Pulping and Bleaching Studies of Rice Straw Leading to Dose Optimization

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ABSTRACT

Paper making potential of rice straw as a fibrous raw material has been evaluated through pulping and bleaching studies. Soda process, widely accepted for pulping of cereal straws, has been adopted in different doses, keeping the other conditions, viz. bath ratio, temperature, time to attain maximum temperature and cooking time, constant.

Effect of alkali charge on pulp properties has been discussed, and strength and surface properties of unbleached and bleached pulps are compared leading to alkali dose optimization. Graphical evaluation of pulp and paper properties of rice straw, yielding most desirable outputs, results in an optimum dose of about 10.5% during cooking.

INTRODUCTION

The continued demand for paper and paper boards shall require more and more fibrous raw materials in future, for which, the paper industry will have to depend on other non conventional raw materials, mainly agro-residues and waste paper, as the forest based resources are becoming scarce. As an estimate, nearly 10% of the total paper is being produced from non-wood plant fibre pulps worldwide. In some countries, non-wood pulps represent more than 50% of the overall fibrous furnish.

Cereal straw is an important source of raw material for pulp and paper making in developing countries, like India, where grain is grown in large quantities. Nearly, 100 million tons of paddy is grown annually in India, which results in almost an equal amount of rice straw suitable for pulp and paper manufacturing, particularly in small mills.

Normally, soda process is employed for straw cooking with chemical application of 6 to 15% NaOH (as Na_2O) under varied conditions of bath ratio (1:4 to 1:7), cooking temperature (150 to 170°C), cooking time (2.5 to 4 hours), resulting in 40 to 45% pulp yield. Considerable work reported in literature on cereal straws concentrate mainly on wheat straw whereas work on rice straw is limited, and in the small paper mills, similar conditions are maintained for rice straw, as those for wheat straw. In the present investigation, therefore, pulping and bleaching studies of rice straw have been carried out leading to cooking chemical dose optimization.

MATERIALS AND METHODS

The raw material used for the studies was prepared by chopping it into small size fraction, followed by wet cleaning and drying. -40+60 mesh fraction obtained from grinding of chopped material was used for proximate analysis using Tappi methods, while the whole raw material (washed and dried)

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was used for pulping studies. Proximate analysis of rice straw is shown in **Table-1.**

Table-1

Parameter	Value*
Moisture	7.8
Ash content	13.6
Silica content	12.2
Pentosans	22.0
Lignin	25.2
Lignin**	14.9
Hollocellulose	72.0
Solubilities	
Cold water	4.8
Hot water	15.2
1% NaOH	49.8
Alcohol-benzene	4.9

* All values in percentage.
** Ash corrected

Pulping

Cooking experiments were performed in a 15 litres capacity, electrically heated WEVERK rotary digester, applying 8, 10, 11 and 12% chemical (NaOH as Na_2O) doses. The other conditions, viz. bath ratio (1:5), cooking temperature (150°C), time to attain maximum temperature (90 min), and cooking at maximum temperature (60 min) were maintained.

The digested pulps (cooked with different chemical doses) were defibrated for 5 minutes in wet defibrator followed by screening and washing. Pulp evaluation was done as per Tappi methods. Fibre content (+100 mesh fraction) was determined through Mcnett-Bauer classifier.

Beating & Testing

The unbleached pulps were beaten in a valley beater upto a freeness level of 45 °SR, and 60 g/m^2 sheets were made on British Sheet Former. The optical, Strength and surface properties of unbleached and bleached pulp sheets were evaluated as per Tappi procedures.

Bleaching

All the four batches of pulp beaten to 45 °SR were bleached following conventional bleaching sequence CEH under identical conditions. Though CEH bleaching is not so appealing to the developed countries because of its impact on pollution, yet it is considered to be the most dependable, and popular bleaching process in asian countries, particularly, in India and China, and shall continue till an economically viable process is sought for agro-residues.

Approximately, 300 g pulp was bleached in appropriate plastic containers. The chemical consumption, bleached pulp yield, brightness and paper properties were also determined.

RESULTS AND DISCUSSIONS

Pulping and bleaching experiments on rice straw have been conducted in the laboratory to study the effect of chemical application (NaOH) at digestion stage. Pulp evaluation and paper properties of unbleached and bleached pulps are analysed graphically leading to dose optimization.

