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Production of Paper Using Chemical Pulping Process of Sugarcane Bagasse

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Abstract- There are many sources of solid waste such residential, industrial, commercial, agricultural and biomedical that cause hazardous impact on the environment. The annual production of agricultural waste in Egypt is about 34% of the total amount of waste generation. For this reason; the recycling process is applied to get rid of the different agricultural wastes. The aim of this work is the production of paper from bagasse by applying the chemical process to produce pulp using NaOH as an alkaline reagent. Response Surface Methodology (RSM) was used to optimize the process variables affecting the yield of the product namely as temperature (℃), time (min), and solid to liquid ratio (%). Thus, the mass percent of bagasse to NaOH solution is varied to be 10, 12.5, and 15 %, the temperature of reaction is changed from 160 to 180℃, and the reaction is performed for several retention time varied from 60 minutes to 180 minutes. The optimum conditions are found to be 180 min, 160℃, and solid to liquid ratio of 0.1 to produce pulp with yield equals to 56.8 g for every 100 g of sugarcane bagasse. The produced paper was characterized based on basis weight, tensile strength, tearing strength, and burst strength and it was found that the produced paper is in compliance with the commercial kraft paper.

Key words- Agricultural waste, Paper production, Solid waste management, Statistical model, Sugarcane bagasse.

I. Introduction

Egypt is considered an agricultural country, as about 50% of the population depend on it as a main source of their outcome. Consequently, the processing of agricultural products generates about 34% of the total waste produced in Egypt. In 2017, The total amount of agricultural waste produced in Egypt is about 34 million tons, they are classified based on their source as shown in Table (1). It is obvious that wheat straw, sugarcane bagasse, maize residues and rice straw are the main sources of agricultural waste [1].

Sugarcane bagasse is defined as the residue generated after extracting sugar from sugarcane. It consists of 36.3 – 69.4% cellulose, 6 – 30% hemicellulose, 4.4 – 29 % lignin, 0.6 – 5.5 waxes and the rest are ash, saccharose, glucose and silica [2, 3]. According to its nature that is rich in organic matter, this waste is managed through energy recovery or recycling to produce beneficial products such as paper. It is found that the calorific value of sugarcane bagasse on dry basis ranges from 15.98 to 18.9 MJ/kg. These values are considered so small by comparing them with the ordinary fossil fuels, as the heating value of fossil fuels vary from 30 MJ/kg for coal to 50 MJ/kg for natural gas [4, 5]. On the other hand, sugarcane bagasse is recycled to be used in paper production due to its high fiber length that increase the quality of the produced paper [6].

A. Raw Materials for Paper Production

Wood is considered the main raw material from which paper is obtained, where about 25,000 plants worldwide use wood to produce paper, so they consume a massive amount of wood annually. This high consumption affects the environment negatively, as cutting of trees increasing the impact of greenhouse gases. Therefore, recycling of agricultural waste that contains high cellulose percent is considered a good solution to get rid of waste in an environmentally friendly way and to reduce the negative impact of paper production from wood. There are different agricultural wastes to be used in this process such as rice straw, wheat straw, cotton linters, corn stalks and sugarcane bagasse. Between these raw materials, sugarcane bagasse is considered the most recommended raw material for pulp production as it has the largest fiber length [7-11].

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Table 1: Amount of agricultural waste in Egypt in 2017 [1]

Agricultural waste	Amount (million ton per year)	Agricultural waste	Amount (million ton per year)
Wheat straw	6.9	Vegetable residues	0.7
Sugar cane	6.8	Date palm residue	0.7
Maize residues	4.5	Sesame straw	0.6
Rice straw	3.6	Bean straw	0.4
Trees trimming residues	1.7	Sugar beet residue	0.3
Banana residues	1.7	Potato	0.3
Cotton stalks	1.6	Barely straw	0.2
Sorghum residues	1.2	Pea straw	0.04
Public garden residues	1.2	Lentil straw	0.01
Tomato wastes	1.1		
Total amount of waste (million ton per year)		33.4	

B. Manufacturing Process of Paper

The manufacturing process of paper consists of two main steps, the pulping process and bleaching process [12-14].

