Effect of Active Alkali to Material Ratio on Sulphate Pulping of Bambusa Arundinacea and on Paper Properties

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This work deals with the effect of cooking chemical (Active Alkali) to material ratio with other variables maintained constant for sulphate pulping of bamboo (Bambusa arundinacea). The degree of pulping, pulp yield, etc. have been determined. The unbleached pulp quality has been studied by measuring the strength properties of the hand sheets, also the bleaching of the pulps has been studied. The quality of resulting black liquor has been ascertained by measuring the residual active alkali, total solids, inorganics and calorific values. Under the conditions studied for the particular variety of bamboo, optimum chemical ratio and Kappa number of the pulps have been stated.

Bambusa Arundinacea has been a major component of material furnish for pulping at the west Coast Paper Mills. Till the year 1972 bamboo species were the sole raw materials used for pulping out of which *bambusa Arundinacea* constituted 75–88 per cent of the furnish, rest being *Dendracalmus strictus* and *Oxythenenthra monostigmma*. Various cooking conditions have been studied of this raw material (*Bambusa Arundinacea* or dowga bamboo, as locally called and hereinafter mentioned only as bamboo in the present paper) and the present paper deals with the effect of cooking chemical to raw material ratio on the pulping of bamboo, the properties of the pulp obtained and the properties of black liquor.

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bambusa Arundinacea belongs to a wild grass species, rising as high as 9–12 meters having dia. of 15–25 cms, is hollow with a wood wall thickness of 1 to 2 cms and possesses nodes and internodes. Generally the main trunk of the grass is used for pulping and the branches which offer diffllculty in handling and chipping are left out. The grass has a high holocellulose content, over 71 per cent and rich in pentosans. The fibres are sufficiently long. 2–4 mm and possess good paper making properties. The species has also high lignin content i.e. over 25 per cent and hard outer wall containing considerable quantity of silica. The proximate chemical analysis of the material used for pulping is given in Table No. I.

At the West Coast Paper Mills Ltd. sulphate chemical pulping process is being used. The concentration and ratio of chemical on the raw material is an important variable in the pulping process. The other major variables are : the types of raw material and its condition, age, storage, degree of decay, the chip size, ratio of cooking liquor to wood, sulphidity of the cooking liquor, cooking temperature, cooking time to reach maximum temperature and at maximum temperature and method of heating, direct or indirect. In a particular mill the number of variables like the raw material used, liquor to material ratio, sulphidity, digestion cycle, method of heating etc. are generally fiexd depending upon the conditions of the particular mill,

Table I

Proximate chemical analysis of bambusa arundinacea %

1.	Cold water solubility	2.9
2.	Hot water ,,	4.8
3.	1% sodium hydroxide solubility	23.0
4.	Ethyl alcohol-benzene "	3.1
5.	Pentosans	19.25
6.	Klason lignin	25.6
7.	Cross and Bevan cellulose	62.1
8.	Hollocellulose	71.4
9.	Alphe cellulose (Ash free)	48.6
10.	Ash	4.7
11.	Silica	2.8
12.	Moisture	8.2

NB: i. All values are expressed on oven dry basis except moisture which is on as such basis.

ii. 60-80 mesh wood meal is used for analysis

iii. Pentosans are by volumetric method of analysis. (T-18m-54)

such as the availability of the raw material, the pulp washing and evaporating capacities, black liquor burning, salt cake addition capacity, etc. Pulping is adjusted generally by varying the chemical ratio, the cooking time and temperature We shall be dealing here only the effect of chemical (Active Alkali) to material ratio.

Alkaline sulphate process is generally non-specific in nature and dissolves both the carbo-hydrates and lignin. It has been observed that 0.17 to 0.23 gram of alkali as Na_2O is consumed per gramme of wood dissolved and there is a straight line relationship between the active alkali consumed and the wood dissolved[1].

In order to obtain high organic content in black liquor both liquor to wood ratio and chemical to wood ratio are adjusted. In alkaline pulping most of the alkali is consumed in dissolving the pentosans and neutralising the acid formed during the cooking reaction and only a small amount is required for dissolving the lignin. However, a certain minimum amount of residual alkali is required to keep the dissolved lignin in solution and also to obtain brighter coloured unbleached pulp. It is stated that if the pH of the black liquor falls below 9.0, the lignin starts being precipitated and the colouring matter gets absorbed on the fibres giving dark coloured pulp[2].

Rydholm states that in kraft pulping sodium hydroxide and sodium hydrosulphide have independent function. While the former promotes hydrolysis of phenolic ether bonds of lignin and neutralises the acid formed by alkaline degradation of both carbohydrates and lignin, the latter almost exclusively reacts with lignin[3].

In bamboo the major pentosan in arabinoglucurano xylan consisting of chains of xylan residues connected by 1-4 xylosidic linkages. Some xylose residues are substitute ted at carbonatom 3 with arabinose, glucuronic acid or 4-oxy methyl glucuronic acid[4].

During the heating period of kraft cook at 100°-120°C, there is alkaline degradation of wood xylans by peeling reactions and the products of degradation are soluble in alkaline solution 3-4. But when cooking proceeds and alkali concentration is reduced to a critical limit the short chain degraded xylans again precipitate almost in crystalline form.

In a batch kraft cook (of Scots pine) the dissolution of glucuroxylan and lignin is accelerated by increasing the alkali charge 3.

At high temperatures such as the top temperature of a kraft cooking, the alkaline hydrolysis is of major importance and is directly proportional to the concentration of the alkaline aqueous solution 4.

It has been reported by Bray and co-workers that though increasing chemicals on wood increases the total consumption of the alkali, the percentage of active alkali consumed of the active alkali added actually reduces 2. When 15% A.A. was added on wood the consumption was 93% while when 25% A.A. was added the consumption reduced to 75%.

The pulp manufacturers are not only concerned with obtaining the best quality pulp at the highest yield, but they are also concerned with the quality of the black liquor obtained after digestion. The black liquor should have maximum organic content, be free flowing and have no lignin precipitation. This requires that sufficient residual active alkali is maintained in the black liquor, at the same time the calorific value is not brought down which will affect the burning properties in a furnace. This, therefore, necessitates optimum alkali charging for digestion. Similarly the concenttration of the black liquor, obtained is dependent on the input active alkali charged to the digester as well as the dissolution of the wood. This is again concerned with the pulp yield. Therefore proper balance is to be made between alkali charged, the pulp yield and the black liquor quality.

