PULPING OF SISAL FIBRES: EFFECTS OF CHEMICAL CONCENTRATION, Na_2SO_3/Na_2CO_3 RATIO AND FIBRE TO CHEMICAL RATIO.

J.H.Y. Katima, M.R. Halfani, J.W. Ntalikwa.

Dept. of Chemical and Process Engineering, University of Dar es Salaam, P.O. Box 35131, Dar es Salaam, Tanzania.

ABSTRACT

This paper reports on pulping of hard fibres extracted from the leaves of agave sisalana using sodium sulphite buffered with sodium carbonate as pulping chemical. The cooking was carried out at 168°C for a cooking period of 6 hours, with varying chemical concentration, sodium sulphite to sodium carbonate ratio and fibre to chemical ratio. The results show that both the pulp yield and pulp viscosity decrease with increasing chemical concentration, whereas Kappa number of pulp decreases to a limit of about 16.45. Brightness increases significantly with an increase in the ratio of Na_2SO_3/Na_2CO_3. The pulp yield obtained indicated the following maximum strength indices: tensile index:75.60 [Nm/g], burst index: 6.05 [kPa.m2/g] and tear index : 19.30 [Nm2/kg]. These values are higher than those reported for bleached pine kraft pulp; that is tensile index: 50.52 [Nm/g], burst index: 5.77 [kPam2/g] and tear index: 18.91 [Nm2/kg] with a brightness of 81.0% ISO. These make sisal a promising candidate for non-wood pulping process.

INTRODUCTION

Sisal fibre is a hard fibre extracted from the leaves of *Agave sisalana* and its hybrids. It is one of the major cash crops of the coast regions of Tanzania. Sisal fibres have conventionally been used in the manufacture of ropes and twines, carpets, padding, mat, sacks, cordage, and fishnets. After invention of synthetic fibres such as nylon and polypropylene, the demand for natural fibres dropped tremendously. This is due the fact that the items mentioned above could also be made using synthetic fibres. This consequently resulted to a decrease in the production of sisal fibres due to uncertainty of price in the world market. Thus, in order to revitalize the sisal industry in Tanzania efforts are being made to find an alternative utilization of these fibres and other by-products from sisal leaves.

One of the alternatives is to use the fibres in the production of high quality paper pulp. On the other hand, non-wood pulping is currently being encouraged globally due to the problem of deforestation created by the conventional wood pulping (Casey,1980 ; Manfred,1988). Thus, the present effort of utilizing the sisal fibres in paper making contributes significantly to forest conservation.

THEORY

Paper is usually made up of fibre mat which contains mainly cellulose. Plant fibres are usually the major source of cellulose. However, in order to provide rigidity and toughness of the fibre, plant fibres are usually cemented together by an amorphous, highly branched, three dimensional, phenolic polymer called "lignin". In paper making lignin has a general effect of inhibiting the fibre from swelling and water absorption (Britt,1984). This makes the fibre less responsive to mechanical refining during the stock preparation stage. Thus, in the context of paper making lignin is unwanted material which has to be removed as far as possible during pulping process.

The percentage composition of sisal fibre in comparison to wood fibre is shown in Table 1. The higher amount of cellulose in sisal fibre suggests that sisal can make a good pulp. This pulp can be used in making high quality and speciality paper. Higher amounts of hemicellulose content in sisal fibre compared to wood fibre shows that sisal pulp has higher bonding potential compared to wood pulp. Less amounts of lignin reveals that less amount of cooking chemical is required in chemical pulping of sisal fibre compared to wood pulping.

Table 1: Percentage chemical composition of sisal fibre in comparison to that of wood fibre [4].

COMPONENT	SISAL	WOOD
Cellulose	78 - 80%	49 - 58%
Hemicellulose	10 - 12%	1.3 - 3.9%
Lignin	8 - 9%	26 - 31%
Waxes	2 - 3%	10 - 21%
Ash	1.0%	0.1 - 0.4%

Ash content of sisal fibre is relatively high compared to wood fibre. This reflects some inconveniences in chemical recovery of sisal pulping spent liquor due to the presence of silica and other metals.

