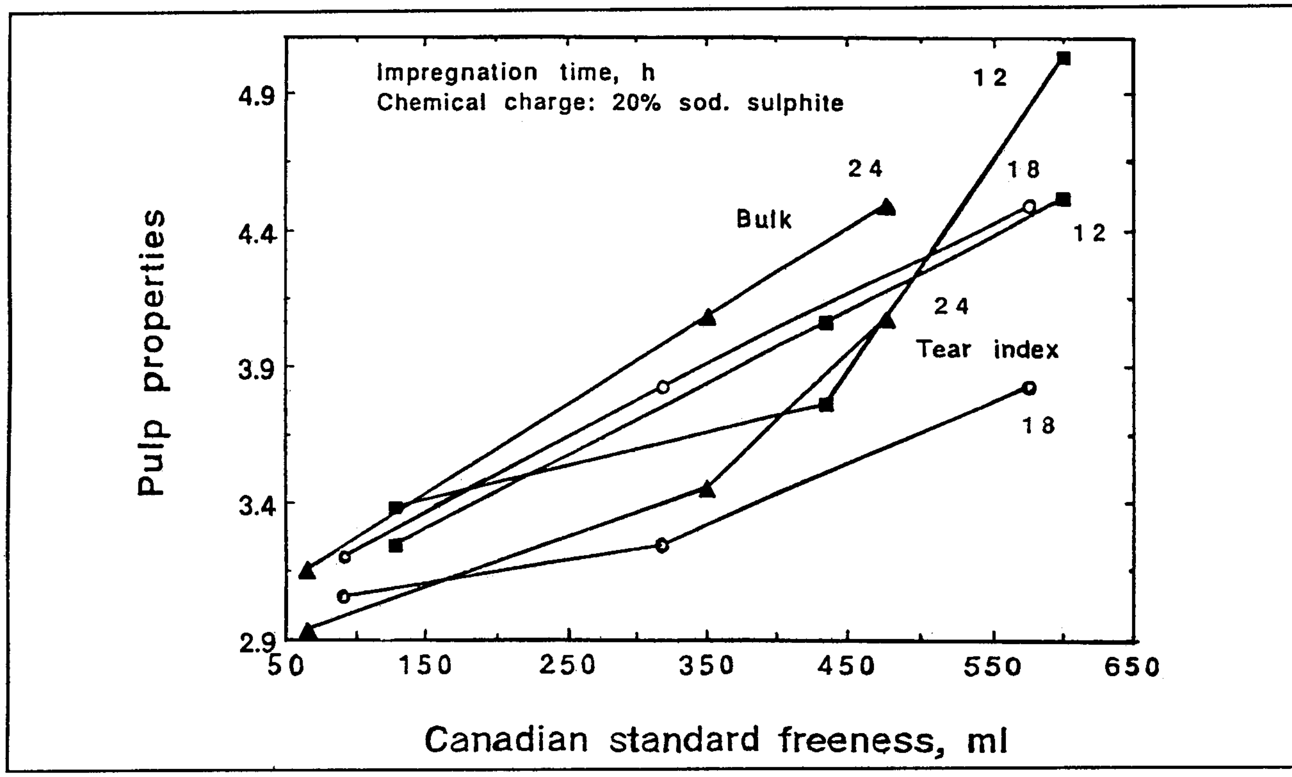

Fig. -7 Pulp properties as a function of Candian Standard Freeness (CSF) with impregnation time as a parameter

PROPERTIES OF PULP AND IMPREGNATION PARAMETERS

Variations of brightness, scattering coefficient and opacity as a function of CSF with chemical charge as a parameter are shown in Figs. 9 and 10. In general, increase of brightness, decrease of scattering coefficients and opacity are observed. It

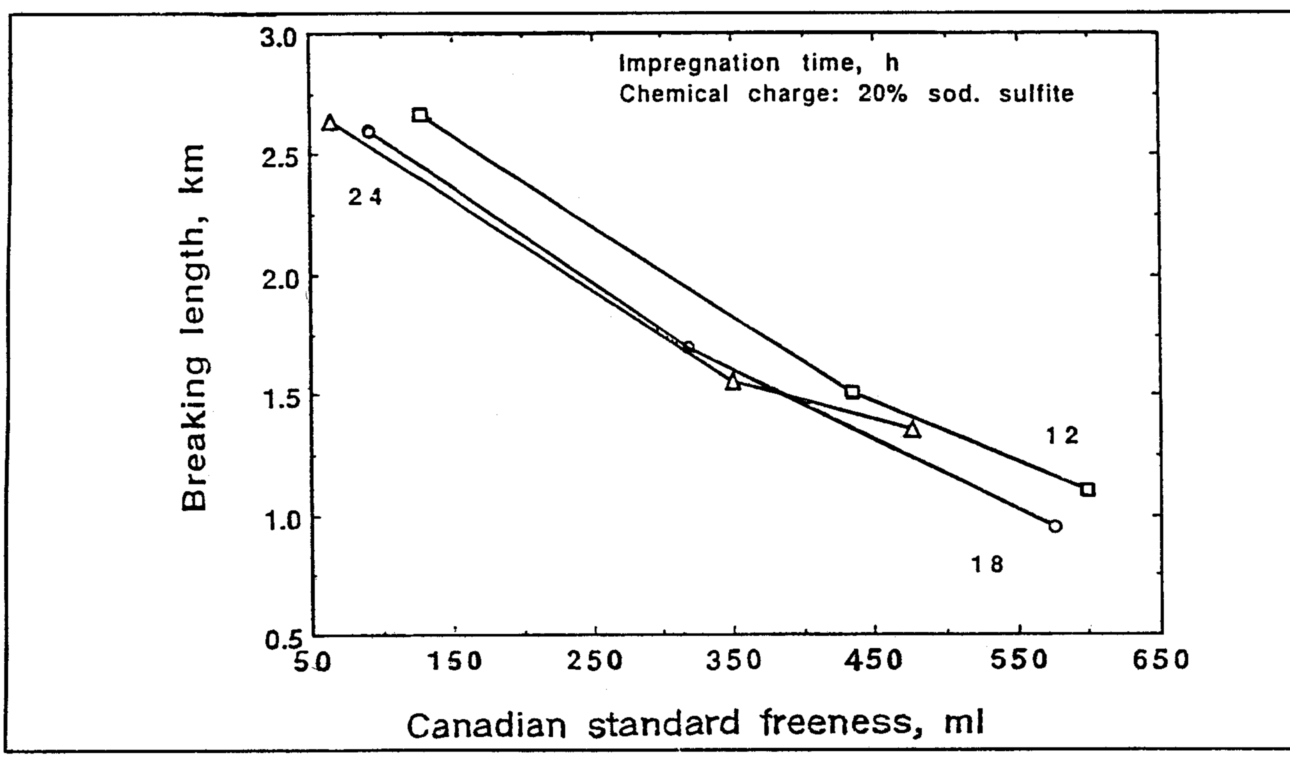

Fig. -8 Breaking length as a function of Canadian Standard Freeness and Impregnation time.

