Mesta/Kenaf as Raw Material For Kraft Pulping

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SUMMARY

In recent years, the shortage of conventional raw materials for pulping has intensified a world-wide search for alternate raw materials. Among other cellulosic materials, attention has focussed on agricultural residues and annual plants. In this category, Kenaf, also called Mesta, has been studied as a fibre source in many countries including the USA, Phillippines and India.

The West Coast Paper Mills Ltd. are at present engaged in the evaluation of various agricultural residues as a part of their R & D activities in the area of alternate cellulosic raw materials. As a part of this investigation, a comprehensive study on kraft pulping of mesta was carried out where the fibre morphology, pulping, bleaching and papermaking characteristics were investigated. Black liquor properties were also determined. The results of this study have been reported in this paper in comparison to the conventional raw material bamboo.

The present investigation has shown that mesta is easily pulped and bleached and forms sheets of excellent strength properties, comparable to or better than bamboo pulps.

The black liquor from mesta is similar to bamboo in calorific value but is very low in silica, which is highly desirable from chemical recovery point of view.

As with all agricultural residues and annual plants, mesta has a high bulk per unit weight. The problems arising from this, viz., baling, transportation, proper utilisation of digester capacity have to be tackled before mesta can be widely accepted in the paper industry.

INTRODUCTION

Kenaf is one of the annual plants which has captured world attention and has been extensively investigated for its papermaking properties and economic utilisation. Strictly speaking, Kenaf refers to the Hibiscus cannabinus species although Hibiscus sabdariffa (Roselle) is also referred to as Kenaf (1). Another common name used in India is "Mesta". Series of articles has been published in Tappi on the evalution of this raw material and it has been given a five point(excellent)rating by the Northern Regional Researeh Laboratory, Peoria, Ill., USA (2). This rating covers botanical aspects, chemical composition, fibre dimensions, individual inspection and maceration yield. A similar rating has been assigned to bamboo.

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The Regional Research Laboratory, Jammu-Tawi procured some improved strains to test the feasibility of growing these in India (3). Some varieties were reportedly subject to rot fungus attack. The acclimatisation and evaluation was done under Jammu conditions. However, studies in U.P. have shown that Kenaf can grow under a wide variety of conditions, and it can be grown successfully as an intercrop in eucalyptus plantations of 2-3 years of age (4). Articles about the availability, growth factors and pulping studies of these species have appeared in the Indian journals (1, 3, 4 and 9).

The present study is a part of extensive studies on agricultural residues/annual plants in progress at the West Coast Paper Mills Ltd. and was undertaken to evaluate in a comprehensive way the technical feasibility of utilisation of mesta. The raw material was obtained from Mahrashtra.

RAW MATERIAL

Mesta is an annual crop which takes about 6-8 months for full growth. The height of the

stems often reaches 5 to 6 metres with a basal diameter of 5 cms (5). About 13-22 tonnes of Kenaf can be produced per hectare of land. McGovern reported that the application of fertiliser of 225, 450 and 675 Kgs/ha gave yields of about 27, 29 and 40 tonnes (6). Traditionally it is grown as a crop fibre for the manufacture of twine and rope of the bast fibre with a yield of about 20% on weight of the stalk. The bast fibre content of Kenaf ranges from 18-29% (7). The bast fibres are longer (fibre length of 2.5 mm) than those of woody material, which are, on the average, 0.58 mm (8). The bast portion normally gives a higher yield than the woody portion and hence the final pulp contains 30-40% bast pulp. This is useful for the improvement of lower quality pulps by blending.

The material used for this study had been planted just before the first monsoon showers. The period of growth was 5-6 months. The average height of the plants was 2 metres and the plants had been harvested before flowering. The availability of the raw material in that area is reported to be 200-300 tonnes/season which, it is expected, can increase to 1500-2000, tonnes if there is an adequate demand.