i. Pulping Process

The pulping process is performed to convert the hard raw materials into soft fibers to ensure easy fabrication and formation of the final product. At first, the hard raw materials are pre-treated via washing and crushing, then the pulping process begin. It is carried out through one of the following techniques that differ in their yield, operational cost and quality of product [12-14]:

- *Chemical pulping*

It is mainly applied to remove almost all lignin present in the feedstock through depolymerization and dissolution of it into the chemical solution, as it interferes with the hydrogen bond between fibers, which decreases the strength of the product. Also, it causes color change in paper as it converts into yellow if it is exposed to air and light. On the other hand, the yield from this process ranges from 43–65%. It is classified according to the reaction medium and chemicals applied into kraft process (sulfate process) and acid or bisulfite process. The kraft process is performed in a basic medium (pH ranges from 13 – 14) using some reagents like sodium hydroxide (NaOH) and sodium sulfide (Na_2S), while the acid process is implemented in an acidic medium (pH ranges from 1.5 – 5) using some reagents like $H_2SO_3^-$ or HSO_3^- combined with Ca^{+2}, Mg^{+2}, or Na^+. the yield of pulp from acid process is low when it is compared with sulfate process.

- *Mechanical pulping*

In this process, pulp fibers are separated from the raw materials physically using mechanical energy, so its yield is high and ranges from 92 – 96%. Nevertheless, the produced pulp has lower strength than that generated from the chemical process as it depends on the bulking only and there is no fiber-to-fiber bond that increase the strength. Also, the paper produced has high bulk and its color turns into yellow because the lignin content is not separated during processing. For this reason, this process is applied to produce cardboard and paper bags.

- *Thermo-mechanical pulping*

A steam pressurized process in which the temperature is raised up to 170℃. The temperature is considered the main factor that controlled the softening of the product.

- *Chemical thermo mechanical pulping*

This process requires mild conditions in which NaOH or $NaHSO_3$ are used as chemical reagents and produces pulp with relatively high yield ranges from 88 – 95% with moderate strength.

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ii. Bleaching process

After pulping process, bleaching agents are applied to eliminate residual lignin that cause color change. In this process, chlorine or one of its compounds such as sodium hypochlorite or sodium chlorite is applied to remove lignin to get brighter paper. Then the product is neutralized, washed to get rid of the excess chemicals [15].

C. Types of Paper

There are many uses for paper. It isn't just restricted to printing; it may also be used in packaging or for decoration. As a result, they have a variety of types with different specifications. Consequently, there are differences in the processing steps, as certain applications require high yield, while others are concerned with the appearance of the final product. Paper is classified according to the end-use into kraft paper, newsprint paper, coated and uncoated paper, … etc. [16].

i. Kraft Paper

It is generally fabricated through sulfate process to produce high strength pulp that is used in packaging. It has two types according to the application in which they will be used into natural (unbleached) paper that is brownish used in production of industrial bags, grocery, linear, or corrugated board and bleached paper that is white in color and has strength lower than that of natural kraft paper by about 15% and requires higher cost for production, but it is used when cleanness and printability are important like the packaging of edible products such as flour and sugar packages [16, 17].

ii. Newsprint Paper

Newspapers, magazines, or advertisements are all made from newsprint paper. It is produced by one of the previously mentioned techniques of pulp production, but usually up to 30% softwood is applied to ensure good operability through the printing process. They are manufactured with good smoothness, brightness, and opacity to avoid ink showing through [18].

iii. Coated Paper

They are papers that are coated by a certain compound to improve one of their properties such as weight, surface gloss, smoothness, or reduction ink absorption during printing process. The produced paper is used in various end-use applications such as food packaging, magazines, advertising materials [19-21].

iv. Uncoated Paper (Offset Paper)

Due to their rough surface, they absorb more ink. Also, ink does not stick directly to the paper, so they require two printing steps. At first, ink is transferred to a rubber cylinder, then it is printed on paper [19, 20].