Pulping processes can be categorised into three groups, namely; mechanical pulping, chemical pulping and a combination of the two. In all of these processes the main aim is to remove lignin selectively from the fibre matrix leaving cellulose and hemicellulose intact for pulp strength. However, in regard to production of high quality paper pulp, chemical pulping is the superior pulping method compared to the other two pulping processes. This is due to its ability to attack lignin selectively using suitable chemicals, and splitting up the lignin molecule into small fragments which are eventually removed along with spent liquor.

Conventional chemical pulping processes include: Kraft or Sulphate process and Sulphite process. The Kraft process utilizes a solution of NaOH and Na_2S in pulping. The advantages of this process include; efficient chemical recovery, higher strength of pulp obtained and shorter cooking times. However, the major disadvantage of this process is odour problem. This is due to gaseous emissions which are mainly hydrogen sulphide, methyl mercaptan and dimethyl sulphide emitted from multiple effect evaporators and recovery furnace.

The Sulphite process utilizes a solution of sulphur dioxide in water, or sodium and magnesium based sulphites. The advantages of this process include: highest brightness of pulp obtained and very low odour. The disadvantages of this process include; lack of an efficient chemical recovery system and has inferior strength of the pulp obtained compared to kraft pulps.

In this work, an attempt has been made to merge the Sulphate process with the Sulphite process in order to retain the good features of both processes. Thus sodium sulphite buffered with sodium carbonate was selected as a pulping chemical and the pH of black liquor discharge was maintained at around neutral point for the purpose of environmental conservation.

In chemical pulping, many factors may affect the rate of lignin removal. Among these factors are: chemical concentration, fibre to chemical ratio, coking temperature, cooking time, presence of pulping additives or catalyst and soaking of the material in cooking liquor before pulping. This paper focuses on the effect of chemical concentration, fibre to chemical ratio and ratio of Na_2SO_3 to Na_2CO_3 on pulp quality parameters such as pulp yield, Kappa number, pulp viscosity, pulp brightness and strength properties (according to standard testing methods TAPPI, 1980; BSI, 1982).

EXPERIMENTAL

Raw Sisal fibres from sisal estate were chopped in sizes of 3 to 5 cm and then analyzed for moisture content. The fibres were then fed into four autoclaves each 0.85 litres along with calculated amount of cooking chemical. The autoclaves were mounted on a shaft and then inserted in a 32.0 litres steam chest. The shaft was connected to a variable speed motor set at a rotation of 28 revolutions per minute. Saturated steam at 10 bar was used as a heating medium whereby cooking temperature was maintained at 168°C within a cooking period of 6 hours. The experimental set up of the pulping unit is as shown in Fig. 1 (Ntalikwa, 1994). Chemical concentration was varied in the range of 80 to 120 g/l, ratio of Na_2SO_3 to Na_2CO_3 was varied in the range of 3:1 to 7:1, and fibre to chemical ratio was varied in the range of 1:5.5 to 1:6.5. Black liquor was also analyzed according to routine standard tests such as pH, total suspended solids, residual Na_2CO_3, and residual Na_2SO_3.