The cost of raw marerial as reported in literature is about Rs. 200/- per A.D. M.T. (4). In countries like U S.A. the cost of Kenaf is comparable to wood. In a cost study it had been found that the cost of mill delivered Kenaf was slightly lower than that of Southern pine chips (6). It has been estimated that in U.S.A., a 100 t.p.d. bleached pulp plant could utilise the productions of 610-810 hectares of land (8).

Kenaf has also been found useful for producing thermo-mechanical pulp (10).

EXPERIMENTAL

I. The physical properties of mesta sticks tested are reported below :

(a) Moisture, %	.....	12
(b) Length. cms.	.....	100
(c) Maximum diameter, cms.	.....	2.5
(d) Minimum diameter, cms.	.....	0.3
(e) Bast fibre, %	.....	37.0

II. CHEMICAL CONSTITUENTS OF MESTA

Representative sample of Mesta as such-whole stalk-was taken and powdered to pass through 40 mesh in a Wiley mill (Tappi Std. T 11m—59). All the chemical analyses were carried out as per Tappi Standards. The results are recorded in Table I. The values of bamboo chemical constituents are included for comparison.

III. PULPING AND SHEET MAKING

Mesta sticks were cut manually into chips of 3—4 cm length. The bulk density of the chips was found to be 127 Kg/m^3 at 10% moisture which is low compared to bamboo for which bulk density is around 250 Kgs/m^3. Owing to its lower weight per volume or higher bulk, the liquor to wood ratio was optimised before the chemical optimisation. Cook number 1 to 4 (Table II) employed varying liquor to wood ratio, viz., 3.5:1 to 7:1. In these cooks, the chemical charge was kept constant at 16% active alkali as Na_2O on wood. Considering the kappa number or lignin content of the pulp, total yield and the residual active alkali it became apparent that 5:1 is the optimum liquor to wood ratio.

Four more cooks with varying the alkali charge, were carried out keeping all other conditions same and liquor to wood ratio of 5:1. This showed a topical pulping curve with maximum screened yield at 16% active alkali as Na_2O. With higher charge the kappa number did not show a drop but the yield did. At lower charge, the total yield was a little higher (52. 7% at 14% A.A.) due to increase in screenings. Hence the bomb cook studies showed 16% active alkali at 5:1 liquor to wood ratio to be optimum. The 'H' factor of 1065, gave a pulp of satisfactory kappa number and hence it was retained as the other optimum condition. The results of these experiments are presented in Table No. II. These cooks were carried out in autoclaves of 2.5 litre capacity and the temperature was adjusted by thermostat controlled polyethylene glycol bath. The maximum temperature chosen was 165°C.

With the above optimum conditions larger scale digestion was carried out in a 16 litre

TABLE-I PROXIMATE CHEMICAL ANALYSIS OF MESTA AS COMPARED TO BAMBOO (—40 MESH)

Particnlars	Mesta	Bamboo (D. Strictus)
1. Cold water solubility, %	6.8	2 9
2. Hot water solubility, %	8.6	5.8
3. Alcohol benzene solubility, %	3.0	4.3
4. 1% NaOH solubility, %	30.2	24.0
5. Lignin,, %(ash corrected)	18 0	26 6
6. Pentosans, %	17.9	17.7
7. Holocellulose, % chlorite method	66.8	67.3
8. Ash, %	4 2	4.07
9. Silica, %	0.14	2.53

