Production and Characterization of Bioethanol from Sugarcane Bagasse as Alternative Energy Sources

Abdulkareem A Saka *Member, IAENG,* Ayo S. Afolabi, *Member, IAENG* and Ogochukwu M.U

***Abstract*—Energy crisis and environmental pollution that characterized overdependence on fossil fuel as source of energy motivate researchers and government all over the world to search for sustainable and environmentally friendly alternative energy sources. This study is aimed at production of bioethanol form sugarcane bagasse using 2^4 factorial experimental design method to investigate the influence temperature, time, catalyst concentration and mass of sugarcane bagasse on the yield of bioethanol. Results obtained indicate that the optimum bioethanol yield of 14.5% was obtained at optimum conditions of operating temperature of 35°C, time of 72hours, catalyst concentration of 2gw/w and mass of sugarcane of 30g. The statistical analysis of variance indicated that fermentation temperature, time, catalyst concentration and mass of feedstock had significant effect on the yield of bioethanol from sugarcane bagasse. However, temperature had the highest contribution of 79.45%, while the time, catalyst concentration and mass of feedstock had contribution effect of 12.63%, 3.23% and 0.32% respectively. The bioethanol produced was then characterized to the determine the basic properties such as flash point, specific gravity, cloud point, sulphur content, acid value, refractive index, pour point, density and kinematic viscosity. The results obtained on the basic properties tested conform to the set limit with little variation. It can therefore inferred from the results obtained that production of bioethanol from sugarcane bagasse is possible.**

Keywords*—Energy, bioethanol, optimization, characterization and sugarcane bagasse.*

I. INTRODUCTION

Biofuel can be referred to as fuels derived from biological carbon fixation leading to dissipation of energy. Biofuels can also be derived from conversion of various lignocellulosic biomasses into liquid fuels and biogases [1]. In recent times, biofuels have received constant attention from the general public and science fields inclusive. This new found interest build up is attributed to certain factors such as oil price hikes and the urgent need for increased security in the world's energy sector and most importantly Africa's. Some fuels which can be gotten from solid biomass include ethanol, methanol, biodiesel, and hydrogen and methane also known as gaseous fuels. Research and development in biofuel production is made up of three basic areas: production of the fuels, uses and applications of the fuels, and distribution of infrastructure [2]. Primarily biofuels are used to power vehicles, but can also be used to fuel engines or fuel cells for generation of electricity. Some of such fuels include biodiesel, bioethanol, and many other liquid fuels derived from lignocellulosic biomass [3]. Ethanol, butanol and propanol are classified as alcohols that can be produced biologically by microorganism and enzymatic action on starches, sugars and cellulose; this biological process is called fermentation. Of all the biofuels, the one which is most acceptable and readily produced worldwide is ethanol fuel, particularly in Brazil and USA [4]. Fermentation of sugars derived from wheat, sugar beets, corn, cane, bagasse and molasses leads to the production of alcohols. The stages involved in ethanol production are, enzyme digestion (to release sugars stored in starch crops), fermentation of the sugars, distillation and lastly drying. Cellulosic ethanol production involves the use of inedible or non-food crops, waste products and does not cause food shortage for humans and animals alike [5]. Bagasse which is the dry, fibrous reminant after the juice has been extracted from the crushed sugarcane, has recently become a source of bioethanol. The recent research and development is focused on the potential of energy crops with lignocellulosic residues for bioethanol production [6]. Conversion of this feedstock into biofuel is an important choice for the study of sources of alternative energy and hence, reducing polluting gases which are contained in fossil fuels. Furthermore, the use of biofuels has important economic and social effects. For instance, as pointed out by Kuchler and Linner, [7] that the diversification of fuel research would stabilize America's economy by bringing money and jobs back into the economy.