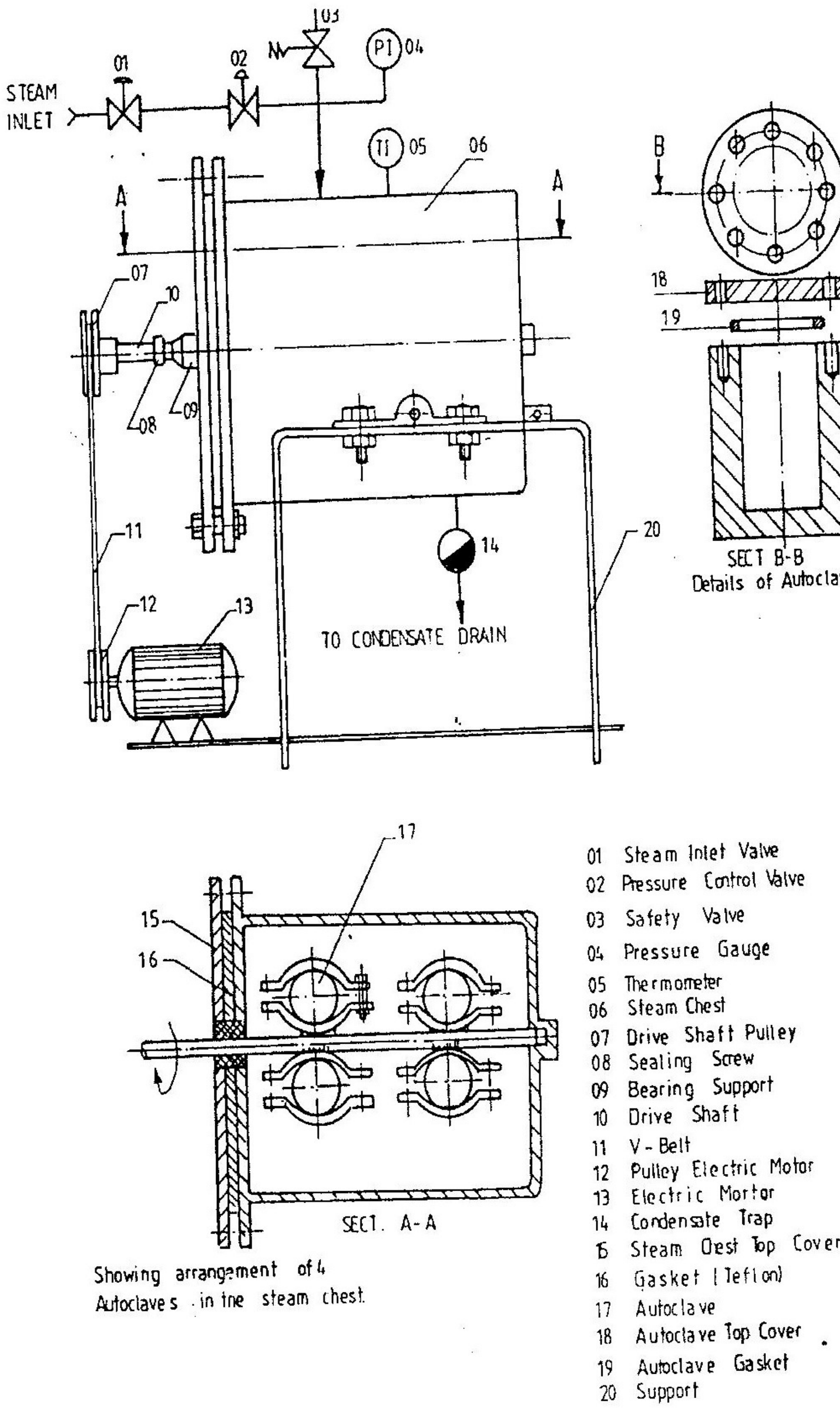

Fig. 1: Experimental rig

RESULTS AND DISCUSSION

Effect of chemical concentration on pulp yield and Kappa number

Fig. 2 shows the effect of chemical concentration on pulp yield and Kappa number. It can be observed that as the chemical concentration increases the pulp yield decreases linearly with a slope of approximately - 0.155. This predicts that as the rate of chemical concentration increases the rate of cellulose and hemicellulose degradation also increases resulting to a decrease in pulp yield. The Kappa number of pulp also decreases with increasing chemical concentration to a limit of about 16.45. Two reasons may be used to explain this behaviour depicted on Fig 2. Firstly, the domination of cellulose and hemicellulose degradation results to very low lignin dissolution at higher concentrations of cooking chemical. Secondly, the behaviour could be caused by the condensation reactions of lignin which seem to occur at higher concentrations of cooking chemical.

