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Effects of Pulping Conditions on Yield and Kappa Number of Paper Pulp Produced from Corn Sheaths.

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Abstract- The global paper industry has raised serious environmental concerns on multiple fronts from deforestation to climate change, CO2 emissions, loss of biodiversity and soil erosion to various degrees of health issues as a result of removing forest trees for pulp and paper production. To address the environmental challenges posed by the paper industry, there is need to focus on alternative non wood fibre sources such as corn sheaths for paper making. The study investigated the suitability of corn sheaths for quality paper production and evaluated the influence of soda pulping conditions on yield and kappa number of pulp produced from corn sheaths, promising lignocellulose biomasses for paper production. The influence of alkaline concentration (10-30% NaOH), pulping temperature (120 - 160°C) and time (40-60 minutes) on pulp yield and pulp kappa number was examined. The results show that optimal pulping conditions of 10% NaOH, 160°C, 60 minutes resulted in a maximum pulp yield of 68% and a kappa number of 32.96. Pulp yield and kappa number decreased with increase in alkaline concentration, temperature and time. Under optimal conditions, the pulp exhibited acceptable yield, indicating potential for paper production. This research demonstrates the feasibility of utilizing corn sheaths as sustainable raw materials for paper making, highlighting the importance of pulping conditions to achieve desirable pulp for paper production.

Index Terms - Corn Sheaths, Soda Pulping, Pulp Yield, Kappa Number, Tensile Strength, Paper Production.

I. INTRODUCTION

Corn sheaths, by-products of corn processing, have been identified as potential lignocellulose biomasses for pulp and paper production (Alcaide, 1991). However, the pulping process plays a significant role in determining the yield, kappa number and quality of pulp for paper production. Pulping is the process of breaking down the bulk structure of corn sheath chips into individual fibers (Jimenez, 2002). This is achieved through chemical pulping, which breaks down lignin and hemicellulose into tiny, water-soluble molecules that can be washed away from the cellulose fibers without weakening them chemically. Lignin acts as the agent biding the fibers found in the cell walls of corn sheaths and other plant material (Boerjan, 2003). The higher the amount of lignin present, the more chemicals will be needed for the pulping process (Oluwadare *et al*, 1998), as well as higher pulping temperatures and longer pulping times. When the links in corn sheath structures that hold their cells together are broken during the pulping process, a fibrous substance known as pulp is produced (Smook, 1992).

Soda pulping process is a known chemical method of extraction of pulp from lignocellulosic materials (Akgül, 2009). However, it is important to evaluate the influence of soda pulping conditions on yield and kappa number of pulp from corn sheaths (Jimenez, 2002, Holia, 2005). Pulp yield and pulp kappa number are crucial parameters in paper production, influencing the strength and overall quality of the final products. Pulp yield represents the percentage of raw material converted to usable pulp, while kappa number measures the residual lignin and pulping efficiency. This study investigated the effects of soda pulping conditions, including alkaline concentration, temperature and time, on yield and kappa number of pulp from corn sheaths (Wan, 2004). By optimizing these conditions, this research seeks to maximize pulp yield and minimize kappa number and increase paper quality, ultimately contributing to the development of sustainable paper production and eco-friendly paper products from corn sheaths. By exploring the effects of soda pulping conditions on pulp yield and kappa number, this research contributes to the advancement of sustainable paper production from agricultural wastes.

II. MATERIALS AND METHODS

2.1 The Soda Pulping Process and Delignification of Corn Sheaths

Corn sheaths were collected from local markets and road side sellers around Mowe and Ofada, Obafemi Owode Local Government Area of Ogun State, South Western Nigeria. The collected residues were washed with clean water and sorted to remove unwanted substances such as sand, stone etc. They were dried under natural conditions for 2 weeks. The dried corn sheaths collected were chipped into smaller sizes of about 12-25mm with cutting tools such as knives, scissors etc. Pulping was done in batches, 1kg of each of the agro residues was weighed and poured into a vertical rotary digester (Model Y2-712- 4 | Standard JB | T II 07 – 2013), and 5Lt of water was also weighed in ratio 1:5 solid to liquid for all the processing conditions (Fagbemi, 2014). The concentration of sodium hydroxide in the pulping processes was varied from 10 % to 30% i.e. 10 %, 15 %, 20 %, 25 % and 30 % while temperature at 60^0C and time 60min were kept constant. Temperature was also varied from 120^0C to 160^0C i.e. 120^0C, 130^0C, 140^0C, 150^0C and 160^0C while sodium hydroxide concentration and pulping time were both kept constant at 10 % and 60min respectively. Similarly, Sodium hydroxide concentration and temperature were both kept constant at 10 % and 160^0C respectively while only pulping time was varied from 40min to 60min i.e. 40min, 45min, 50min, 55min and 60min. As the digester rotated, there was agitation in the digester, heat from the digester made it possible for easy penetration of sodium hydroxide into the agro residues which helped delignification of the agro residues, breaking down and separating lignin from cellulose fibres (Akgül, 2009). As the temperature of digester increased, pressure also increased which also contributed to quick delignification. The pulping processes were subjected to multiple regression analysis across 75 observations (Table 1) to evaluate the effects of sodium hydroxide, temperature and time on yield and kappa number of pulp from corn sheaths.