Ethanol can be used as an alternative for petrol in motor vehicle engines; it can be mixed with gasoline to any percentage. Most existing car engines are presumably able to function using ethanol-petrol blends of up to 15 % bioethanol with petroleum/gasoline. The energy density of ethanol is smaller than that of gasoline; this means more fuel is required (volume and mass) to duplicate an equivalent amount of work. One advantage of ethanol (CH_3CH_2OH) over gasoline is that its octane rating is

---

Manuscript received March 6, 2015; revised March 27, 2015

Abdulkareem A.S is with the Department of Chemical Engineering, Federal University of Technology, PMB 65 Gidan Kwano Minna, Niger State Nigeria and Civil and Chemical Engineering Department, College of Science, Engineering and Technology, University of South Africa, Johannesburg South Africa. E-mail: kasaka2003@futminna.edu.ng

Ayo S Afolabi* is with the Department of Civil and Chemical Engineering, University of South Africa, Florida Campus, Johannesburg, South Africa. (*Corresponding author: phone: +27 114713617; e-mail: afolaas@unisa.ac.za).

Ogochukwu M.U is with the Department of Chemical Engineering, Federal University of Technology, PMB65 Gidan Kwano Minna, Niger State Nigeria.

higher than that of pure gasoline which is readily available at roadside gas stations; this allows an increase in compression ratio of an engine for increased thermal efficiency. Atmospheric emissions can be greatly reduced when gasoline-petrol blends are used as winter oxidizer in high-altitude (thin air) locations; therefore its use is encouraged in many countries. Ethanol is also used as fuel to burn wood in fireplaces because it does not require a chimney due to the fact it does not generate dark smoke and is "flueless", bioethanol fires are extremely useful for newly built homes and apartments without a flue [8]. Despite the realization that bioethanol will serve as perfect alternative energy source to replace the existing energy sources, product is still not available in commercial quantities in developing nations like Nigeria. This study therefore, focuses on the production of bioethanol from the sugarcane bagasse that is readily available in the country in large quantities as a waste. The use of waste biomass such as sugarcane bagasse to generate energy can reduce problems associated with waste management such as pollution, greenhouse gaseous emissions and fossil fuels use. The rate of global warming can be greatly reduced through the use of bioenergy derived from municipal or agricultural wastes such as sugarcane bagasse and waste newspapers. According to a recent report, by the year 2020, constant use of biomass will produce 19 million tons of petroleum equivalents. Out of this, 46% is obtained from bio-wastes like farm waste, agricultural waste, municipal solid waste and other biodegradable waste streams [4].

II. MATERIALS AND METHODS

The sugarcane bagasse was sourced locally from Minna, Niger State, Nigeria. In conversion of lignocellulosic biomass such as sugarcane bagasse into bioethanol; four major unit operations are employed. These include: pretreatment, hydrolysis, fermentation and product recovery/ distillation. Pretreatment is the first stage in the production of bioethanol. Pretreatment was carried out by employing the dilute acid pretreatment method. Sugarcane bagasse is chipped and grinded to powder form; subsequently the dried and weighed bagasse was poured into a 500 ml conical flask and was infused with 250 ml of 4% H_2SO_4 solution. The conical flask was introduced into a water bath and allowed to shake and stir for two hours at 60^{o}C. The pretreated bagasse was collected and washed thoroughly with distilled water to reduce the pH level [9]. The treated sugarcane bagasse was then prepared for hydrolysis. Since lignocellulosic materials contain molecules which are primarily made up of long chains of glucose, it becomes paramount to breakdown these glucose chains into smaller chains to free sugars which are fermentable. To this effect, the glucose present in the sugarcane bagasse was hydrolytically converted to monomeric sugars by means of enzymatic hydrolysis. Here 10 ml of the enzyme Aspergillus niger was introduced into the broth and allowed to sit for 24 hours before fermentation. The pH level was adjusted to 4.5 by adding KOH, which is suitable for enzymatic activity [10]. This process was then followed by fermentation process, which involves the fermentation of monomeric sugars with the aid of fungi, bacteria or yeast in an oxygen-free environment [10].