Table-2

Pulp Evaluation

Parameters	Alkali Charge (NaOH as Na_2O)			
	8%	10%	11%	12%
Total Yield	51.6	49.0	50.4	45.9
Total Yield (ash corrected)	42.3	40.6	42.2	40.5
Screened Yield	49.5	47.2	48.9	40.1
Rejects	2.1	1.8	1.5	4.8
Ash content	18.0	17.1	16.2	11.7
Silica	15.6	16.1	12.4	10.3
Pentosans	15.5	22.8	23.1	18.2
Lignin content	16.6	14.5	14.9	9.8
Solubility				
1% NaOH	22.1	22.0	18.0	15.7
18% NaOH	7.1	9.0	9.0	8.7
Kappa No.	26.6	22.4	17.5	18.3
Brightness, % ISO	32.4	33.8	39.0	36.0
Residual active alkali, mg/l	16.0	48.0	117.0	155.0
Fibre Fractionation				
+ 100 mesh (Fibres	67.6	66.6	60.7	57.5
- 100 mesh (Fines)	32.4	33.4	39.3	42.5

All values, mentioned otherwise are in percentage.

EFFECT OF ALKALI CHARGE ON PULP EVALUATION

Rice straw pulp analysis for different chemical doses is given in **Table-2.** Total and screened pulp yield are inversely proportional to alkali charge and reduce with increased chemical application. This may be due to degradation of hemicelluloses and partly of cellulose alongwith lignin, thereby resulting in low yield.

Residual lignin content in pulp reduces with increase in alkali dose, while pentosans first increases and then decreases. 1% NaOH sulubility representing the resistance of pulp to hot dilute alkali solution decreases with alkali charge, whereas 18% NaOH solubility representing the amount of degraded hemicelluloses first increases to a maximum value (for 11% alkali dose) and then decreases. Redeposition of hemicelluloses on the surface of fibres may be the possible reason for such behavior. Ash and silica content are also found to decrease with alkali charge, in general.

The bleaching requirement depicted by kappa No. is found to decrease with alkali charge, lowest being at 11% dose. Brightness of unbleached pulps confirm the trend observed for kappa number. Fines fraction (-100 mesh) increases with alkali charge upto 42% at 12% dose, and a similar trend is observed for residual active alkali in B/L. Due to practical limitations of the fibres classifier system used, the -200 mesh fraction could not be determined separately. -100 mesh fraction being treated as fines, was the lowest possible size separation available.

EFFECT OF ALKALI CHARGE ON BLEACHING CHARACTERISTICS

Based on pulp kappa No., the total chlorine demand for bleaching was calculated, of which 60% was used in chlorination (C) and rest 40% in hypochlorite (H) stage. Identical bleaching conditions were maintained for all the pulps. The total chlorine consumption in C-stage was found to be more than 99.5%. The bleached pulp yield increased with increase in alkali concentration within the specified range, 58 to 62% based on O.D. unbleached pulp **(Table-3).**

The lower yield of bleached pulps may be attributed to the fact that rice straw pulp contain high amount of fines (upto 40%), which are lost in successive washing after each (C, E & H) stage of bleaching. Manual washing after each stage of bleaching might have shorten the fibres dimensions, allowing them to pass through the wash table screen, thereby, resulting in lower yield of bleached pulps. The brightness of bleached pulps ranged between 66 to 74%.

Table-3

Applied Bleaching Conditions and Results Obtained

Stage	Cy. (%)	Temp. (K)	Time (min)	pH	Chemical Requirement for Unbleached Pulps			
					8%	10%	11%	12%
Chlorination	3	Amb.	60	<2	3.6	3.1	2.4	2.6
Extraction	8	338	60	11	2.0	1.8	1.5	1.6
Hypochlorite	8	313	120	9	2.5	2.1	1.6	1.7
Bleaching results								
Total Cl_2 consumption, % (C&H stages)					97.1	96.5	96.8	94.6
Pulp Yield, % (based on unbleached pulp)					58.2	59.3	56.5	61.4
Brightness, % ISO					68.2	74.0	72.8	70.0