Table 1: Raw Results on Determination of Effects of Sodium Hydroxide, Temperature and Time on Pulp Yield and Kappa Number of Corn sheaths

NaOH Conc.	Temp ℃	Time Min.	Pulp Yield %	Kappa Number
10	160	60	68.00	32.96
10	160	60	66.14	33.85
10	160	60	65.26	32.54
10	160	60	66.13	31.90
10	160	60	67.04	32.84
15	160	60	65.00	26.10
15	160	60	64.82	26.02
15	160	60	65.00	25.19
15	160	60	63.91	25.29
15	160	60	64.73	24.96
20	160	60	60.00	21.71
20	160	60	60.00	21.70
20	160	60	59.91	20.84
20	160	60	59.45	20.92
20	160	60	58.93	21.63
25	160	60	57.00	19.58
25	160	60	56.89	19.56
25	160	60	56.92	19.80
25	160	60	56.96	18.89
25	160	60	55.90	18.99
30	160	60	56.00	15.39
30	160	60	55.81	13.31
30	160	60	55.36	15.22
30	160	60	55.84	14.29
30	160	60	54.99	14.96
10	120	60	78.00	34.38
10	120	60	77.81	33.31
10	120	60	76.36	32.22
10	120	60	76.84	33.29
10	120	60	74.99	31.96
10	130	60	75.00	28.37
10	130	60	74.87	28.31
10	130	60	73.36	25.22
10	130	60	73.84	25.29
10	130	60	72.99	24.96

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10	140	60	74.00	19.58
10	140	60	73.91	19.31
10	140	60	72.36	17.22
10	140	60	73.84	18.29
10	140	60	72.99	18.96
10	150	60	71.00	15.39
10	150	60	70.81	15.31
10	150	60	68.36	14.22
10	150	60	66.84	13.39
10	150	60	67.99	14.46
10	160	60	67.00	15.15
10	160	60	66.31	15.11
10	160	60	66.16	13.22
10	160	60	65.84	14.29
10	160	60	64.99	15.26
10	160	40	66.00	35.30
10	160	40	64.81	32.11
10	160	40	64.36	33.26
10	160	40	65.84	33.21
10	160	40	63.99	34.96
10	160	45	66.00	33.60
10	160	45	64.89	31.31
10	160	45	63.36	32.22
10	160	45	65.74	33.28
10	160	45	63.79	31.92
10	160	50	55.00	32.50
10	160	50	54.21	31.36
10	160	50	54.55	32.42
10	160	50	52.84	31.29
10	160	50	53.65	32.66
10	160	55	51.00	31.60
10	160	55	50.78	31.31
10	160	55	50.36	32.22
10	160	55	49.84	31.29
10	160	55	48.99	32.96
10	160	60	48.00	30.12
10	160	60	46.67	30.22
10	160	60	47.33	30.89
10	160	60	47.86	28.25
10	160	60	46.24	26.73

2.1.1 Washing and Drying of Pulp

When cooking was done, the pressure generated in the digester was first released into a bucket of water, through a connecting pipe making pop sound. The release of pressure aided the fast cooling of the digester. The digester was opened and the resulting mixture of black soapy water containing the lignin and cellulose fibres was discharged from the digester into a 50litre bowl and was thoroughly washed with distilled water to completely separate the black liquor and the lignin from the cellulose fibres. Washing was done until the water became colourless and was no longer soapy, remaining only the wet pulp. Water was completely quizzed out of the wet pulp, the wet pulp was spread on a dry, clean tray and air dried for 48hrs.

