

A Critical Analysis of Bagasse Pulps for Variety of end Products

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ABSTRACT:-- Soda pulping was carried out using 12.5, 10.0, 7.5 and 5.0 NaOH as Na₂O at 170°C maximum pulping temperature and at 170°, 160°, 150° and 140°C using 7.5% NaOH as Na₂O for 0, 30, 60, 90, 120 and 150 minutes at maximum temperature. It was observed that pulp yield, degree of delignification and strength properties of pulps were dependent on alkali charge. Prolonged cooking time beyond 30 minutes at 170°, 160° and 150°C have shown adverse effect on degree of delignification, pulp yield and strength properties of pulp produced. 10.0% NaOH as Na₂O charge at 160°C for 30 minutes pulping time at maximum temperature produced fairly good quality pulp almost comparable to pulp produced using 12.5% pulping chemical. Results of all pulping experiments are recorded in the paper and have been discussed for selection of pulping parameters for variety of end products.

INTRODUCTION

Alkali pulping systems are heterogenous unless the conditions are very favourable (effective pre-impregnation of chemicals, thin chips and high alkalinity through out the cook). Chemical transport phenomena (liquid penetration and diffusion) controls the rate of delignification (Hartler, 1962; Kleinert and Marraccini, 1965). Alkali sorption in the outer layers of wood chips may be a major cause of non-uniformity in alkali distribution particularly at low alkali concentration (Wardrop, 1968).

In wood chips, lignin is preferably removed from secondary cell wall first, at about 50% of delignification, the middle lamella lignin and lignin in cell wall corner areas dissolves rapidly (Goring et.al., 1967) leaving the residual lignin in secondary cell wall at the end of the cooking. However, in a very thin section of wood ($\approx 20/\mu$ thick), the lignin is completely removed from the middle lamella, before any delignification could be observed in the cell wall (Bixler, 1938). Beside alkali penetration and diffusion, the actual distribution and physico-chemical

nature of lignin in different morphological region of cell wall exerts a major effect on practical delignification (Szabo and Goring, 1968; Whiting et.al., 1982; Luner and Roshmen, 1968).

The bagasse lignin in cell wall differs from wood lignin and has several supper molecular forms (Bevenzen and Bogomolov, 1977). Secondary cell wall contains oblong shape and structureless lignin while primary cell wall, inter cellular substances and middle lamella consists of lamellar and structured lignin. During the alkaline pulping even at 120°C major portion of structureless lignin dissolves, at 140°C a major portion of structured lignin of secondary cell wall also dissolves and considerable amount of lamellar lignin of primary cell wall and inter cellular space dissolves at 160°C. Since, the alkali penetration is not a problem in bagasse and alkali can diffuse at an approximately equal rate in all the structural directions due to its bulky nature

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and open anatomical features, it could be expected that removal of lignin from middle lamella and cell walls would start at the early stage of pulping compared to wood chips.

In the present investigations, depithed bagasse was cooked using 12.5, 10.0, 7.5 and 5.0% NaOH as Na_2O at 170°C and at 170°, 160°, 150° and 140°C using 7.5% NaOH for 0, 30, 60, 90, 120 and 150 minutes to assess the pulping behaviour and paper making characteristics of bagasse under different set of pulping parameters. On the basis of these preliminary experiments 10% NaOH as Na_2O and pulping time 30 minutes were considered to be optimum. Pulps produced using 10% NaOH as Na_2O at 140°, 150°, 160° and 170°C were subjected to physico-chemical analysis and strength properties determination. Results are discussed in the paper in detail.

EXPERIMENTAL

Pulping

All the pulping experiments were carried out in a stovlets autoclave bomb digester consisting of six bombs rotating in electrically heated poly-ethylene-glycol bath. Depithed bagasse was cooked at four different pulping chemical charge using (5.0, 7.5, 10.0 and 12.5% NaOH as Na_2O) at 170°C. Pulping was also carried out at constant chemical charge (7.5% NaOH as Na_2O) and different maximum temperature (140°, 150°, 160° and 170°C). In both the cases the cooking was carried out for 0, 30, 60, 90, 120 and 150 minutes at maximum temperature. The temperature was raised from room temperature to 100°C in 30 minutes, followed by a rise of 10°C in 15 minutes upto maximum temperature. 1 : 5 material to liquor ratio was maintained.

