Application of Factorial Design to the Production of Bioethanol from Maize Kernel

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***Abstract*—**The production and characterization of bioethanol from maize kernel was carried out through fermentation process using a 2^4 factorial experimental design. The maize kernel was milled, cooked, liquefied, saccharise with malt and fermented with yeast. The optimised operating parameters include reaction temperature, reaction time, quantity of yeast and quantity of maize. The two levels used for each parameter are: temperature (30 ^oC and 37 ^oC), time (48 hours and 72 hours), yeast (1 g and 2 g) and maize (50 g and 100 g). The optimum yield of bio ethanol obtained was 45.77 % at 100 g, 72 hours, 2 g and 37 ^oC for mass of maize, reaction time, yeast and reaction temperature respectively. In addition, the properties of the bio ethanol produced was characterised and were found to compare favourably with the standard values recommended in the literatures.

***Keywords*—** Bioethanol, Characterization, Energy, Maize and Optimization

I. Introduction

IN our present society, energy has become an important driving factor to socioeconomic development of any developing nation. Its impact affects all aspects of human endeavours such as health, education, transportation, agriculture among others [1]. Burning of fossil fuel has been discovered to be an immense contributor to the increase in the level of carbon dioxide (CO_2) in the ambient air which is openly linked with global warming experienced in recent time. The unfavourable effects of the emission of greenhouse gases (GHG) on the surroundings, collectively with the decreasing reserves of petroleum have drawn all attentions to an alternative source. Several negative effects are associated with the use of fossil fuels such as change in climate, loss of biodiversity and rise in sea level [2], [3]. A boost in the energy demand is often leads to the rise in the price of crude oil and this negatively affects the economic activity of the world. From the economic, environmental and ecological point of view, many questions are been raised about the sustainability of fossil fuel [4]. Consequently, the need for environmentally and sustainable harmless energy sources for our consumer societies and industrial economies has grown necessary in modern times [5]. Bioethanol has been considered as an alternative energy source that can compete with the existing energy source which is fossil fuel.

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This study is focus on the production of bioethanol from maize through fermentation process. It also include investigating the effect of reacting parameters such as quantity of yeast, reaction time, reaction temperature and quantity of maize on bioethanol yield using a 2^4 factorial experimental design. The study also involves characterization of the bioethanol produced and comparing the results with the available standards and literature. Lastly, analyzing the effects and interactions of the four parameters (quantity of yeast, time, temperature and quantity of maize) and development of a statistical mathematical model that can represent the system. The significance of this work includes enhancement of an alternative fuel source that is sustainable and renewable in developing the engineering sector in Nigeria and Africa at large.

II. Methodology

The raw material (maize kernel) used in the work was gotten from Kure market, Minna, Nigeria. The sample was dried for two days in order to prevent moisture and dirt handpicked. The dried maize was then grinded to powdered form so as to reduce the particle size and increase effective penetration of the enzyme. The maize kernel sample was soaked in a container with warm water at about 40 ^oC for 24 hours. After, the water drained off, more warm water added and allowed to soak for another 15 minutes. The water in the sample mixture was drained and the soaked seeds spread on a wet towel and covered with another wet towel and then after with plastic. The towels were kept moist at every 12 hours while the seed sprout. The sprouted seeds were observed and measured at every 12 hours until a length of one inch was noticed; the sprout and seeds were then removed and dried under the sun for another one week. After drying, the sprout and seed were grinded and hereafter referred to as malt and kept for use in the mash.

50 g and 100 g of the grinded maize malt were separately mixed in two different beakers with 300 ml and 600 ml of preheated distilled water at temperature of 60 ^oC and 120 ^oC respectively. Each of the mixture was stirred continually for about 30 minutes, after which it was set aside to cool in a water bath and stirred occasionally. The mash was stirred in order to obtain an even mixture as this helps to release the formed gel during gelatinisation process. The mixture was further cool to a temperature of 28 ^oC, 2 drops of sulphuric acid added and pH checked. 20 g of malt prepared was then mixed with 50 g maize mixture and 40 g malt was mixed with 100 g of maize mixture. A known amount of baker's yeast was dissolved in 20 ml warm water of about 29 ^oC. and a pinch of sugar added to the yeast solution prepared in order to confirm if the yeast was active. After 10 minutes, the confirmatory result shows bubbles forming in the solution [6].