Table-4

Strength and Surface Properties of Unbleached Pulps

Parameters	Unit	Alkali Charge (NaOH as Na_2O)			
		8%	10%	11%	12%
Freeness	°SR	45	45	45	45
Tensile index	N.m/g	32.84	36.33	39.86	37.00
Burst Index	KPa.m²/g	1.38	1.48	2.00	2.71
Tear index	mN.m²/g	3.43	3.49	3.91	3.38
Smoothness	cc/min				
range		1950-2300	2300-2700	1700-2200	1800-2200
average		2070	2550	1950	2020
Softness	cc/min				
range		900-1300	1300-1800	1000-1450	1000-1400
average		1120	1550	1175	1175
Porosity	cc/min				
range		370-430	475-500	410-445	400-430
average		410	495	430	425

Temperature 31°C, Relative humidity 56%

Table-5

Strength and Surface Properties of bleached Pulps

Parameters	Unit	Alkali Charge (NaOH as Na_2O)			
		8%	10%	11%	12%
Freeness	°SR	40	37	37	38
Tensile index	N.m/g	34.50	44.17	53.00	55.67
Burst Index	KPa.m²/g	1.75	2.57	3.09	3.47
Tear index	mN.m²/g	2.54	2.88	3.20	3.74
Smoothness	cc/min				
range		1700-2300	1700-2100	1800-2100	1150-1500
average		1920	2030	1950	1375
Softness	cc/min				
range		900-1300	1000-1300	1200-1350	600-850
average		1120	1150	1225	720
Porosity	cc/min				
range		370-390	410-460	420-450	370-410
average		380	440	435	390

Temperature 31°C, Relative humidity 56%

Table-6		
Optimization Parameters		
Design Variable	**Desired Optimum Output**	
Pulp Evaluation		
Pulp Yield	Towards	Maximum
Lignin content	Towards	Minimum
Pentosans	Towards	Maximum
Kappa No.	Towards	Minimum
Brightness	Towards	Maximum
Fines fraction	Towards	Minimum
Paper Properties		
Tensile indes	Towards	Maximum
Burst index	Towards	Maximum
Tear index	Towards	Maximum
Smoothness	Towards	Maximum
Softness	Towards	Maximum
Porosity	Towards	Minimum

EFFECT OF ALKALI CHARGE ON PAPER PROPERTIES

Strength and surface characteristics of paper produced from unbleached pulps are presented in **Table 4.** Tensile and tear index increases to a maxima for 11% soda pulp, and then decreases, whereas burst index continues to increase with alkali charge.

Surface properties of paper produced from pulp beaten to 45 ^{0}SR show maximum smoothness, softness and porosity for 10% soda pulp, however no specific trend is observed with alkali charge.

An increasing trend is observed in strength properties of paper **(Table-5)** produced from bleached pulps. Similar to unbleached pulps, no specific trend is observed in surface properties of bleached pulps also.

Table-7				
Optimization Results				
Design Variable	**Unit**	**Figure**	**Optimum Output Variable**	**Optimized Alkali Dose**
Pulp Evaluation				
Total yield	%	1a	49.84	10.30
Screened Yield	%	1a	48.00	10.30
Lignin Content	%	1b	22.54	10.47
Pentosans	%	1b	22.36	10.47
Kappa No.		1c	19.20	10.71
Brightness	% ISO	1c	37.06	10.71
Fibres fraction	%	1d	35.00	10.12
Fines fraction	%	1d	65.00	10.12
Paper Properties of Unbleached Pulps				
Tensile index	N.m/g	2a	38.10	10.65
Burst index	KPa.m^2/g	2a	18.44	10.65
Tear index	mN.m^2/g	2a	36.25	10.65
Smoothness	cc/min	2b	2300	10.12
Softness	cc/min	2b	1375	10.12
Porosity	cc/min	2b	450	10.12
Paper Properties of Bleached Pulps				
Tensile index	N.m/g	3a	50.00	10.62
Burst index	KPa.m^2/g	3a	28.64	10.62
Tear index	mN.m^2/g	3a	30.45	10.62
Smoothness	cc/min	3b	2000	10.31
Softness	cc/min	3b	1167	10.31
Porosity	cc/min	3b	438	10.31