In this research, the production of paper from sugarcane bagasse using the kraft process is carried out, followed by a bleaching process to improve the quality of the product. After that, the produced paper is tested based on the Technical Association of the Pulp and Paper Industry (TAPPI) and its specifications are compared with the specifications of different types of paper to know the most suitable applications.

II. Experimental Work

A. Materials

Sugarcane bagasse is collected from local Egyptian farms, while the chemical reagents used are sodium hydroxide (NaOH), anthraquinone ($C_{14}H_8O_2$), sodium chlorite ($NaClO_2$), glacial acetic acid (CH_3COOH), methanol (CH_3OH). All chemicals are purchased from El-Shark El-Awsat company.

B. Characterization of Raw Materials

Sugarcane bagasse is characterized through thermal gravimetric analysis and differential thermo gravimetry (TGA/DTG) to obtain the most suitable range of temperature for elimination of lignin. In this test, the sample is heated at a constant rate equals 10℃/min in an inert atmosphere using nitrogen gas. The thermal analysis was performed in the Scientific & Technology Center of Excellence (STCE) using TGA Q500 V20.10 Build 36.

C. Sample Preparation

Sugarcane bagasse was the main raw material. It was washed using distillate water to eliminate any residual sugar, then it was dried and crushed to increase the surface area that would be exposed to chemicals during reaction. The kraft process is applied using a 0.5 M NaOH solution and 0.5 g of anthraquinone. To perform this reaction, the solid (bagasse) to liquid ($NaOH_{solu.}$) ratio varies from 10 to 15%, the time of reaction ranges from 60 – 180 min, while the temperature is changed from 160 – 180℃. These conditions are varied, and the optimum conditions that correspond

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to the highest yield are obtained using the Response Surface Methodology (RSM) program. After reaction, the produced pulp is filtered, washed, and dried to eliminate black liquor that contains lignin. Finally, pulp is bleached through three steps of one hour each using sodium chlorite ($NaClO_2$), glacial acetic acid (CH_3COOH), and distillate water at 70℃. In the first stage, each 20 g of pulp is bleached using 7.2 g of sodium chlorite, 2 ml of glacial acetic acid, and 640 ml of distillate water. In the second and third steps, 0.75 g of sodium chlorite with 0.25 ml of glacial acetic acid are added to the resultant mixture from the first step. After bleaching, the product is filtered, washed, and neutralized using methanol to eliminate any residues as shown in Figure 1.