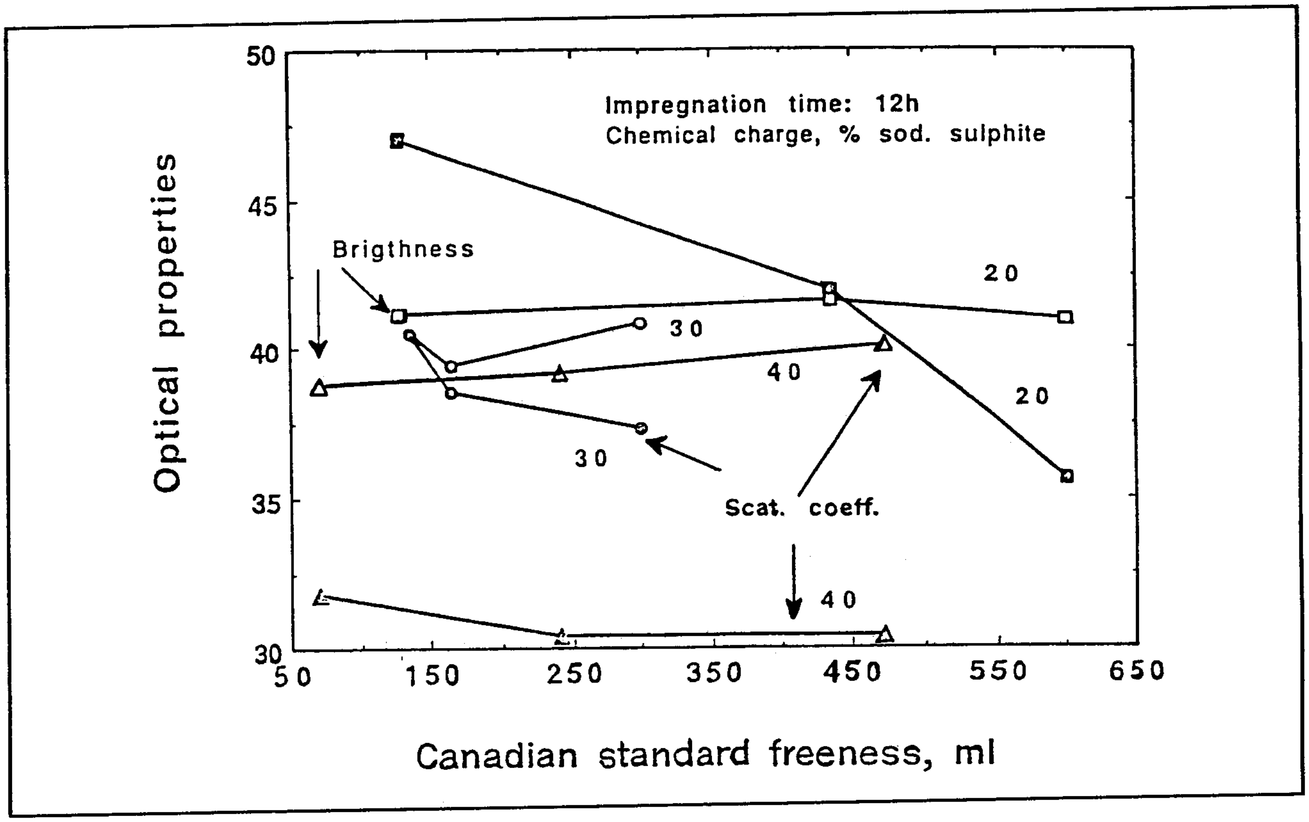

Fig. -9 Optical Properties as a function of Candian Standard Freeness with Chemical Charge (Sod. Sulfite) as aparameter.

interestingly portrays the target values of newsprint at the expense of lowering strength properties, especialy the burst and breaking length.

STRENGTH PROPERTIES OF PULP AND CANADIAN STANDARD FREENESS

Variation of roughness and zero span breaking length as a function of canadian standard freeness is depicted in Fig. 11. While the roughness increases with increase of CSF, the zero span breaking length decreases sharply. The effect of impregnation time on roughness though have distinct trend the zero span breaking length exhibits indifferent behaviour for 24 hour impregnation time in the lower range of CSF 100-400. However the difference of values are marginal. The value of zero span breaking length (CSF=435;6.2km) for 20% sulphite impregnation charges are compared with the predicted values for unbleached bagasse pulp at almost the same CSF (425, Z.S.B.L.=6.51 with fibre length factor =0.41). Slightly impregnation charge (30%sulphite) with longer time (24h) gives equivalent zero span breaking length (CSF=400,6.48). This comparison provides the reproducibility of data and accuracy of experimental methodology.

VARIATION OF DRAINAGE CHARACTERISTICS OF PULPS

The dependence of the drainage characteristics of sulphite pulp on the impregnation time is drawn in Fig. 12. Longer the time of impregnation, inferior is the drainage characteristics. Therefore, from the angle of drainage quality short time impregnation is preferred. Therefore operating impregnation beyond 12 h is not helpful from machine runnability point of view. Prolonged impregnation has detrimental effect during actual production.

EFFECT OF SECONDARY CHEMICALS ON PULP PROPERTIES

The effects of various chemicals such as sod. hydroxide, sod. Carbonate, and sod. bi-carbonate on yield, fibre fractions, the strength properties like bulk, stifffness, zero span breaking length, energy of rupture, burst index, and tear index are described (17). The variations of the optical properties like brightness, scattering coefficient and also the drainage time are also reported. However the effect of these chemicals on elongation and opacity are not shown. The