Cooked bagasse was washed with hot water in each case. Bagasse cooked using 12.5 and 10.0% alkali was pulped and further fiberization was achieved by disintegration. Bagasse cooked using lower chemical charge were semi-cooked, hence subjected to two stage refining in a Sprout Waldren laboratory disc refiner at plate clearance of 10 μ followed by 5 μ to achieve complete fiberization.

On the basis of these pulping experiment optimum conditions NaOH (10.0% as Na_2O) and pulping

time (30 minutes) were chosen. Pulps were produced under these conditions at 170°, 160°, 150° and 140°C and disintegrated in valley beater at 3.0% consistency to a freeness level of \approx 550 ml csf.

All the pulps were screened in a flat laboratory screen using 0.20 mm slots. Total and screened pulp yield, screened rejects and kappa number of pulps were determined.

Beating, sheet making and testing of hand sheets

Pulps were beaten at 3.0 consistency in valley beater. Hand sheets of 60 ± 2 gsm of all the beaten pulps were made on a standard British sheet making machine. The sheets were air dried, conditioned at $27 \pm 1^\circ\text{C}$, temperature and $65 \pm 2\%$ relative humidity. Physical strength properties of these hand sheets were determined.

Physico-chemical analysis of pulps

Bagasse pulps (produced under optimum conditions) meal (40-60 mesh) were subjected to ash, alpha cellulose, pentosans, klsson lignin and 1% NaOH solubility determination adopting TAPPI standard methods, T-15-OS-58, T-203-OS-74, T-223-OS-71, T-222-OS-74 and T-212-OS-16, respectively. Holocellulose was determined by the method of Wise et al (1946).

RESULTS AND DISCUSSION

Effect of alkali charge and cooking time

Effect on pulp yield and delignification: Result recorded in Table-1 revealed that pulp yield decreased with the increase in alkali charge and pulping time, as expected. At 12.5% alkali charge, the pulp yield was 61.36% for zero minute and 53.10% for 150 minutes at maximum temperature while for 10%, 7.5% and 5% alkali charge, the pulp yield decreased from 62.20% to 54.00%, 63.00% to 56.91% and 70.12% to 69.0%, respectively. Thus, decrease in pulp yield with pulping time was more pronounced at higher alkali charge than that for lower alkali charge.

Kappa number increased with the decrease in alkali charge, as expected. The average for different pulping time (from 0 to 150 minutes at maximum

temperature) for these pulps was 22.11 ± 0.60 , 45.00 ± 4.05 , 71.21 ± 4.85 and 121.85 ± 9.35 for 12.5, 10.0, 7.5 and 5.0% alkali charge respectively (Table-1).

Surprisingly, at any level of alkali charge kappa number was in increasing order with cooking time at maximum temperature (Table-1). This is contrary to wood pulping (Wilson and Kerr, 1976) and could be attributed to easy accessibility of pulping chemical in different morphological region of cell wall of bagasse (Kuang, 1981; Luner and Roseman, 1968) and presence of large amount of lignin, soluble at lower temperature (Zhong 1983; Kleppe, 1970; Xlao-An et al 1989). Consequently, consuming major portion of alkali in the initial period of pulping and yielding pulp with higher kappa number due to redeposition of lignin on to the fibre due to lower alkalinity. Even at higher alkali charge, major portion of lignin dissolved in initial period of cooking might have undergone po-

lymerization reactions due to lower alkalinity and higher concentration of internal nucleophiles generated during delignification leading to formation of relatively high molecular weight lignin molecule (in situ) as the cooking proceeds.

Further, it is also observed that after the removal of major portion of lignin, the formation of lignin carbohydrate bonds between aldehydic lignin fragments and carbohydrate fragment occur via aldol condensation followed by benzylic acid rearrangement. The lignin carbohydrate bond formation increases the molecular weight of the molecule. The high molecular weight makes it difficult to dissolve/escape from insitu (Gierer and Ljunggren, 1979; Gierer and Wannstrom, 1983). This could perhaps be the reason for the more wider difference in kappa number and comparatively less difference in pulp yield on prolong cooking with lower pulping chemical charge.

