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Production and Characterization of Bioethanol from Sugar Cane Bagasse Blended with Mormodica Charantia Seed Oil

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Abstract: *Biofuels recently have been developed to partially substitute the use of conventional fossil fuels for the effect of the later on our climate. Climate change and its effect have become the problem of many developed and developing countries, as the whole is working towards adapting and mitigating the effect of climate change to the Environment. The focus of this research is to produce and characterize bioethanol blended with Mormodica charantia oil extracted from Mormodica charantia seeds by varying production parameters. The sugarcane bagasse was source locally from Shika town Giwa local government Kaduna State, Nigeria. In conversion of lignocellulosic biomass such as sugarcane bagasse into bioethanol; four major unit operations were used. The production of bioethanol from the hydrolysate that was obtained from hydrolysis of sugarcane bagasse comprised the fermentation of the hydrolysate with the aid of a catalyst under anaerobic condition (absence of oxygen). 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.*

Keywords*:* Characterazition, Bioethanol, Sugar Cane, Bagasse, Mormodica Charantia, Seed Oil

Introduction

It is believed that ethanol production for biofuels began during the 1970s-1980s, however during this period bioethanol production and its usage as a fuel re-entered the industry and product capacity increased. During 1902, in Paris the application of alcohols as fuel to power farm machinery, stoves, heaters and spirit lamps was introduced (Rosillo-Calle and Walter, 2006). When the production of stoves and spirit lamps increased in Germany, the production of ethanol increased from 38 million litres to 98.5 million litres (Rosillo-Calle and Walter, 2006; Mussatto *et al.,* 2010). This paved the way for the use of ethanol in motor vehicles and in the year 1908, another milestone was reached when Henry Ford built the Quadricycle, also known as the Model-T which was run on ethanol (Rosillo-Calle and Walter, 2006; Mussatto *et al.,* 2010). Henry Ford also stated that, ethanol would be "the fuel of the future" (Chandel *et al.,* 2007) and "the fuel of the future is going to come from apples, weeds, sawdust-almost anything" (Chandel *et al.,* 2007). Since the 1900s and more importantly in present day, this statement is in the limelight towards alternate energy and sustaining the environment. Furthermore, the interest in bioethanol for fuel purposes was provoked by two additional events, the oil crisis during 1973-1974 and the Kyoto Protocol (Jankowski and Sandel, 2003; Alpanda and Peralta-Alva, 2010; Solomon and Krishna, 2011). The oil crisis of the Organization of Petroleum Exporting Countries embargo during the 1970s caused increasing energy prices (Alpanda and Peralta-Alva, 2010) and this called for developing ideas towards energy saving. The Kyoto Protocol was directed towards climate change with an emphasis on strategies for the reduction in carbon dioxide and other greenhouse gas (GHG) emissions, as a 70% rise in GHG emissions was reported between the years 1970 to 2004 (Jankowski and Sandel, 2003; Koh and Ghazoul, 2008; Solomon and Krishna, 2011).

In the United States, bioethanol production dates back to the 1980s and as early as 1975 in Brazil (Balat and Balat, 2009). During 2004 Brazil was the leading bioethanol producer and by the year 2006, the US became the dominant producer. Other countries contributing to bioethanol production are in Africa, the production of biofuels is regarded as an "unexploited resource" (Amigun *et al.,* 2008) mainly due to: inadequate economic and political management; underdeveloped infrastructure for commercial energy production; and the use of biomass as important food sources (Amigun *et al.,* 2008). Sub-Saharan regions of Africa such as Malawi, Swaziland, Zimbabwe and South Africa have taken the initiate to contribute to world biofuel production by developing small-scale bioethanol plants (Balat *et al.,* 2008). South Africa is ranked as the seventh leading bioethanol producer worldwide, with 102 million gallons produced in 2006. Today the energy crisis becomes one of the global issues confronting us. Fuels are of great importance because they can be burned to produce significant amounts of energy. Many aspects of everyday life rely on fuels in particular the transport of goods and people. Main energy resources come from fossil fuels such as petrol oil, coal and natural gas.