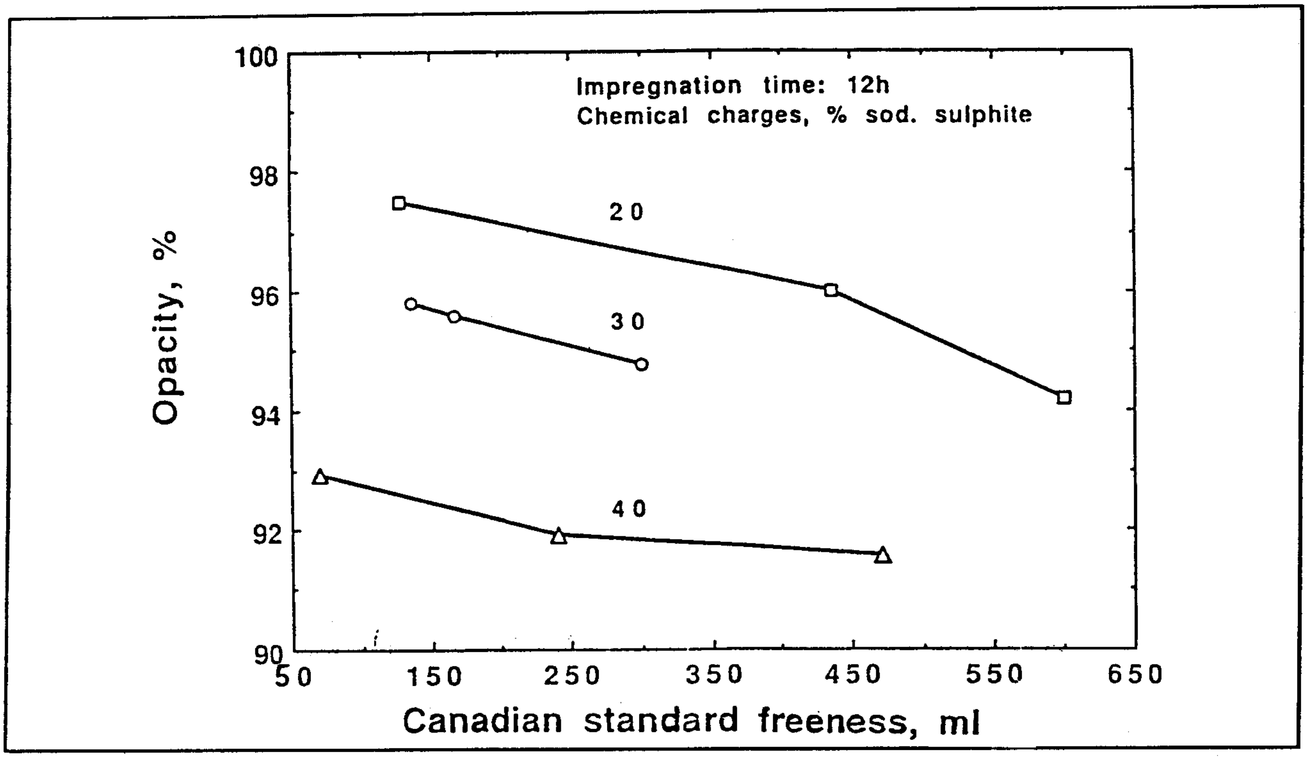

Fig. -10 Opacity- Canadian Standard Freeness relationship with the effect of Chemical charge (Sod. Sulfite)

variations of these properties as a function of CSF are shown in Figs 13 and 14. The values are compared among the pulps with only 40% sulphite addition and those with extra chemical charge. It is revealed that hydroxide chemical gives higher values at lower values of CSF while at higher values of CSF bicarbonate imparts more elongation values. Carbonate gives the intermediate values. Lowest values are obtained in

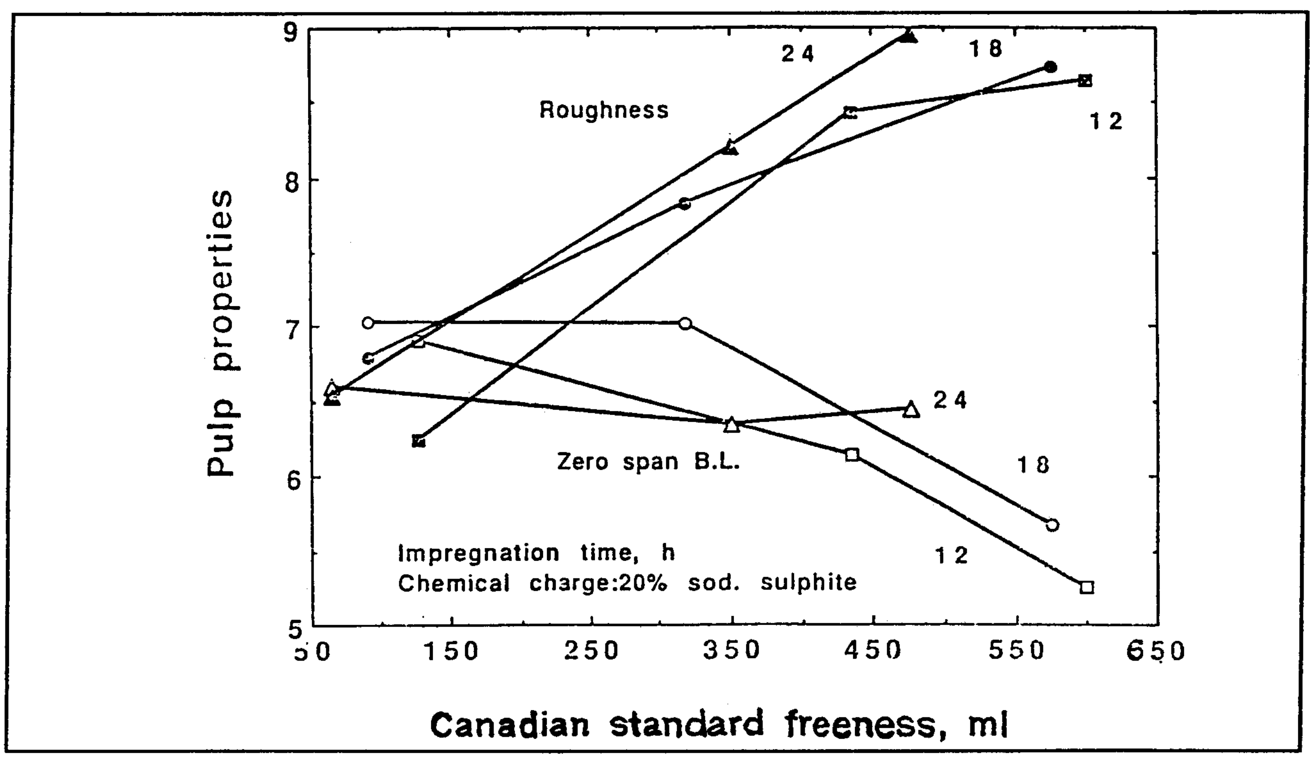

Fig. -11 Effect of Impregnation time on the relationship of pulp Properties and CSF.