The production of bioethanol from the hydrolysate obtained from hydrolysis of sugarcane bagasse involves fermentation of the hydrolysate with the aid of a catalyst under anaerobic condition (absence of oxygen). Fermentation is expected to take place for a period of time in which weighed amount of hydrolysate was put in conical flasks with fungi which was properly seal with foil paper and left to ferment. After fermentation, CO_2 is evolved from the mixture which bioethanol is distilled out from it. Bioethanol distills out of the mixture at 78^{o}C. A 2^4 factorial design was employed to optimize the process of production of bioethanol from sugarcane bagasse. This implies that four factors were studied at 2 levels (low and high) as shown in Table I. The variables optimized were temperature, time, and ratio of load and concentration of fungi as shown in Table II. All the experimental analyses were conducted in triplicate and results presented are the average values with average deviation of ±0.00125. The bioethanol produced was then characterized to determine the basic properties such as density, flash point, viscosity, boiling point, refractive index, sulphur content, moisture content, specific gravity, ash content and pour point.

TABLE I
VARIATION OF PARAMETERS OF THE 2^4 FACTORIAL DESIGNS

Level	Time (hrs)	Temp. (^{o}C)	Catalyst conc. (w/w)	Mass of feedstock
Low	48	48	1	20
High	72	72	2	30

III. RESULTS AND DISCUSSION

Bioethanol's potential as substitute for conventional petroleum based fuels has been the issue at the tip of everyone's tongue. To this effect, several research attempts have been made towards validating the use of non-petroleum sources to generate fuel. The focus of this study is to produce bioethanol from sugarcane bagasse by varying production parameters such as fermentation time, temperature, catalyst concentration/enzyme loading and the feedstock ratio. These were considered at two coded levels; high and low levels and the results obtained were presented in Table I. As presented in Table 2 the optimum bioethanol yield of 14.5% was obtained under the operating conditions of 35^{o}C (operating temperature), 72 hours (fermentation time), 2 g concentration of catalyst and 30 g (mass of feedstock). The optimum yield of 14.5% obtained in this study conforms to the values of 10-15% reported in literature which is in the ranges of 10-15 %. The variation could be attributed to difference in reaction parameters and variation in quantity of sugarcane bagasse utilized as feedstock.

In comparison to the parameters which affect bioethanol production by fermentation of lignocellulosic biomass or substrates, the effect of temperature cannot be overlooked this is because the hydrolysis of enzymes and fermentation rate both depend on the surrounding temperature. Most times an increase in temperature in turn brings about a positive influence on fermentation rates due to an increased rate of bacterial growth and also product formation. Temperature increased can have adverse effects when the temperature increases more than the optimum level required for bacterial activity thus leading to the death of cells, reduction in product formation speed and denature of enzymes [11]. From the experimental results, it was noticed that the highest ethanol yields were recorded at temperature values of 35°C. Results as presented in Table II indicate that increment in fermentation temperature resulted in increment in the yield of bioethanol. For instance at constant production parameters and varying the temperature from 30°C to 35°C the yield of bioethanol also increases from 11.9% to 14.5%. Hence fermentation temperature of 35°C is the best temperature for the production of bioethanol from sugarcane bagasse used in this study. It is also worth mentioning that care must be taken not to increase the temperature beyond the set limit which might affect the fungi activities. Dawson and Boopathy reported in 2008 [12] that a temperature range of 25-35°C is usually used for fermentation but this rule depends on the kinetic activity of the inoculums (bacteria/yeast) used. He observed during fermentation of sugarcane bagasse using *Trichordema reesei* that higher microorganism activity was observed at 35°C than that recorded at 30°C. Inoculums' concentration accounts for more than 50 % of the experimental errors encountered in fermentation processes. Therefore there is a need for careful scrutinization of yeast use in order to achieve maximum conversion of sugars to the desired product; bioethanol. From the results presented in Table II, it can be seen that the highest yields of ethanol were gotten when yeast of 2 g was used. The results as presented indicate that by keeping other parameters constant and varying the yeast load, increment in yeast led to increase in bioethanol yield. For instance the yield at yeast concentration of 1g and corresponding temperature of 35°C, and mass of sugarcane bagasse of 30 g was 14.3 %. When the yeast concentration was raised to 2g at same operating conditions, the yield of ethanol from sugarcane bagasse became 14.5%. Daphne (2007) while fermenting sugarcane bagasse obtained a maximum ethanol yield of 0.49 g/g at a yeast level of 3% and at yeast level of 5% corresponding ethanol yields of 0.46 g/g was reported, which implies that the results obtained are inconformity with the literature.