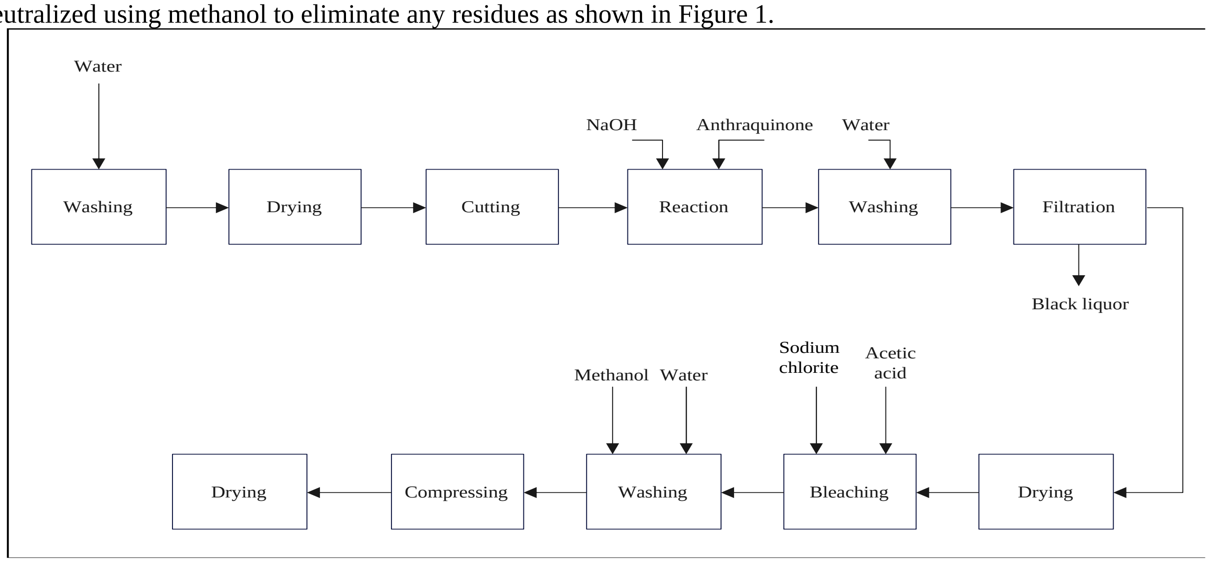

Figure 1: Block flow diagram of paper production using kraft process

D. Response Surface Methodology (RSM) Program

Response surface methodology (RSM) is a factorial design based on a combination of statistical and mechanical techniques developed in the 1950s to determine the optimum operating conditions in applications such as biological science and chemical industry. RSM analysis in which a response is affected by several independent variables to optimize this response [22]. It is used to reduce the time, cost and effort, and to prevent the overlapping between the variables, due to its ability to vary all these variables simultaneously according to a specific scheme and determine the output function on each run based on the experimental measurements. The program has several techniques like Box – Wilson method, Box – Behnken method, and Tagoshi method, … etc. [23]

The number of the required experiments (N) is calculated from equation (1) based on the number of independent variables (k) that should be three variables or more. In addition to the number of center experiments (C_o) that are repeated to indicate the error that may exist during performing the experimental work [24].

$$\mathbf{N = 2k\,(k - 1) + C_o} \qquad (1)$$

For the current work, experimental Statistical Design-Expert 11.1.2, Stat-Ease, Inc., MN, USA, software was used applying Box-Behnken statistical design model. A second order model was selected that relates the target variable or response (Y) to the three independent variables X_1, X_2 and X_3 by the relation as shown in equation (2) [25].

$$\mathbf{Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{23} X_2 X_3 + \beta_{31} X_3 X_1 + \beta_{11} X_{12} + \beta_{22} X_{22} + \beta_{33} X_{32}} \qquad (2)$$

Where β_0, β_1, β_2… are constants obtained based on the experimental results. Then the software enables drawing two- and three-dimensional plots for response surfaces.

E. Characterization of The Product

The characterization is performed on bleached pulp, from which paper are manufactured by pressing then drying. Then some factors are measured to be able to characterize the product as discussed below:

i. Basis Weight (Grammage)

The basis weight is defined as the mass of paper per unit area. it is considered a characteristic property in paper production as paper in most cases categorized by its weight. It has the unit of gram per square meter (GSM). It is very important to indicate the strength properties of paper, it is also used to determine the index values of these properties [26].

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ii. Tensile Strength

This method is used to determine the ability of paper to sustain tension forces and it is performed according to TAPPI. The constant rate of elongation apparatus is applied as mentioned in T- 494 by tying the two ends of a paper sheet and exerting force until it breaks, hence it is mainly governed by fiber direction [27].

iii. Tearing Strength

This test is performed using the Elmendorf-type tearing tester, through which the force perpendicular to the plane of the paper required to tear multiple sheets of paper from a specified distance after the tear has been started is measured. Then the tear strength of a single sheet may be determined. This test is done according to T- 414 [28].

iv. Burst Strength and Burst Index

Based on T- 403, the maximum burst strength is obtained by holding a sheet between clamps and increasing the pressure by a rubber diaphragm maintained under the sheet. The pressure increases until reaching the maximum value that led to rupture of paper. Burst index is calculated by dividing the burst strength by the value of basis weight. It is considered more specific and characteristic for the produced paper [29].

III. Results and Discussion

A. Characterization of Raw Materials

From TGA/DTG results shown in Figure 2, it is found that there is a reduction in weight of about 10% of the total mass around 100℃ due to evaporation of moisture content. Then the weight of sample begins to decrease from 160 to 250℃ that represent the decomposition of lignin. Another pattern of loss ends at 320℃ that shows the decomposition of hemicellulose. Finally; a major loss in weight of about 48% takes place in the range of 320 - 400℃, it demonstrates the decomposition of cellulose.

