Some Aspects of High Yield Kraft Pulping of Bamboo

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High yield kraft pulps in the yield range of 52-63 percent were obtained from Bambusa arundinacea by applying chemical treatment to the chips at higher temperature and pressure, followed by gentle refining in the Sprout Waldron refiner. Differnt pulp yields were obtained by varying the active alkali charges, while other conditions were maintained constant. By reduced alkali charges the increase in pulp yield was due to the retention of greater amount af ash, extractives, lignin and holocellulose. Beyond the yield of 59 percent, the increase in pulp yield was solely due to the increase in the lignin content. The viscosity of the isolated holocelluloses from pulps of different yield was found to vary and was lowest at 52 percent yield.

At any Schopper Riegler the breaking length of various pulps yield was found to vary, the highest yield (63%) pulp giving the lowest breaking length. For this reason the basis for comparing the other strength properties like tear and burst factor was taken against breaking length. If the results for the tear factor are compared at any breaking length, the tear factor was found to be highest at 54 percent yield.

Bleaching of the pulps of 52, 54, 57 and 59 percent pulp yield was carried out using the sequence chlorinaiion — chlorination + lime neutralization—alkali extraction—hypochlorite. Bleached yields were not found to vary much, though the consumption of the bleaching chemicals was different at different yields. For bleachable pulps the optimum degree of cooking, as determined from the kappa number seems to be 34, corresponding to the unbleached pulp yield of 54 percent. Under the conditions used the strength properties of the bleached pulps were found to be dependent on unbleached pulp yield.

INTRODUCTION

High yield kraft pulps in the yield range of 60-70 per cent have been obtained by various workers (1-3) by using reduced active alkali, temperature and cooking time. Briston and Kelly (4) in a continuous pulping together with hot stock breaking, refining and screening of kraft pulp from pine obtained the yield of 60 per cent. For one reason or the other these high yield kraft pulps were recommended for use in the manufacture of Liner boards, corrugating medium etc. Literature survey revealed that very little work has been published on high yield kraft pulping of bamboo chips. Few years ago a research programme on high yield kraft pulping of bamboo chips was initiated at the West Coast Paper Mills Ltd., and as a part of this programme Jauhari etal (5) prepared high yield kraft pulps from Bambusa arundinacea and found that pulps in 60-62 per cent yield with satisfactory strength properties could be obtained. The pulps were easily bleached by the C/E/C. $Ca(oH)_2$/H sequence to 76-78 per cent brightness. However, the bleach requirement and bleaching losses were high. The present study is also a part of the said research programme and was carried out chiefly. for the bleachable varieties of pulps, through the studies on lignin-holocellulose relationship at varying unbleached pulp yields bleach consumption, bleached yields and the over all economics.

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EXPERIMENTAL

For carrying out all the experiments bamboo chips prepared from air dried and sound bamboos were used. The chips were made in the mill chipper and after hand sorting of the chips to ensure chip size uniformity, the chips were kept in a polythene bag. The average dimensions of the chips used were length 20-30 mm, width 15-20 mm, thickness 3-5 mm.

Table I Pulping conditions and Results

Constant conditions:

Material to liquor ration	1 : 3
Sulphidity of white liquor	22.4%
Maximum temperature,	160°C
Time to get the max. temp.	2 hrs.
Cooking time at max. temp.	1 hr.

Cook No.	1	2	3	4	5
1. Active Alkali added as such on chips, %	12.8	14.7	16.7	18.6	20.5
2. Pulp yield, %	63.0	59.4	57.2	54.0	52.1
3. Kappa No.	85.3	63.5	46.3	34.2	28.6

The preparation of the pulps was carried out in two stages, the first stage consisted of cooking the chips (A.D. chips equivalent to 1.5 Kg O.D.) in an electrically heated rotary digester of 16 litre capacity tumbling at 2 r.p.m. For making up the liquor to chip ratio, black liquor of known active alkali concentration was used as diluent. The active alkali added on chips included the alkali added from the white liquor and also the black liquor. After the cooking period was over the contents were emptied out from the digester and refined hot at 7-8 per cent consistency in a 12″ laboratory Sprout Waldron refiner. Very mild refining (plate clearance 375 microns) which was just enough to disintegrate the fibre aggregates and knots resulting in an uniform pulp was used. The pulp so obtained was thoroughly washed free of alkali and dissolved matter in a hydra extractor and thickened to a consistency of approximately 25 per cent. The pulp was granulated, weighed and a portion used for moisture determination, and finally the yield was calculated. The pulps were neither screened nor cleaned. The unbleached pulps of different yields were analysed for kappa number, ash, and extractives, according to standard TAPPI methods. Holocellulose was determined accordinp to the method of Sen Gupta, Majumdar and MacMillan (6). The cupriethylene diamine disperse viscosity of the air dry holocellulose (0.5 per cent solution) was determined according to SCAN C15:62. The lignin was found by difference i.e. 100 minus ash, extractives and holocellulose.