Bioethanol has a potential to damage combustible engines in conventional cars and truck (Yossapong, 2010). It is more corrosive than gasoline, highly susceptible and prone to picking up dirt and other contaminants that can damage fuel system engines. Thus, it is essential to blend the bioethanol with other appropriate additives in order to compensate for these shortcomings. The blend of bioethanol and *Mormodica Charantia* seed oil is expected to improve both combustion rate, efficiency and biodegradation properties under appropriate blending conditions through the study of its morphology and other characterizations. The aim of this research is to produce and characterize bioethanol blended with *Mormodica charantia* oil extracted from *Mormodica charantia* seeds.

Literature Review

Biofuel and Bioethanol

Biofuel is a type of fuel whose energy is derived from biological carbon fixation. Bio- fuels include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases. Although fossil fuels have their origin in ancient carbon fixation, they are not considered biofuels by the generally accepted definition because they contain carbon that has been "out" of the carbon cycle for a very long time. Biofuels are gaining increased public and scientific attention, driven by factors such as oil price hikes, the need for increased energy security, concern over green- house gas emissions from fossil fuels, and support from government subsidies. Biofuel is considered carbon neutral, as the biomass absorbs roughly the same amount of carbon dioxide during growth, as when burnt, (Shala, 2013). The last century has brought unprecedented advances in all of life domains and, along with it, a proportional growth in energy consumption. In the last 40 years, the world energy consumption has doubled, reaching 8978.86 Million tonne in 2012 of which a share of 27.9% is attributed to the transport sector. In the same year, fossil fuels accounted for 81.7% of the world's primary energy supply (31.4% oil, 29% coal and 21.3% natural gas). Because of the continuous increase in energy consumption, environmental impact awareness, high fluctuations of oil market prices and the search for a sustainable fuel supply, biofuels are attracting more and more interest.

Biofuels are renewable energy sources produced from agricultural residues, forest biomass, energy crops, algae/aquatic biomass and other sources of organic matter that can substitute fossil derived fuels. These types of fuels have several advantages over the conventional fossil fuel like: higher combustion efficiency, sustainability and improved fuel security, stimulation of rural development, reduced environmental impact, reduced dependency on petroleum imports, conversion of wastes and residues. There are several factors that need consideration in order to ensure a sustainable, clean and conflict free energy supply competition between food and biomass production for land use and its influences on food prices; land degradability; overall environmental/economic impact – the life cycle assessment and the renewable fuel/fossil fuel ratio (output/input); social impact. Currently, the most common biofuels are ethanol (produced from crops such as corn, wheat, sugar cane and sugar beet) and biodiesel (produced from oil seeds, animal fats and algae).

Ethanol as Biofuel

Ethanol (CH_3CH_2OH) is a clear colorless liquid also known as ethyl alcohol, grain alcohol and EtOH. It is obtained through fermentation of biomass like corn, sugar beet, sugar cane and wheat (also called first generation ethanol). In order to obtain the desired purity, distillation is followed by a dehydration process. Currently, the largest ethanol producers in the world are Brazil and the USA. Ethanol can be used as fuel for internal combustion engines either directly or in blends. Making ethanol available as a vehicle fuel involves several steps: growth, collection and transportation of feedstock; production of first/second generation ethanol; preparation of E10, E15 or E85 and their distribution to the gas stations. Its production is not limited by the feedstock supply (according to Lin and Tanaka, 7-18 billion tons of lignocellulosic biomass are available for use every year) but by technical and economic challenges: due to the resistance of biomass, a relatively harsh pre-treatment process of the feedstock is required, which causes fermentation problems; production of efficient enzymes to hydrolyze the cellulose at a cost competitive to first generation enzymes hydrolyzing starch; cost of feedstock. In order to assess the environmental performance of all life stages of a product (material extraction, processing, manufacturing, distribution, use and disposal/recycling) a so-called life cycle analysis is performed. Regarding the energy balance analysis of ethanol production, the majority of studies presented a positive value but, there are also some that state the contrary.