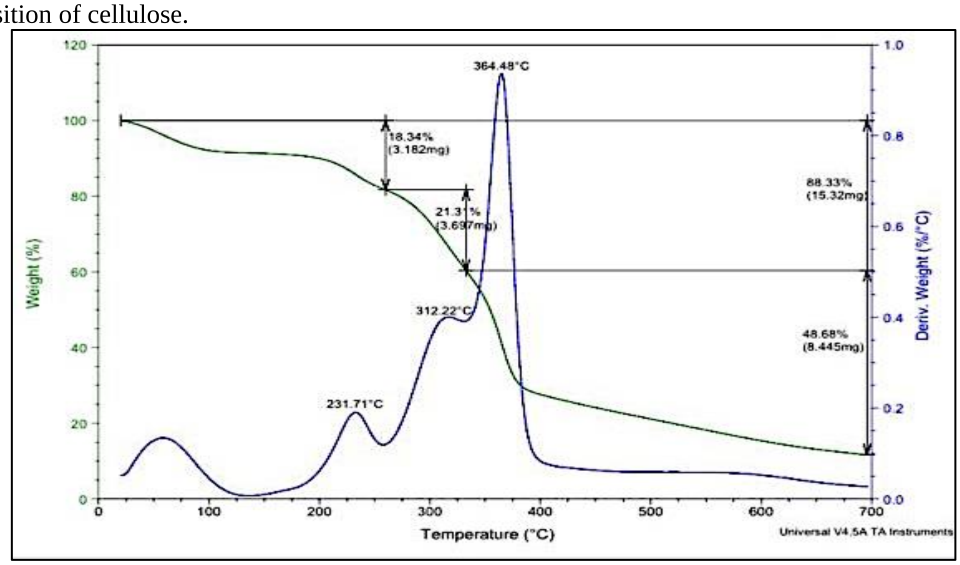

Figure 2: TGA/DTG pattern of sugarcane bagasse

B. Response surface methodology (RSM) Results

By using RSM, the best model that represents the yield is found to be 2FI, as the determination factor (R^2) for this model is 0.9287. High R^2 value indicates this model fits the results obtained in laboratory. The relation between the studied parameters and the yield is represented by equation (3):

$$Y = 99.77 - 0.19736 * Time - 0.408 * Temperature + 1.656 * Solid\ to\ Liquid\ Ratio + 0.002283 * Time * Temperature - 0.0138 * Time * Solid\ to\ Liquid\ Ratio \quad (3)$$

i. Statistical Model Contour Graphs

A contour graph is the projection of a 3D graph model on a 2D plot, it indicates the maximum, minimum points as well as the effect of two parameters on a certain response on a 2D plot. In this model two parameters change while the third remains constant at its minimum, average, and maximum values to determine the maximum yield that can be obtained at these values. Changing the color from blue to red indicates increasing in the yield, as getting closer to red-colored regions indicates a higher yield, and getting closer to blue regions indicates a minimum yield obtained at the

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corresponding conditions to each region. Each line shows the yield obtained at any condition corresponding to the two other parameters through the line. Contour plots are useful for establishing the response values and operating conditions as required.

- *Effect of the Reaction Time and Temperature on the Yield*

The effect of both temperature and reaction time on yield was studied while maintaining the solid to liquid ratio at its minimum, maximum and average values. As shown in Figure 3 (1), and Figure 3 (2). At the minimum value of solid to liquid ratio (10) and the average value of solid to liquid ratio (12.5%), the yield will decrease when the temperature increases. However, the yield will increase when time increases. when both temperature and time increase simultaneously the yield increases. While at Figure 3 (3), at a maximum value of solid to liquid ratio (15%). The yield will decrease when the temperature and time increase, however, when both temperature and time decreases simultaneously, the yield will increase.