TABLE–II SULPHATE PULPING OF MESTA (WHOLE STALK) AND BAMBOO

Particulars	Bomb Cooks								Rotary Digester	
	1	2	3	4	5	6	7	8	Mesta	Bamboo (D. strictus)
Active alkali as Na_2O, %	16.0	16.0	16.0	16.0	14.0	15.0	16.0	17 0	16.0	17 5
Liquor to wood ratio	3.5:1	5:1	6:1	7:1	5:1	5:1	5:1	5:1	5:1	2.7:1
Cooking Schedule :										
70-165°C., Min.	90	90	90	90	90	90	90	90	90	*
At 165°C., Min.	90	90	90	90	90	90	90	90	90	–
'H' factor	1065	1065	1065	1065	1065	1065	1065	1065	1065	780
Unbleached pulp yield, %	48 5	49.6	49.5	49.9	52.7	49.2	49.6	48.5	48.1	51.0
Kappa number	18.4	19.7	20.4	21.4	35.8	22.7	20.3	19.7	20.5	20.8
Unbleached pulp viscosity, cp. (CED)	41.8	47.5	47.0						54.5	
Residual aetive alkali as Na_2O,gpl	2,8	3.1	3.2	3.1	1.8	3.5	3.6	5.3	5.6	9.o

* Cooking schedule : 70° - 120°C., Min. 45
at 120°C , Min. 60
120° - 170°C., Min. 90
at 170°C., Min 30

TABLE III BLEACHING OF MESTA AND BAMBOO PULPS

Particulars	Mesta	Bamboo (D. strictus)
Kappa No. of unbleached pulp	20.5	25.1
Viscosity, cp. (CED)	54.5	20.1
Chlorination :		
Chlorine added, %	4.0	6.0
Chlorine consumed, %	3.96	5.63
Alkali Extraction :		
NaOH added, %	1.75	1.6
Final pH	10.8	9.6
Hypochlorite Stage 1 :		
Chlorine added, %	1.0	2.5
Sulphamic acid on pulp, %	0.15	0.15
Chlorine consumed, %	0.84	2.41
Hypochlorite stage 2 :		
Chlorine added, %	...	1.25
Sulphamic acid on pulp, %	...	0.05
Chlorine consumed, %	...	1.05
Total Chlorine added, %	5.0	9.75
Total Chlorine consumed, %	4.8	9.10
Shrinkage, %	7.8	6.00
Bleached pulp yield, % on chips	44.5	45.2
Brightness, % (Elrepho)	79.2	79.0
Viscosity, cp. (CED)	17.5	8.7

Constant Conditions :	**Consistency %**	**Temperature °C**	**Time Min.**
Chlorination	3.0 (3.0)	30 (28)	60 (45)
Alkali Extraction	5.0 (5.0)	55 (55)	60 (60)
Hypo I	10 (10)	45 (45)	90 (180)
Hypo II	(10)	(45)	(90)

Data in parentheses refer to bamboo bleaching conditions,

Rotary digester electrically heated and tumbling at the rate of 2.5 rpm. The cooked chips were defibred in the Sprout Waldron disc refiner at a plate clearance of 25 thou. These results are also included in the above table.

Mesta pulp was found to be easily bleachable. With a three stage CEH bleaching employing only 5.0% total chlorine, 80% Elrepho brightness pulp was obtained. The bleaching characteristics are given in Table III.

The behaviour of the black liquor was investigated by concentrating it in a rotary vacuum flash evaporator to different total solid concentrations and testing for Brookfield viscosity. The spindles for the viscometer were chosen so as to get the readings in the 30-70% of full scale deflection at 30 rpm. The viscosity values were evaluated at 80, 90 and 100°C and are recorded in Table IV. The values for bamboo and eucalyptus liquors are also included for comparison.

The black liquor was analysed for its chemical constituents and the data are provided in the Table No. V. The values for a typical bamboo black liquor are included for comparison.

The unbleached and bleached pulps were beaten in laboratory Hollander "Valley" beater to various slowness levels and standard handsheets of 60±1 gsm basis weight were made on the British Sheetmaking Machine. After conditioning, the sheets were tested for their physical properties. The strength values are reported in Table No. VI and those of bamboo pulps are included for comparison.

The unbleached and bleached pulps of Mesta were subjected to Bauer McNett fibre classification using 14, 30, 100 and 150 mesh screens. The results have been presented in Table No. VII.

Detailed morphological studies were undertaken and the values are given in Table VIII.