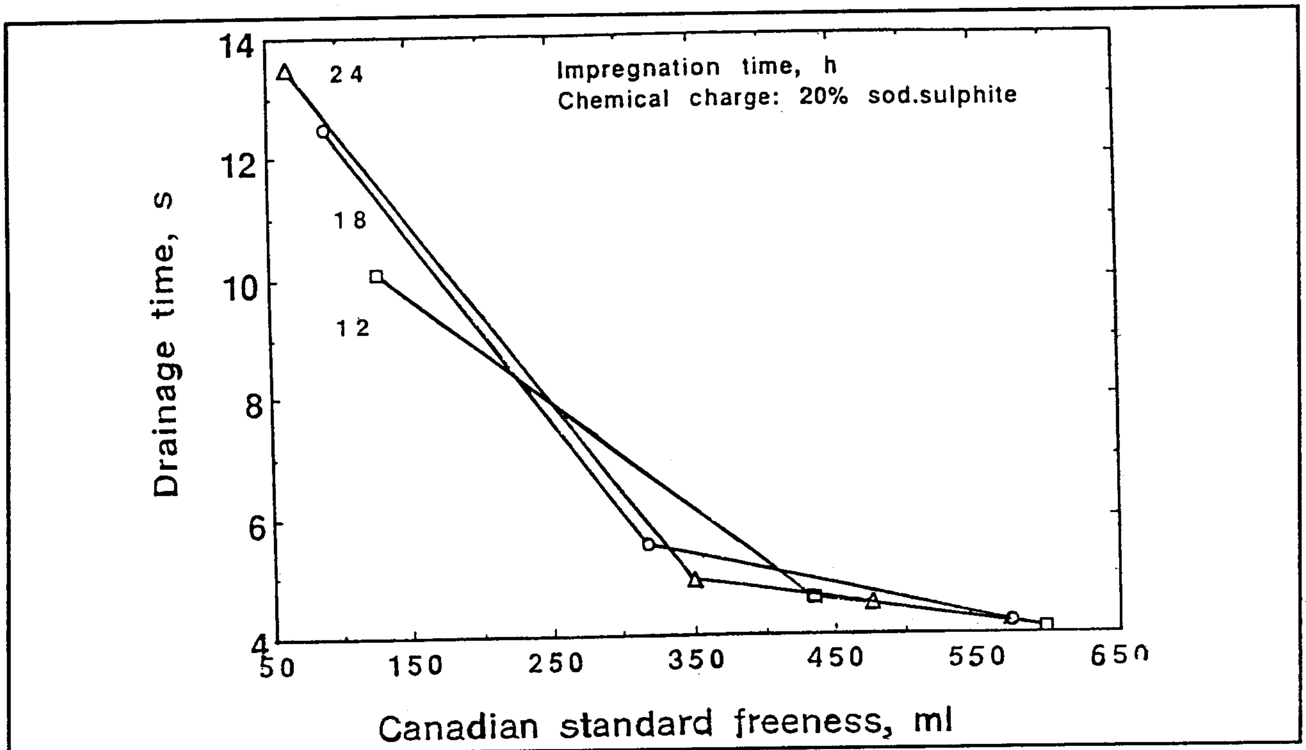

Fig. -12 Drainage time as a function of Canadian Standard Freeness with impregnation as a parameter.

case of sod. sulphite alone. Opacity - CSF relationship predicts that the hydroxide gives the lowest whereas only sod. sulphite without any chemicals - the highest. The order is as follows: no.extra c.c. >bicarbonate>carbonate>Hydroxide.

INFLUENCE OF SECONDARY CHEMICALS, CHEMICAL CHARGE AND TEMPERATURE ON PULP PROPERTIES

Figs. 15-19 indicate the variation of bulk, tear index, breaking length and the optical properties viz, scattering coefficient and opacity when the secondary chemical charge (NaOH) changes at a particular temperature (190°C) keeping the primary charge (sod. sulphite=40%) constant. To examine the effect of change of temperature a set of experiment has been conducted at the same chemical charge (sod. sulphite = 40%; 2.5% NaOH). From the inspection of data it reveals that higher the sec. chemical charge lower is the bulk, higher the breaking length. But the tear has in different behaviour which practically do not changes at 2.5% and 5% charge while remains at the lowest position for the charge without secondary chemical addition. Decrease of temperature at the same charge gives lower tear index, slightly higher bulk, and marginally lower breaking length. The light scattering coefficient becomes highest without any seconary chemical charge and the 5% chemical charge yields the lowest. Change of temperature does not reflect any appreciable difference in these values. The same type of behaviour are displayed by the pulp in its opacity values. These are expected behaviour.

PRESENT INVESTIGATION AND PLANT/ PILOT PLANT DATA

Table-5 compare and table 6 the data from present investigations with plant data for newsprint grade CMP/CTMP pulp obtained from various reports. On closer scrutiny it reflects that steam explosion pulp presents higher strength (tear index and burst index) but marginally lower opacity, brightness and scattering coefficient value when compared to pulp produced by BELOIT-SPB process. Bulk becomes nearly equal. The data are also in good agreement with those from other processes.

COMPARISON OF EXPLOSION PULP PROPERTIES WITH OTHER EXPLORATORY INVESTIGATIONS

The pulp properties from the pesent investigation with those from parallel processes are recorded in Table-7. The process conditions are elaborated in Table-3. It is evident that the explosion pulp though

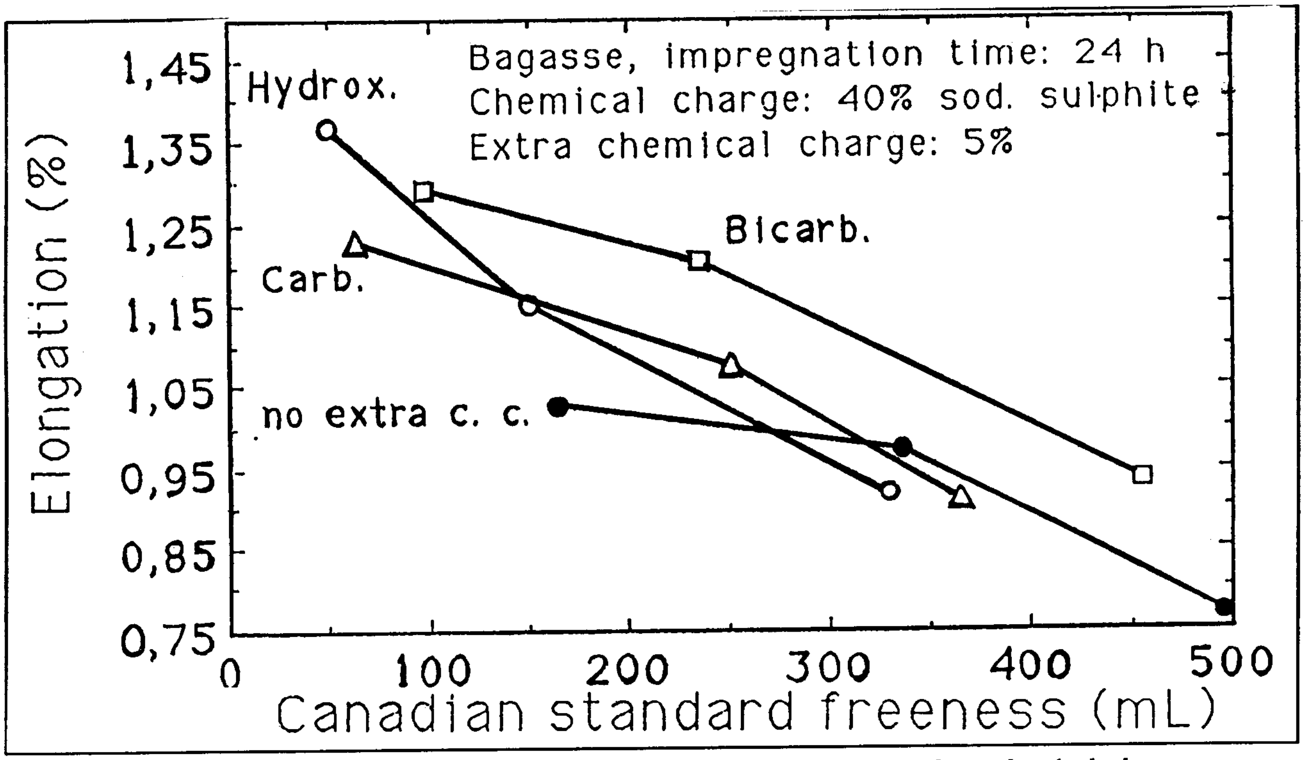

Fig. -13 Elongation-CSF relationship as a function of various secondary chemical charge.