For evaluating the physical strength properties, the pulps were beaten either in the Lampen mill or in the hollander beater. The sheets were made on the Noble and Wood sheet making machine. Initially bleaching experiments were carried out with 50 g of pulps for calculating the bleached yield, bleaching losses and bleach consumption etc. For making detailed studies on the strength properties of

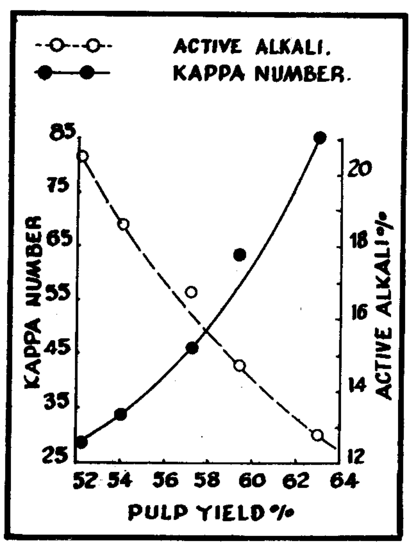

Fig. 1 Relation of Kappa No. and active alkali at different unbleached pulp yields

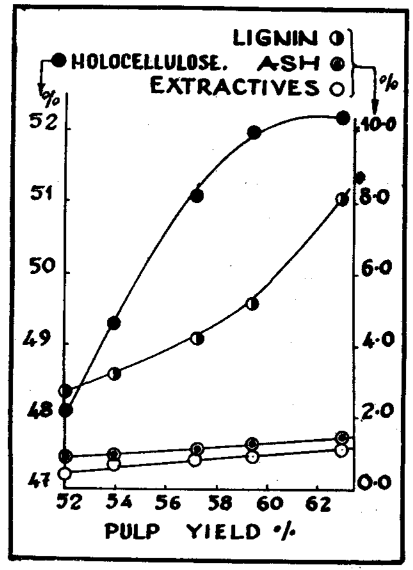

Fig. 2 The unbleached pulp constituents at different unbleached pulp yields.

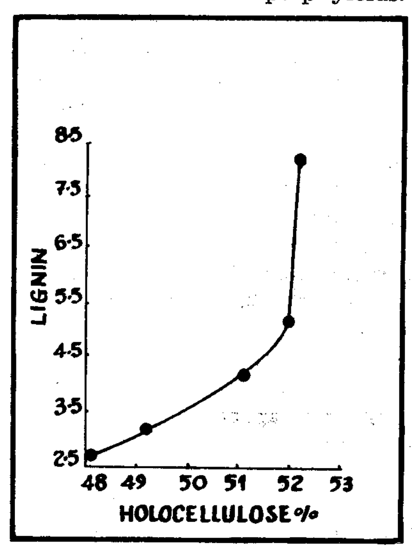

Fig. 3 Relationship between holocellulose and lignin expressed on O.D. chips

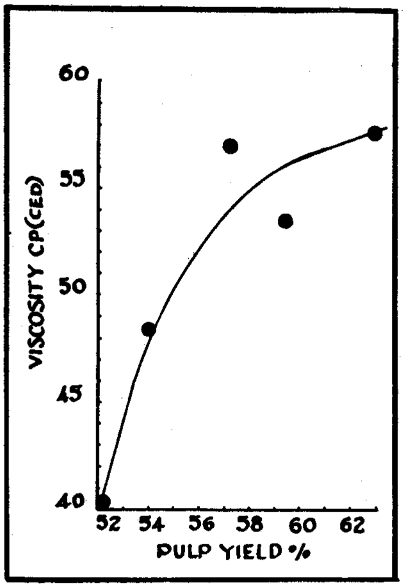

Fig. 4 Viscosity (0.5% pulp solution CED) of unbleached pulp i.e. chlorite holocellulose at various unbleached pulp yields.