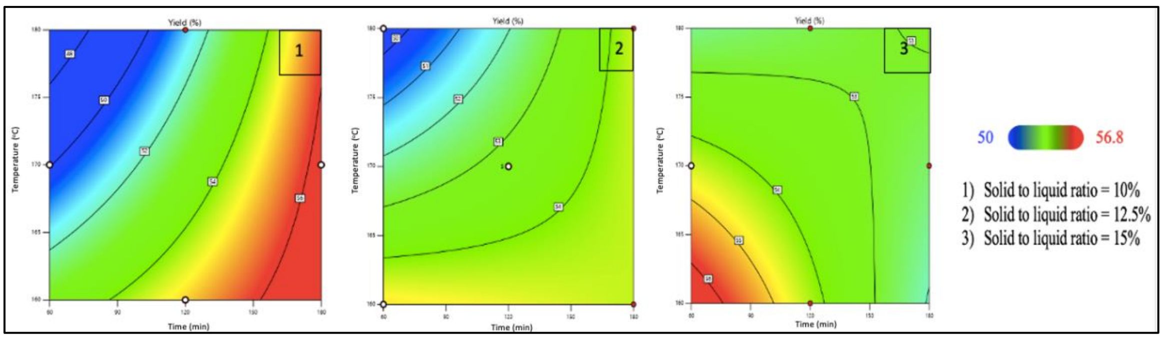

Figure 3: Effect of reaction time and temperature on the yield

- *Effect of the Reaction Time and Solid to Liquid Ratio on the Yield*

The effect of changing both the reaction time and solid to liquid ratio on the yield was studied while maintaining the value of the reaction temperature at its minimum, average, and maximum values as shown in Figure 4 (1), Figure 4 (2), and Figure 4 (3). At the minimum value of temperature (160 ℃), average value (170℃) and the maximum value (180℃), The yield will increase when both time and solid to liquid ratio increases.

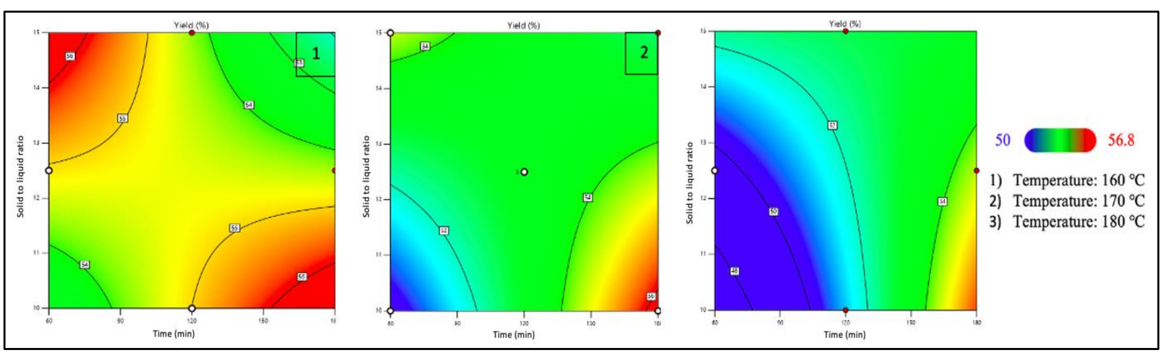

Figure 4: Effect of reaction time and solid to liquid ratio on the yield

- *Effect of the Reaction Temperature and solid to liquid ratio on the Yield*

The effect of changing both the reaction temperature on X-axis and solid to liquid ratio on Y-axis on the yield while maintaining the value of the reaction time at its minimum, average, and maximum values is shown in Figure 5 (1), Figure 5 (2), and Figure 5 (3). At a minimum value of time (60 min) and the average value of time (120 min), the yield will decrease when temperature increases. However, yield will increase when solid to liquid ratio increases. At a maximum value of time (180 min), when both temperature and solid to liquid ratio increase, the yield will decrease.