Pulp yield is a major factor in the economic production of pulp. But, at higher yield and consequently higher lignin content the pulp properties and bleaching processes are affected Above 55% yields the pulps are generally considered as high yield semi–chemical pulps and are useful as furnish for corrugating and insulating medium as well as cheaper grades of printing papers. Such pulps require refining to fiberise the partially cooked chips before the washing process. Stockman[6] states that in case of sulphate semi–chemical pulps, above 53% of pulp yield, the amount of screening increases quickly. However, upto 57% pulp yield, birch pulps have the same strength properties after refining as chemical sulphate pulps with 51–52 percent yield and these high yield pulps are easily refined. Jauhari, *etal*[7] have mentioned that bamboo pulps of high Kappa numbers require higher amount of alkali in the extraction stage of bleaching and also give bleached pulp of higher viscosity.

Macdonald[5] has stated that the effect of increasing effective alkali in a kraft cooking are : 1) lower yields of pulp at a given Kappa number; 2) longer beating time for pulp to reach a given breaking length; 3) breaking length is reduced slightly; 4) the tear factor at a given breaking length is increased approximately in proportion to the increase in the number of fibres per unit weight of pulp; 5) the xylan content is lowered and the glucumannan content is increased; 6) the brightness of the unbleached pulp increases.

The paper properties are greatly influenced by degree of delignification and the extent of carbohydrate degradation and dissolution. The lignin checks the swelling of fibres and therefore beating and development of fibre to fibre bond is decreased on increasing the Lingin content of pulp. The dissolution and degradation of carbohydrates are fairly independent of sulphidity and very much depend on the charge and concentration of sodium hydroxide as well as cooking time and temperature which is indicated by decreased average degree of polymerisation[3]

Experimental

Mature sound dowga bamboo culms from the mill yard were chipped in the chippers and uniform size chips of 23–25mm length were taken in all the experiments. For proximate chemical analysis of the material the chips were split to small pieces and further reduced to wood meal in a Laboratory hammer mill. The material was sieved and the fraction passing through 60 mesh and retained on 80 mesh was taken for the chemical analysis. The test results are given in Table No. 1.

Cooking experiments were carried out in a laboratory rotary digester of 15 litres capacity. Chips equivalent to 1 Kg oven dry material were taken for each digestion. White liquor containing active constituents sodium hydroxide and sodium sulphide obtained from the mills chemical recovery plant and stored in a closed bottle, was used in all the experiments. The sulphidity of the white liquor was 19.5%. The chemical analysis of the white liquor used is given in Table No. 2. Sulphate black liquor obtained from the mill having residual active alkali content of 4 grammes per litre and

Table II

Chemical analysis of white liquor

Total titrable alkali expressed as Na_2O, gpl	113.9
Sodium hydroxide expressed as Na_2O, gpl	79.4
Sodium sulphide ,,	19.2
Sodium carbonate ,,	15.3
Sodium sulphate ,,	1.8
Causticity %	83.8
Sulphidity %	19.5

***

solid content of 18% was also stored and used in all the experiments. In each experiment, chips were charged in the digester and required quantity of white liquor which was initially heated to 85°C was added to the chips. Required amount of black liquor to make up the liquor to material ratio 3:1 was added to the digester after making necessary corrections for moisture content of the bamboo chips.

Five sets of experiments were performed by varying the active alkali charged on the raw material, but maintaining other conditions of cooking constant. The temperature of the digester was raised to 160°C gradually and constantly during a period of two hours by electrical heating The digester was continuously rotated at the rate of two revolutions per minute till the end of the cook. During the heating period, the air from inside the digester was vented by relieving the steam at regular intervals.

The maximum temperature of 160°C was maintained for one hour with the auto-transformer provided with the equipment.

After the cooking period, the steam was let off from a relief valve, the digester cover opened, and the contents of the digester were transferred quantitatively to a diffuser type of washing equipment. The contents were diluted with water to maintain 1.2% consistancy and mixed and defibred with a slow speed agitater for two minutes. After five minutes of retention time, the black liquor was collected in a vessel. The above treatment of dilution and diffusion was repeated three more times and the black liquor was made up to a volume of 74, litres for further study. Four times washing was done to simulate the process of brown stock washing as done in the mill, though practically it was not possible to maintain all conditions of counter current brown stock washing.

The unbleached pulp was then trasferred to a centrifuge washer and washed twice with hot water. The pulp mat from the centrifuge was then removed, defibred and granulated by hand. The uncooked, partially cooked chips and shive pieces were separated and dried for rejects estimation. The pulp portion was preserved in a polyethene bag for further experiments and tests.

After conditioning the pulp granules in a closed polyethene bag for one day, representative samples of pulps were oven dried and weighed for yield determination.

The Kappa number of the unbleached pulp was determined by Tappi standard method T236-m60. The lignin content of pulp was calculated from the Kappa numbers.

The coooking conditions, the pulp yields, rejects percentage, Kappa number and lignin content of unbleached pulp are given in Table No. III.

Black liquor study :

The black liquor obtained from the digestion after different stages of washing was made up to a total volume of 74 litres. Representative sample was bottled and tested for solids content, residual active alkali, calorific value and other data are given in Table No. IV.

Bleaching experiments

Representative samples of granulated unbleached pulp equivalent to 50 grammes oven dry weight were used in each experiment. The bleaching was done by C.E.H. sequence (chlorination, alkali extraction and calcium hypo chlorite treatment) using different

Table III

Chemicals added & properties of pulp

Cook No.	1	2	3	4	5
1. Active alkali added on BD chips as Na_2O, %					
a) From white liquor	12.79	13.95	15.11	16.28	17.44
b) From black liquor	0.50	0.46	0.40	0.34	0.26
Total	13.29	14.41	15.51	16.62	17.70
2. Active alkali consumed in digestion. Na_2O, %	10.98	12.09	12.40	12.32	12.92
2a. AA consumed out of AA added, %	82.6	85.3	79.9	74.1	72.9
3. Unbleached pulp yield on BD chips, %					
a) Gross yield	54.7	52.5	51.2	49.8	48.6
b) Screened yield	44.2	46.7	47.3	47.2	47.8
4. Rejects on BD chips, %	10.5	5.8	3.9	2.6	0.8
5. Carbohydrate in pulp on OD chips %	49.3	48 2	47.1	46.5	45.8
6. Lignin in pulp ,, ,, :	4.3	3.2	2.5	2.1	1.7
7. Carbohydrate dissolved,% of Total carbohydrates	30.9	32.5	33.2	34.4	36.0
8. Lignin dissolved, % of total lignin.	84.1	87.4	90.3	91.9	93.2
9. Ratio of lignin: carbohydrate	8.70	6.60	5.36	4.38	3.74
10. Kappa number of pulp	36.4	31.4	24.4	22.3	21.6
11. Lignin content of screened pulp %	5.46	4.71	3.66	3.35	3.27
12. Material dissolved, %	45.3	47.5	48.8	50.2	51.4
13. Active alkali consumed as Na_2O per 100 g. of material dissolved	24.4	25.4	25 4	24.5	25.1

amounts of chlorine, depending upon the Kappa number of the pulps to obtain 77–78 per cent brightness on magnesium oxide scale.

