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Effect of delignification Process on Physical Properties of Sugarcane Baggase Paper

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Abstract. Wood fiber derived cellulose has been mainly used as the raw material in the papermaking. However, currently the paper production capacity is greater than the availability of wood. To overcome this problem, there have been many attempts to use non-wood fibers as substitutes for papermaking such as the fibrous materials derived from agriculture wastes. In this research, the paper was made from sugarcane bagasse which was previously delignified using soda process. The research was conducted by varying NaOH concentrations of 8 –16%, delignification temperatures of 60–100^{o}C and times of 30 –150 min. The aim of the research was to study the effect of delignification process on physical properties of sugarcane baggase soda pulping. The results showed the increase in tensile strengths as the NaOH concentrations increased. Tensile strength was increasing up to optimum temperature and time and then decreased. The water uptake results showed the opposite tendencies with those of tensile strength. The optimum condition was achieved at the NaOH concentration of 10 %, delignification temperature of 80 ^{o}C, and time of 90 min. Tensile strength and water uptake achieved at this optimum condition were 27.42 N/mm^2 and 240 g/m^2, respectively.

Keywords : sugarcane baggase, soda delignification, tensile strength, water uptake

INTRODUCTION

The advent of new information and communication technology and the growing use of computers would lead to a decreased the use of paper worldwide. However pulp and paper products is one commodity that will continue to be consumed along with the growing population in the world. World paper demand is expected to grow by an average of 2.1 percent annually, while national pulp and paper industry is expected to continue to grow by 3-4 % (CDR, Pulp and Paper Industry, 2013).

Non-wood fibers such as wheat, rice straw, corn husk, pine apple and baggase account for 5-7% of the total pulp and paper production worldwide. (R.W. Hurter, et.al., 2001; P.Zugenmaier, 2008). Production of pulp from non-wood resources has many advantages such as easy pulping capability, excellent fibers for the special types of paper. Non wood fibers have been investigated to be used as environmentally –benign alternatives to the use of trees due to its abundance as the sole effective source of cellulose fiber and cost effectiveness.

Bagasse is a by-product of the stem of sugar cane after crushing and juice extraction. Large quantity of bagasse is produced annually and not much use is made of them except to incinerate. Use of bagasse will lead to conversion of waste to wealth especially for pulp and paper making. Bagasse contains 52.42% cellulose, 25.8% hemicellulose and 21.69 % lignin (A.Samariha and A.Khakifirooz, 2011). The cellulose content is high enough to be used for paper making. The production of paper is essentially a process of removing the lignin contained in the fiber of raw materials, in order to obtain a high cellulose content and low lignin content in pulp or paper (D.Fengel. and G.Wegener, 1995). The soda process has been known to be the older and simplest pulping process. It is a also applicable to leafy and conifer wood, as well as to non-wood raw material such as agricultural residues (A.Rodriguez,et al.,2010).

Research of papermaking from bagasse with a variety of processes and additional raw materials have been done by several researchers, among others: organosolv and alcohol pulping of baggase (M.El-Sakhawy,et al., 1995), the

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soda twice delignification for soda and kraft pulping (Doherty,et al., 2006), delignification of sugarcane baggase with alkali and peracetic acid (Xuebing Zhao,et al., 2010), sugarcane baggase conversion to high refined cellulose using nitric acid, sodium hydroxide and hydrogen peroxide as the delignificating agents (S.Supranto, et al.,2015).

Paper products use depends on the strength properties of the paper. The strength of paper depends on the fiber length and the method of pulping process used. In spite of much study in non-wood pulping, little research has been conducted on the pulping of sugarcane baggase by soda process in order to study the physical properties (tensile strength and water uptake) in relation with the delignification process condition. Therefore the aim of this experiment is to study the effect of soda delignification process (NaOH concentration, temperature, time) to the paper sheet physical properties (tensile strength and water uptake). It was also to establish the optimum operating pulping conditions.

METHODOLOGY

Soda Pulping Process

The wastes of sugarcane bagasse from juice were used for the pulping process. In the delignification process of sugar cane various NaOH concentration (8, 10, 12, 14,16) %, delignification temperature (60, 70, 80, 90, 100)^{o}C and time (30, 60, 90, 120, 150) min were varied. Delignified sugarcane baggase was mixed with NaOH with a ratio

1:12 (w/v) in a laboratory flask. The resulting pulp were neutralized by washing with water. Delignified sugarcane baggase was added with water and blended with motor stirrer in 500 rpm. The mixtures were poured into a filter and pressed by water aided by a gravity force to remove out water. The resulting cake was a sheet of paper which was then dried in the oven for further characterization.

Paper characterizations

Several characterization, such as the measurement of tensile strength and water uptake, as well determination was conducted.Tensile strength was measured using an autograph. A small piece of paper was pulled with an increased force until it was broken. The obtained tensile strength was recorded from the monitor (TAPPI T-404).