As shown in Table 1, fermentation temperature, time, quantities of yeast and maize were varied at two different levels using a 2^4 factorial experimental design. These varied parameters were selected for optimizing the fermentation process based on the fact that they are more efficient and less expensive. Figure 2 shows the fermented maize. A simple batch distillation apparatus was used to separate the mixture of water and ethanol based on their different boiling points [7]. The ethanol produced from the 16 runs as shown in Table 1 was distilled further so as obtain a higher percentage ethanol for characterization. The qualities of bioethanol tested for are; specific gravity, flash point, boiling point, refractive index, viscosity, density, cloud point, moisture content and ash content [6], [7].

III. Results And Discusssion

The need for alternative energy source to meet the intensifying demand for fossil fuel, couple with environmental degradation which is the consequence of fossil fuel burning led scientists and researchers to source for alternative energy source. Results of their findings reveled that obtained on the influence of the quality and efficiency. This present study focus on the production of bioethanol from maize kernel via 2^4 factorial designs. Results obtained on the influence of various reacting parameters such as temperature, reaction time, quantity of yeast and that of maize on the yield of bioethanol are presented in Table 2. As shown in Table 1, the highest yield of ethanol was 45.77 % at operating conditions of 100g of maize, 2g of yeast, operating temperature 37^{o}C and fermentation time of 72 hours.

TABLE I
EXPERIMENTAL DESIGN SHOWING BIOETHANOL YEILD AT DIFFERENT VARIABLES

Runs	Reaction temperature {A} (^{o}C)	Reaction time {B} (hours)	Quantity of yeast {C} (g)	Quantity of maize {D} (g)	Percentage Yield of ethanol (%)
1	30	48	1	50	14.68
2	37	48	1	50	14.88
3	30	72	1	50	23.88
4	37	72	1	50	24.09
5	30	48	2	50	21.16
6	37	48	2	50	30.00
7	30	72	2	50	32.08
8	37	72	2	50	33.08
9	30	48	1	100	35.68
10	37	48	1	100	38.10
11	30	72	1	100	38.10
12	37	72	1	100	32.27
13	30	48	2	100	21.94
14	37	48	2	100	41.32
15	30	72	2	100	43.07
16	37	72	2	100	45.77

TABLE II
FACTOR EFFECTS AND COMBINATIONS

Term	Effect	Sum of Square	% Contribution
A	3.615	52.2729	3.72701
B	6.8225	186.186	13.2749
C	5.8425	136.539	9.73513
D	12.8	655.36	46.7266
AB	-4.095	67.0761	4.78247
AC	4.365	76.2129	5.43392
AD	1.0525	4.43103	0.315928
BC	3.0725	37.761	2.69233
BD	-1.28	6.5536	0.467266
CD	-3.855	59.4441	4.23831
ABC	-2.035	16.5649	1.18106
ABD	-2.1375	18.2756	1.30304
ACD	2.0075	16.1202	1.14936
BCD	4.175	69.7225	4.97116
ABCD	-0.0725	0.021025	0.00149906
Lack Of Fit	1	0	0
Pure Error	0	0	0

A=Reaction Temperature, B= Reaction Time, C= Quantity of Yeast, D= Quantity of Maize

Effect of Reaction Temperature on Bioethanol Yield

Temperature is an important factor in bioethanol production, during fermentation, enzymes have different temperature mediums. The rate of the reaction increases with an increase in temperature to a temperature where the enzymes are destroyed. Also at very low temperatures, enzymatic activities are deactivated and there is a stop in reaction or the process is slowed. In this present study, the two level of temperature used were 30^{o}C and 37^{o}C and the optimum yield was obtained at 37^{o}C. Results obtained as presented in Table 1 indicate that increase in temperature favours the yield of bioethanol from maize. For instance, at constant operating parameters of fermentation time of 72 hours, 2g of yeast and 100g of maize, 43.07% yield of bioethanol was obtained at operating temperature of 30^{o}C, when the temperature was raised to 37^{o}C the percentage yield of bioethanol was also raised to 45.77%. Though an increase in temperature positively favoured the yield of bioethanol, care should be taken not to increase the operating temperature beyond the set limits, which will lead to destruction or deactivation of enzymes

Effect of Reaction Time on Bioethanol Yield

As shown in Table 1, the maximum yield of ethanol was obtained at fermentation time of 72 hours. Futher analysis of result obtained indicate that bioethanol yield increases with an increase in reaction time from 48 hours to 72 hours. This is attributed to the fact that the longer the reaction time, the more the interaction between the enzyme and the feedstock and the more yield of bioethanol [9].