The bleached pulp was tested for yield, brightness and cuprethylene diamine (0.5%) viscosity.

The bleaching conditions and the results of bleaching are given in table No V.

Paper properties

The unbleached pulp was beaten in a Tappi Stadandard valley beater to a freeness of about 42° schopper Reigler and hand sheets of 60 grammes per square meter substance were made in a British Standard Sheet Making Machine according to Tappi standard procedures. The paper sheets were conditioned at 65% relative humidity for minimum 24 hours. The papers were then tested for specific volume (bulk) tensile and bursting strengths, folding endurance, stretch, internal tearing resistance and folding endurance. The test results are shown in Table No. VI.

Discussion of Results

The active alkali ratio on the material used for digestion has distinct effect on the pulping, pulp properties and the black liquor obtained. The various functions of the active alkali in sulphate cooking have already been narrated in the introduction. we shall now deal with effects obtained in the cooking of bamboo.

Active Alkali Consumption

In these experiments active alkali on bamboo was increased from 13.3 per cent to 17.7 per cent. The consumption has been in the range of 11.0 to 12.9%. The alkali consumption is not in the same proportion as that added. In the first cook out of the alkali added 82.6 percent was consumed. In the second cook there is a slight rise in the consumption (i e. 85.3% showing further reaction and conversion of rejects into pulp. But in further stages the per cent active alkaii consumed of the active

Table IV

Black Liquor Study

Cook Nos.	1	2	3	4	5
Material added from bamboo chips, g.	1000	1000	1000	1000	1000
Inorganics added from white liquor, g.	286	293	317	342	367
Inorganics added from make up black liquor, g.	82	71	60	47	37
Organics added from black liquor, g.	146	126	108	87	67
Total organics added, g.	1146	1126	1108	1087	1067
Total solids input, g.	1496	1487	1485	1476	1471
Total solids obtained in black liquor, g.	929	945	953	958	965
Organics obtained in black liquor, g.	599	601	596	589	581
Inorganics obtained in black liquor, g.	330	344	357	369	384
Organics in black liquor, %	64.5	63.6	62.5	61.5	60.2
Inorganics in black liquor, %	35.5	36.4	37.5	38.5	39 8
Active alkali in black liquor solids, %	2.48	2.35	3.26	4.49	4.98
Calorific value of black liquor, cals/g.	3260	3180	3190	3160	3060
Black liquor solids per g. of whole pulp, g.	1.69	1.80	1.86	1.92	1.98

Table V

Bleaching of pulp

1.	Pulp from cook No.	1	2	3	4	5
2.	Kappa No. of pulp	36.4	31.4	24.4	22.3	21.6
3.	Total chlorine consumption on unbleached pulp, %	15.44	12.86	10.22	10.10	8.20
4.	Caustic soda consumption in alkali extraction stage, %	2.82	2.20	1.61	1.60	1.38
5.	Bleaching loss : % on unbl. pulp	9.0	8.2	7.6	7.5	6.3
6.	Bleached pulp yield, %	39.80	42.88	43.71	43.63	44.48
7.	Brightness of bleached pulp, %	76.5	77.0	77.0	78.0	77.0
8.	CED viscosity of pulp (0.5%) cp.	13.4	12.0	13.0	12.2	12.0

Constant conditions of bleaching ;

	Consistency %	Temp. °C	Time hours	pH
Chlorination	3.0	28	1	1.5- 2.0
Alkali extraction	5.0	60	1	9.5–10.5
Hypochlorite	5.0	40	2–3	8.5- 9.5

Table VI

Strength properties of unbleached pulps

1.	Pulp from cook number	1	2	3	4	5
2.	Kappa Nos of pulp	36.4	31.4	24.4	22.3	21.6
3.	Initial freeness, °SR	11	9	9	11	9
4.	Final freeness, °SR	42	42	43	42	43
5.	Beating period, minutes	44	48	46.5	46	55
6.	Basis weight, g/m²	61.3	62.8	59.1	60.8	60.0
7.	Thickness, microns	116.9	118.5	109.2	106.3	104.4
8.	Bulk, cm³/g	1.91	1.89	1.85	1.75	1 74
9.	Breaking length, metres	5800	5960	6400	6110	6050
10.	Stretch, %	3.0	3.2	3.1	3 1	3.0
11.	Burst factor	33.8	33.8	36.7	36.4	34.7
12.	Tear factor	84.8	80.4	83.7	76.5	71.7
13.	Folding endurance, No. of D.F.'s	16	21	12	10	8
14.	Strength index	1510	1550	1490	1410	1310