has lower sheet density, has almost equal tear index with higher yield and brightness in comparison to those from PA and other processes. Scattering coefficient is also found to be markedly higher. The opacity values also conform to the values required for newsprint grade pulp.

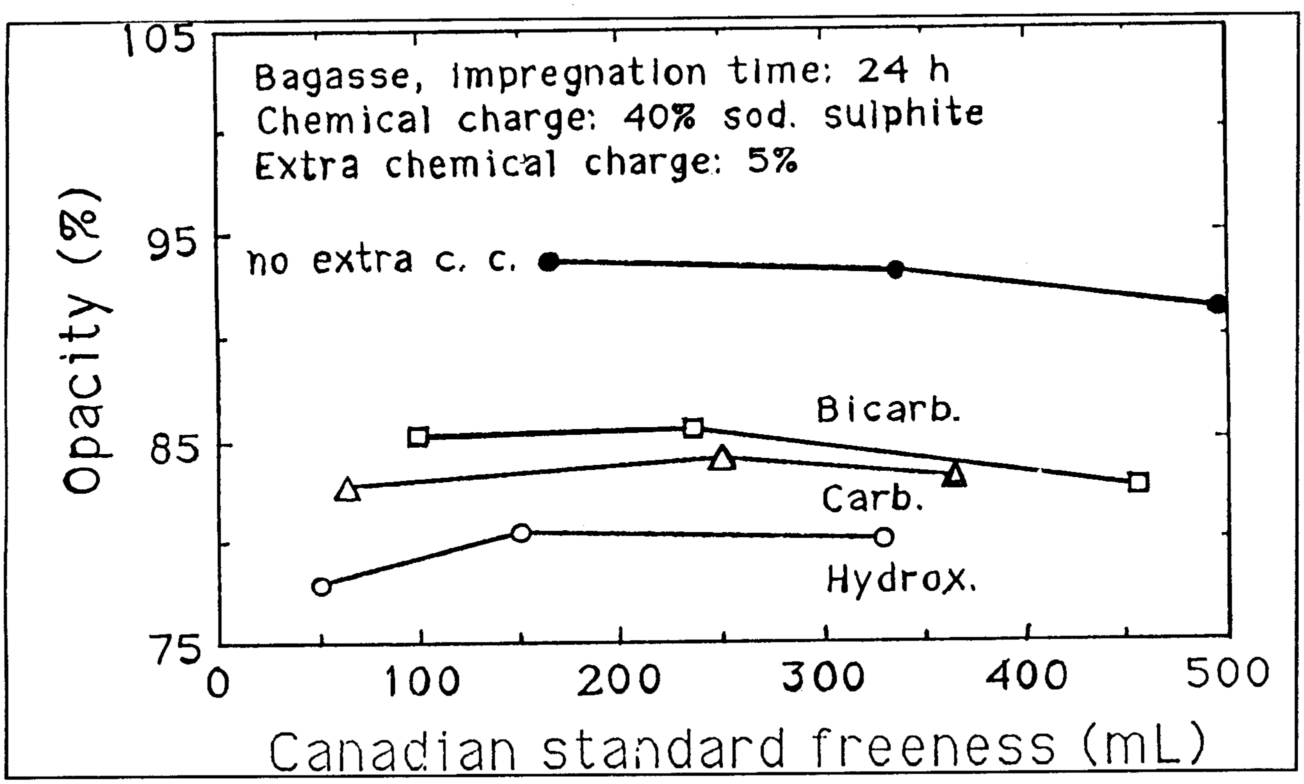

Fig. -14 Effect of Secondary Chemical Charge on opacity with CSF as Parameter.

PULP QUALITY COMPARISON WITH THOSE FROM CSIRO, AUSTRALIA

The comparison of properties and drainage time of the present pulp (B2 and B22) with those due to Mammers et al. for kraft pulp (BB1) and high pressure explosion pulp (BX) is depicted in Table-8. It is found that the present pulp compares well in terms of drainage characteristics and tear value (BX). The bulk and the strength properties are found to be inferior. This is attributed to the highly alkaline solution used in Mammers et al. work (except BX). It may be pointed out that the data of the present investigation is based on pure sod. sulphite solution. It is more importantly mentioned that alkali addition is absolute necessity for bagasse pulp. In order to examine the above the data of the relevant parameters evaluated from the pulp obtained from the use of primary and secondary chemicals are compared. As expected the addition of secondary chemicals enhances the values.

CONCLUSION

Higher percentages of sodium sulphite addition at the impregnation stage can impart the require properties of newsprint grade pulp to the explosion pulp. Further addition of secondary chemicals like sodium hydroxide, sodium bicarbonate and sodium carbonate can give better strength properties but at the cost of lower yield values. The optical properties will also be changed in some undetermined manner. To get the explosion pulp geometry of the reactor does not play a dominant role. Effect of chemical, the nature of chemical and the temperature are the critical parameters. Change of temperature with in the range of 180°C - 190°C gives marginal difference of properties in most of the situations.