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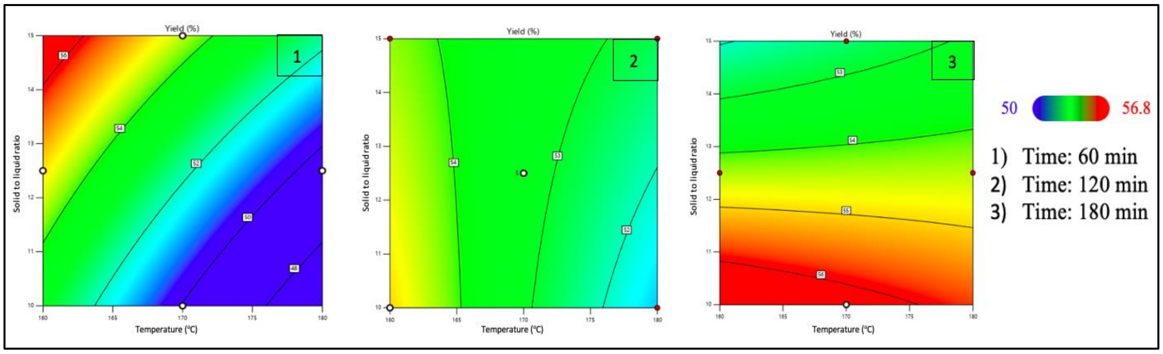

Figure 5: Effect of reaction temperature and solid to liquid ratio on the yield

- *Representation of Data on a 3D Cube*

In box-Behnken, the data can be represented on a 3D Cube. The minimum and maximum values of the three parameters affecting the yield namely, Time, Temperature and solid to liquid ratio lies on X, Y, and Z axis respectively, the cubic model indicates that the maximum yield can be obtained at a value of 56.81 at highest reaction time (180 minutes), lowest solid to liquid ratio (10) and at a temperature of 160°C as shown in Figure 6.

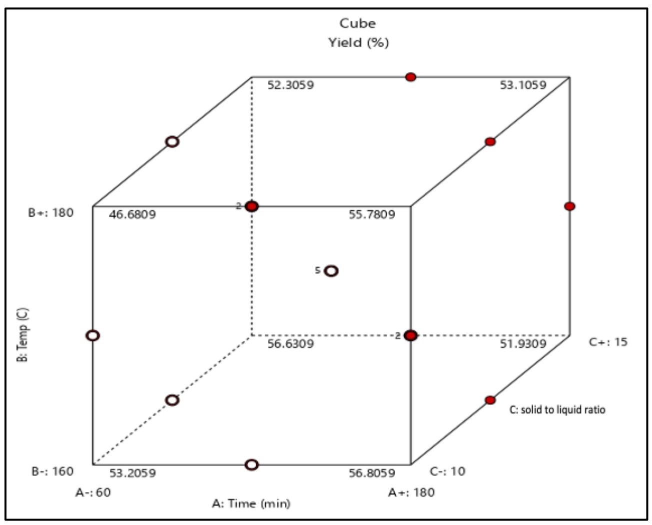

Figure 6: 3D plot for the model

C. Characterization of The Kraft Paper

Depending on the results of the model, the characterization tests were performed for the optimum sample that produced the highest yield obtaining the results shown in Table (2). These values were compared with that of paper available in the market and it was found that all the specifications of the produced paper are compatible with that of kraft paper [30].

Table 2: Specifications of produced paper

Parameter	Value
Average Basis Weight (GSM)	73.93
Tensile Strength (kN/m)	1.7
Tearing Resistance (mN)	196.2
Burst Strength (kPa)	107.807
Burst Index (kPa.m^2/g)	1.397

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IV. Conclusion

When compared to rice straw, wheat straw, and cotton stalks, sugarcane bagasse is utilized as a raw material in paper manufacture since it has the longest fiber length. Consequently, the kraft process is applied to produce pulp using NaOH as an alkaline reagent. The Response Surface Methodology (RSM) program is used to investigate the factors that influence the product's yield. Thus, the mass percent of sugarcane bagasse to NaOH solution is varied from 10 to 15 %, the temperature of reaction is changed from 160 to 180℃, and the reaction is performed for several values for retention times ranging from 60 to 180 minutes. According to RSM data, it was found that, by performing the reaction at 160℃ for three hours using a solid to liquid ratio of 10%, the maximum yield was obtained, which was 56.8 g of pulp for each 100 g of sugarcane bagasse. After that, the generated paper was characterized with respect to basis weight, tensile strength, tearing strength, and burst strength and they were found to be 73.93 GSM, 1.713 kN/m, 196.2 mN, and 107.807 kPa respectively, which are all in the range of commercial kraft paper.

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