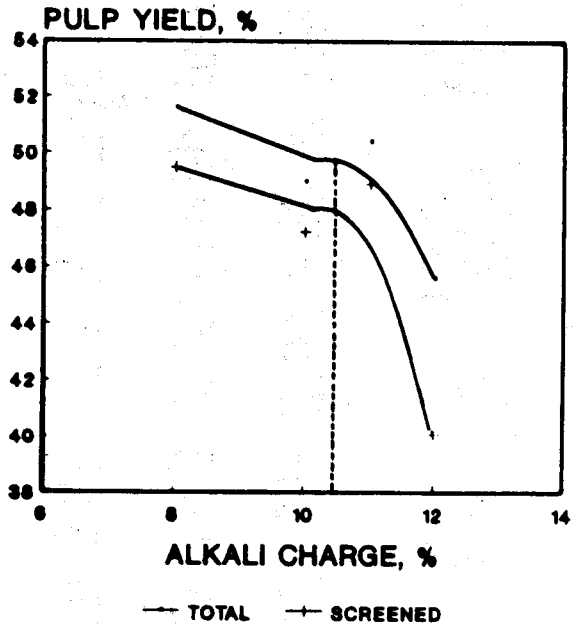

FIG. 1a

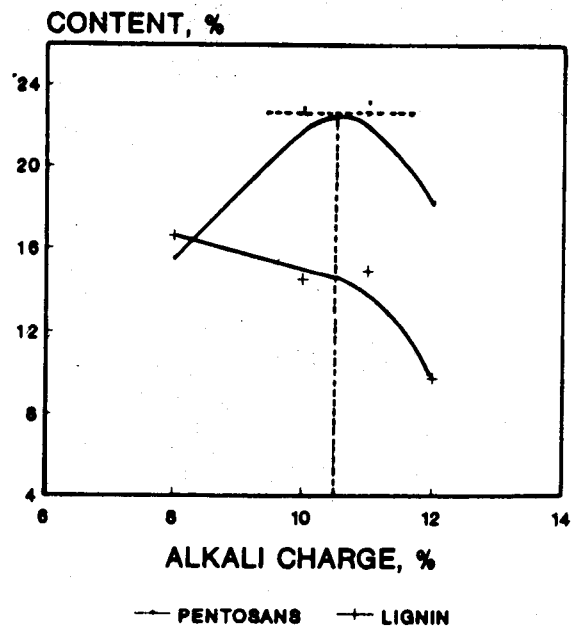

FIG. 1b

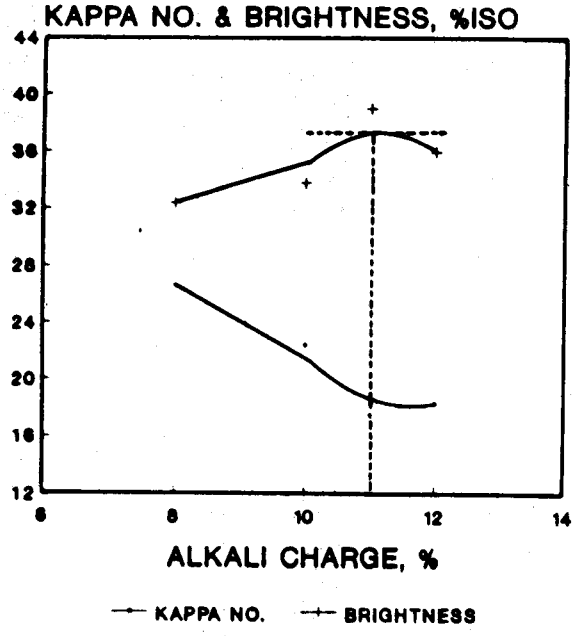

FIG. 1c

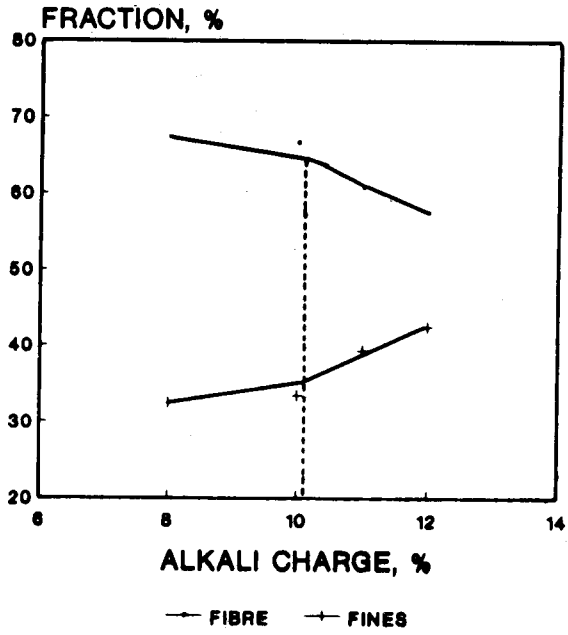

FIG. 1d

FIG.1 EFFECT OF ALKALI CHARGE ON PULP EVALUATION; a) PULP YIELD; b) PENTOSANS & LIGNIN; c) KAPPA NO. & BRIGHTNESS and; d) FIBRE & FINES FRACTION

