On the High Yield Pulping of Agricultural Residues For a Range of Products

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ABSTRACT

The object of this study was to evaluate pulping characteristics of bagasse, wheat straw and rice straw with the prime aim of achieving high yield pulps (65-85% Yield). Keeping chemical charge as low as possible, for making a range of products (viz., newsprint, cheap variety of printing papers. writing papers, packing papers etc.) To do so experiments on cooking with caustic soda. sodium sulphite. sodium sulphite/sodium carbonate/caustic soda. caustic soda/anthraquinone were carried out. It was found that by choosing a paper combination of chemicals and conditions of pretreatments, pulping and refining, pulps of as high as 65-85% yield could be obtained with strength properties in the range as follows : tensile index 4.0-5.5 N.m/g, tear index 3.6-4.8 mNm2/g, burst index 2.0-3.3 Kpam2/g, the chemical charge being 4-8% on raw material.

A comparison of the strength properties of these high yield pulps prepared under various combinations with those of chemical pulps (≈50% yield) did not reveal any appreciable difference. A satisfactory response of a few high yield pulps towards conventional bleaching would make these pulps suitable to produce a variety of cultural and industrial papers. Since in high yield pulps mechanical treatment is necessary to achieve fibre separation, the economies of using high yield pulps in papermaking Vis-a-vis energy requirements is important.

INTRODUCTION

Agricultural residues such as bagasse, wheat straw, rice straw etc. undoubtedly, are playing an important role in supplementing the fibrous raw material requirement of expanding pulp and pape r Industry. Based on these raw materials a number of small scale mills have mushroomed all over the country, mainly with indigenous technology. Nevertheless, there exists a large scope for innovative research to be carried out to develop appropriate technology for making more rational use of our fibrous resourcers. The problems with agricultural residue based small units, as we see to-day, are mainly centred around, pulp yield, chemical requirements, handling of spent cooking liquor, pulp drainage characteristics and sheet properties etc.

Employing conventional soda process for pulping results in low pulp yield. There is no suitable recovery system availaable at present for small scale units. Replenishment of cooking chemical with fresh one results in high operating cost and direct discharge of the spent cooking liquor in the form of effluent creates high pollution load of organic and inorganic matter. Therefore, while drawing up the research programme these areas have been taken up with great concern, so as to provide technical data for improving upon the economics of existing mills and the viability of new Units.

The object of this study was to evaluate, at the first instance, pulping characteristics of bagasse, wheat straw and rice straw with prime aim of achieving high yield pulps (65-85% yield), keeping chemical charge as low as possible for making a range of products (both cultural and industrial varieties of papers). To do so, experiments on cooking with caustic soda, sodium sulphite, sodium sulphite/sodium carbonate/caustic soda, caustic/anthraquinone (AQ) combinations were tried, the results of which are recorded and discussed in this paper.

RESULTS AND DISCUSSION

All the results reported in this paper are on depithed bagasse and dusted and water washed wheat straw/rice straw.

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SEMI-CHEMICAL HIGH YIELD PULPS

The high yield pulps from all the three raw materials (bagasse, wheat straw and rice straw) were prepared by giving a mild chemical treatment followed by mechanical separation of fibres in sprout waldron disc refiner. The variation in chemical and their percentages applied for chemical treatment and the properties of high yield pulps thus obtained are recorded in Tables 1–4. The strength properties have been interpolated at 200 ml. (C.S.F.). Table–1 gives the data on properties of bisulphite semi-chemical (BSSC) pulps (pH 4.5–5.0). tl will be seen from Table 1 that strength properties of hand sheets were better in case of wheat straw/rice straw than bagasse. The pulp yield in case of bagasse was 89.3%. The pulp from wheat straw in particular at 74.2% yield possessed good strength properties; tear index 4.14 mNm^2/g and tensile index 36 38 N.m/g. The strength prope ties of pulps from rice straw and bagasse are adequately sufficient for use in furnishes for making varieties of papers.