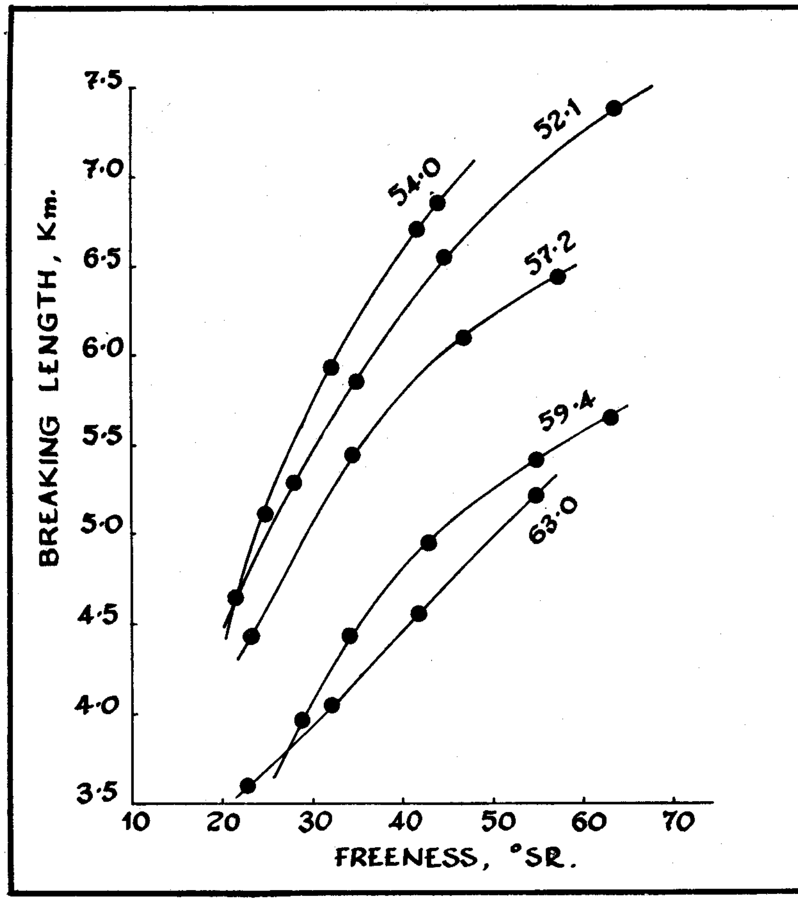

Fig. 5 Breaking length against freeness (°SR) at various unbleached pulp yields

bleached pulps, about 360 g of the bleached pulp was prepared, beaten in the valley beater and sheets made on the Noble and wood sheet making machine.

RESULTS AND DISCUSSIONS

The conditions used during pulping and the results obtained are given in **Table I** and graphically in **Fig. 1.** It could be seen from the figure that under all other constant conditions of cooking, the yield of pulp is dependent on the amount of active alkali used. With increasing pulp yield the kappa number shows a continuous increase. In addition the ash, extractives and holocellulose also increase **Fig. 2.** The maximum holocellulose which could be retained on the basis of bamboo chips by using milder alkali charges was approximately 52 per cent corresponding to the unbleached pulp yield of 59.4 per cent. Any further increase in pulp yield was not accompanied with increase in the holocellulose content, only the lignin content increased sharply. This could be seen from **Fig. 3** where it is shown that at 52 per cent holocellulose content, 5.2 and 8.2 per cent lignin could be obtained. The fact that only 52 per cent holocellulose could be obtained, indicates that in bamboo which has about 65 per cent holocellulose, about 13 per cent of the carbohydrates are quite reactive to alkaline solutions and are lost either directly or through degradation and peel-

Table II Chemical Analysis of Unbleached Pulps

Pulp yield on OD chips, %	63.0	59.4	57.2	54.0	52.1
1. Ash, %	2.3	2.1	2.0	1.8	1.7
2. Alcohol Benzene solubility, %	1.8	1.6	1.4	1.1	0.8
3. Chlorite holocellulose, (corrected for ash), %	82.9	87.5	89.3	91.2	92.3
4. Lignin, % By difference (100-1+2+3)	13.0	8.8	7.3	5.9	5.2

All results expressed on moisture free basis ing off reaction. The reason for this interpretation is based on the fact that even when the degree of delignification is limited to a somewhat higher level, the losses of carbohydrates are high and occur rapidly. Further the viscosity of the isolated holocelluloses also indicates that even when the delignification is not carried out too far, considerable degradation has occurred **Fig. 4.**

The results for the analysis of pulps are given in **Table II** and for the Lampen ball mill (T 224Sm-45) evaluation of unbleached pulps are given in **Fig. 5, 6 and** 7. It is shown in **Fig. 5** that at any Schopper Riegler test, lowest breaking lengths are obtained for 63 per cent pulp yield. An important consequence of increasing the yield is that less number of fibres are involved in a hand sheet at a certain basis weight, when compared to a low pulp yield, because the fibres are loaded with more of lignin and hemicelluloses. The number of fibres by virtue of their effect on formation influences most of the hand sheet properties. The higher amounts of lignin in 63 per cent pulp yield because of their adverse effect on the swelling of fibres and interfibre bonding might have restricted the development in breaking lengths to a lower level when compared to 52 or 54 per cent pulp yields. The adverse effects of the lignin on hand sheet properties have been reported in the literature. Jappe (7) showed that there is a linear relationship between lignin content and the swelling power of fibres. Jayme (8,9) believes that the presence of lignin always tends to lower the bonding strength. However, several workers (9, 10, 11) have found that there is an optimum lignin content at which maximum strength could be developed. For bamboo sulphate pulps in the yield range studied a 5.5 — 6 per cent lignin in pulp seems to be