DISCUSSION

I PHYSICAL CHARACTERISTICS :

The sample of Mesta was found to contain 37% bast portion which seems to be a little higher than most of the values reported in the literature. This could be due to the local variations in growth, but it is important to note that this particular sample consisted of plants growing to the height of 2 metres with basal diameter of 2.5 cms. However, Kenaf in other places can reach a height of 5-6 metres, about three times longer by comparison and a basal diameter of 5 cms. Obviously, as the width and the height increase the contribution by the woody portion increases, thus reducing that of the bast portion.

II CHEMICAL CONSTITUENTS :

From the data provided in Table I it can be inferred that the cold water, hot water, and 1% NaOH solubility of Mesta are considerably

TABLE IV COMPARATIVE BROOKFIELD VISCOSITY DATA ON THE SULPHATE BLACK LIQUORS OF MESTA, BAMBOO AND EUCALYPTUS

Total Solids,	Viscosity cp. of Mesta black liquor at			Viscosity, cp. of Eucalyptus black liquor at			Viscosity, cp. of Bamboo black liquor at		
%	80°C	90°C	100°C	80°C	90°C	100°C	80°C	90°C	100°C
45	10	9 (5)	8	14	10 (1)	7	8	6 (1)	6
50	19	17 (1)	14	35	23 (1)	16	14	10 (1)	8
55	38	33 (1)	27	130	70 (1)	44	31	21 (1)	16
60	92	77 (1)	61	600	270 (3)	140	74	47 (1)	36
65	320	250 (3)	160	4000	1300 (4)	530	200	120 (2)	92
70	5200	3300 (4)	1 700	...	...	...	...	...	...

N. B. : Numbers within brackets refer to the spindle type used.
Spindle speed 30 rpm Brookfield Viscometer.
Spindle type 1 LV1
2 LV2
3 LV3
4 LV4
5 U. L. adapter

higher than those of bamboo. Holocellulose content compares with that in bamboo. Lignin content (72% H_2SO_4) is much less than in bamboo and silica content of 0.14% compared to 2.53% in bamboo shows a very good advantage in the chemical recovery. The scale problem in the evaporator and the difficulties usually encountered in the recovery of lime from lime reburning are expected to be substantially reduced. It is interesting to note that even-though silica is less, ash is a little higher than in bamboo.

III. PULPING, BLEACHING AND BLACK LIQUOR CHARACTERISTICS

Owing to the high bulk of the material, it is expected that the liquor to wood ratio would be high. Even with this high bath ratio, it is seen that the charge of active alkali is 16% showing that the material is easily pulpable. The kappa number of the pulp was 20.5 and the yield 48.1%, with the unbleached pulp viscosity 54.5% cp. (CED). For a similar kappa number, bamboo needs 1.5% more alkali, about 27% lower H-factor and produces 3% higher pulp yield.

From Table III. it is seen that unbleached pulp of Mesta could be bleached by three stage CEH sequence. The total chlorine demand was 5,0% for Elrepho brightness of 80 ± 1%. The bamboo pulp taken for comparison had a somewhat higher kappa number, Viz., 25 1. This needed 9.1% total chlorine and a CEHH-4 stage sequence to reach 80 ± 1% brightness. The total chlorine requirement for bamboo pulp at the same kappa number as the mesta pulp would be in the region of 7%. Further, the unbleached and bleached viscosities of mesta pulp can be observed to be higher than that of bamboo pulp. Hence, it may be concluded that, (i) mesta pulp can be bleached in only 3 bleaching stages to 80 ± 1% brightness as opposed to 4 for bamboo pulp.

(ii) The total chlorine requirement is less than bamboo pulp and

(iii) Viscosity of mesta pulp is higher compared to bamboo pulp.