For the water uptake measurement, a piece of paper was put into the instrument and then 100 ml water was added an held for 1 minute. Paper was vibrated to remove the water in the surface and then was weighed water uptake percentage was calculated as the ratio of difference in weight after and before to water absorbed area (SNI 0499:2008)

Optimization of the Soda Pulping Process

The optimum condition in the delignification process was determined using the response surface methods. In this method, input variables and output variables were modelled using a second order polynomial equation.

$$Y_1 = \beta o + \beta_1 . X_1 + \beta_2 . X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{12} . X_1 . X_2 \quad (1)$$

where X_1 and X_2 are independent or input variables, i.e. NaOH concentration, delignification temperature and time.Y_i (i = 1-2) is the response or output variables, i.e. tensile strength and water uptake. βo is a constant, β_1 and β_2 represent the linear coefficients, whilst β_{11} and β_{22} are the quadratic coefficients, β_{12} is the interaction coefficients,

Result of physical test were analysed by statistic with 95% significance level. The software Microsoft Excel was performed to analyse the results in the form of analysis of variance (ANOVA). The data analysis in the Microsoft Excel software was performed for regression whereas Matlab software was employed to visualize the results.

RESULTS AND DISCUSSION

In this soda delignification process, NaOH concentration, temperature and time were varied in order to obtain the optimum condition. In Table 1, fifteen experiments conducted, together with the delignification conditions and their corresponding paper physical properties (tensile strength and water uptake). For each variables such as NaOH concentration and its corresponding variables such as delignification temperatures, the tensile strength Y_1 and water uptake Y_2 were determined.

The correlation of the response Y_1 and Y_2 to independent variables was estimated by multiple linear regressions. The obtained regression coefficient and analysis of variance (ANOVA) were depicted in Table 2 and Table 3. The

experimental data (Table 1) was fitted with a second-order polynomial model by performing multiple linear regressions (equation 2,3).

TABLE 1. Effect of Process Conditions on Tensile Strength andWaterUptakeof Paper

C_{NaOH} (%)	Temperature (°C)	Time (min)	Tensile Strength (N/mm^2)	Water uptake (g/m^2)
8	90	90	8.73	360
10	90	90	18.8	270
12	90	90	7.10	340
14	90	90	6.21	370
16	90	90	4.57	400
10	60	90	8.07	390
10	70	90	13.15	360
10	80	90	26.43	240
10	90	90	18.86	290
10	100	90	5.30	400
10	80	30	11.07	320
10	80	60	18.56	250
10	80	90	27.42	240
10	80	120	21.94	260
10	80	150	16.96	330

Effect of Temperature, NaOH Concentration and Time on Tensile strength

The correlation between tensile strength (Y_1) and the two independent variables each for NaOH concentration and temperature, Na OH concentration and time, temperature and time were showed in Table 2

TABLE 2. Significance of Regression Coefficients for Tensile Strength

	Coefficients	Standard Error	t Stat	p-value
Intercept	40.58	10.89	3.73	5.82×10^{-3}
X_1^2	-4.33×10^{-1}	$3.30.\times10^{-1}$	−1.31	2.27×10^{-1}
X_2^2	-4.22×10^{-2}	1.17×10^{-2}	−3.60	7.00×10^{-3}
X_3^2	-2.12×10^{-3}	1.26×10^{-3}	−1.69	1.30×10^{-1}
$X_1 X_2$	3.41×10^{-1}	9.84×10^{-2}	3.47	8.48×10^{-3}
$X_1 X_3$	-2.43×10^{-1}	9.30×10^{-2}	−2.62	3.05×10^{-2}
$X_2 X_3$	3.59×10^{-2}	1.25×10^{-2}	2.87	2.08×10^{-2}

The influence of the temperature ($X_2^2{}_2$) on tensile strength during the delignification process was statistically significant ($p < 0.05$) in contrast to the influence of NaOH concentration (X_{1^2}) and time (X_3) which $p > 0.05$.

Furthermore, the tensile strength of the resulting paper followed the quadratic function of temperature ($p < 0.05$) as shown in equation (2).

$$Y_1 = 40.58 - 4.33.10^{-1} X_1^2 - 4.22.10^{-2} X_2^2 - 2.12.10^{-3} X_3^2 + 3.41.10^{-1} X_1. - 2.43.10^{-1} X_1 X_3 + 3.59.10^{-2} X_2 X_3 \quad (2)$$

The correlation between tensile strength (Y_1) to the two independent variables (NaOH concentration and temperature) after applying of response surface methodology can be represented by Figure 1.