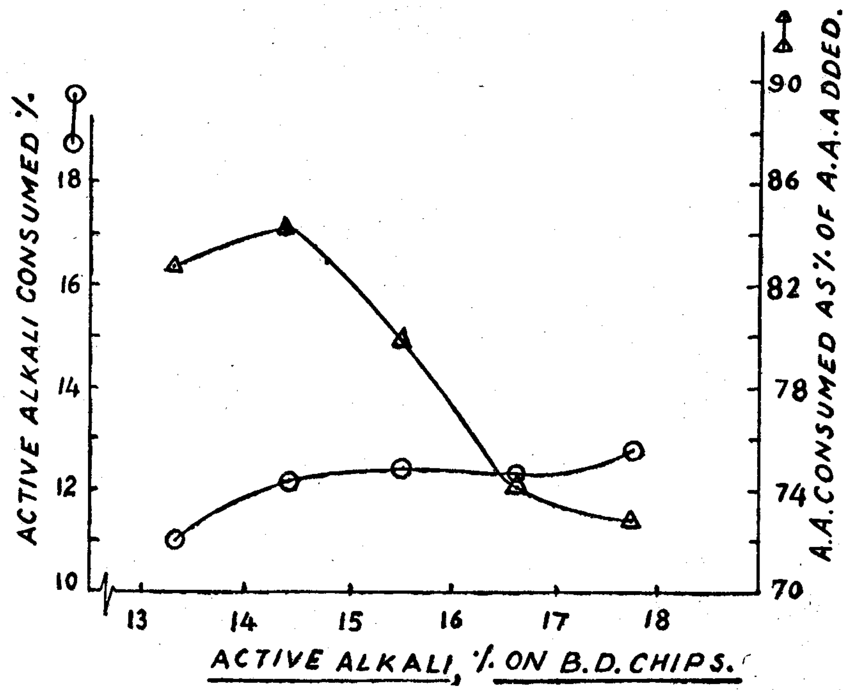

Figure 1

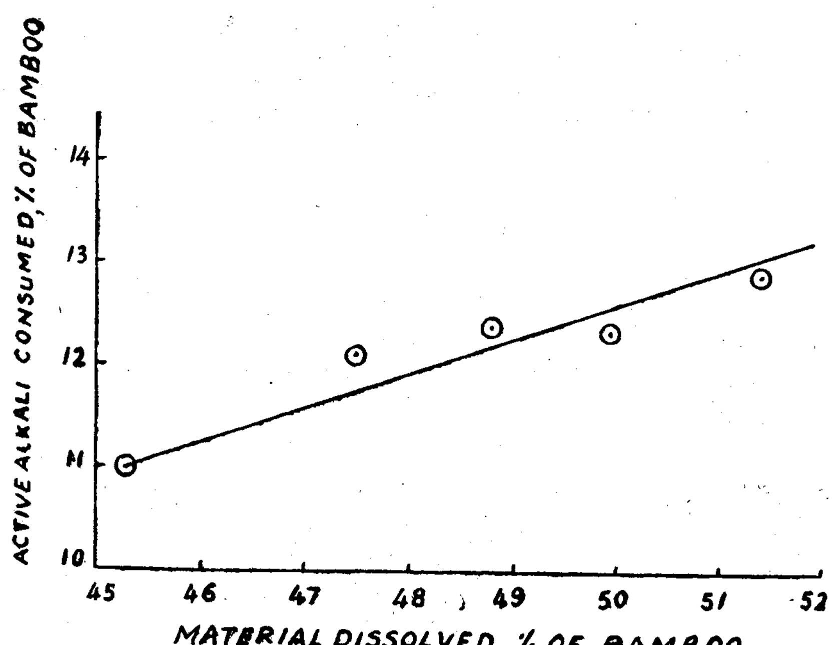

Figure 2

alkali added steadily reduced, bringing down the consumption to 72.9 per cent (vide figure 1), in the final cook. This has increased the residual active alkali in the black liquor solids from 2.48 to 4.98 per cent (vide figure 3B).

Effect In Digestion

The material dissolved from bamboo as a result of increased active alkali is directly proportional to the amount of alkali consumed in the digestion showing a straight line relationship between the material dissolved and alkali consumed. (vide figure 2.). It is found that for every 100 grammes of bamboo dissolved active alkali consumed is in the range of 24.4 to 25.4 grammes as Na_2O.

It is observed that there is retardation in the active alkali consumption at higher levels of active alkali addition. Similar results are observed in the dissolution of material and the pulp yield (vide figure 3A and 4A). Since active alkali was less in the initial experiments, there was less dissolution of bamboo, the gross pulp yield was higher but the pulps were harder with higher Kappa numbers and consequently higher lignin content. The screened yield of the pulps were lower since more rejects were obtained. However, if the partially cooked rejects are defibred by light refining the overall pulp yield could be higher (we have taken that, pulp thus obtained will be about 50% of the rejects).

The pulp yields, Kappa Numbers

(and lignin) and rejects percentage obtained are shown in figure 4A, At higher levels of alkali addition reject are successively converted to pulp, resulting in higher net yield. However, increased alkali charge has also the effect of dissolution of more carbo-hydrates and lignin, Hence there is a combined effect of conversion of rejects into pulp and dissolution of carbohydrates and lignin. There seems to be some balance and at higher levels of alkali addition after a certain stage, the pulp yields tend to level off (under the conditions of digestions studied). The phenomana of dissolutions of carbohydrates and lignin are illustrated in figure 4B. With increased alkali charge in the intial levels, the carbohydrates dissolution is at a lower degree and the lignin dissolution is more pronounced. The lignin dissolution increased from 84.1 to 90.3 per cent (on the basis of original lignin present in bamboo) when alkali charge was increased from 13.3 to 15.5 per cent. However, the degree of carbohydrates removal was much less i e. 30.9 to 33.2 per cent (on the basis of original carbohydrates present in bamboo). But when the alkali charge was further increased to 16.6 per cent the degree of the carbohydrate removal was much pronounced compared with lower alkali charge, whereas the lignin removal was much reduced compared earlier. The ratio of lignin to carbohydrate in pulp against the carbohydrates is illustrated in figure 4C. There is a steady drop in the lignin ratio