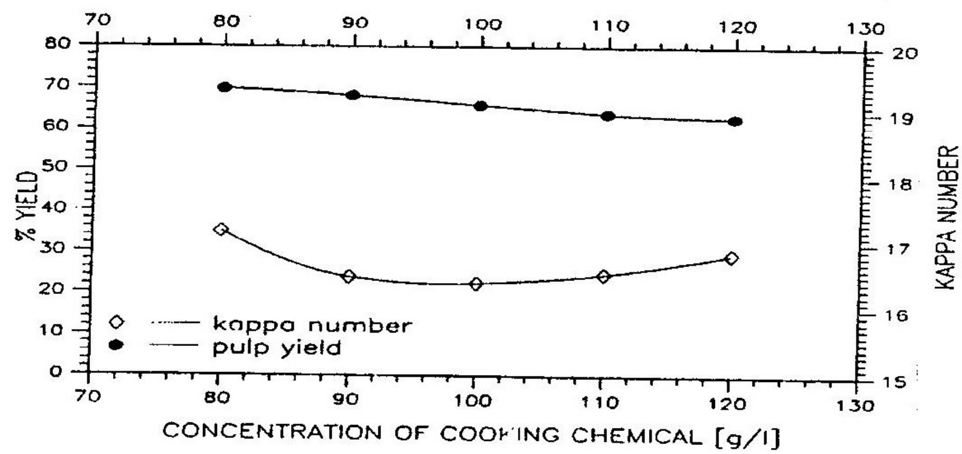

Fig. 2: Effect of chemical concentration on pulp yield and Kappa number

Effect of chemical concentration on pulp viscosity and brightness

Fig. 3 shows the effect of chemical concentration on pulp viscosity and brightness. A decrease in pulp viscosity with increasing chemical concentration can be observed. This is theoretically true, due to cellulose and hemicellulose degradation occurring at higher chemical concentrations.

However, brightness increases as chemical concentration increases. This may be contributed by dissolution of coloured pigments and extractives which occurs at higher chemical concentrations.

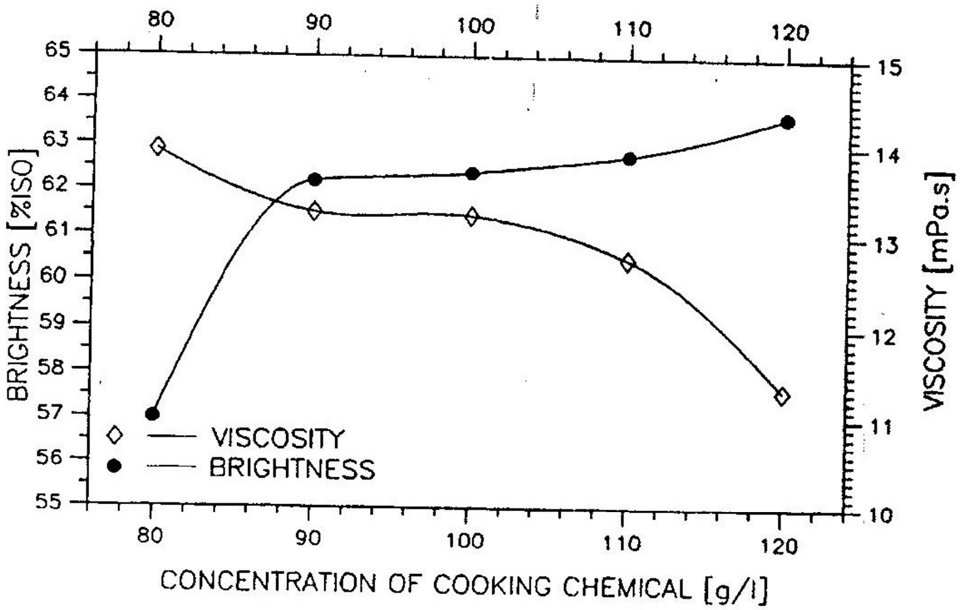

Fig. 3: Effect of chemical concentration on pulp brightness and vis cosity

Effect of ratio of Na_2SO_3 to Na_2CO_3 on pulp yield, and Kappa number

It can be seen form Fig.4 that pulp yield slightly increases with increasing ratio of Na_2SO_3/Na_2CO_3 whereas there is a significant decrease in Kappa number with increasing ratio of Na_2SO_3/Na_2CO_3. This is possibly due to increase in concentration strength of the cooking chemicals as the ratio of Na_2CO_3 increases which results to an increase in the rate of lignin re-moval.