TABLE—1

Strength Properties of Bisulphite Semi-chemical Pulps (pH 4.5 to 5.5) at 200 ml C. S. F.*

Sl. No.	Raw material	Cooking chemicals			Yield	Strength Properties		
		Na_2SO_3 %	NaOH %	Na_2CO_3 %	%	Tensile index N.m./g	Tear index $mN.m^2/g$	Burst index $Kpam^2/g$
1.	Depithed bagasse	8	—	—	89.3	29.63	2.92	0.97
2.	Rice straw	8	—	—	70.8	39.75	3.93	2.23
3.	Wheat str iw	8	—	—	74.2	36.38	4.14	1.88

***Constant Pulping Conditions**

Cooking conditions :

Temperature = 160°C
Time = 3 hours (2 hours to raise the temperature to maximum)
Bath ratio = 1:6
Refining = at 0.05mm plate clearance in 30cm Sprout Waldron refiner.

TABLE—2

Strength Properties of Neutral Sulphite Semi-chemical Pulps (pH 7-7.5) at 200ml C. S. F.*

S. No.	Raw material	Cooking chemicals			Yield	Strength Properties		
		Na_2SO_3 %	NaOH %	Na_2CO_3 %	%	Tensile index N.m/g	Tear index $mN.m^2/g$	Burst index $KPam^2/g$
1.	Depithed bagasse	6	2	2	82.5	43.16	3 50	2.64
		6	3	—	81.2	49.12	4 02	2.54
		6	1	4	80.2	47.51	3.82	2 44
2.	Rice straw	—	—	—	—	—	—	—
3.	Wheat straw	—	—	—	—	—	—	—

*Constant pulping/refining conditions as in Table–1.

TABLE—3

Strength Properties of Alkaline sulphite semi-chemical pulps (pH 8–9) at 200ml C. S. F.*

Sl. No.	Raw material	Cooking chemicals Na_2SO_3 %	NaOH %	Na_2CO_3 %	Yield %	Strength Properties Tensile index N.m/g	Tear index $mN.m^2/g$	Burst index $KPam^2/g$
1.	Depithed bagasse	8	4	—	74.1	54.30	4 98	3.50
		6	4	—	76.0	51.72	4.21	2 90
		8	2	2	80.0	53 69	4.91	3.02
2.	Rice straw	8	2	2	65 6	45.23	4 83	2.73
		6	2	2	66.2	43.41	3.77	1.99
		8	1	3	64.7	49 37	4.60	3.25
		6	1	3	66.0	44.55	4.47	2 74
3.	Wheat straw	8	2	2	70.1	52.20	3.83	2.32
		6	2	2	71 0	51.73	3 51	2.22
		8	1	3	69.7	49.16	3.56	2 88
		6	1	3	70.7	45.78	4.42	3.25

*Constant pulping/refining conditions as in Table—1.

TABLE—4

Strength Properties of soda chemi-thermomechanical pulps from bagasse*

Sl. No.	Cooking Chemicals NaOH gpl	Yield %	Strength Properties Tensile index N.m/g	Tear index $mN.m^2/g$	Burst index $KPam^2/g$
1.	6	83.7	8.89	1.67	—
2.	8	81.0	25 06	3 36	1 88
3.	10	74.7	32.71	3.84	8.88
4.	12	70.6	38.40	4 28	1 73
5.	15	68 6	42.97	4 77	2 13
6.	20	84 7	50.10	5.66	2 72

*Constant pulping/refining conditions as in Table 1.

Table–2 gives data on the properties of bagasse neutral sulphite semi-chemical (NSSC) pulps obtained by chemical treatment with sodium sulphite buffered with caustic soda/sodium carbonate. A perusal of Table–2 indicated that buffering (to obtain pH range of 7.0–7.5) resulted in much improved properties. At pulp yield level of 81.2% (obtained by using 6% sodium sulphite buffered with 3.0% caustic soda) the tear index was 4.02 $mN.m^2/g$ at the tensile index of 49.12 N.m/g.