Table-1

Pulping conditions, pulp, pulp yield and strength properties of pulps produced at 170°C with different alkali charge.

Pulping conditions		Pulp yield %		Kappa number	App. density g/cm ³	Strength properties at 250 ml C.S.F.		
Alkali % as Na ₂ O	Time at max. temp. min.	Total	Screened			Burst index KPam ² /g	Tensile index Nm/g	Tear index mNm ² /g
12.50	0.0	61.36	52.35	20.71	0.83	4.40	71.68	5.06
	30.0	59.00	55.00	20.94	0.84	4.40	74.30	5.41
	60.0	57.10	54.61	22.53	0.85	4.65	74.16	5.44
	90.0	55.20	53.69	23.29	0.86	4.70	74.10	5.45
	120.0	53.30	52.37	22.08	0.86	4.74	70.79	4.92
	150.0	53.10	52.13	23.15	0.86	4.65	71.08	4.70
10.0	0.0	62.20	51.43	40.60	0.79	4.27	68.85	4.52
	30.0	60.50	53.00	41.90	0.80	4.18	68.82	4.58
	60.0	59.00	55.50	44.30	0.80	4.27	69.70	4.60
	90.0	57.00	54.50	45.90	0.80	4.40	74.43	4.51
	120.0	55.50	54.30	48.70	0.80	4.10	71.24	4.24
	150.0	54.00	53.00	48.50	0.80	4.00	70.22	4.21
7.50	0.0	63.00	--	65.30	0.74	4.11	66.72	4.34
	30.0	61.00	--	69.80	0.74	4.16	68.64	4.95
	60.0	60.50	--	70.00	0.75	4.30	66.15	4.94
	90.0	58.20	--	72.60	0.75	4.10	65.51	4.96
	120.0	58.13	--	74.60	0.76	3.77	62.10	4.73
	150.0	56.91	--	75.00	0.76	3.73	61.33	4.77
5.00	0.0	70.12	--	109.80	0.58	2.40	48.41	4.42
	30.0	68.30	--	120.60	0.60	2.74	48.88	4.56
	60.0	68.30	--	125.20	0.65	2.97	50.08	4.50
	90.0	68.10	--	122.60	0.65	2.87	46.58	4.65
	120.0	68.40	--	129.50	0.66	2.70	43.37	4.68
	150.0	69.00	--	123.20	0.67	1.97	59.14	5.13

Effect on strength properties

Bonding properties (burst and tensile index) increased considerably with the increase in alkali charge from 5.0% to 7.5% followed by gradual increase from 7.5% to 10.0% and from 10.0% to 12.5%. With the increase in pulping time, a marginal improvement in bonding properties was observed (Table-1). Average burst index (kPam²/g) from 0 to 150 minutes cooking time falls within the limit of 4.60 ± 0.20 , 4.20 ± 0.20 , 4.03 ± 0.28 and 2.60 ± 0.50 ; tensile index (Nm/g) 72.68 ± 1.75 , 70.54 ± 2.80 , 65.07 ± 3.65 and 46.06 ± 5.47 for 12.5, 10.0, 7.5 and 5.0% alkali charge, respectively. Better bonding properties for pulps produced with higher alkali charge could be attributed to comparatively more removal of lignin, yielding comparatively more flexible and collapsible fibres having more exposed hydroxyl groups of cellulose molecule for inter fibre hydrogen bonding. It was also observed that the difference in kappa number is directly proportional to difference in strength properties.

Tear index (mNm²/g) for pulps produced with lower alkali charge was also lower though the fibers produced at lower alkali charge would have been more stiffer and should possess better tear index. However strength properties exhibited by the pulp is a combined effect of collapsibility, inter fibre hydrogen bond formation capabilities and stiffness of the fiber. Net result of better collapsibility of fibre is, however, the improvement in inter fibre hydrogen bonding. Thus, the fiber produced with lower alkali charge are though more stiffer but the inter fibre bond formation capabilities seems to be comparatively poor and bond failure occur under stressed conditions rather than the fibre failure, consequently, exhibiting poor overall strength properties including tear index.

Effect of time and temperature

Effect on pulp yield and delignification

Results recorded in Table-2 revealed that at 7.5% NaOH as Na₂O charge, pulp yield was

Table-2

Pulping conditions, pulp yield and strength properties of pulps produced using 7.5% alkali at different temperatures.