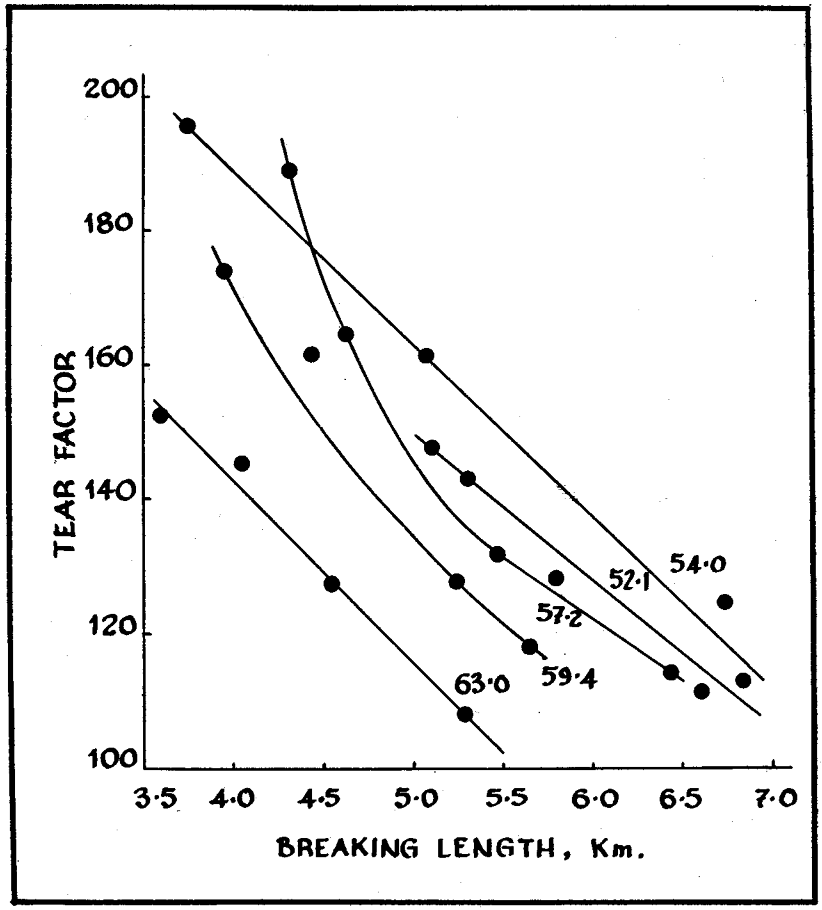

Fig. 6 Tear factor against breaking length at various unbleached pulp yields

Table III. Bleaching with the Sequence $C_1/C_2Ca(OH)_2/E/H$.

Constant conditions:

Bleaching stage	Chlorination	Chlorination + lime neutralisation	Extraction	Hypochlorite
Consistency, %	3	4	5	5
Temperature, °C	32	32	55	40
Time, 1 min.	60	2+3	75	120
Pulp yield, %	59.4	57.2	54.0	52.1
Kappa No.	63.5	46.3	34.2	28.6
1. Chlorination, C_1				
Chlorine added, %	14.0	12.0	8.0	7.0
Chlorine consumed, %	13.8	12.0	8.0	7.0
2. Chlorination + lime neutralization, C_2. Ca $(OH)_2$				
Chlorine added, %	2.5	2.5	2.0	1.5
Ca $(OH)_2$ added, %	4.7	3.9	2.5	2.5
Final pH	7.4	7.1	7.3	8.9
3. Caustic extraction, E				
Caustic soda added, %	2.5	1.5	1.0	1.0
Final pH	10.7	9.5	9.2	10.4

4. Hypochlorite, H

Hypo added as available chlorine, %	4.0	2.0	1.5	1.0
Hypo consumed as available chlorine, %	3.7	1.8	1.5	1.0
Caustic soda added for buffering, %	0.8	0.4	0.3	0.3
Final pH	8.2	8.2	7.8	8.1
Total elemental chlorine consumed, %	16.3	14.5	10.0	8.5
Available chlorine consumed as hypochlorite, %	3.7	1.8	1.5	1.0
Lime as $Ca(OH)_2$ consumed, %	4.7	3.9	2.5	2.5
Caustic soda consumed, %	3.3	1.9	1.3	1.3
Shrinkage during bleaching, %	16.7	15.4	10.6	9.0
Yield of bleached pulp on bamboo chips, %	49.5	48.4	48.3	47.8
Brightness, %	79.0	79.5	79.0	79.5
Viscosity, cP (CED)	17.7	24.0	30.3	30.5