It was noticed that when wheat straw/rice straw were cooked with same amount of chemicals as applied for bagasse, the pH of the spent liquor at the end of chemical treatment was in alkaline range. Therefore data on these raw materials are discussed in the following paragraphs, while dealing with alkaline sulphite semi-chemical (ASSC) pulps.

The results on cooking bagasse/wheat straw/rice straw with sodium sulphite/caustic soda/sodium Carbo-

nate combination (pH range 8.0–9.0) are recorded in Table 3. It will be seen from these data that bagasse gave a pulp of 74 1% yield having tear index of 4.98 m N.m²/g at the tensile index of 54.30 N.m/g. Similaly rice straw and wheat straw also gave pulp of yields ranging between 65–70%. The tensile index value for rice straw being about 49.37 N.m/g at 4.60 tear index m N.m²/g. In case of wheat straw the tensile index was 52.20 N.mg at tear index 3.82 mN.m²/g. The chemical requirement was 8% sodium sulphite buffered with 4% caustic soda for bagasse. In case of wheat straw 1-2% caustic soda in conjuction with 3% sodium carbonate were used for buffering to get pH range 8.0-9.0.

Pulping experiments on bagasse with soda chemithermomechanical (SCTM) process have also yielded interesting results (Table 4). It will be seen from Table-4 that only soaking with caustic soda for 2 hr. followed by steaming in Aspulund defibrator for 5 min. at 1 kg/cm² and subsequent defibration at the same pressure for 10 min., followed by second stage refining in laboratory Sprout waldron disc refiner gave pulps of good strength properties. The optimum results were obtained with 15gpl caustic soda application; the pulp yield was 68 6%, tear index was 4.77 m N.m²/g at the tensile index 42.97 N.m/g.

CHEMICAL PULP

The results on soda chemical (SC) pulping and properties of pulps thus obtained are recorded in Table5 and 6. In case of bagasse for bleachable grade pulp, 10% caustic soda was sufficient to produce pulp of 48.0% yield having tear index of 5.15 m N.m²/g at tensile Index of 54.5 N.m/g. In case of rice straw, only 8%

TABLE—5

Cooking conditions and strength properties of unbleached soda chemical pulps*

Sl. No.	Raw Material	Cooking chemical caustic soda, %	H factor	Total yield %	Screened yield %	Kappa number	Approx density g/cm³/g	Burst index KPam²/g	Tensile index N.m/g	Tear index m.N m²/g	Stretch %
1.	Bagasse	13.0	1730	51.6	48.0	32.0	—	3.5	54.5	5.15	—
2.	Rice straw	8.0	1050	50.3	49.8	23.5	0.55	2.14	42.48	4.92	3.30
3.	**Wheat Straw**										
	(a) without AQ	15 0	1665	52.7	50.6	24.6	0.82	4.28	55.8	6.07	5.26
	(b) With AQ	13.0	1665	53.7	52.4	25.9	0.81	4.42	61.2	5.29	6.08

*Cooking conditions
Maximum temperature 170°C
Bath ratio 1:6

TABLE—6

Bleaching conditions and strength properties of bleached soda chemical pulps

Sl. No.	Raw Materials	Chlorination stage (as available chlorine) %	Alkali extraction, %	Hypo stage as available chlorine	Hypo stage (as available chlorine)	Bleached pulp yield, %	Brightness (Elrepho)	App. density g/cm³	Burst index KPam²/g	Tensile index N.m/g	Tear index mNm²/g	stretch	Roughness	Opacity
1.	Bagasse (H/H)	—	—	8.0	2.0	95.9	68 3	—	3.2	54.2	4.9	—	—	—
2.	Rice Straw H/H)	—	—	5.0	2.5	94.8	—	0.54	1.99	30.89	4.27	2.87	5.05	84.9
3.	Wheat Straw (C/E/H)													
a.	Without AQ	5	2	2.5	—	96.1	72.4	—	3.74	57.2	6.52	6.64	3.85	69.1
b.	With AQ	5	2	2.5	—	94.9	73.4	—	4.08	57.5	6.44	6 88	—	—