Also investigated and optimized is the influence of fermentation time on the yield of bioethanol from sugarcane bagasse. Most times an increase in fermentation time in turn brings about a positive influence on fermentation because more time would mean higher rates of product formation. This is because time avails the yeast the opportunity to judiciously digest most of the sugar contained in the feedstock. On the other hand when fermentation exceeds a maximum of 96 hours then rate of product formation becomes inversely proportional to the increase in time. From the experimental results, it was noticed that the highest ethanol yields were recorded at 72 hours of fermentation. This is in accordance with [13], who noticed the highest ethanol yield of 8 % (w/v) after fermenting for 72 hours. On the other hand Akpan *et al*, [14] noticed a higher product yield of 9.17 % at 48hours when he fermented rotten rambutan seeds with *Saccharomyces cerevisiae.* Another parameters investigated is the influence of mass of feedstock on the yield of bioethanol from sugarcane bagasse. Evidently, a higher quantity of substrate connotes higher quantity of fermentable sugars available for fermentation thus leading to higher bioethanol yield. In addition, the choice of substrate plays an important role in the expected product yield after fermentation of the substrate. Thus; when high cellulose content biomass is subjected to fermentation correspondingly high product yield is expected. Sugarcane bagasse is known to contain 65 % cellulose which is not as high in cellulose content as other starch based biomass like corn or cotton seed hairs which has cellulose content of 80 % [15]. In addition, bagasse is also known to contain high concentrations of inhibitory substances i.e. lignin which inhibits complete fermentation of the inherent cellulose and hemicelluloses [16]. Judging from the experimental results, it was noticed that higher ethanol yield were associated with higher feedstock. The optimum yield of 14.5 % was obtained when 30g of bagasse was used. Statistical analysis of the results obtained indicates that temperature had the highest percentage contribution to the yield of bioethanol and also effect of 79.45 %, with percentage effect of 1.79%. Other parameters with significant percentage contribution are reaction time and catalyst concentration with values of 12.63 % and 3.27 %. The combinations of the parameters such as combination of temperature and time, time and catalyst concentration, temperature and catalyst concentration and combination of temperature, time and catalyst concentrations shows negative effects. This implies that an increase in the values of these parameter interactions will bring about a decrease in the yield of the desired product. While other parameters combinations includes combinations of all the factors had positive influence on the yield of bioethanol.

TABLE II
VARIATION OF PARAMETERS OF THE 2^4 FACTORIAL DESIGNS

Temp. (°C)	Time (hrs)	Catalyst conc. (w/w)	Feedstock (g)	Bioethanol yield (%)
30	48	1	20	11.5
30	48	1	30	11.6
30	48	2	20	11.9
30	48	2	30	12.1
30	72	1	20	12.2
30	72	1	20	12.4
30	72	2	20	12.7
30	72	2	30	12.9
35	48	1	20	13.0
35	48	1	30	13.2
35	48	2	20	13.5
35	48	2	30	13.9
35	72	1	20	14.0
35	72	1	30	14.3
35	72	2	20	14.4
35	72	2	30	14.5