Manufacture of newsprint and offset grade pulp is possible by Medium pressure (1.25 MPa) steam explosion technique at 190°C with 40% primary

Table-5 High Pressure Explosion, CMP, and CTMP Pulping Conditions of Bagasse (4, 5, 21, 23)

Ref.	Pulp	Chem. Charge, %	Impreg.		Cooking			Yield, %
			Time, h	Temp., K	Temp., K	Time, min.	Press., Mpa	
Present	B2	40% S.S.	24	333	463	2	1.55	87.0
Present	B7	40% S.S.						
		+5% C.S.	24	333	463	2	1.55	68.5
5	BX1	34.5% C.S.	-	-	453	10	13.8	52.5
5	BX2	17% S.S.	-	-	453	10	13.8	52.3
5	BX4	4.7% C.S.	-	-	473	3	13.8	53.2
5	BX3	7.4% C.S.	-	-	473	3	13.8	51.8
6	BX	-	-	-	447	30	-	51.9
6	BX5	9.03% C.S.	-	-	-	-	3.4	52.5
6	BX6	8.9% C.S.	-	-	-	-	13.8	52.3
20	BCI	42% S.S.	-	-	418	30	-	88.8
20	BC2	42% X.S.	-	-	418	45	-	83.5
20	BC3	42% S.S.	-	-	438	30	-	68.0
21	CM	2% P.A.	1	-	443	5	-	82.3

Note: S.S.= Sodium Sulfite; C.S.=Caustic Soda

***5 mins heat up peroid.**

Table-6 Comparison of Present Results with Other Semi-Industrial/Industry Trials for Mechanical Bagasse Pulp (22-23)

Parameters	Mills				
	1	2	3	4	5
C.SF, ml	250	390	100	78	241
Density, kg/m³	300	251	470	-	260
Tear Index, mNm²/g	3.9	2.2	3.9-4.4	6.1	5.75
Tensile Index, Nm/g	-	-	30	-	-
Breaking Length, km	-	-	2.49	4.08	2.91
Elongation, %	-	-	1.8	-	-.95
Burst Index, kPam²/g	0.9	0.5	1.96	-	1.1
Brigthness, %	45	42	40-50	39.5	39.2
Opacity, %	95.3	97	90	-	91.9
Scat. Coeff., m²/kg	46	44	38-40	-	30.4

Note: 1: Beloit-SPB; 2: Peadco; 3: Cuba-9 (CMP, Soda Sulfite); 4: C.E. Bauer (CTMP, Soda Sulfite); 5: Present Investigation (40% Sod. Sulfite, 12 h Impregnation Time)

chemical (sodium sulphite) impregnation charge with 12h steping time and addition of 2.5% dosages of sod based chemicals can produce the potential pulp.

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Table-7 Comparison of Pulp Properties for Different Processes

Parameters	Explosion (Present, 40% Sod. Sulfite, 24)	Cold Soda	Processes Alkaline Sulfite	Alkaline Peroxide (23)
C.SF, ml	165	150	200	140
Density, kg/m³	290	424	380	416
Tear Index, mNm²/g	4.29	4.3	2.9	4.5
Tensile Index, Nm/g	-	35.9	24.3	
Breaking Length, km	3.1	-	-	3.4
Elongation, %	1.03	-	1.8	-
Burst Index, kPam²/g	1.16	-	-	-
Brigthness, %	42.7	30	30.5	29
Opacity, %	93.6	-	-	99.8
Scat. Coeff., m²/kg	37	-	-	23.8
Yield, %	87	85	84	82.3

Table-8 Comparison of Hand Sheet Properties Bewtween Present Investigation and others (4, 5)

Pulp	CSF, ml	Drainage time,s	Bulk, cm ³/g	Tear Index,m Nm²/g	Breaking Length,k m	Burst Index,kP am²/g	Brightne ss,%
B_2	495	4.4	4.53	5.0	1.56	0.56	42.1
Bx_5	5514.8	1.61	7.7	4.6	3.5	27.6	
BX_6	467	5.1	1.57	8.2	4.8	3.9	27.6
BB_1	430	5.3	1.63	7.9	5.5	3.7	23.3
BX	-	-	1.33	5.9	9.2	6.9	27.3
BX_1	473	5.0	1.73	8.1	3.4	3.4	35.5
BX_3	519	5.2	1.66	9.2	5.4	3.8	35.5
BX_4	527	5.0	1.69	7.9	5.0	3.6	30.0
BX_{22}	472	5.2	3.90	6.4	2.04	0.76	40.1

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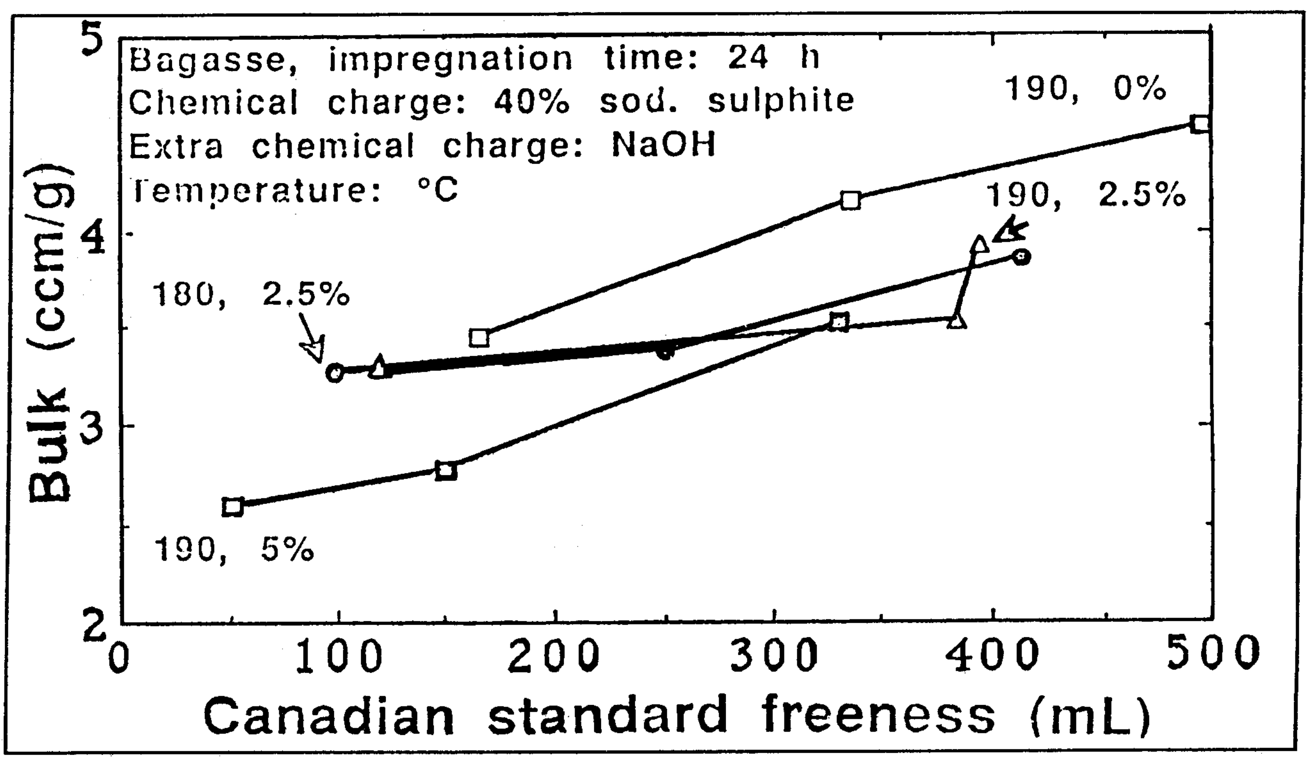

Fig. -15 Bulk-CSF relationship as a function of Secondary Chemical Charge and Temp. of Explosion.