From the Table IV & V and Figure 1 it is observed that black liquor characteristics of Mesta compare well with those of bamboo with respect to Brookfield viscosity and calorific value. Silica content of mesta black liquor was found to be low

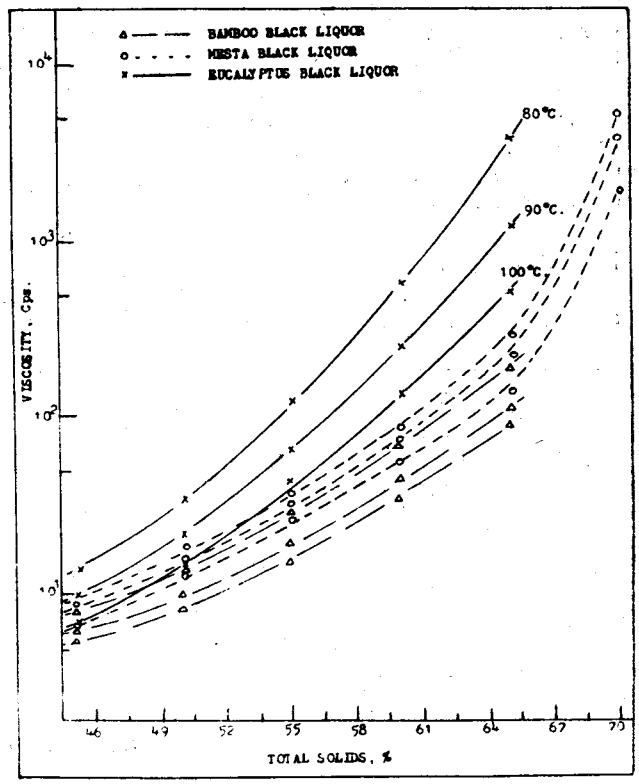

FIG 1 VISCOSITY - TOTAL SOLIDS RELATIONSHIP

TABLE-V CHARACTERISTICS OF MESTA SULPHATE BLACK LIQUOR COMPARED WITH THOSE OF A TYPICAL BAMBOO SULPHATE BLACK LIQUOR

Particulars*	Mesta	Bamboo
NaOH as Na_2O	0.67	2.0
Na_2S as Na_2O	1.67	0.5
Na_2CO_3 as Na_2O	11.35	13.8
Total sulphur as Na_2SO_4	2.91	6.9
Inorganics as NaOH	34.7	34.0
Organics	65.3	66.0
Silica	0.44	4.5
Calorific value, Cal./g.	3,330	3,280

*Components as % T.S.

as expected. There was no granulation problem while concentrating mesta black liquor.

IV. MORPHOLOGICAL STUDIES

The bast and woody portions were separately macerated with acidic sodium chlorite with gentle mechanical stirring by the use of magnetic stirrer (2). The fibres were well separated with a few treatments in case of bast but more chlorite treatment and defibration with a high speed blunt agitator were needed in separating the woody fibres. When seen under the microscope however, hardly a few woody fibres were noticed to have been cut. These were neglected during the course of measurement.

The bast fibres ranged from 3.7 mm to 1.6 mm in length. The woody fibres ranged from 2 mm to 0.2 mm. The table below gives the fibre length data for the raw material :

		Bast	Wood
Fibre length	max., mm	3.68	1.92
	min., mm	1.58	0 18
arithmetic)	avg., mm	2.52	0.92

The average morphological properties of mesta were studied again using sulphate bleached pulp prepared from the whole stalk. The average fibre length was found to be 1.53 mm which is higher than hardwood fibres 0.6 to 1.3 mm but slightly lower than bamboo—D. strictus—fibres 1.75 mm. The slenderness ratio of mesta fibre was lower compared to bamboo fibre. Other derived fibre properties like T/R%, Runkel ratio and flexibility coefficient are given in Table VIII. It is evident from these data that the fibres are thin walled with large lumens. Such fibres collapse into ribbon like structures on drying and provide greater bonding area with other fibres. The resultant sheets are thus strong. In this respect the mesta fibres can be seen to be better than those of bamboo.