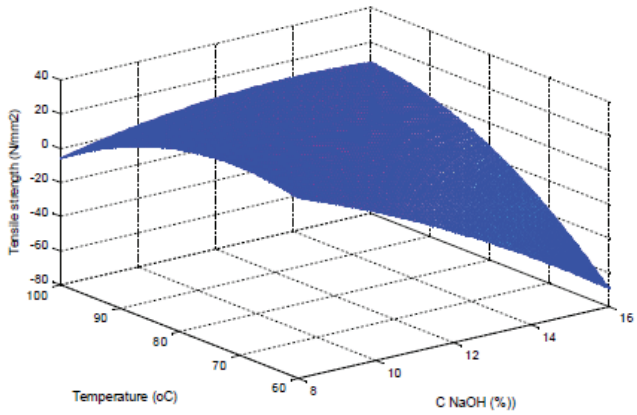

FIGURE 1. Tensile Strength versus NaOH concentration and temperature at optimum time (90min)

Tensile strength was generally influenced by the fiber length and molecular bonds. The longer the cellulose fibers and the stronger the molecular bonds are, the higher the tensile strengths of the paper. Removal of lignin in the cell will increase the molecular bonding between cellulose fibers, thus increasing the tensile strength (Haygreen and Bowyer, 1996; L.Sapei, et al., 2014). The higher the concentration of NaOH, the more lignin could be dissolved. However the possibility of the cellulose fibers degradation is increased as NaOH concentration increased at the certain temperature and time (E.Sjostrom, 1995; L.Sapei et al, 2014). This was the reason of the tensile strength decrease when NaOH concentration above 10% was used.

Effect of NaOH Concentration, Temperature and Time on water uptake

The resistance of paper against water uptake is another important characteristic of used paper. The experimental data (Table 1.) was fitted with a second-order polynomial model by performing multiple linear regressions (Eq. 3). The correlation between water (Y_2) and the two independent variables each for NaOH concentration and temperature, NaOH concentration and time, temperature and time were showed in Table 3.

TABLE 3. Significance of Regression Coefficients for Water Uptake

	Coefficient	Standard	t Stat	p-value
Intercept	132.16	74.51	1.77	$1.14x10^{-1}$
X_1^2	4.42	2.26	1.95	$8.66x10^{-2}$
X_2^2	$3.64x10^{-1}$	$8.02 x10^{-2}$	4.54	$1.90x10^{-3}$
X_3^2	$1.61x10^{-2}$	$8.61x10^{-3}$	1.86	$9.92x10^{-2}$
$X_1 X_2$	– 3.15	$6.73x10^{-1}$	-4.68	$1.57x10^{-3}$
$X_1 X_3$	2.10	$6.36x10^{-1}$	3.31	$1.08x10^{-2}$
$X_2 X_3$	$–2.98x10^{-1}$	$8.55x10^{-1}$	-3.48	$8.32x10^{-3}$

The influence of the temperature (X_2^2) on water uptake during the delignification process was statistically significant ($p < 0.05$) in contrast to the influence of NaOH concentration (X_1^2) and time (X_3^2) which $p > 0.05$. Furthermore, the tensile strength of the resulting paper followed the quadratic function of temperature ($p < 0.05$) as shown in equation (3).

$$Y_2 = 132.16 + 4.42\,X_1^2 + 3.64.10^{-1}\,X_2^2 + 1.61.10^{-2}X_3^2 - 3.15\,X_1X_2 + 2.10\,X_1X_3 - 2.98.10^{-1}\,X_2.\,X_3 \qquad (3)$$

The correlation between water uptake (Y_2) to the two independent variables (NaOH concentration and temperature) after applying of response surface methodology can be represented by Figure 2.

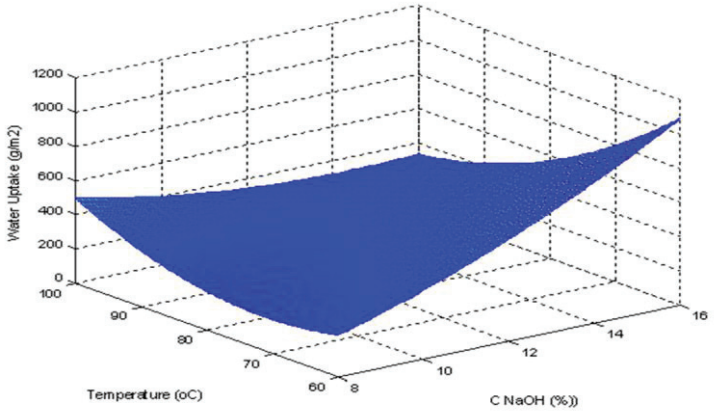

FIGURE 2. Water Uptake versus NaOH concentration and temperature at optimum time (90min)

The same trend was observed by the variations in delignification temperature. The increase in temperature would increase the delignification process thus increasing the tensile strength in the certain NaOH concentration and time. However, above the optimum temperature, tensile strength decreased due to the increasing depolymerisation of cellulose fibers though delignification process was accelerated. High temperature enhanced the solubilisation of polysaccharide chains (D.Fengel and G.Wegener, 1995).

CONCLUSION

The results showed the increase in tensile strengths as the NaOH concentrations increased. Tensile strength was increasing up to certain temperature and time and then decreased. The water uptake results showed the opposite tendencies with those of tensile strength. The optimum condition was achieved at the NaOH concentration of 10 %, delignification temperature of 80 ^oC, and time of 90 min. Tensile strength and water uptake achieved at this optimum condition were 27.42 N/mm^2 and 240 g/m^2, respectively.

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