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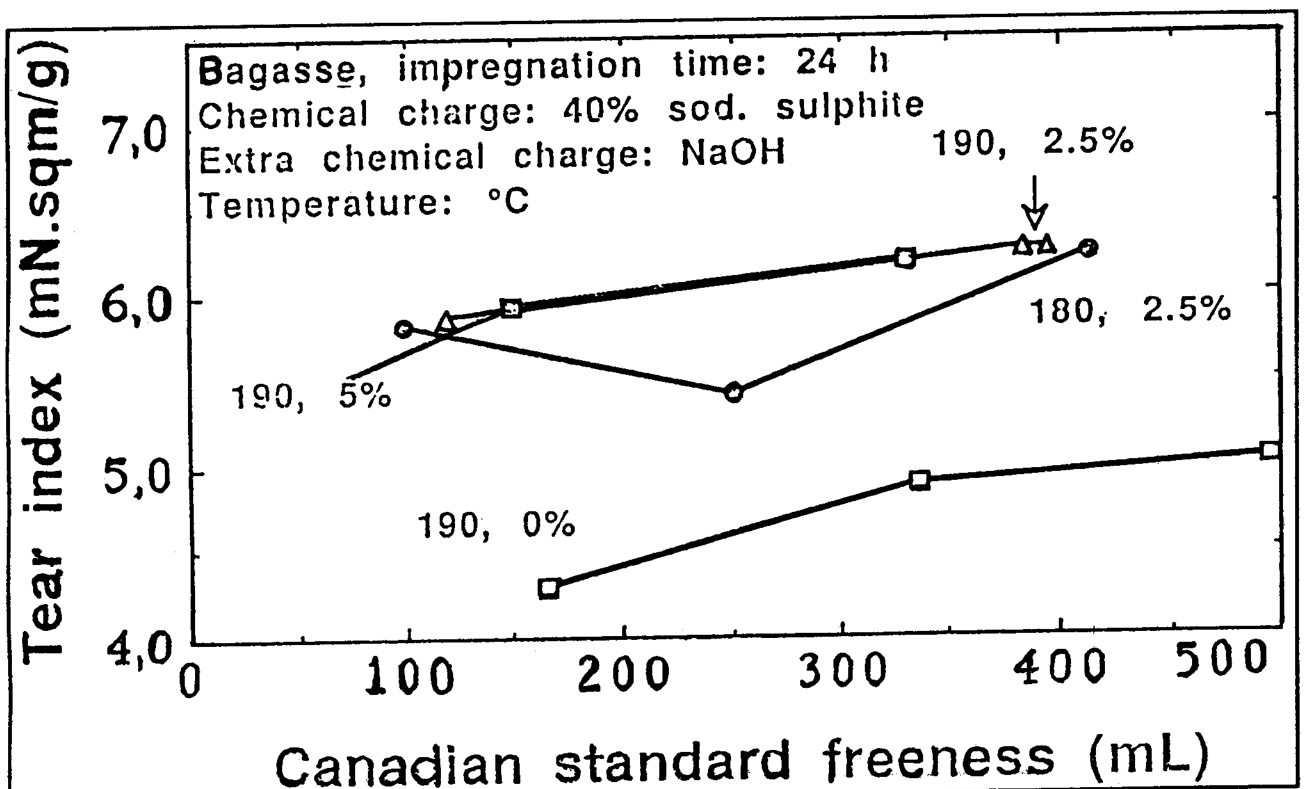

Fig. -16 Tear-CSF relationship and the effect of secondary chemical charge and temperature of explosin.

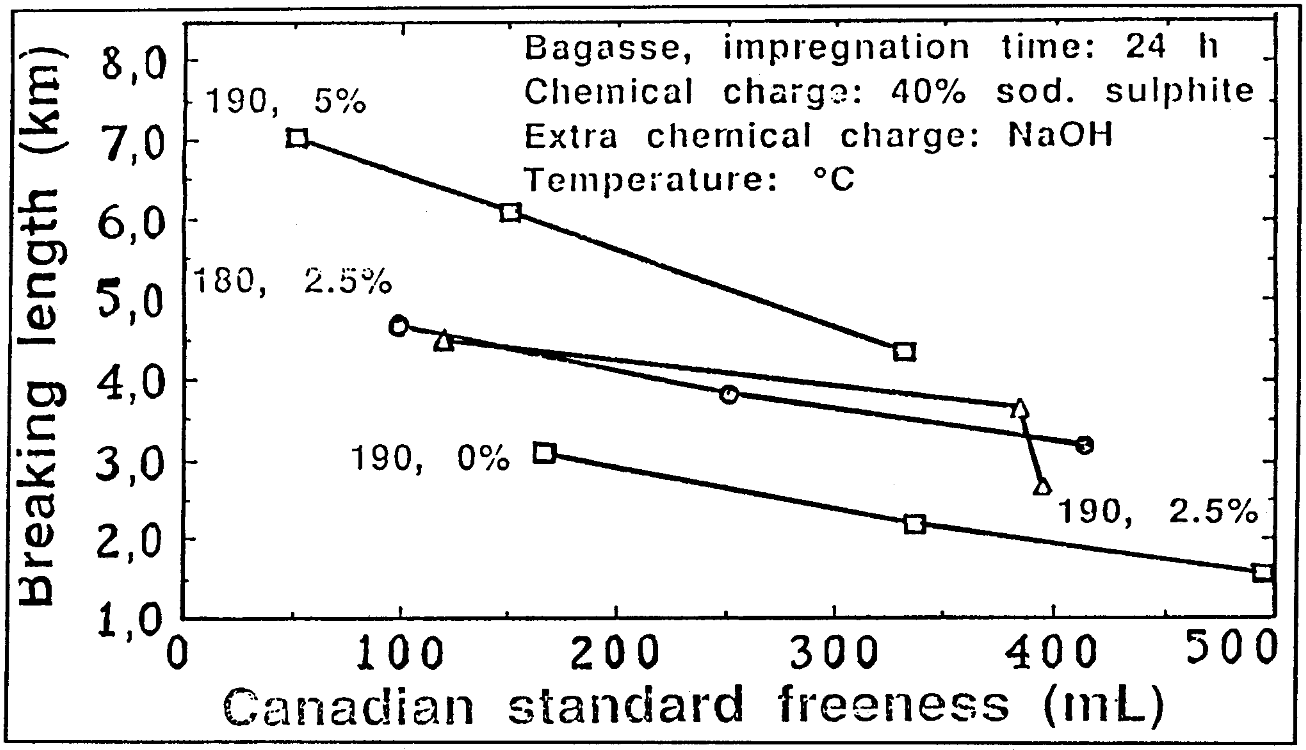

Fig. -17 Breaking length as a function of CSF with varying secondary chemical charge and temperature of explosion.