The fuel properties of the bioethanol produced was conducted and the results obtained are presented in Table III. Refractive index of the produced bioethanol was determined and the results obtained as presented indicate that the refractive index of the produced is 1.37 which is a little higher than the set limit of 1.36. The essence of measuring the refractive index of fuels is to verify the purity of the fuels, it can be deduced from the results obtained that the bioethanol produced is pure. Also tested for is the flash point of the produced bioethanol from sugarcane bagasse. Flash point is described as the lowest temperature at which the fuel will ignite when exposed to an ignition source. These parameters also provide information on the precautionary measures to be applied while handling such fuels. The results as presented indicate that the flash point of the produced bioethanol was 19.20 which is a bit higher compared to the set limit of 18.60, which implies that the bioethanol produced is slightly less flammable than the standard bioethanol fuel. The variation could be attributed to the nature of the feedstock used in this study. Ash content is another fuel properties tested for, it gives quantity of metals present in the fuel. High ash content in fuel could result into injector plugging, post combustion residues or deposits and wear of the injection system of any engine. The ash content of ethanol produced is 0.5%. Hence the need to improve the quality of bioethanol produced so as to reduce the ash content. Sulphur content is associated with health and environmental pollution. Fuels with high sulphur content impact negatively on humans and the entire ecosystem at large. After characterization of the bioethanol sample it was observed that the sulphur content was 0.105%. Distillation properties of the bioethanol produced was determined and since bioethanol is not a carbon based fuel, it is only natural that its boiling temperature should be a single temperature value. The boiling temperature recorded in the distillation of the bioethanol sample was 78.3^{o}C which in compare favorably with the set limit of 78^{o}C. Viscosity determines the ease of flow of fuels through pipes, orifices, nozzles, hence viscosity is a property that determines fuels efficiency in an engine. Low viscosity depicts high flow rate and little or no accumulation in the engine. The results as presented in Table III indicate that the viscosity of the produced bioethanol is 1.34 which is high compared to the set limit of 1.20. The results as presented in Table 3 also indicate that the specific gravity of the produced bioethanol is 0.92 which is slightly higher than the recommended value of 0.87.

TABLE III
PROPERTIES OF BIOETHANOL PRODUCED

Properties	Units	Experimental values	ASTM Standards
Moisture content	%	0.52	20
Density	g/cm^3	0.987	0.99
Refractive index		1.356	1.36
Specific gravity		0.922	0.87
Flash point	^{o}C	19.20	18.60
Viscosity		1.34	1.20
Sulphur content	%	0.105	20
Ash content	%	0.5	30
Cloud point	^{o}C	19.76	23
Pour point	^{o}C	4.75	5.20

Cloud point which is described as the temperature at which a cloud of crystals will first appear in a liquid that is cooled under prescribed conditions is also an important properties of bioethanol tested for in this study. The results as presented indicate that the pour point of the produced bioethanol from sugarcane bagasse is 19.76^{o}C which is lower than the set limit of 23^{o}C by the ASTM. Also measured is the pour point of the bioethanol produced. Pour point is an important characteristic of the bioethanol that gives the lowest operational temperature of the bioethanol. The pour point was determined according to ASTM D97 and the value obtained as presented in Table III is 4.75^{o}C which is also lower than the set limit of 5.20^{o}C, which is an indication that the bioethanol produced can be used even in polar regions where the atmospheric temperature is not less than 5^{o}C. It can be inferred from the various analysis conducted on the bioethanol produced that the properties of the bioethanol produced compared favorably with some of the properties. The variation in some of the properties can be attributed to the nature of the feedstock (sugarcane bagasse) used in this study.

IV. CONCLUSIONS

The search for alternative energy to either replace or complement the existing energy source which is fossil fuel led to the discovery and acceptance of biofuels as a renewable and environmentally friendly energy source. The technology of biofuels is however not commercially available especially in the developing nations due to the lack of understanding of production technology and problems of productions of biofuels from edible oil. This study is focused on the production of bioethanol from sugarcane bagasse that is cheaply and readily available as a waste. The production process was optimized using 2^4 factorial design. The analyses of the results obtained revealed that temperature of 35^{o}C, fermentation time of 72 hours, yeast load of 2 g and sugarcane bagasse of 30 g are the best conditions for the production of bioethanol from sugarcane bagasse with optimum yield of 14.5% of bioethanol. The produced bioethanol was also characterized and the results obtained it can be inferred that the bioethanol produced from sugarcane bagasse conforms to the set limit. The regression model developed also shows that the operating parameters considered in this study have effect on the production of bioethanol from sugarcane bagasse. Fermentation temperature had the highest contribution effect of 79.45 %, while reaction time, catalyst concentration/load and mass of the feedstock had contribution effects of 12.63 %, 3.27 % and 0.32 % respectively. Based on the results obtained in this study it can be concluded that sugarcane bagasse is a good and sustainable feedstock for production of bioethanol since it is an inedible material.