Effect of ratio of Na_2SO_3 to Na_2SO_3 on brightness and viscosity

From Fig. 5, it can be seen that brightness of the pulp increases with in-creasing ratio of Na_2SO_3 to Na_2CO_3, whereas viscosity decreases. The possible reason for this phenomena is the same as that pointed out earlier.

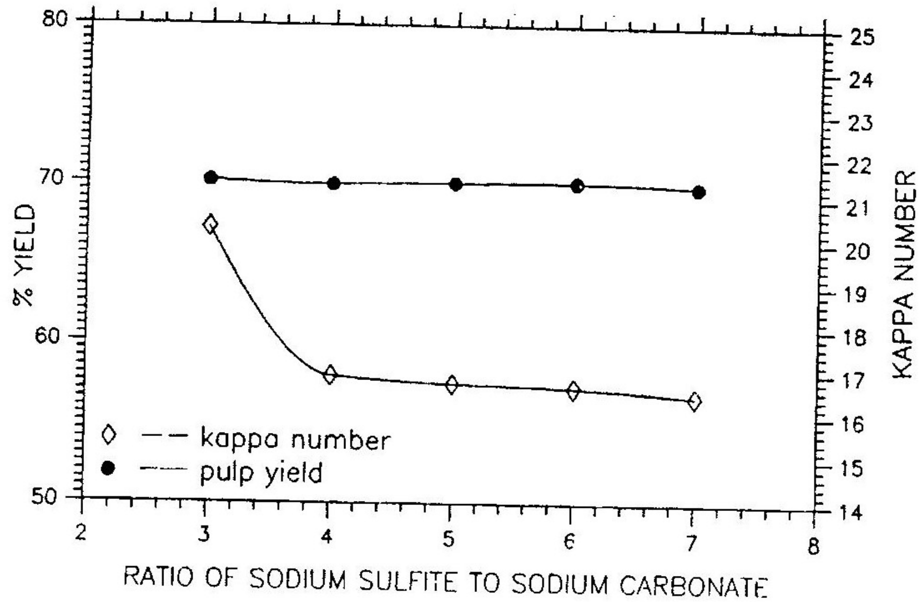

Fig. 4: Effect of Na_2SO_3/Na_2CO_3 ratio on pulp yield and Kappa number

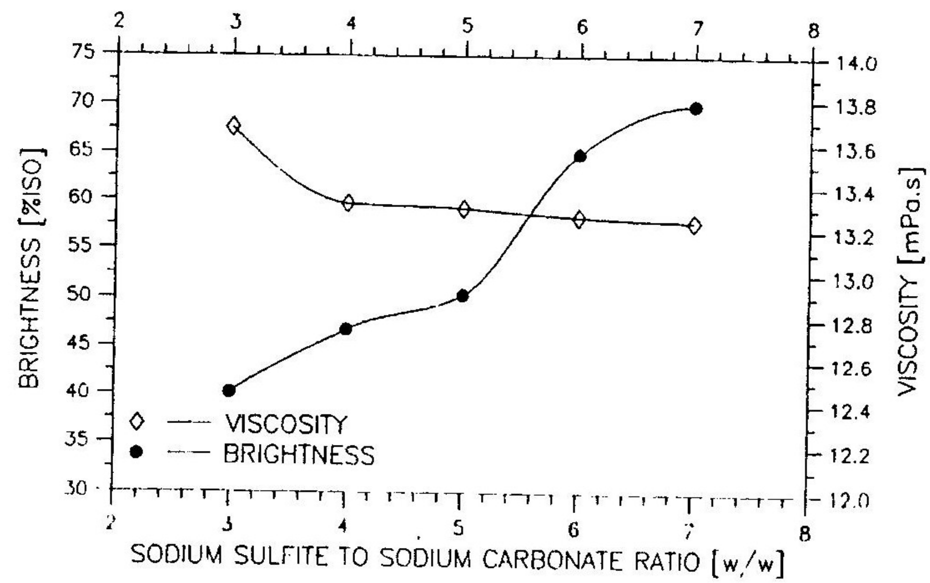

Fig. 5: Effect of Na_2SO_3/Na_2CO_3 ratio on pulp brightness and viscosity

Effect of fibre to chemical ratio, on Kappa number, yield, brightness and viscosity

The effect of fibre to chemical ratio on Kappa number, yield, brightness and viscosity is presented on Figures 6 and 7. Fibre to chemical ratio in the tested range of 1:5.5 to 1:6.5 has very little effect on pulp yield. However, the Kappa number decreases with an increase in fibre to chemical ratio as depicted on Fig. 6.