V. PROPERTIES OF PULP SHEETS

From the Table VI it is observed that the initial slowness of mesta pulp was 25 °SR whereas that of bamboo pulp was 20 °SR, However, further beating characteristics of this pulp were similar to that of bamboo pulp. The drainage time of

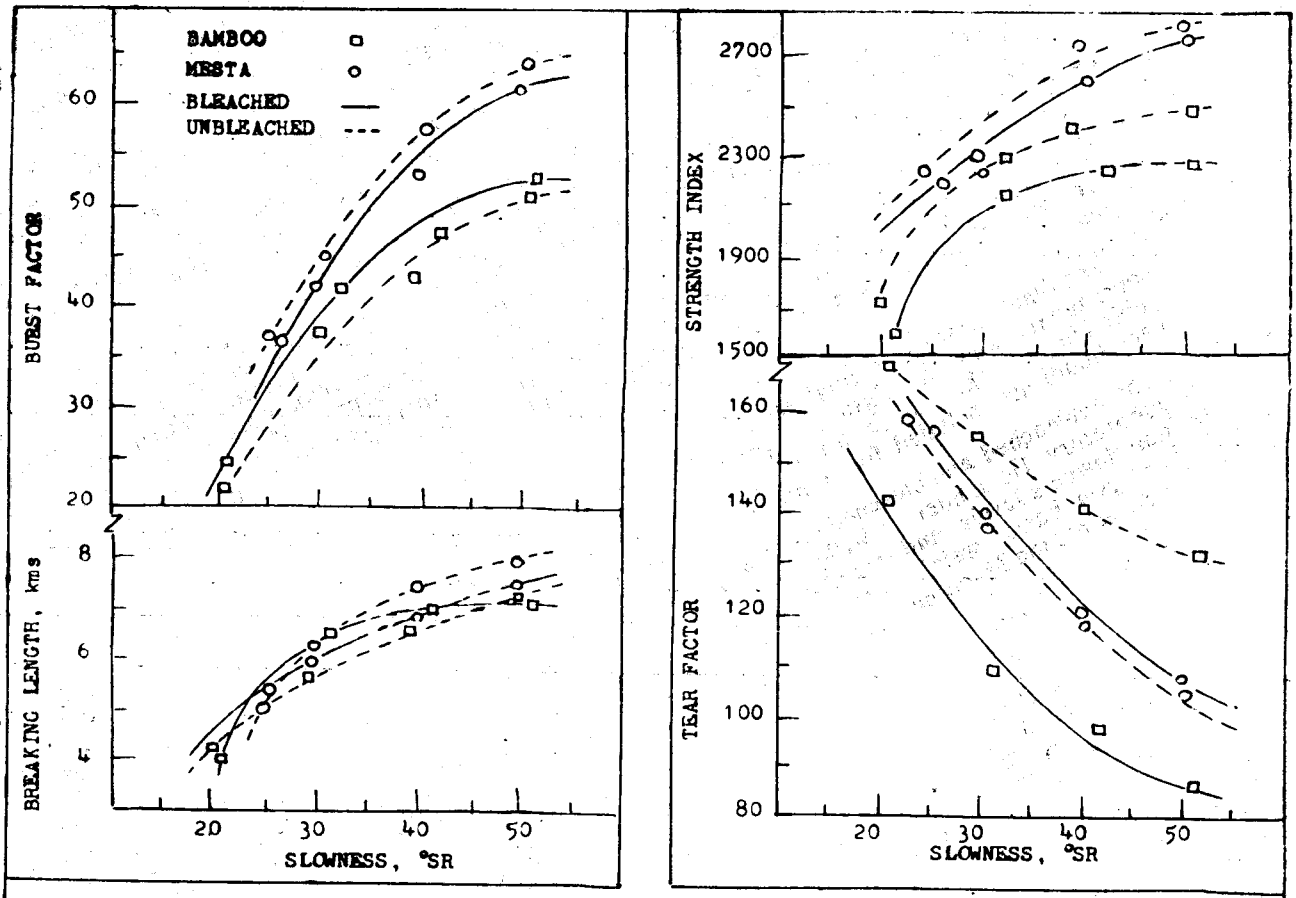

FIG. 2 - STRENGTH PROPERTIES OF PULPS

TABLE–VI STRENGTH PROPERTIES OF UNBLEACHED AND BLEACHED MESTA PULPS AS COMPARED TO THOSE OF BAMBOO PULPS

	Mesta pulp									BAMBOO (D. strictus)						
	Unbleached				Bleached					Unbleached				Bleached		
Kappa No.	20.5									25.1						
Viscosity, cp. (CED)	54.5				17 5					20.1				8.7		
Initial slowness, °SR	25	25	25	25	26	26	26	26	20	20	20	20	19	19	19	19
Final slowness, °SR	25	30	40	50	26	30	40	50	20	29	39	51	21	32	42	51
Beating time, Min.	0	2	6	9	0	1.5	4.5	7.5	0	5	8	11	1	5.5	9	12
Drainage time (700 ml) sec.	15 0	20.0	40.0	60.0	15.0	20.0	40.0	60.0	14.8	23.5	32.6	54.1	10.1	23.4	37.5	59.2
Bulk, cc/g.	1.8	1.6	1.55	1.40	1.60	1.55	1.50	1.40	1.95	1.79	1.70	1.63	1.82	1.62	1.53	1.47
Breaking length kms.	5.06	6.3	7.5	8.0	5.45	6.0	6.8	7.5	4.3	5.83	6.72	7.30	3.96	6.60	7.02	7.23
Stretch, %	2.3	2.6	3.1	3.6	3.6	3.7	3.6	3.6	2.0	2.5	2.8	3.0	2.5	3.2	3.1	3.1