caustic soda was sufficient to produce bleachable grade pulp of 49.8% yield having tear index 4.92 m N.m²/g at tensile index of 42.4 N.m/g. Wheat straw required 15.0% caustic soda to give bleachable grade chemical pulps of 50.6% yield having tear index 6.07 mN.m²/g at the tensile index of 55.8 N.m/g. Addition of AQ in wheat straw pulping reduced the chemical charge by 2% and increased pulp yield of 2.0% without adversely affecting the strength properties of the paper. Bleaching studies of these pulps were also carried out. Bleaching conditions, bleached pulp yield, brightness of pulps are recorded in Table 7. The strength properties of standard sheet are recorded at 250 ml. C.S.F.

COMPARISON OF PROPERTIES OF HIGH YIELD PULPS WITH CHEMICAL PULPS

For comparing the strength properties of various high yield pulps with those of chemical pulps prepared in this investigation, the data at highest tear index have been taken and the comparative values are recorded in Table 7,8 and 9 for bagasse, wheat straw and rice straw respectively.

TABLE—7
Comparison of the properties of bagasse high yield pulps with its chemical pulp (at highest tear/200 ml. C.S.F.)

Pulp Type	Chemicals used, %	pH	Strength Properties			
			Yield %	Tear index m.N.m²/g	Tensile index N.m/g	Burst index K.Pam²/g
Soda Chemical (SC)	NaOH 13.0	—	48.0	5.15	54.50	3.5
Bisulphite Semi-chemical (BSSC)	Na_2SO_3 8.0	4.5–5.0	89.3	2.92	29.63	0.97
Neutral Sulphite Semi-Chemical (NSSC)	Na_2SO_3 NaOH 6 0/3.0	7.0–7.5	81.2	4.02	49.12	2.54
Alkaline Sulphite Semi-Chemical (ASSC)	Na_2SO_3 NaOH 8.0/4.0	8.0–9.0	74.1	4.98	54.30	3.58
Soda chemi-thermomechanical (SCTM)	NaOH 15 gpl	—	68.6	4.77	42.97	2.13

TABLE—8
Comparison of the properties of wheat straw high yield pulps with its chemical pulp (at highest tear/200 ml CSF)

Pulp Type	Chemicals used, %	pH	Pulp properties			
			Yield %	Tear index m.N.m²/g	Tensile index N.m/g	Burst index KPam²/g
Soda Chemical (SC)	NaOH 15.0	—	52.7	6 07	55 8	4.28
	NaOH/AQ 13 0/0.25	—	53.7	5.29	61 2	4.42
Bisulphite Semichemical (BSSC)	Na_2SO_3 8.0	4.5–5.0	74.2	4.14	36 38	1.88
Alkaline sulphite Semi-chemical (ASSC)	Na_2SO_3/ NaOH/Na_2CO_3 8.0/1.0/3.0	8.0–9.0	69 8	3.56	49.15	2.88

TABLE—9

Comparison of the properties of rice straw high yield pulps with its chemical pulp (at highest tear 200 ml. C.S.F.)