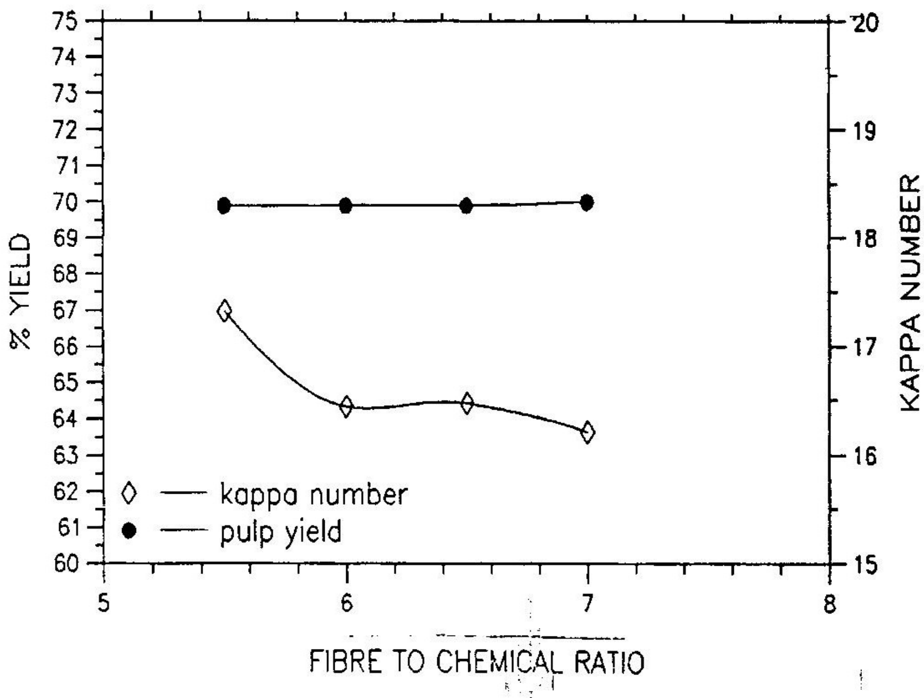

Fig. 6: Effect of fibre to chemical ratio on pulp yield an Kappa number

Figure 7 shows an increase in pulp brightness, whereas pulp viscosity decreases slightly with increasing fibre to chemical ratio. This can be explained by the liquor penetration into the fibre matrix so as to attain saturation concentration at the fibre to fibre interphase. This penetration seems to be higher for high fibre to chemical ratio, and thus results to increased lignin dissolution, which is portrayed by the decrease in Kappa number and increase in brightness.