Pulping conditions		Pulp yield %	Kappa number	App. density g/cm ³	Strength properties at 250 ml C.S.F.		
Max. temp. °C	Time at max. temp.				Burst index KPam ² /g	Tensile index Nm/g	Tear index mNm ² /g
170	0.0	63.00	65.53	0.74	4.11	66.72	4.34
	30.0	61.00	69.80	0.75	4.16	68.64	4.95
	60.0	60.50	70.00	0.75	4.30	66.15	4.94
	90.0	58.20	72.60	0.75	4.10	65.51	4.96
	120.0	58.13	74.60	0.76	3.77	62.10	4.73
	150.0	56.91	75.00	0.76	3.73	61.33	4.77
160	0.0	63.84	65.34	0.76	3.20	54.73	5.54
	30.0	63.42	67.12	0.77	3.37	56.11	5.61
	60.0	62.15	67.97	0.77	3.39	56.66	5.67
	90.0	60.62	70.00	0.77	3.43	57.44	5.38
	120.0	60.47	70.50	0.78	3.43	58.33	5.26
	150.0	59.60	70.90	0.78	2.80	49.80	5.31
150	0.0	64.93	65.50	0.61	2.44	48.73	4.88
	30.0	64.00	66.40	0.62	3.56	56.14	6.03
	60.0	63.67	66.57	0.65	3.45	54.46	6.38
	90.0	63.00	63.76	0.66	3.28	50.86	6.29
	120.0	63.10	69.03	0.68	3.22	45.24	6.11
	150.0	62.50	69.03	0.70	2.53	37.50	6.17
140	60.0	64.74	64.92	0.60	2.86	35.74	6.11
	90.0	64.00	60.94	0.61	0.93	43.23	6.19
	120.0	63.56	62.94	0.62	3.01	48.99	5.67
	150.0	63.00	64.64	0.63	3.00	50.87	5.38

decreased with the rise in maximum pulping temperature (from 140° to 150°, 160° and 170°C) and increase in pulping time at any maximum temperature. Pulp yield at 170°, 160°, 150° and 140°C falls within the limit of $59.95 \pm 3.05\%$, $61.68 \pm 2.12\%$, $63.53 \pm 1.22\%$ and $63.82 \pm 0.87\%$, respectively, for pulping time from 0 to 150 minutes.

The decrease in pulp yield with pulping time became more significant as the maximum pulping temperature was increased. Kappa number (Table-2) for 0 minute pulping time at maximum temperature 170°, 160°, 150°, and 140°C was almost the same i.e. 65.50 ± 0.50 but as the cooking proceeds, the increase in kappa number at pulping temperature 170°, 160° and 150°C was observed and was more prominent at 170°, followed by 160° and 150°C.

Comparatively higher increase in kappa number with time at high temperature may be due to the higher rate of alkali consumption followed by higher rate of polymerisation and formation of lignin carbohydrate complexes followed reprecipitation of lignin onto the fiber.

Kappa number at 140°C decreased up to 120 minutes of cooking time and then increased. It indicated that due to lower rate of reactivity and alkali consumption, the removal of lignin was continuous up to 120 minutes of pulping time. Lower pulp yield with pulping time may be due to higher rate of polysaccharides degradation at lower alkalinity on prolonged cooking.

Effect on strength properties

The strength properties at 170°C for pulps obtained with at 7.5% alkali have been discussed

earlier. The bonding properties decreased with the decrease in pulping temperature (Table-2). While strength properties of pulps increased upto 30 minutes of pulping time at 170°C, 160° and 150°C, these properties increased consistently with increase in the pulping time for pulps produced at 140°C pulping temperature. This indicate perhaps, the swelling of fibres (to develop better collapsibility) continue to improve on prolonged cooking (up to 120 minutes) at 140°C besides the continuous removal of lignin (Table-2), while at higher temperature, the swelling of fibres might have attained a saturation point even in less time (30 minutes). Tear index, however, was higher for pulp produced at lower temperature as compared to respective pulps-(at same pulping time) produced at higher temperature (Table-2).