Pulp Type	Chemicals used, %	pH	Pulp properties			
			Yield %	Tear index $mN.m^2/g$	Tensile index N.m/g	Burst index $KPam^2/g$
Soda chemical (SC)	NaOH 8.0	—	49.8	4.92	42.48	2.14
Bisulphite Semi-Chemical (BSSC)	Na_2SO_3 8.0	4.5–5.0	70.8	3.93	39.75	2.23
Alkaline sulphite semi-chemical (ASSC)	Na_2SO_3/NaOH Na_2Co_3 8 0/1.0/3.0	8.0–9.0	64.7	4.60	49.37	3.26

It will be seen from Table 7 that pulp of 74.1% yield having both tear index of 4.98 $mN.m^2/g\%$ and tensile index 54.3 N.m/g equivalent to soda chemical pulp (yield 48.0%, tear index 5 15 mN m^2/g tensile index 54 5 N.m/g) could be obtained from bagasse using alkaline sulphite chemical treatment (8.0% sodium sulphite with 4% caustic soda) followed by controlled refining in a disc refiner. The pulps produced with NSSC and Chemi-thermomechanical treatments gave high yield pulps of only slightly lower strength (tear index 4.02 and tensile index 49.12). On the basis of strength properties it could be seen that the bagasse pulps are in the following order ASSC SCTM SC NSSC BSSC.

The results of wheat straw pulping recorded in Table 8 indicate that ASSC pulp is almost equivalent to SC pulp in respect of strength properties. The yield of ASSC pulp being 69.8% as compared to 52.7% of SC pulp. The BSSC pulp had slightly lower strength than ASSC pulp but the yield was higher (74.2%).

A persual of data in Table 9 reveals that for rice straw also ASS Cpulp at 64.7% yield is equivalent to SC pulp of 49.8% yield as far as values of tear index and tensile index are concerned. BSSC pulp was inferior to ASSC pulp in strength but higher in yield.

BLEACHING RESPONSE OF HIGH YIEELD SEMI-CHEMICAL PULP

When alkaline sulphite semi-chemical (ASSC) pulps were bleached by two stage hypochlorite treatment (5% available chlorine at each stage) with intervening washing, it was found that the brightness in general improved from 25 ± 2 to $50\pm2\%$ (Elrepho) in case of all the three raw materials studied. The opacity was over 88. NSSC BSSC and SCTM pulps did not give good bleaching response by this treatment.

CONCLUSIONS

(1) Both wheat straw and rice straw gave better response towards bisulphite cooking (pH range 4.5-5.0) as compared to bagasse. However, the yield of pulp was lower in former case. The high yield pulps were not equivalent to their chemical pulps in strength in either case.

(2) In case of NSSC pulping (pH range 7.0-7.5), bagasse gave high yield pulp (over 70% yield) equivalent to that the chemical pulp (48% yield) Rice straw and wheat straw did not come in this cooking range (pH 7.0–7.5) when cooked under the conditions applied for bagasse.

(3) Cooking in alkaline range (pH 8.0-9.0) with sodium sulphite, greatly increased the strength properties of high yield pulps in all the three raw material studied. There were conditions when bagasse (Na_2 So_3 8.0% NaOH4%) and both rice straw/wheat straw (Na_2 SO_3 80% NaOH 1% and Na_2 SO_3 3%) gave high yield pulps (65.75% yield) having strength properties equivalent to their soda chemical pulps of 40-50% (tear index about 5.0 $mN.m^2/g$ and tensile index about 50.0 N.m/g).

(4) Soda chemi-thermomechanical pulping of bagasse gave pulp of about 70% yield. The strength properties were slightly lower than its chemical pulp of 48% yield.

(5) On an overall assessment of strength properties vis-a-vis yield of pulp, it may be concluded that all the three raw material (bagasse, wheat straw and rice straw could be used to produce high yield pulps (65–70% yield) having strength properties similar to their soda chemical pulps (48-50% yield) by choosing proper chemical combinations and refining conditions. In addition, pulps of still high yield (upto 80%) with sufficient strength properties could also be prepared for furnishes which could be used for paper manufacture.

(6) The bleaching response of ASSC pulps for two stage hypochlorite treatment using 5% available chlorine at each stage was satisfactory and the pulps could be bleached to 50 ± 2 brightness having an opacity of over 88.0.

Thus it can be said that bagasse/wheat straw/rice straw could be economically processed to produce high yield pulps for making a range of products by applying appropriate technology depending upon the raw material and product in question.