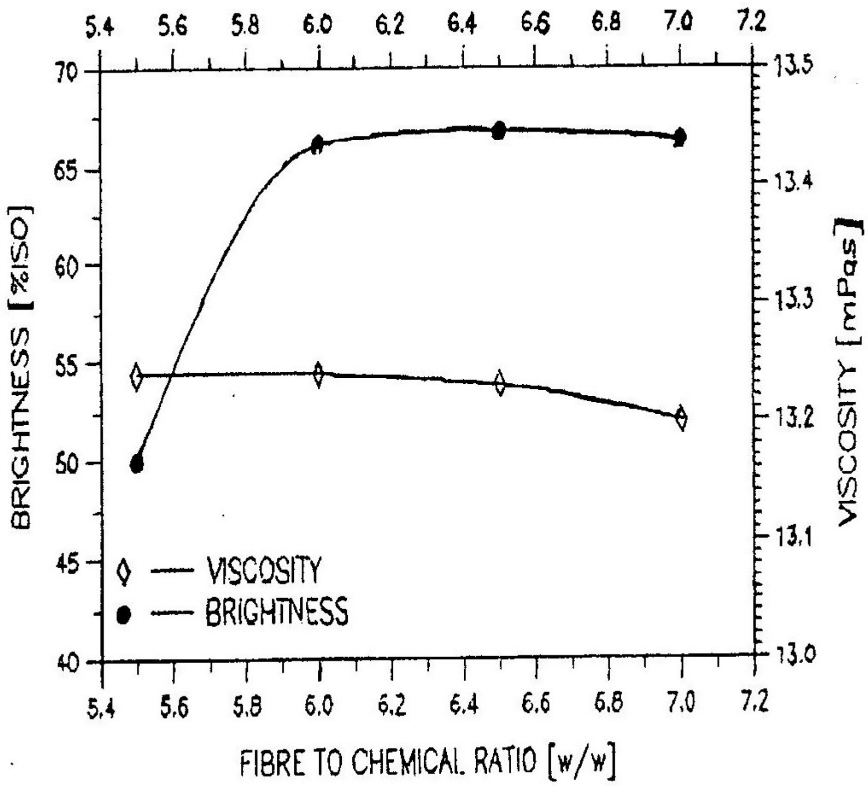

Fig. 7: Effect of fibre to chemical ratio on pulp brightness and viscosity

Strength properties of pulp

Figure 8 shows the strength properties of pulp obtained using Na_2SO_3/ Na_2CO_3 . It can be observed that the strength indices i.e tensile, burst and tear correlate well with that for bleached pine kraft pulp reported from Southern Paper Mills (SPM) as presented on Fig. 9. However, maximum strength indices for Na_2SO_3/Na_2CO_3 pulp are higher than those of bleached kraft pulp obtained at SPM. That is tensile index: 75.60 [Nm/g], burst index: 6.05 [kPam2/g] and tear index: 19.30 [Nm2/kg] compared to tensile index: 50.52 [Nm/g], burst index: 5.77 [kPam2/g] and tear index: 18.91 [Nm2/Kg] for pine kraft pulp. These properties reveal the superiority nature of sisal pulp for paper making.