Tear factor	160	139	119	106	157	141	121	109	171	157	143	134	143	110	97.5	86.2
Burst factor	37.4	45.0	58.0	64.5	37.2	42.0	53,0	61.5	21.8	38.0	43.6	48.0	24.5	42,5	47.5	51.3
Double folds (MIT)	79	85	1000	1800	66	90	450	1150	24	108	183	250	15	104	196	276
Porosity, ml/min	220	90	25	10	115	65	20	10	1670	300	130	80	2900	700	260	120
Strength index	2250	2300	2760	2820	2210	2270	2580	2750	1720	2295	2420	2490	1590	2120	2200	2220

TABLE VII–COMPARISON OF BAUER McNett FIBRE CLASSIFICATION DATA OF UNBEATEN PULPS OF MESTA AND BAMBOO

	Mesta Pulp		Bamboo Pulp (D. strictus)	
	Unbleached	Bleached	Unbleached	Bleached
Slowness, °SR	25	26	20	19
Fraction	Weight, percent			
+ 14	16.6	12.2	37.8	38.7
— 14 + 30	20.1	22.5	13.2	16.5
— 30 + 100	14.2	9.6	8:2	5.2
— 100 + 150	27.0	30.2	8.6	6.5
— 150	23.1	25.5	32.2	33.1

TABLE VIII–FIBER MORPHOLOGY AND DERIVED RELATIONS OF MESTA AND BAMBOO PULPS

		Mesta	Bamboo (D. Strictus)
1.	Fibre length (L), mm		
	(a) average	1.53	1.75
	(b) maximum	5,62	...
	(c) minimum	0.35	...
2.	Fibre width (D), μ	28.0	15 5
3.	Lumen width (1), μ	18.0	5.5
4.	Cell wall thickness, (T), μ	5 0	5.0
5.	T/R ratio (R-radius of the fibre)	35.7	64.5
6.	Slenderness ratio (L/D)	54 7	113.0
7.	Runkel ratio (2T/1)	0.556	1.82
8.	Flexibility coefficient $1/D \times 100$	64.3	35 0