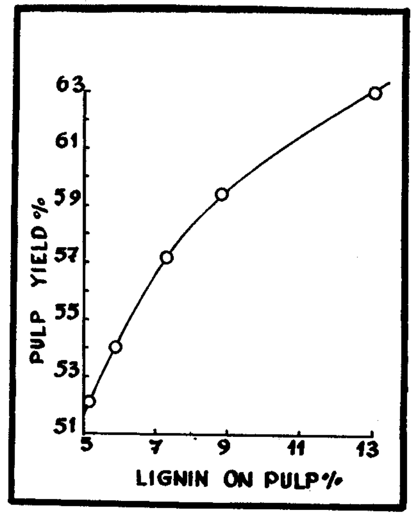

Fig. 8 Relationship between unbleached pulp yield and lignin content of pulp

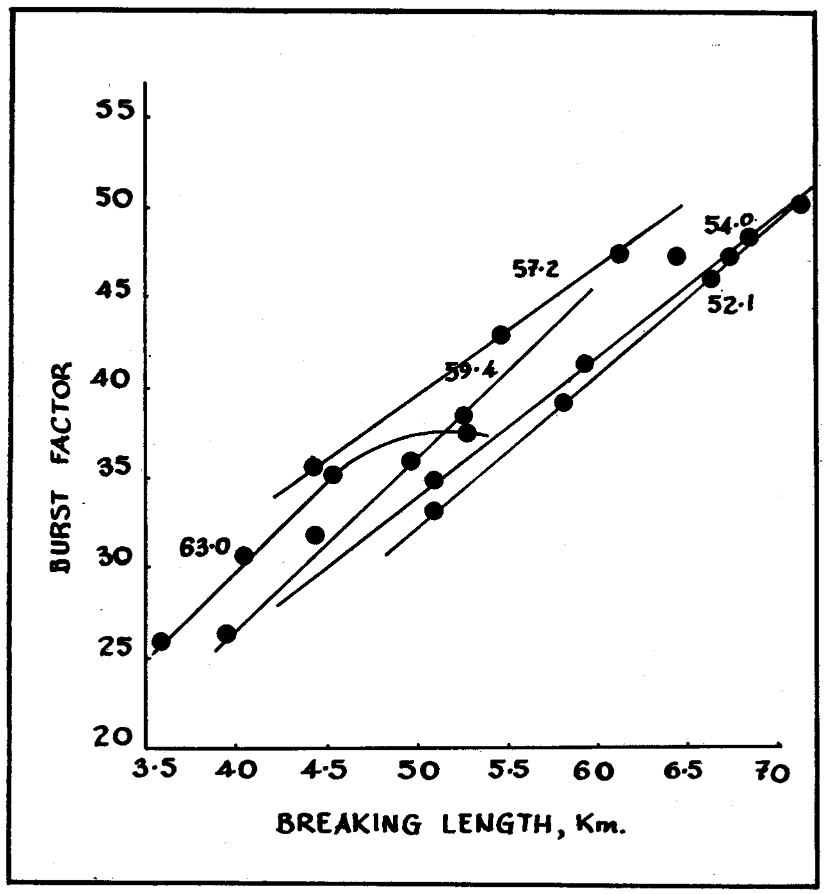

Fig. 7 Burst factor against breaking length at various unbleached pulp yields

optimum for strength development. The results for the tear factor plotted against breaking length are shown in **Fig. 6.** It is interesting to see that 54 per cent yield pulp have given the highest tear factor. This may be due to differences in the fibre lengths, fibre strength, number of fibres involved, degree of fibre bonding and stretch. Obviously at higher yield (57 — 63 per cent), the less number of fibres the lower stretch and presence of broken and short fibres produced during defibering (due to incomplete softening of the middle lamella) have contributed to low tear factor. Varying pulp yields also show differences in the burst factor at a certain breaking length, however the extent is small.

The pulps of 52, 54, 57 and 59 per cent yield (Ca 50 g) were bleached by following C_1/C_2.Ca $(OH)_2$/E/H sequence. The conditions used and the results obtained are given in **Table III.** One problem often realized in the bleaching of high lignin pulps to high brightness by conventional bleaching agents is the excessive consumption of bleaching chemi-

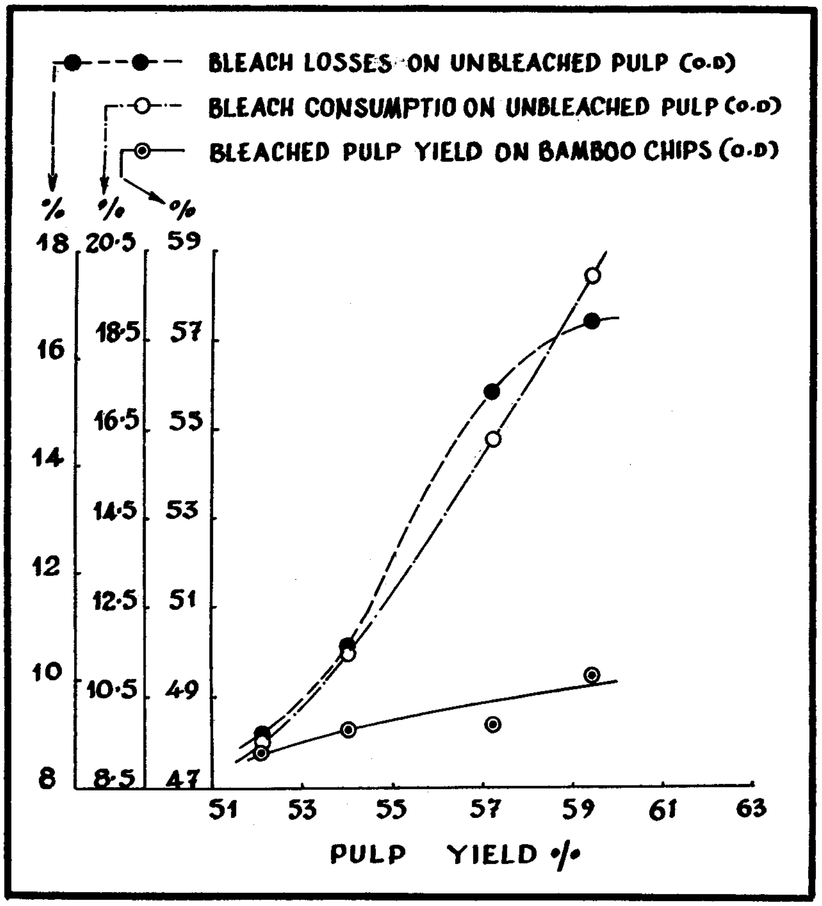

Fig. 9 Showing bleach losses, bleach consumption and bleached pulp yield against various unbleached pulp yields

cals, the cost of which is often difficult to balance against the increments in bleached pulp yield. This was an important consideration while working out the best sequence for bleaching of pulps prepared in this study. Double chlorination with or without intermediate alkali extraction has been recommended for bleaching high lignin pulps (12-15) and to reduce the consumption of caustic soda the use of milk of lime in various ways was recommended. (5, 15).