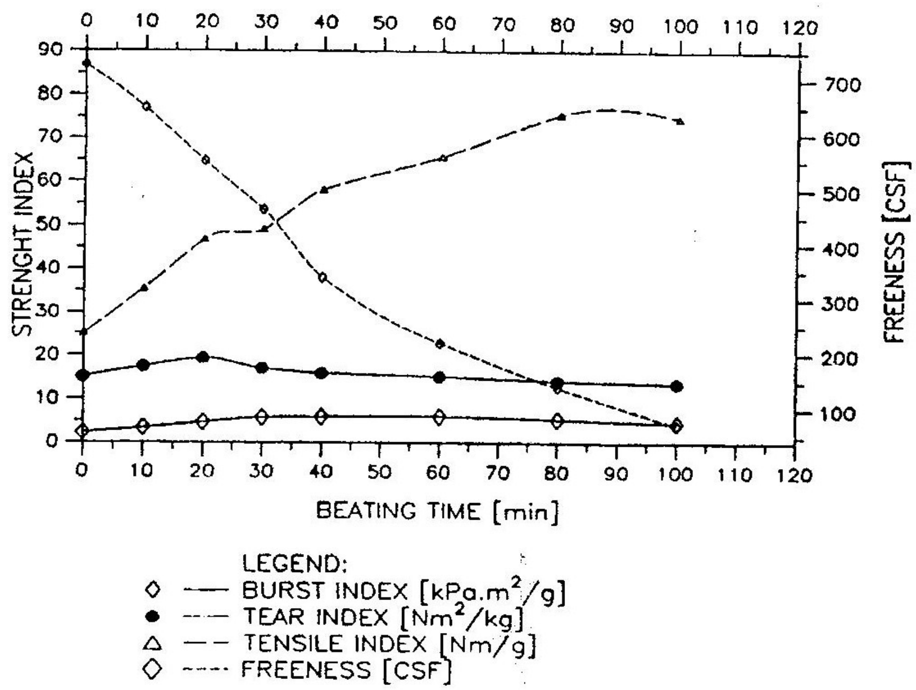

Fig. 8: Effect of beating time on pulp strength and freeness

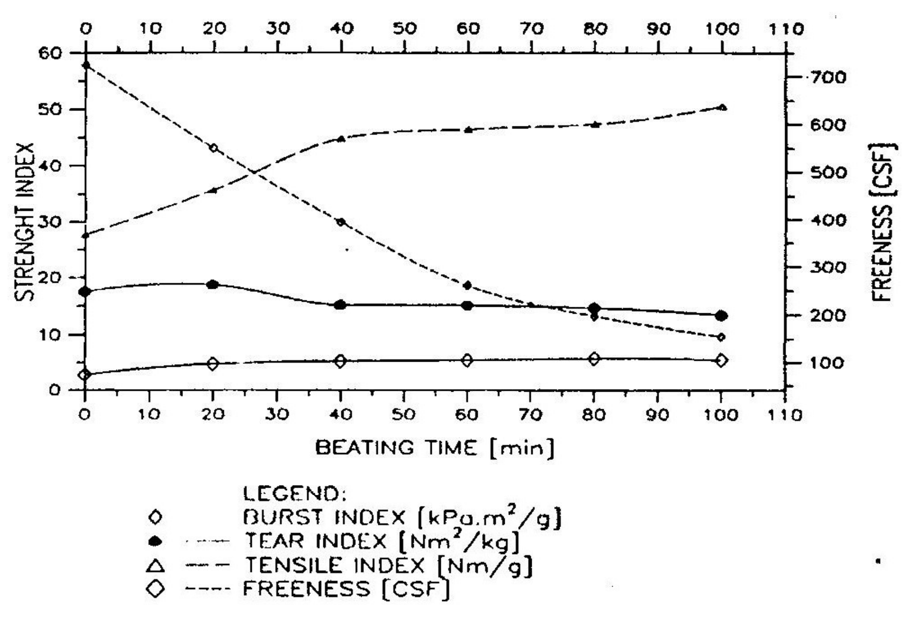

Fig. 9: Effect of beating time on pulp strength and freeness of bleached Kraft pulp produced at SPM

Black liquor analysis

The results for black liquor analysis are presented on Table 2. The results for total solids and pH obtained in this work are lower than those reported by Goyal et al; (1988) for soda pulping of rice straw. Also, Jackson (1990) recommends a pH range of 6.5-8.5 for effluent stream to water bodies, which is in good agreement with that obtained in this study. This suggests that, the process has relatively less environmental impact. However, residual alkali reported by Goyal et al; (1988) is lower than that revealed in this work. This could be due to difference in pulping methods used i.e soda pulping and Na_2SO_3/Na_2CO_3 pulping.

Table 2: Result for black liquor analysis at suitable pulping conditions

Parameter	Value	GOYAL et al (1988)
PH	7.10	9.30
Total solids	4.56 %	8.42%
Residual Na_2CO_3	0.85 g/l	0.048 g/l
Residual Na_2SO_3	2.41	-

CONCLUSION AND RECOMMENDATIONS

Chemical concentration of 95 g/l of Na_2SO_3 /Na_2CO_3 at a ratio of 7:1, and fibre to chemical ratio of 1:6 have been observed to represent better conditions for sisal pulping. Also, pulp yield generally decreases with increasing chemical concentration whereas Kappa number of pulp decreases to a limit of about 16.45 with increasing concentration. Pulp brightness increases significantly with increasing ratio of Na_2SO_3/Na_2CO_3. The superiority nature of sisal pulp compared to wood pulp revealed in this work indicates that sisal pulping is a promising alternative for sisal industry in Tanzania.

Since further studies are still going on, following recommendations can be made for future work: investigation of the kinetics and temperature dependence of the rate equation during sisal pulping. Establishment of these data will enable optimization of the process. Also in order to improve further the pulp quality properties, investigation on pulping additives or catalysts need to be carried out. These include: organic catalysts such as anthraquinone and its derivatives as well as inorganic catalysts.

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ABBREVIATIONS

BSI	=	British Standards Institution
ISO	=	International Standard Organisation
SPM	=	Southern Paper Mills
TAPPI	=	Technical Association of Pulp and Paper Industries