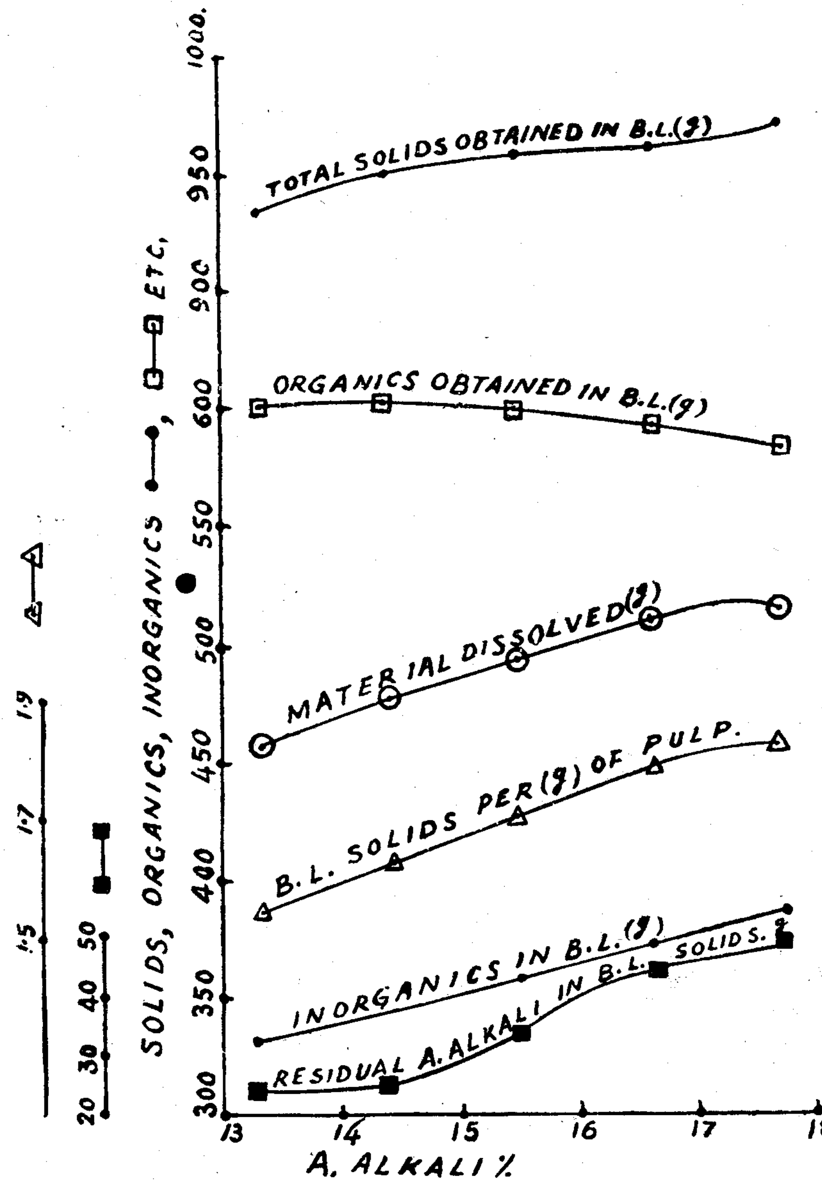

Figure 3A

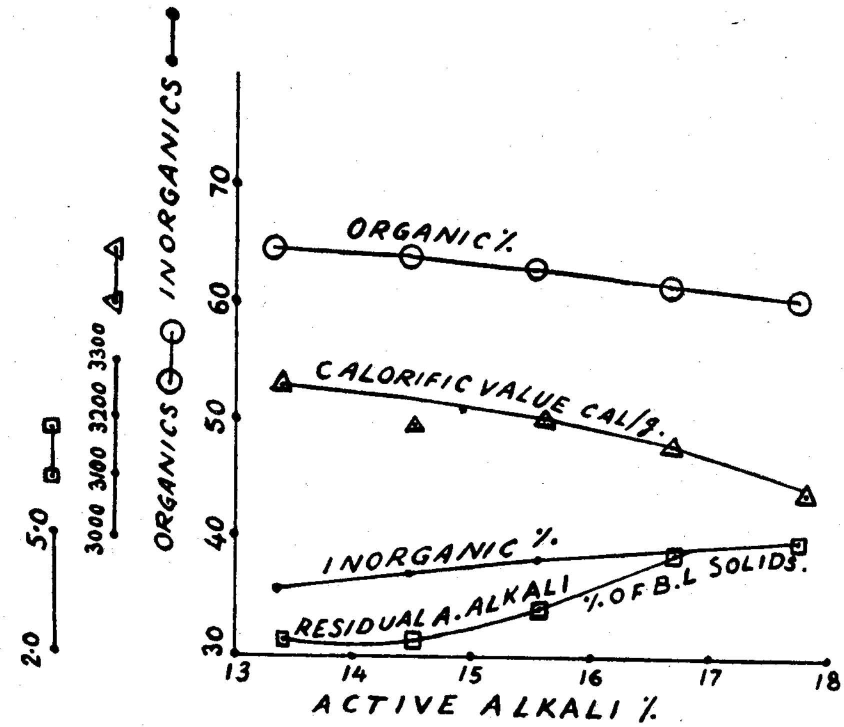

Figure 3B

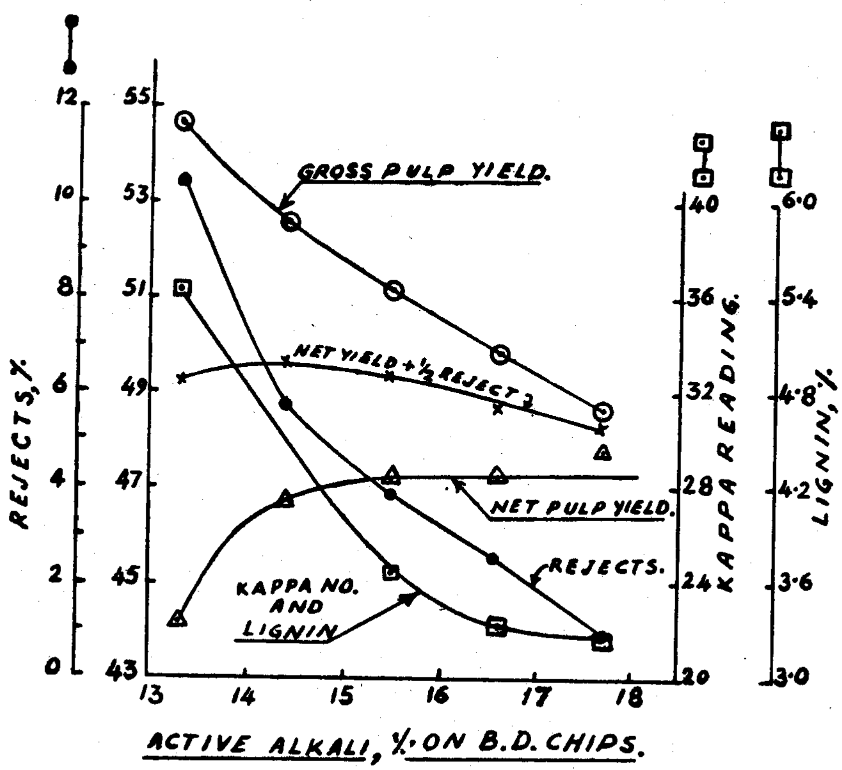

Figure 4A

until the alkali charge is increased to 15.5 per cent, and thereafter the drop in residual lignin is quite low. Similar phenomena has also been observed earlier by one of our co-authors when the time factor of cooking was increased keeping the alkali charge and other cooking conditions constant. Cooking time was varied from 100 minutes to 220 minutes at cooking temperature of 150°C, with active alkali charge of 16.7 per cent and 25% sulphidity. The quality of the bamboo was slightly different with higher lignin and lower cellulose contents. The cooking method was also slightly different. However, the pattern of carbohydrate and lignin removals were of similar type though of different degrees, since the cooking temperature was lower, and the time intervals were different. The results are illustrated in figure 4D and 4E. At increased cooking period (220 minutes), the carbohydrate fraction was increased due to precipitation and absorption of xylans from the black liquor, while there was slight reduction in the lignin content[8].

It is, therefore evident, that, after some optimum addition of active alkali there is no advantage in adding more alkali as far as pulp yields and lignin removal are concenned. However, in further studies of the unbleached pulp it has been observed that the strength properties of the pulps fall steadily with increased amount of alkali in cooking. Hence the need for adding optimum amount of alkali for digestion is quite clear.