Pulping at optimised conditions

Above pulping experiments indicate that perhaps the 10% active alkali charge would be a better choice for the production of a fairly good quality pulp, almost comparable to pulp produced with 12.5% alkali charge. The pulping time at maximum temperature however, should be maintained for 30 minutes. The pulping experiments carried out at different maximum temperatures reveal that though there was significant difference in the bonding properties of pulps produced at different temperature, the level/degree of delignification is almost the same (same kappa number at all pulping temperatures). Hence, it is believed that the maximum temperature beyond 160°C and prolong cooking time beyond 30 minutes may not be of any significance. It is the pulping chemical charge which plays major role in delignification and development of strength proper-

Table-3.

Pulping conditions, pulp yield and kappa number of pulps produced at different temperature and black liquor analysis

Pulp code	Pulping conditions			Pulp yield (*) % (*)		Kappa number	Black liquor analysis		
	Alkali % as Na ₂ O	Max. temp. °C	Time at max. Temp. min.	Total	Screened		pH	Total solid %	Residual alkali %
B ₀	10.0	170	30	60.50	53.00	41.90	--	--	--
B ₁	10.0	160	30	61.36	57.16	36.07	10.89	8.84	1.48
B ₂	10.0	150	30	61.80	56.70	36.62	11.42	8.97	1.98
B ₃	10.0	140	30	62.14	55.54	37.12	11.52	9.07	2.10

ties. Keeping this in view experiments were carried out using 10% alkali charge and 30 minutes pulping time at different temperature (170°, 160°, 150° and 140°C) (Table-3).

The pulp yield using 10.0% alkali charge at 140°, 150° and 160°C for 30 minutes pulping time was almost the same. Though the difference among the values of holocellulose, alpha cellulose and klason lignin content for the pulps produced with 10.0% alkali charge at 140°, 150° and 160°C was insignificant but increasing order was observed with the decrease in pulping temperature (Table-4) which indicate that the degradation of cellulose and overall removal of lignin was higher at higher temperature. Increased ratio of holocellulose to lignin, and alpha cellulose to lignin with the increase in temperature (Table-5) indicated that though not significant yet at

high temperature selectivity of lignin removal was higher when cooked for short time <30 minutes.

It was observed that the pulp produced at lower pulping temperature possess marginally but insignificant lower bonding properties as compared to pulp produced at higher temperature. Burst index (kPam²/g) tensile index (Nm/g) and tear index (mNm²/g) of pulp produced at identical conditions of pulping at 140°, 150°, 160°C were 3.54 ± 0.16, 68.20 ± 4.70, 5.57 ± 0.7 (Table-6). Decrease in strength properties with decrease in chemical charge was also observed as earlier.

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Table-4.

Proximate chemical analysis of depithed bagasse and pulps produced at optimised conditions

Pulp code	Ash %	1% NaOH solubility %	Holocellulose, %		α-Cellulose, %		Klason lignin, %		Pentosan, %	
			A	B	A	B	A	B	A	B
B ₁	2.03	5.85	92.52	56.77	73.00	44.79	5.18	3.17	25.2	15.46
B ₂	1.98	5.66	93.36	57.69	74.45	46.01	5.35	3.30	27.4	16.80
B ₃	1.47	4.07	94.81	58.91	75.94	47.18	5.56	3.45	29.7	18.45

A and B stands for percentage on pulp and bagasse basis.

Table-5.

Relative ratio of holocellulose : lignin, α-cellulose : lignin pentosan : lignin and pentosan : α-cellulose.

Pulp code	Holocellulose : Lignin	α-Cellulose : Lignin	Pentosan : lignin	Pentosan-α-Cellulose
B ₁	17.86 : 1	14.13 : 1	4.87 : 1	0.59 : 1
B ₂	17.45 : 1	13.94 : 1	5.09 : 1	0.37 : 1
B ₃	17.07 : 1	13.66 : 1	5.35 : 1	0.39 : 1

Table-6.

Physical strength properties of pulps produced at different time, temperature and alkali charge at freeness 250 ml C.S.F.

Pulp Code No.	App. Density (g/m ²)	Strength properties		
		Burst index KPam ² /g	Tensile index Nm/g	Tear index mNm ² /g
B ₁	0.80	3.68	63.50	5.63
B ₂	0.80	3.82	64.5	5.50
B ₃	0.84	4.00	73.9	5.58

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