As caustic soda alone adds considerably to the cost of bleaching, because of its high price, it was important that its consumption was kept to a minimum. We have found that though double chlorination with intermediate alkali extraction is most effective in the removal of oxidisable impurities, the requirement of caustic soda was fairly high. We have for this reason chosen the sequence chlorination — chlorination and lime neutralization — alkali extraction — hypochlorite in

Table IV Raw Material and Chemical costs for various pulp yields

1. Unbleached pulp yield, %	59.4	57.2	54.0	52.1
2. Bleached pulp yield, %	49.5	48.4	48.3	47.8
3. Bamboo, tonnes	2.02	2.06	2.07	2.09
Cost @ Rs. 125/tonne, Rs.	252.50	258.30	258.70	261.20
4. Cooking chemicals, tonnes	0.297	0.346	0.385	0.428
Cost @ Rs. 350/- tonne, Rs.	104.0	121.20	134.80	149.80
5. Unbleached pulp (O.D) tonnes	1.200	1.184	1.118	1.089
6. Cost of one tonne unbleached (O.D.) pulp, Rs.	297.1	320.5	352.1	377.3
7. Elemental chlorine, tonne	0.198	0.172	0.112	0.093
Cost @ Rs. 300/- tonne, Rs.	59.4	51.6	33.6	27.9
8. Lime, 70% purity, tonnes	0.060	0.050	0.030	0.029
Cost @ Rs. 120/- tonne, Rs.	7.26	6.00	3.60	3.48
9. Available chlorine as calcium hypochlorite, tonnes	0.048	0.024	0.017	0.011
Cost @ Rs. 610/- tonne, Rs.	29.28	14.64	10.37	6.71
10. Caustic soda, tonnes	0.041	0.023	0.015	0.014
Cost @ Rs. 1,000/- tonne, Rs.	41.0	23.0	15.0	14.0
11. Cost of bleached pulp, Rs./ tonne	493.44	4.74.74	456.11	463.11

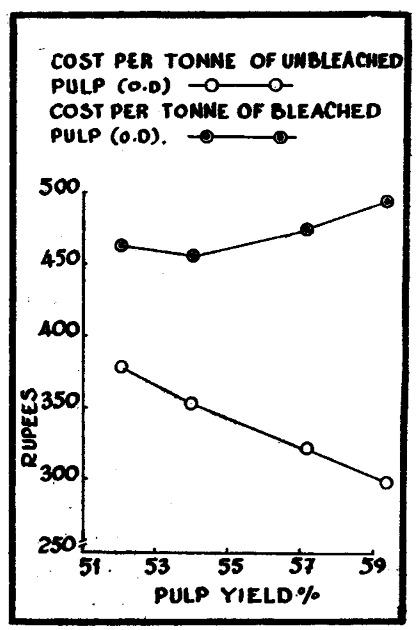

Fig. 10 Showing the cost of one tonne of O.D. unbleached and bleached pulps at various unbleached pulp yields

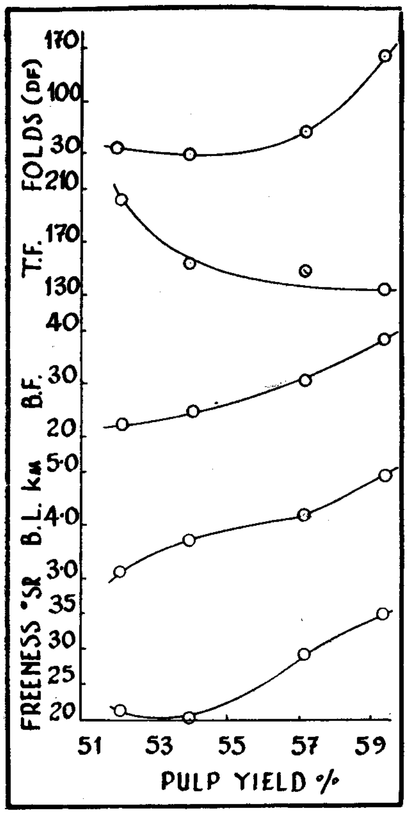

Fig. 11 Strength properties of bleached pulp at 3000 revolutions (Lampen Ball Mill)