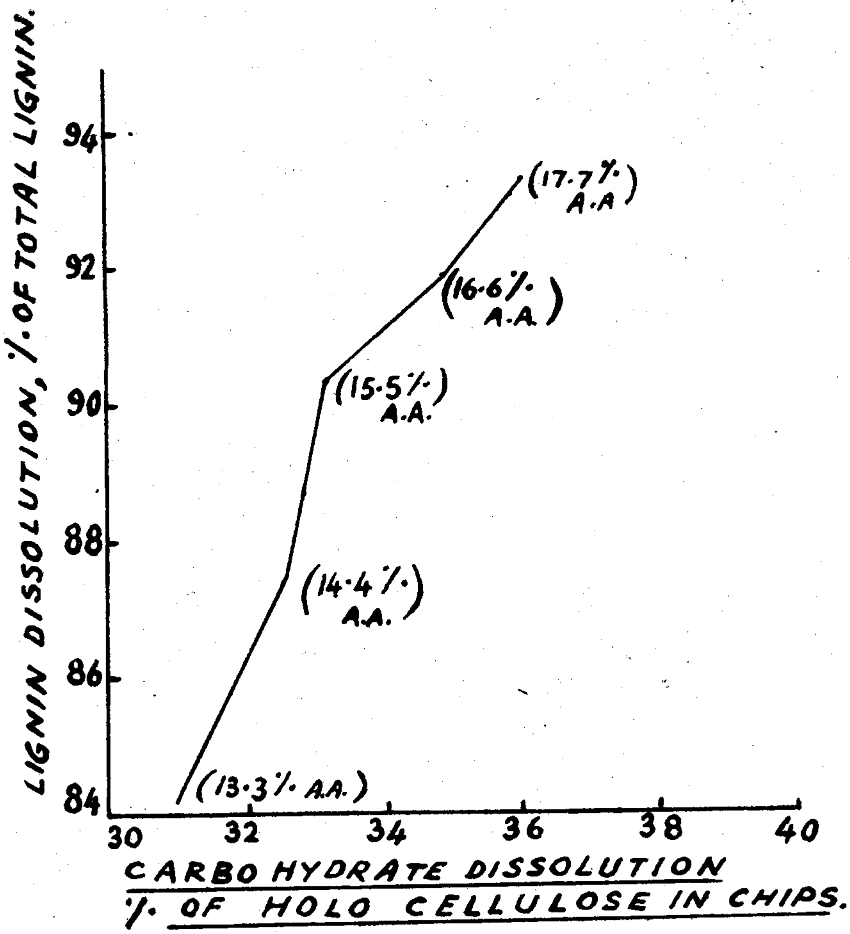

Figure 4B

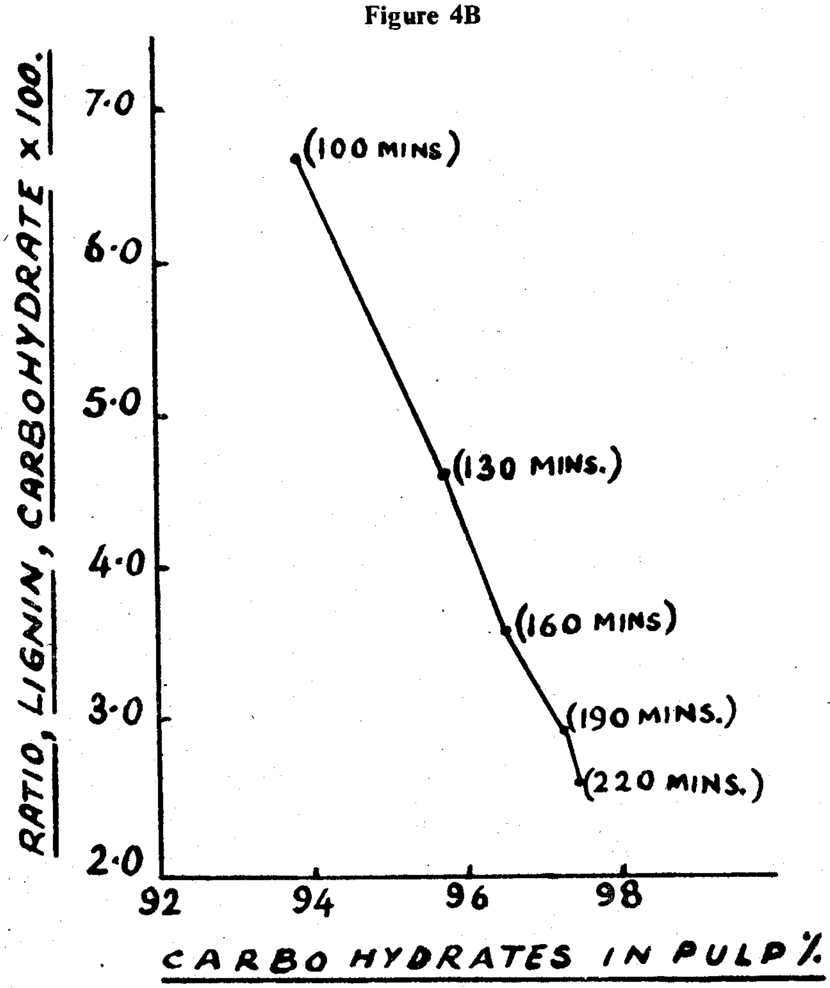

Figure 4C

Study of Black Liquor Solids:

The properties of black liquor solids and the quantities obtained are shown in Table 4 and figures 3A and 3B. Though the input material was constant, i.e. 1000 g. in our experiments, the amount of inorganic chemicals in white liquor and make up black liquors as well as organic compounds from black liouor was varying. The total solids, and organic inputs were gradually reducing in the successive experiments, while the inorganic inputs steadily increased. There was gradual increase in the black liquor solids obtained depending on the material dissolved from bamboo, as well as input solids. The percentage of inorganic content increased from 35.5% to 39.8% in the black liquor solids obtained, with corresponding reduction in the organic content. This had effect on the calorific value of the black liquor, which reduced from 3260 calories per gramme of solids to 3060 calories. With increased inorganic contents in the black liquor and reduced calorific value at higher levels of alkali addition there is bound to be adverse effects in the burning process in the recovery furnace. Besides, the black liquor solids obtained per tonne of pulp goes up which increases the load on the chemical recovery plant.