ACKNOWLEDGEMENT

This work was supported by the Nigerian Tertiary Education Trust Fund (TETFund under grant number TETFUND/FUTMINNA/2014/18

REFERENCES

[1] F.T Ademiluyi and H.D Mempha,"Yield and properties of ethanol biofuel from different whole cassava flours", *ISRN Biotechnology*, 6, 2012.

[2] O.J, Sanchez and C, Cardona, “Trends in Biotechnological Production of Fuel Ethanol from Different Feedstock”, *Bioresource Technology,* 99, 5270-5295, 2008.

[3] E. Tomas-Pejo, J.M. Olivia and M. Ballesteros, “Realistic Approach for full Scale Bioethanol Production From Lignocellulose: A Review”. *Journal of Scientific and Industrial Research*, 67, 874-884, 2008.

[4] M.R Xavier, 2007. The sugarcane ethanol experience. Issues Analysis No.3. Competitive Enterprise Institute, Washington, DC.

[5] A. Almodares and M. R. Hadi, “Production of bioethanol from sweet sorghum: A review”. *African Journal of Agricultural Research,* 4 (9), 772 – 780, 2009.

[6] J. Leif, B.A, Jonsson and N. Nilvebrant, “Bioconversion of lignocellulosic inhibitors and detoxification”, Biotechnology for biofuels, 2013.

[7] M. Kuchler and B. Linner, “Pros and Cons of International Biofuel Production: An overview of Research and Policy reports”. *Centre for Clumate Science and Policy Research,* 3, 2008.

[8] R. Arumugam and .M. Manikandan, “Fermentation of Pretreated Hydrolyzates of Banana and Mango Fruits Wastes for Ethanol Production”. *Asian Journal Exp of Biological sciences,* 2(2), 246-256, 2011.

[9] C. Efe, A.J.J Straathof and L.A.M Van Der Wielen L.A.M, “Technical and Economic Feasibility of Production of Ethanol from Sugarcane Bagasse”, 34-48.

[10] A. Verma, S. Kumar and P. K. Jain, “Key Pretreatment Technologies on Cellulosic Ethanol Production”. *Journal of Scientific Research Banaras,* 55, 57-63, 2011.

[11] M. Umamaheswari, M. Jayakumari, K. Maheswari, K, M. Subashree, P, Mala, T. Sevanthi and T. Manikandan, “Bioethanol Production from Cellulosic Materials”. *International Journal of Current Research,* 1, 005-011, 2011.

[12] L.Dawson and R. Boopathy. “Cellulosic Ethanol Production from Sugarcane Bagasse without Enzymatic Saccharification”. *Bioresources,* 3(2) 452-460, 2008.

[13] W.A Pippo and L.A Carlos, “Sugarcane energy use: accounting feedstock energy considering current agro-industrial trends and their feasibility”, *International Journal of Energy and Environmental Engineering*, 4-10, 2013.

[14] U. G. Akpan, A. A. Alhakim, and U.J.J. Ijah, “Production of Ethanol Fuel from Organic and Food Wastes”. *Leonardo Electronic Journal of Practices and Technologies*, 13, 1-11, 2008.

[15] N. Sarkar, S.K. Ghosh, S. Bannerjee and K. Aikat “Bioethanol Production from Agricultural Wastes: An Overview”. *Renewable Energy*, 37, 19-27, 2012

[16] P. Sannigrahi and A. Ragauskas “characterization of fermentation residues from the production of bioethanol from lignocellulosic feedstock”, *Journal of biobased materials and bioenergy*, 5, 514-519, 2011.