Effect of Quantity of Yeast on Bioethanol Yield

The rate of yield of bioethanol is directly proprotional to the amount of yeast used. However, care must be taken not to increase the yeast beyound the optimum level as this will make the substrate become a limiting reactant [8]. The optimum mass of yeast obtained in this study confirms with the value of 1-3g reported in the literture [9].

Effect of Quantity of Maize on Bioethanol Yield

Table 2 showed that an increase in the quantity of maize leads to more yield of bioethanol. For example, the maximum yield of bioethanol is at 100 g of maize malt. Therefore, the higher the quantity of the feedstock, the higher the percentage yield of ethanol.

The effects of varied parameters and their interaction with reference to the percentage yield of bioethanol using the analysis of variance (ANOVA) of a statistical design expert 7.0.0 package is shown in Table 2. The quantity of maize has the highest effect of 12.8 on the production of bioethanol from the experiment with a percentage contribution of 46.73%. The reaction time come next with a percentage contribution of 13.28 % and reaction temperature had the lowest percentage contribution of 3.73. In order to optimize the production of bioethanol from Maize kernel, interactions between two or more variable parameters were investigated. For two factors interaction, AC has the highest percentage contribution of 5.43%. However, AD is the interaction with the lowest percentage contribution of 0.32 %. Comparing the interaction between three factors, ACD has the lowest percentage contribution of 1.15% and BCD has the highest contribution of 4.97 %. Concisely, all percentage contributions are positive while some factors such as AB, BD, CD, ABC and ABD have negative effects; this could be as a result of poor distillation process carried out.

Model Equations from the 2^4 Experimental Designs

Equation 1 is the final model equation derived from the 2^4 experimental designs,

$$\text{Yield} = 63.32196 - 5.24036A - 1.73314B - 16.8546C + 0.77331D + 0.10027AB + 2.4335AC + 0.032671AD + 0.83545BC + 0.011090BD - 1.75779CD - 0.048452ABC - 1.01786E\text{-}003ABD + 0.022943ACD + 0.013917BCD \quad (1)$$

TABLE III
COMPARISON OF THE PREDICTED VALUE WITH THE ACTUAL YIELD

Standard Order	Actual value	Predicted value	Residual
1	14.68	14.72	- 0.036
2	14.88	14.84	0.036
3	23.88	23.84	0.036
4	24.09	24.13	- 0.036
5	21.16	21.12	0.036
6	30.00	30.04	- 0.036
7	32.08	32.12	- 0.036
8	33.08	33.04	0.036
9	35.68	35.65	0.036
10	38.10	38.14	- 0.036
11	38.10	38.14	- 0.036
12	32.27	32.23	0.036
13	21.94	21.98	- 0.036
14	41.32	41.28	0.036
15	43.07	43.03	0.036
16	45.77	45.81	- 0.036

TABLE IV
CHARACTEIZATION OF THE BIOETHANOL PRODUCED FROM MAIZE KERNEL

	Unit	ASTM standard	Bioethanol produced from maize
Specific gravity		0.87	0.91
Density	g/cm^3	0.79	0.80
Viscosity	cP	1.30	1.20
Boiling point	^oC	78.4	79.00
Flash point	^oC	18.60	18.00
Cloud point	^oC	23.00	10.00
Refractive index		1.40	1.36
Moisture content	%	1.0	2.00
Ash content	% wt	0.1	0.3

The positive and negative values of the variables in "(1)" show that they are directly and indirectly proportional to the yield of the bioethanol respectively. Table 3 gives the predicted and actual percentage yields with a good correlation in between due to the small residue between them.

The bioethanol produced from maize kernel was analyzed and the characterized properties compared with literatures and set standard. The bioethanol produced was characterized to test for basic properties and the results obtained are presented in Table 4. The values of various properties tested are either within or close to the acceptable range specified in the literatures. [6], [7].

IV. CONCLUSIONS

This work clearly demonstrates the possibility of producing bioethanol from an agricultural product, maize kernel through the use of corn malt by fermentation process. The bioethanol produced was characterized and its properties as a transportation fuel for car engines agrees consistently with ASTM standard for marketable bioethanol or ethanol blend with gasoline and literatures. A 2^4 factorial design was successfully used to optimise the yield of ethanol and studied the effect and interaction of the operating parameters on the yield of ethanol. An optimum condition of 37 ^oC temperatures, 2 g of yeast, 100 g of feedstock and a reaction time of 72 hours was then established for the production of bioethanol from maize kernel. The linear regression model equation developed shows that all the independent variables considered are relevant as there are interaction effects between them.

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