2.2 Determination of Pulp Yield

Percentage pulp yield was determined as follows:

$$\text{Pulp Yield (\%)} = \frac{\text{Final Weight of Oven Dried Pulp (After Pulping)}}{\text{Original Weight of Oven Dried Agro Residues (Before Pulping)}} \times 10 \quad (1)$$

2.3 Determination of Pulp kappa Number

Kappa number is the measure of the residual lignin in the pulp after the pulping of corn sheaths. This was done following TAPPI standard T236cm-85. A mass of 0.5 g of oven dry pulp was weighed and poured into a 1000ml beaker; 300ml of distilled water was weighed and poured into the beaker containing the pulp. The pulp was mildly disintegrated with a laboratory blender till a suspension was formed. The beaker containing the blended pulp was placed on a magnetic stirrer with a titrating set-up, it was on and 25ml of potassium permanganate ($KMnO_4$) was weighed into a beaker and 25ml of sulfuric acid was added to the beaker containing the potassium permanganate. The solution of potassium permanganate and sulfuric acid was poured into the pulp suspension, in the beaker on the magnetic stirrer, having a purple colour, while the magnetic stirrer was on, and the reaction was monitored and timed for 10 min at 25^0C with continuous stirring such that it produced a vortex of about 25mm deep. After 10min of the reaction, 10ml of potassium iodide was added to the reaction and the purple colour changed to dark brown, with continuous stirring , the reaction was titrated with sodium thiosulphate, a reducing agent that was gradually changing the reaction colour from dark brown to yellow, 2 drops of starch iodine solution was added to the reaction, while titration continued, the reaction colour consequently changed to sky blue and then became colourless at a particular end point of sodium thiosulphate at which the lignin in the pulp was completely broken down and consumed. A repeat of the procedure (blank experiment) was carried out without pulp. The kappa number was then calculated using equation (2) according to TAPPI standard T236 cm-85.

$$k = \frac{P \times f}{W} \quad (2)$$

$$P = \frac{(b-a)N)}{0.1} \quad (3)$$

Where,
K , Kappa number

P , Amount of permanganate actually consumed by the test specimen
f, Factor for correction to a 50% KMn04 consumption
a ,Amount of the thiosulfate consumed by the test specimen.
b , Amount of the thiosulfate consumed in the blank titration.
N, Normality of the thiosulphate
W, Weight of the moisture free sample

III. RESULTS AND DISCUSSION

The regression coefficients obtained for corn sheath pulp yield are presented in (Table 2) to evaluate the influence of sodium hydroxide concentration, temperature, and time on pulp yield and kappa number of corn sheaths. The constant in the regression model Table 2 (B=145.552, P<0.001) represents the baseline pulp yield when all predictors are held at zero, which serves as a reference point for interpreting the coefficients of the predictors. Among the independent variables, temperature (B= −0.491, p<0.001 was identified as a significant negative predictor, this suggests that for every unit increase in temperature (°C), pulp yield decreases by 0.491 units, holding other variables constant. This reduction in yield can likely be attributed to the thermal degradation of cellulose fibers at higher temperatures, which leads to a loss of material during the pulping processes.

Regression model:

$$Y = \beta 0 + \beta 1 X 1 + \beta 2 X 2 + \cdots + \beta n X n + \varepsilon$$

Where: Y represents continuous outcome variable
β0 represents interceptor or constant term
β2…..βn represent the regression coefficients for each predictor variable
X1 X2 …..Xn represent predictor variables
ε represents error term (residual)

Table 2: Regression Coefficients for Corn Sheath Pulp Yield

Model	Unstandardized Coefficients		Standardized Coefficients Beta (β)			95%Confidence Interval for B	
	B	Std. Error		T	Sig.	Lower Bond	Upper Bond
(Constant)	145.552	13.305		10.939	.000	119.022	172.082
Sodium Hyroxide	-0.142	0.125	-0.104	-1.138	.259	-.391	.107
Temperature	-.0.491	0.062	-0.716	-7.855	.000	-.615	-.366
Time	-0.098	0..125	-0.071	-.782	.437	-.347	.151

a. Dependent Variable: Pulp Yield

Conversely, the coefficients for sodium hydroxide concentration (B=−0.142, p=0.259B and time (B=−0.098, p=0.437 were not statistically significant. This indicates that under the tested conditions, sodium hydroxide concentration and time did not have substantial effect on pulp yield unlike temperature. It is worth noting that while their individual effects are minimal, potential interactions between these variables and temperature, or their nonlinear relationships with pulp yield, could contribute to the unexplained variance in future studies. The regression results (Table 3), which included these three predictors, was statistically significant (F (3.71)

=28.396, p<0.001) indicating that the predictors collectively explain a significant portion of the variability in pulp yield. The R square value of 0.545 demonstrates that 54.5% of the variation in pulp yield can be attributed to the combined effects of sodium hydroxide concentration, temperature, and time. The adjusted R square value of 0.526 further confirms the robustness of the model while accounting for the number of predictors.