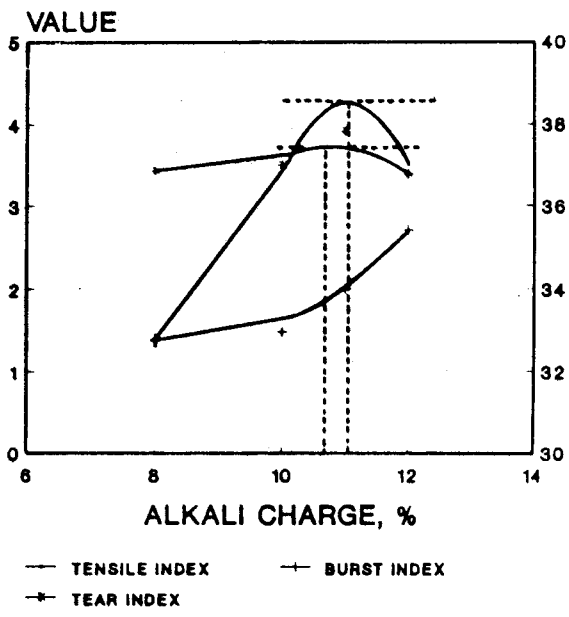

FIG. 2a

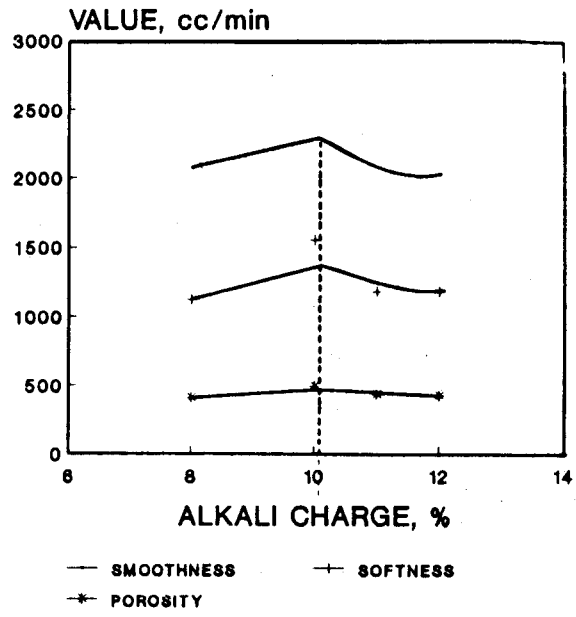

FIG. 2b

FIG.2 EFFECT OF ALKALI CHARGE ON STRENGTH AND SURFACE PROPERTIES OF UNBLEACHED PULPS

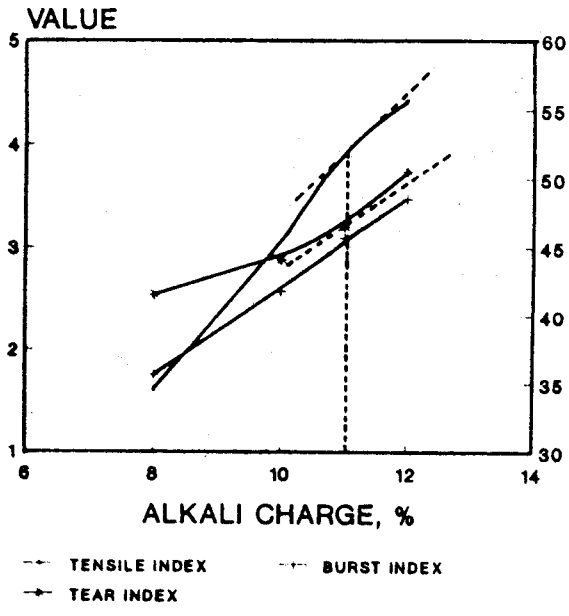

FIG. 3a

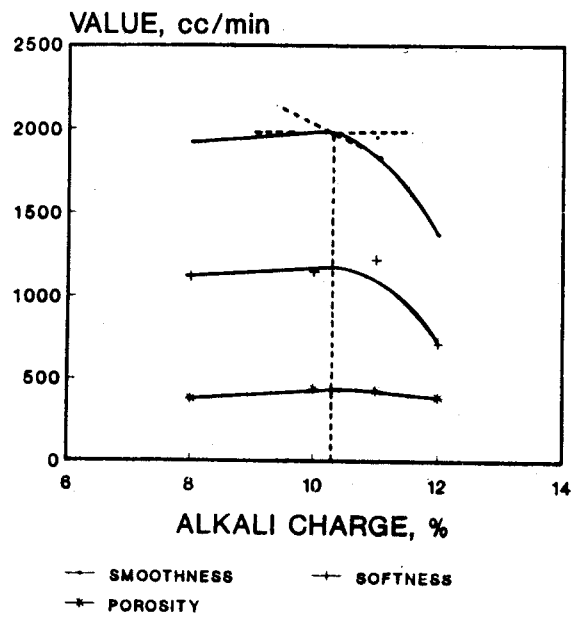

FIG. 3b

FIG.3 EFFECT OF ALKALI CHARGE ON STRENGTH AND SURFACE PROPERTIES OF BLEACHED PULPS

ALKALI DOSE OPTIMIZATION

Several output variables of unbleached pulp, viz. pulp yield, lignin content, pentosans, kappa no., fibre and fines fraction with respect to cooking chemical application are evaluated to optimize the cooking dose.

Further, strength and surface properties of unbleached and bleached papers are evaluated for the purpose. Though, for a particular grade of paper, a specific property may be important/desirable, the optimum output variables approaching towards maxima or minima as classified in **(Table-6)** are used for dose optimization.

Adopting this technique, desired output varialbes are graphically presented as a function of alkali charge, and best fit curves are drawn, Further, tangents are drawn yielding optimum outputs. Pulp evaluation represented by total & screened pulp yield, pentosans & lignin content, kappa no. & brightness, and fibres & fines fraction is shown in **Figs.1** (a,b,c&d) respectively.

Strength and surface properties of paper produced from unbleached pulps, as a function of alkali charge are depicted in **Figs.2** (a&b), whereas for bleached pulps, these are shown in **Figs.3** (a&b).

The optimum output variables obtained at the optimized alkali dose have been summarised in **Table-7.** Conclusively, the optimum alkali dose yielding the most of the output variables as desired shall be approx. 10.5% (NaOH as Na_2O) with standard deviation of 0.4%.