mesta pulp was nearly the same as that of bamboo polp at the same level of slowness, The graphical representation—Fig, 2 - of various strength values of mesta and bamboo pulps shows that breaking length, burst factor and strength index of unbleached pulp of mesta were higher than those of unbleached bamboo pulp, except tear factor which was comparatively lower. However, the tear factor of bleached mesta pulp was higher than that of bamboo bleached pulp. The breaking length values of bleached pnlp of mesta and bamboo were very similar. Burst factor and strength index of mesta bleached pulp were higher than those of bleached bamboo pulp, The double fold values of unbleached as well as bleached pulp of mesta were very high, compared to those of bamboo pulp.

VI. FIBRE CLASSIFICATION RESULTS.

The results of Bauer McNett fibre classification Table VII—show that the long fibre fraction, +14, is less in mesta pulp than in bamboo. However, the −14+30 fraction is more for the former. This confirms the results of the fibre length determination on whole mesta pulp which showed that bamboo pulp had a longer average fibre length than mesta.

With regard to the fines in the pulp,—100 fraction this is considerably more in mesta than in bamboo. This fact will be important for the commercial utilisation of mesta. Special attention may be necessary in the design of washers, paper machine and other equipment.

CONCLUSIONS

1) As the bulk density of Mesta chips is almost half of that of bamboo chips the digester capacity would be reduced to half. In addition, there would be problems of collection and transportation. It is expected that proper baling in the field and utilisation of continuous digesters equipped with pressure impregnation systems would help to resolve the problems of lower bulk density.

2) Pulp of satisfactory quality was obtained from mesta chips using 16% chemicals as Na_2O at 165°C., with 'H' factor of 1065.

3) Mesta pulp could be bleached easily by CEH sequence at lower bleach requirement compared to bamboo pulp.

4) The viscosity values of unbleached and bleached pulp from mesta were higher than those of bamboo pulps.

5) The strength values of mesta pulp have been found comparable to or higher than those of bamboo pulp.

6) The black liquor characteristics of mesta were similar to those of bamboo black liquor Silica content in mesta black liquor was very low which is favourable for black liquor evaporation.

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Articles of Interest

*Shashank Bharti and Rekha Bharti**

Z STRENGTH OF MECHANICAL PULPS

M. Andersson, U. B. Mohlin

Paperi ja puu 62 (10) 583, 1980.

The studies were carried out to evolve the utility of Z strength measurement on mechanical pulp as a measure of their bonding ability. The method of Z strength measurement for chemical pulp is well established to be used as an indication of bonding in the sheet. Thirty five commercial pulp belonging to stone-ground-wood and thermo-mechanical grade, bleached and unbleached, wet and flash dried were prepared for the studies.

Evaluating the data it appeared that inter-relation between apparent density, (Kg/m^3) and Z strength in (kpa) did not change for ground wood and thermo-mechanical pulps. The effect of bleaching and drying did not also show any effect on the two parameters.

Co-relationship in between whole pulp C.S.F. in ml. and Z-strength give no direct effect but with the various fraction on Bauer-McNett classifier, gave deviation in the co-relationship between C.S.F. and Z strength.

Although freeness value of middle fraction (30-200 mesh) did not vary, the practical size distribution gave an important influence as the Z strength with the increasing amount of long fiber in the pulp, Z strength is reduced.

In order to describe different strength properties general formula used was

$$P = l^{\alpha}.z.k$$

Where

P—a strength property

l—term correlating to average fiber length.

α—Exponent indicating degree of long fiber dependence on various properties.

z—z-strength

k—Constant, specific for each strength property

In agreement with Pase's thing the exponement α for tensile index was closed to 1. Folding endurance was dependent on long fiber content whereas tear index was proportional to square of long fiber content. Combining the equation for various proportion, tear index was proportional to tensile index time long fiber content.

Comparison of scott bond add Z strength revealed the same information provided gsm of the sheet is kept constant. Fiber length distribution did not have any influence on scott bond z-strength relationship.

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