Bleaching Studies

With variations in the degree of cooking of the pulp, the bleaching properties and bleached pulp properties are affected. The harder pulps with high Kappa numbers consume more chlorine. Also caustic soda consumption in the alkali extraction stage are higher with higher Kappa numbers of pulp. The drop in the consumption of bleaching chemicals is steeper in the case of pulps of first three cooks and thereafter the consumption curves generally flatten off. It is observed that in the case of pulp from first cook the viscosity is slightly higher showing less degradation. However, the viscosities are not much affected in further stages. When the kappa numbers of the pulps are successively reduced the pulp is getting more delignified and the loss on bleaching is reduced. The consumption of bleaching chemicals and other properties are shown in figure 5.

Hand Sheet Properties

The effect of higher chemicals in cooking on pulp has been greatly evidenced from the bulk and strength properties of the pulps, beaten to constant slowness. The pulp of the first two cooks are harder having high Kappa number and lignin content; but are less degraded. The strength proporties as exhibited by the strength indices are higher compared to the other pulps. In these pulps there is less fibre bonding and matting as evidenced from the specific volumes, since the fibres are more ligneous. The presence of more hemicelluloses seems to have beneficial effect in improving the strength properties of the hand sheets. With increasing chemicals and consequent reduction in the

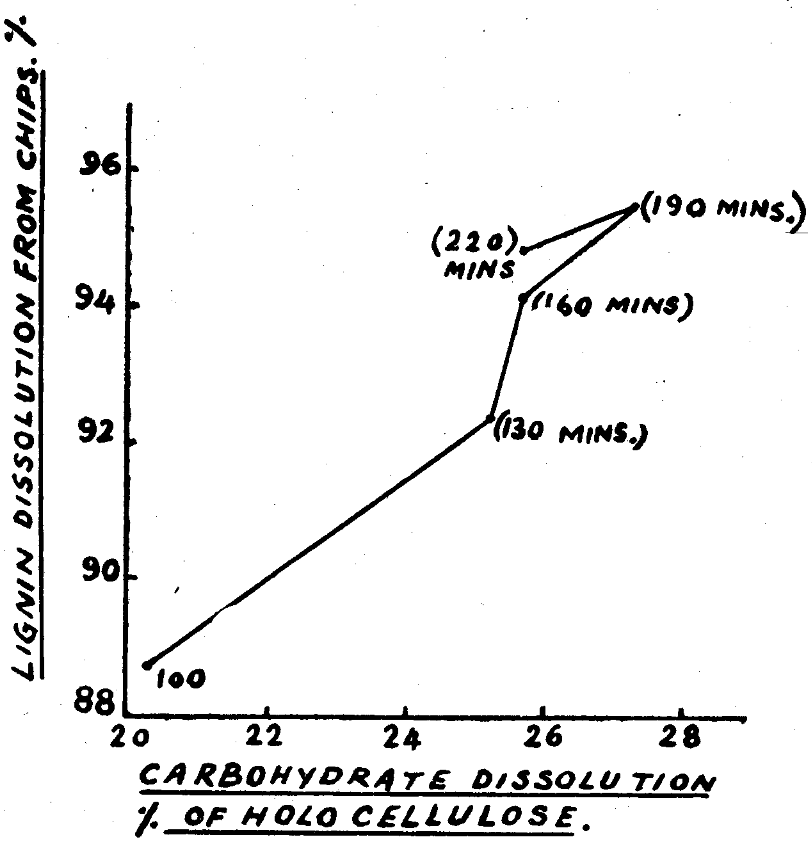

Figure 4D

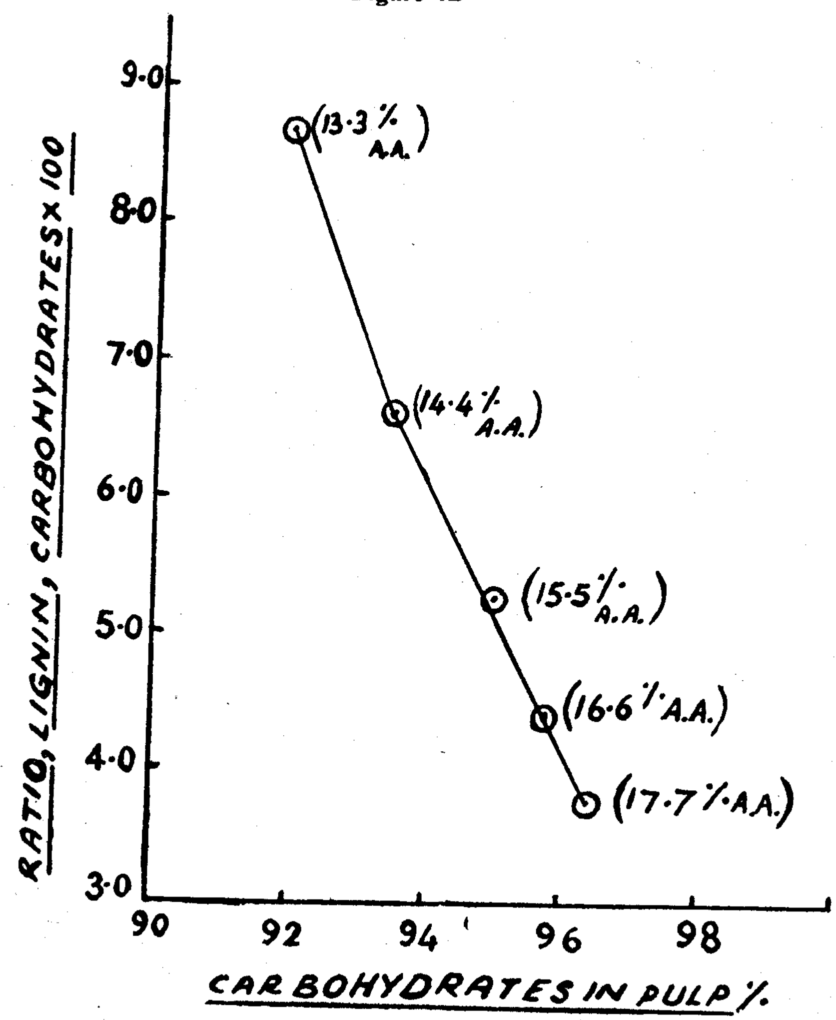

Figure 4E

lignin content the effect of hemicelluloses and fibre flexibility seems to be prominent till the first three cooks. The breaking length and burst factor have markedly increased, whereas the folding endurance and tear factor reduced steeply from the 3rd cook. The effect on the breaking length and burst factor are not much pronounced though their slopes have gradually declined after 3rd cook. From the strength curves it is evident that increasing chemical up to the 2nd cook is beneficial and further increase up to 3rd cook is advantageous where bursting and tensile strength are important. Further increase is detrimental to the fibres as all the strength properties drop considerably. The curves of strength properties and bulk are illustrated in figure 6 and 7.