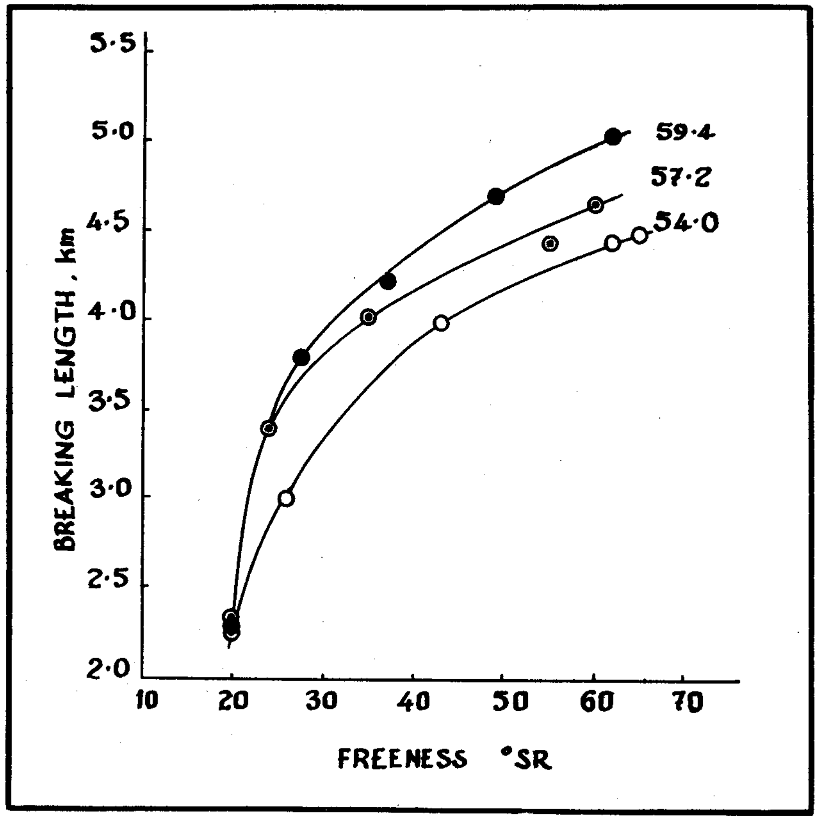

Fig. 12 Breaking length against freeness (°SR) (bleached pulp)

which the alkali requirement was reduced considerably. An important feature of this sequence is that the second stage of chlorination and lime neutralization was completed in 5 min. which implies that the reaction can be carried out to completion in a small retention vessel and a large tower can be eliminated, thus bringing down the capital investment and also simplifying the bleaching sequence. Further this sequence could be adopted in the mill with slight modifications in the existing equipments. It is important in this sequence, that only so much milk of lime is added which is enough to give the final pH of about 7.5. Excessive amounts of milk of lime will interfere in subsequent solubilization of chlorolignins in alkali by rendering them inactive.

The relation of total pulp yield to the lignin content of pulp is shown in **Fig. 8.** This relation is important for the production of bleached pulp and it could be inferred that at the lignin content of 13 per cent corresponding to the unbleached pulp yield of 63 per cent, the bleach consumption will be excessive as the chlorine demand normally increases in direct proportion to the lignin content of the pulp. From **Fig. 9** it could be seen that as the pulp yield is increased, the bleach consumption and bleaching losses increase rapidly whereas the bleach pulp yield shows a small increase. The fact that in the range of 52 — 59 per cent unbleached pulp yield, the holocellulose (on chips basis) content shows a continuous increase but the same is not reflected to the equal extent in bleach pulp yield, indicates that even if some of the carbohydrate fraction is retained by using milder conditions of cooking, it is easily lost during subsequent bleaching operation. This will be an important consideration while working out the economics of the process. The economics of the process has been worked out as shown in **Table IV** and **Fig. 10.** In figure 10 the cost

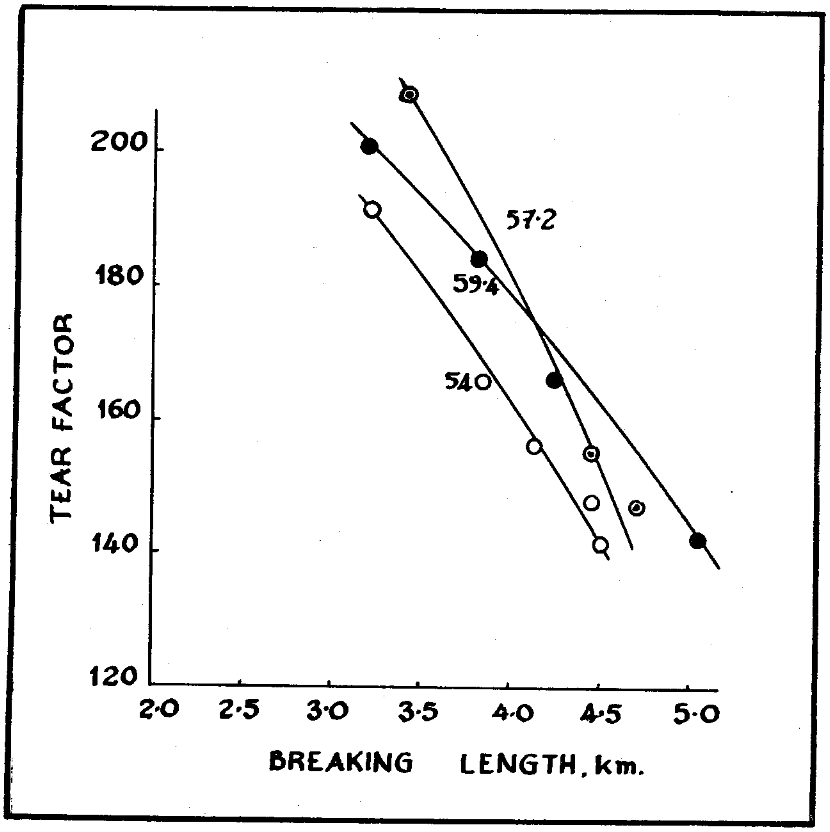

Fig. 13 Tear factor against breaking length (bleached pulp)