Different sources of biofuel

Here are 4 biofuel sources, with some of their application in developmental stages, some actually implemented:

Algae

Algae come from stagnant ponds in the natural world, and more recently in algae farms, which produce the plant for the specific purpose of creating biofuel. Advantage of algae focude on the followings: No CO2 back into the air, self-generating biomass, Algae can produce up to 300 times more oil per acre than conventional crops. Among other uses, algae have been used experimentally as a new form of green jet fuel designed for commercial travel. At the moment, the upfront costs of producing biofuel from algae on a mass scale are in process, but are not yet commercially viable, . (Emad, 2013)

Carbohydrate (sugars) rich biomaterial

It comes from the fermentation of starches derived from agricultural products like corn, sugar cane, wheat, beets, and other existing food crops, or from inedible cellulose from the same. Produced from existing crops, can be used in an existing gasoline engine, making it a logical transition from petroleum. It used in Auto industry, heating buildings ("flueless fireplaces"). At present, the transportation costs required to transport grains from harvesting to processing, and then out to vendors' results in a very small net gain in the sustainability stakes, (Emad, 2013).

Oils rich biomaterial

It comes from existing food crops like rapeseed (aka Canola), sunflower, corn, and others, after it has been used for other purposes, i.e food preparation ("waste vegetable oil", or WVO), or even in first use form ("straight vegetable oil", or SVO). Not susceptible to microbial degradation, high availability, re-used material. It is used in the creation of biodiesel fuel for automobiles, home heating, and experimentally as a pure fuel itself. At present, WVO or SVO is not recognized as a mainstream fuel for automobiles. Also, WVO and SVO are susceptible to low temperatures, making them unusable in colder climates.Biofuel: Sources, Extraction and Determination Dense algal growth in four pilot-scale tank bioreactors fed by treated wastewater from the Lawrence, Kan- sas (USA) wastewater treatment plant (photo by B. Sturm). Each fiberglass bioreactor has an operating volume of ten cubic meters of water, and is operated as an air-mixed, flow-through vessel. Nutrientrich wastewater inflows are pumped in through the clear plastic hose (blue clamp), and water outflow occurs through the white plastic pipe shown at the waterline. These bioreactors are intended to be operated year-round, as the temperature of the inflow- ing wastewater is consistently ca. 10 - 8°C. (Emad, 2013)

Agriculture wastes (organic and inorganic sources)

It comes from agricultural waste which is concentrated into charcoal-like biomass by heating it. Very little processing required, low-tech, naturally holds CO2 rather than releasing it into the air. Primarily, biochar has been used as a means to enrich soil by keeping CO2 in it, and not into the air. As fuel, the off-gasses have been used in home heating. There is controversy surrounding the amount of acreage it would take to make fuel production based on biochar viable on a meaningful scale. Furthermore, use of agriculture wastes which rich with inorganic elements (NPK----) as compost (fertilizer) in agriculture, (Emad, 2013)

Bioethanol production

Generally, the raw materials commonly used for the production of bioethanol are materials with carbohydrate content to which fermentation technology is applied. Degradation of cellulose is the breakdown of cellulose into glucose subunits. Microbiologically, cellulose is mainly degraded by an enzyme known as cellulase which is commonly produced by cellulolytic bacteria and fungi e.g *Saccharomyces cerevisiae, Aspergillus sp,Pleurotus ostreatus* (edible mushroom) e.t.c. Studies have revealed that white paper has abundance of cellulose, hence its choice for the production of bioethanol. Currently, bioethanol production is focused on sugar crops including sugar cane, sugar beets and starch crops, including wheat, potatoes and sweet potatoes, which is often based on excess agricultural production and it is generally recognized that this volume is too small in comparison with the anticipated levels of production required for total conversion of transportation fuel markets from gasoline to ethanol.