CONCLUSIONS

Paper making potential of rice straw has been evaluated through pulping and bleaching studies with different alkali doses, keeping the other conditions constant. Based on detailed experimental investigation, the following conclusions are drawn.

Total and screened pulp yields reduce with increase in alkali charge, mainly due to loss of hemicelluloses and partly cellulose alongwith lignin. Lower lignin content is observed in pulps and also the Kappa No., thus requiring less bleach chemicals.

Fines fraction of pulp is found to be of the order of 42% for 12% soda pulp, thus resulting in low pulp yields (56-62%) on bleaching. Further, manual washing after each stage of bleaching has resulted is shortening of fibres, thus, lowering the bleached pulp yields.

Considerably good strength and surface properties are observed, for both, the unbleached and bleached pulps. Tensile and burst index of bleached pulps are found superior to unbleached pulps, whereas in case of tear index, it is reversed. No specific trend is observed in surface properties of unbleached and bleached pulps.

Graphical analysis of unbleached pulp characteristics, and strength and surface properties of unbleached and bleached pulps with alkali charge yielding desirable optimum output, suggest alkali application in the range of 10.1 to 11.0% with an average value of 10.5%.

Strength properties of unbleached and bleached pulps favour an alkali dose of about 11%, whereas surface properties suggest about 10.2% chemical application. Therefore, depending upon the specific requirement, the rice straw can be digested with the suggested optimum alkali dose, yielding desirable properties.

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