per tonne of unbleached and bleached pulp against pulp yield is shown. For bleached pulps the cost shows a minimum at about 54 per cent unbleached pulp yield, while the cost for unbleached pulp shows a continuous decrease with increasing pulp yield. It is evident that while working out the overall economics one has to consider the relative amounts of unbleached and bleached pulps produced in a mill so that the choice for cooking bamboo chips to a certain yield is profitably fixed. For a mill having 50, 50 per cent production of the unbleached and bleached pulps a higher yield of 59.4 per cent could be economically used.

The strength properties of the bleached pulps at constant number of revolutions (3000 in the Lampen ball mill) against unbleached pulp yield are given in **Fig. 11.** It will be seen from this that the bleached pulp obtained from the unbleached pulp of 59 per cent yield develops strength properties rapidly, which indicates that the power for refining this pulp will be low. To evalute the strength properties in greater detail about 360 g of bleached pulp was prepared from 54, 57.2 and 59.4 per cent pulp yield and beaten in the valley beater to different freeness. The results for the breaking length against freeness are shown in **Fig. 12** and it could be seen that highest breaking length was obtained with 59.4 per cent yield. The tear factor **Fig. 13** and burst factor **Fig. 14** are also high at any breaking lengths for 57.2 and 59.4 per cent yield when compared to 54 per cent yield. This is a point in favour of bleaching pulps of 57 — 59 per cent yield, especially if the strength requirements for the end product are high.

CONCLUSIONS

1 Unbleached kraft pulps upto the yield of 59.4 per cent with satisfactory strength properties can be obtained.

2 Depending on the strength properties required in the end product, the yield for the unbleached pulps could be varied between 54-59.4 per cent. For strong kraft pulps 54 per cent yield may be preferred.

3 Under the conditions studied the maximum holocellulose which could be retained was 52 per cent, corresponding to the pulp yield of 59.4 per cent.

4 The cost per tonne of bleached pulp was lowest at 54.0 per cent unbleached pulp yield corresponding to the kappa number of 34. The cost for the unbleached pulp shows a continuous decrease with increasing pulp yield. The over all economics has to be worked out considering the cost of both and the proportion of each variety produced in the mill.

5 The strength characteristics of the bleached pulps increases, as the unbleached pulp yield is increased (upto 59 per cent).

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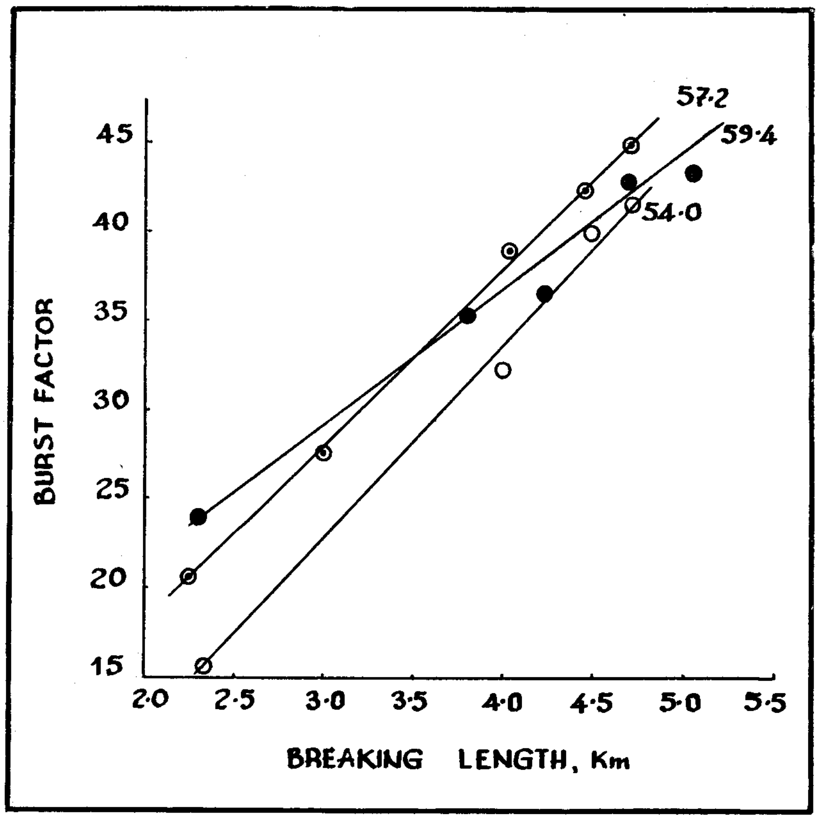

Fig. 15 Burst factor against the breaking length (bleached pulp).

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