Bioethanol production

Bioethanol production from renewable resources continues to attract considerable interest as an alternative to fossil fuel (Rortrup-Nielsen, 2005; van Maris et al., 2006; Lynd et al., 2008). The research and exploitation of bioenergy, such as bioethanol and biodiesel, are not recent topics. In order to cope with the predicted depletion of fossil fuel in the near future, a number of countries have taken steps to reduce their dependence on gas and oil imports, by developing and industrializing new energy forms (de Vries et al., 2007; Groom et al., 2007). Potential energy forms include nuclear energy and some renewable and clean forms, such as solar, hydro, biomass and wind. The research and application of bioethanol for energy purposes were pioneered by the United States and Brazil.

Sugarcane (*Saccharum officinarum*) Bagasse

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**.** Recent upsurge interest in the demand of alternative source of energy and economic meltdown in the price of petrol in world market and advancement in science and technology facilitate the scientific research efforts toward commercial production of bioethanol. The bioethanol is the most promising biofuel from renewable resources, and it is well known that a low-cost feedstock is a very important factor in establishing a cost-effective technology (Mojovic, 2006). The production of ethanol from any lignocellulosic biomass generally involves four process steps—feedstock pretreatment, enzymatic saccharification, fermentation, and ethanol recovery.Pretreatment is one of the most expensive and least technologically mature steps in the process of converting biomass to fermentable sugars (Saha, 2004 and Sarita, *et al.,* 2014). Sugarcane (*Saccharum officinarum*) bagasse is one of the lignocellulosic materials that composed of up to 75% carbohydrates. Small amounts of pectin, extractives and ashes were also included in biomass composition. Bagasse has high tensile strength crystalline cellulose fibers, embedded in an amorphous matrix of cellulose, hemicellulose and lignin.

Production Methods for Bioethanol

The bioethanol that was produced was produced by the following methods**.**

Biochemical Methods

The production of bioethanol is a two stage biochemical procedure of hydrolysis and fermentation, followed by product recovery via distillation (Hahn-Hagerdal, 2006; Balat and Balat, 2009; Jegannathan et al., 2009).

Hydrolysis

Hydrolysis is defined as a chemical reaction that breaks chemical bonds between the starch molecules of polysaccharides into simple sugars or monomers in the presence of water and a catalyst (Thaker and Kastner, 2004; Chandel *et al.,* 2007; Balat and Balat, 2009; Dwivedi *et al.,* 2009, Guo *et al.,* 2012).

Fermentation In ethanol production, the method of fermentation to convert sugars by microorganisms (MOs) is the oldest and frequently used industrial process (Caylak and Vardar Sukan, 1998; Paul Ross *et al.,* 2002; Malherbe *et al.,* 2007; Balat, 2009).

As early as 1750-4000BC the Egyptians and Sumerians produced dough and alcoholic beverages such as wine and beer by fermentation (Paul, *et al.,* 2002). The fermentation of milk, meat, cereals and vegetables for food products and food preservation dates back to 6000BC in the Middle East During 6000BC, in Iraq it is believed that cheese was the first fermented product.

However, the role of MOs in the fermentation process was unknown (Paul Ross *et al.,* 2002; Blandino *et al.,* 2003).

Materials and Methods

Materials

The following materials were used during the experimental exercises;

1. Sugarcane Bagasse
2. *Mormodica Charantia* seeds
3. Dilute Sulphuric acid
4. Distilled water
5. Calcium hydroxide
6. Sodium Chloride
7. Acetic acid
8. Acetone
9. Acetate buffer
10. Sodium Carbonate

Apparatus

The following apparatus were used in the research during the experimental work;

1. Weighing balance (triple beam balance, model 2016 MB)
2. Hand gloves

3. Specimen Bottles
4. Sieve
5. Stop watch
6. pH meter
7. oven
8. Mechanical grinder
9. Thermometer

EQUIPMENT

The following equipment were used during the research analyses

1. **High performance liquid chromatography machine**
2. **Atomic absorption spectrophotometer**
3. **Fourier-transform infrared Spectroscopy (FTIR) Machine**