Conclusions

1. The results obtained reveal that the effect of active alkali charge ratio on bamboo in cooking follows the trends evidenced in other varieties of raw materials.
2. An optimum active alkali charge is required to get good quality pulp for paper-making, keeping other variables same.
3. The black liquor properties change considerably by varying active alkali charged which may affect the chemical recovery performance.
4. It is essential to maintain correct alkali ratio to get unbleached pulp having minimum bleach requirement.

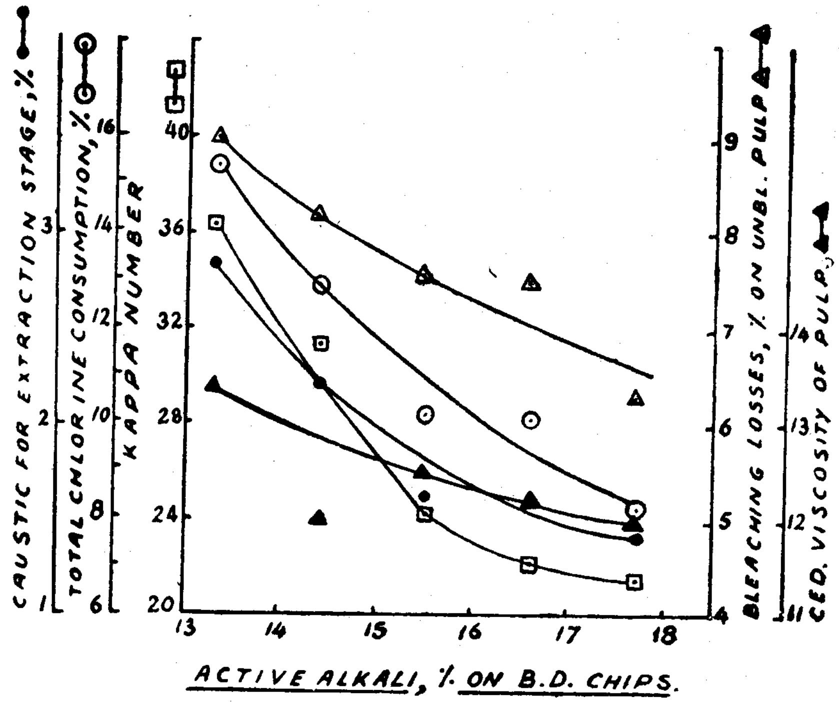

Figure 5

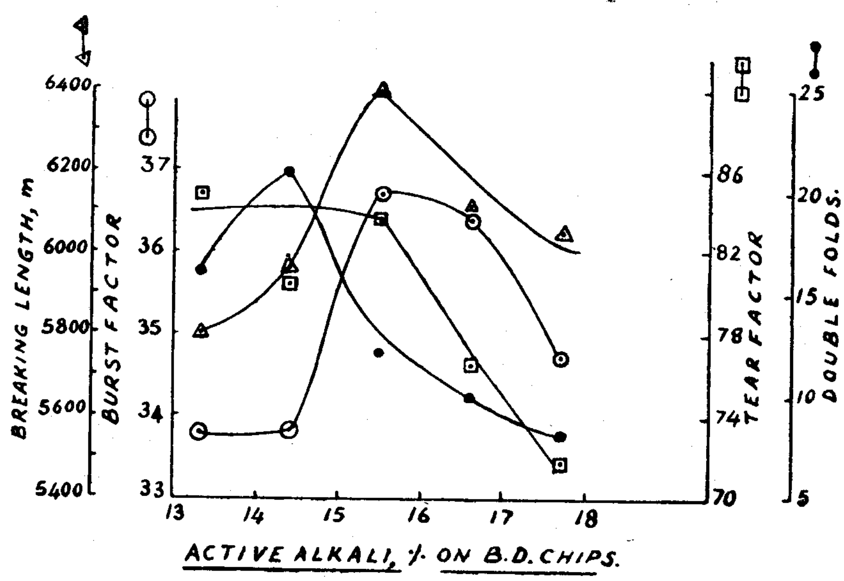

Figure 6

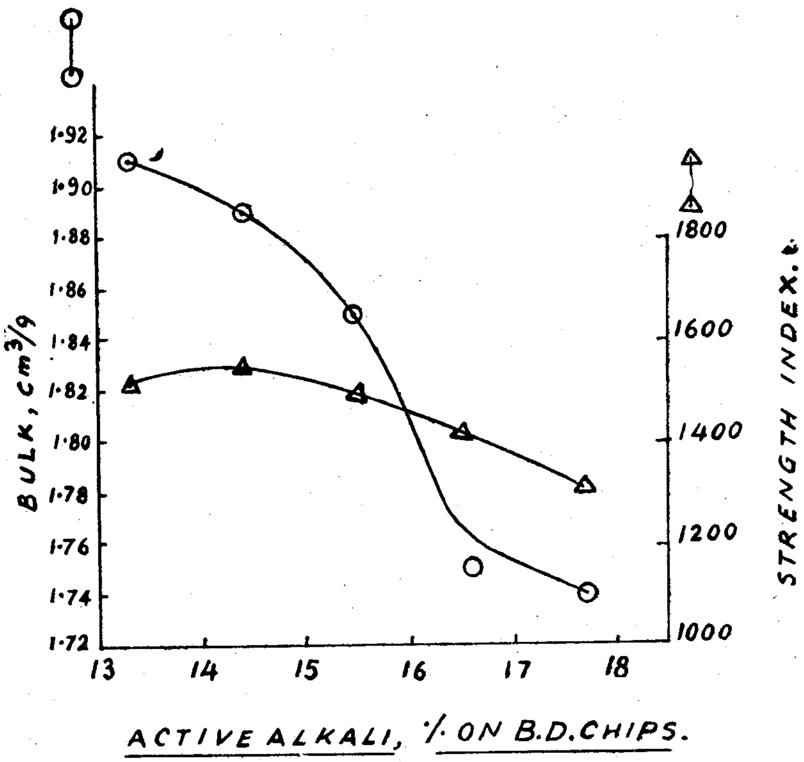

Figure 7

5. For bamboo, under the conditions of cooking studied, the optimum alkali charge is found to be in the range of 14.4 to 15.5 per cent Na_2O with corresponding Kappa numbers 24.4 to 31.4.

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