Table 3 Regression Model Summary for Corn sheath Pulp Yield

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R square Change	F Change	df1	df2	Sig. F Change
1	.739[a]	.545	.526	5.92402	.545	28.396	3	71	.000

a. Predictors: (Constant), Sodium Hydroxide, Temperature, time
b. Dependent Variable: Pulp Yield

The overall model highlights the dominant role of temperature as a critical factor influencing pulp yield. The significant negative association underscores the importance of optimizing temperature during the pulping process to maximize yield while minimizing fiber degradation (Jimenez, 2002). The non-significance of sodium hydroxide concentration and time, however, suggests that their influence on yield might only become apparent under specific conditions or in interaction with other factors.

Table 4 displays the regression coefficients for corn sheath kappa number; the coefficients indicate that sodium hydroxide concentration and time significantly predict the kappa number, while temperature does not show a statistically significant effect. Specifically, sodium hydroxide concentration (B=-0.388, P=0.002) negatively impacts the kappa number, with each unit increase in sodium hydroxide concentration reducing the kappa number by 0.388 units. This reflects its critical role in dissolving lignin during the pulping process (Neis et al., 2019). Similarly, time (B=-0.569, P<0.001) shows a strong negative effect, with longer cooking time leading to greater lignin removal. The lack of significance for temperature (B=-0.068, P<0.254) suggests that within the tested range, it does not substantially influence lignin dissolution, potentially due to already optimized thermal conditions. In conclusion, this analysis highlights the importance of optimizing sodium hydroxide concentration and time to enhance delignification efficiency. While temperature did not significantly affect the kappa number under the tested conditions, its role should not be discounted entirely, as nonlinear effects or interactions with other variables be relevant. The regression model summary (Table 5) produced an R square value of 0.444, indicating that 44.4% of the variation in kappa number is explained by the predictors. The adjusted R2 value of 0.420 confirms the robustness of the model while accounting for predictor inclusion. The model was statistically significant (F(3,71)=18.896,p<0.001), demonstrating the combined importance of sodium hydroxide concentration, temperature, and time in influencing the kappa number.

Table 4 Regression Coefficients for Corn Sheath Kappa Number

Model	Unstandardized Coefficients	Standardized Coefficients Beta	95%Confidence Interval for B

	B	Std. Error		T	Sig.	Lower Bond	Upper Bond
(Constant)	73.173	12.532		5.839	.000	48.186	98.160
Sodium Hyroxide	-.388	.118	-.332	-3.296	.002	-.622	-.153
Temperature	-.068	.059	-.116	-1.150	.254	-.185	.050
Time	-.569	.118	-.488	-4.841	.000	-.804	-.335

a. Dependent Variable: Kappa Number

Table 5 Regression Model Summary for Corn Sheath Kappa Number

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R square Change	F Change	df1	df2	Sig. F Change
1	.666[a]	.444	.420	5.57953	.444	18.896	3	71	.000

a. Predictors: (Constant), Time, Sodium Hydroxide, Temperature

b. Dependent Variable: Kappa Number

IV. CONCLUSION

This study reveals the potentials of corn sheaths for pulp production and also demonstrates the significance of optimizing pulping conditions to maximize pulp yield, minimize kappa number and improve the quality of papers for corn sheath pulp. The study shows the dominant role of temperature as a critical factor influencing pulp yield, the importance of optimizing temperature during the pulping process to maximize yield while minimizing fiber degradation. It also shows the importance of optimizing sodium hydroxide concentration and time to enhance delignification efficiency. The results showed the influence of the processing conditions: temperature, alkali concentration and time, and their effects on pulp yield and kappa number. These findings suggest that corn sheaths can be effectively converted to quality pulps suitable for paper production, providing a sustainable alternative to traditional wood-based pulps. The optimized pulping conditions can be used as a benchmark for future studies and industrial applications.

Furthermore, this study highlights the potential of corn sheaths as valuable resources for pulp production for the paper industry, contributing to a more circular and sustainable economy. The agricultural wastes generated can be reduced while producing high-quality pulp for paper from corn sheaths. Future research should focus on scaling up the pulping process, exploring various paper products, and investigating the economic viability of using corn sheaths as raw materials for pulp and paper production. In conclusion, this study has successfully demonstrated the significance of soda pulping conditions, indicating the effects of processing conditions on pulp yield, kappa number of pulp and papers produced from corn sheaths.

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