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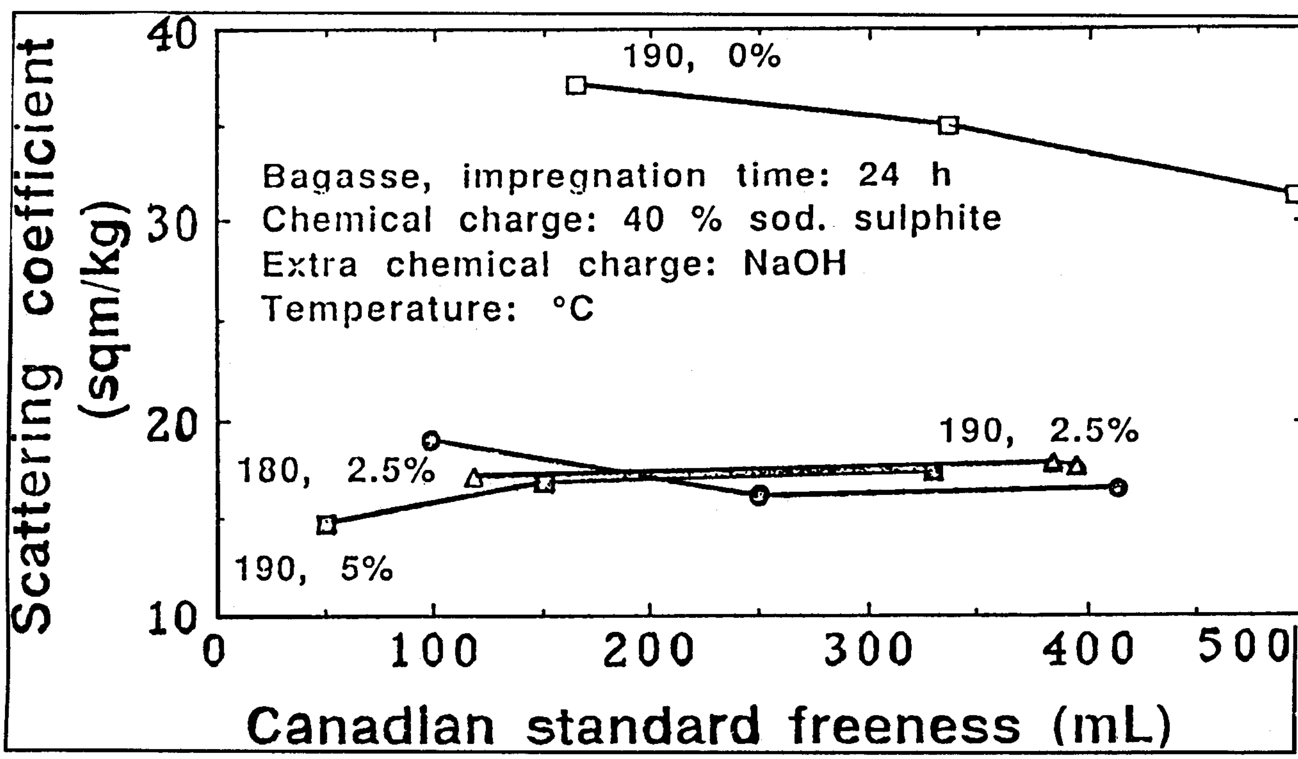

Fig. -18 Relationship of scatering coefficient and CSF as a function of secondary chemical charge and temperature of explosion pulping.

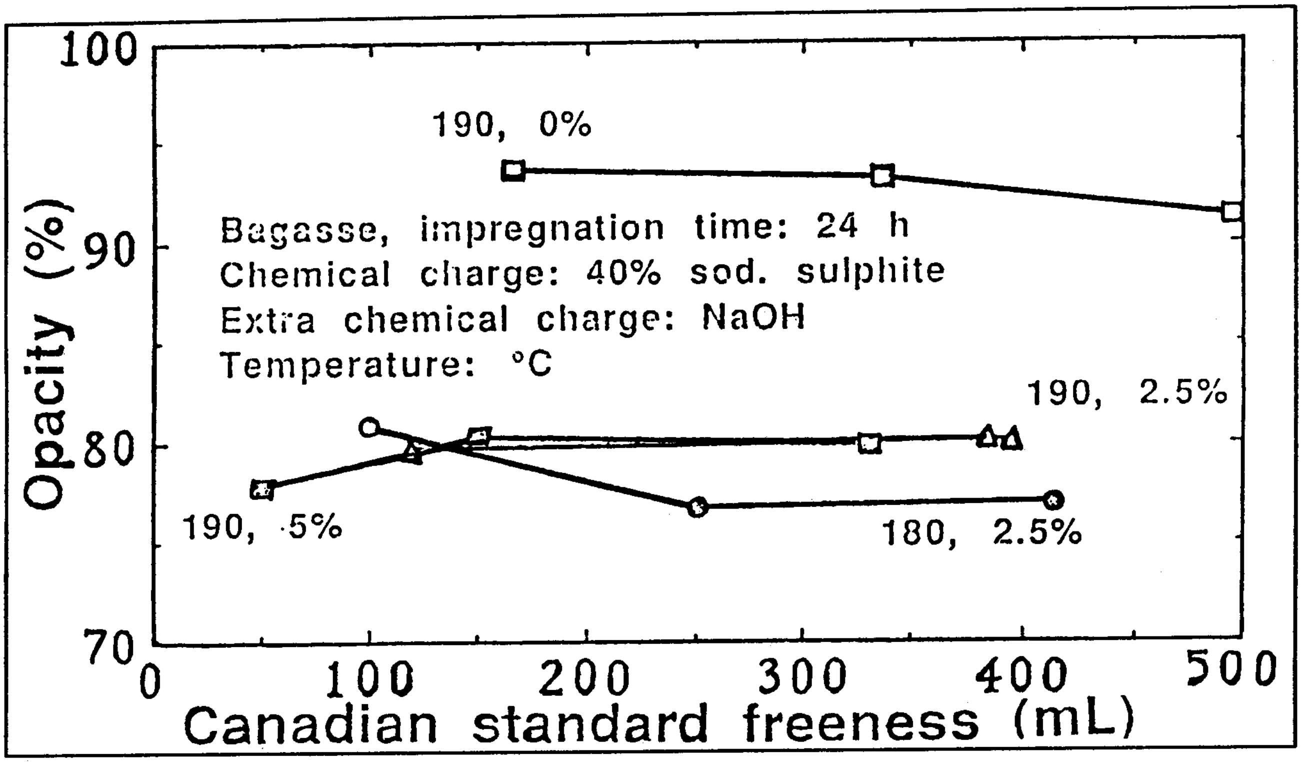

Fig. -19 Opacity as a function of CSF with varying secondary chemical charge and temperature of steam cooking.

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