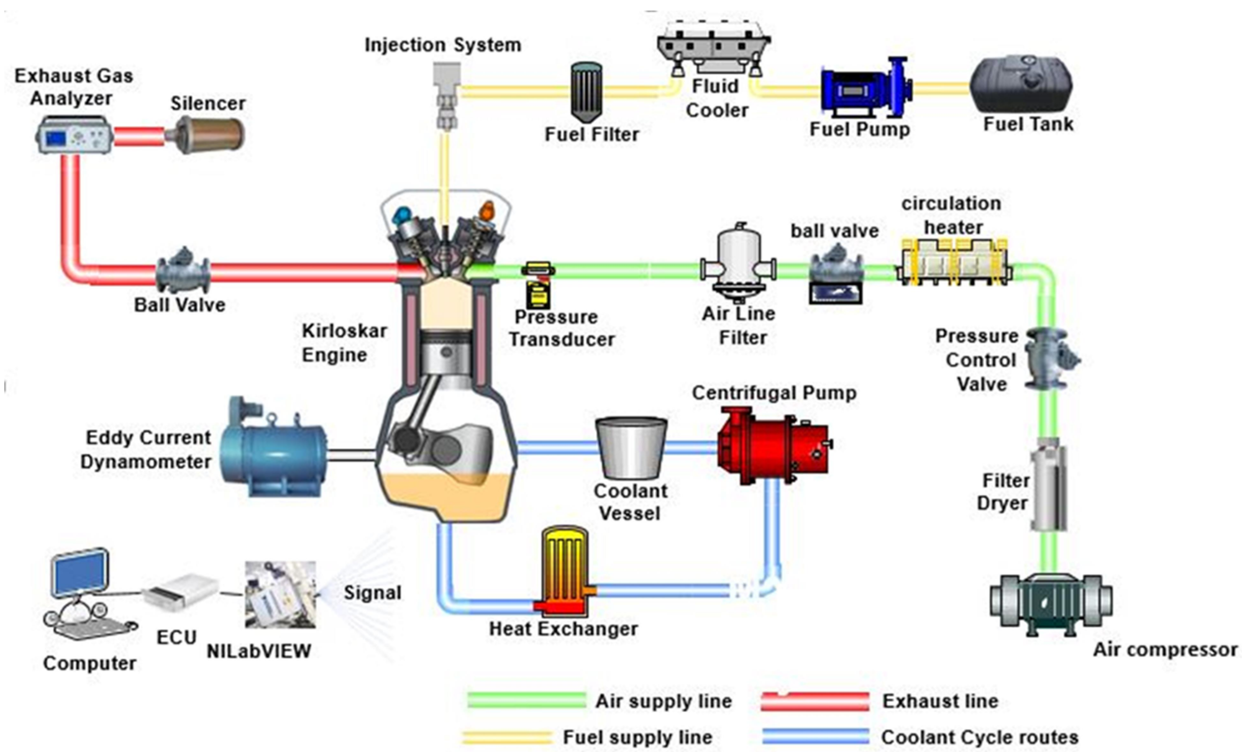

Fig. 2-1 Schematic of the proposed experimental set-up

Table 1- Engine specifications

Item	Specifications
Make	Kirloskar TV1
Type	1-cylinder, direct
Rated power	3.5 kW
Engine speed	1500 rpm
Stroke × Bore	110×87.5 mm

Displaced volume	661 cm^3
Compression ratio	17.1:1
Rated power	3.5 kW
Number of nozzles	3
Number of valves	4
Diameter of nozzle holes	0.3 mm
Injection pressure	210 bar
Injection timing	23° BTDC

Methods

The sugarcane bagasse was source locally from Shika town Giwa local government Kaduna State, Nigeria. In conversion of lignocellulosic biomass such as sugarcane bagasse into bioethanol; four major unit operations was employed. These include: pretreatment, hydrolysis, fermentation and product recovery/ distillation. Pretreatment is the first stage in the production of bioethanol. Pre-treatment as carried out by employing the dilute acid pretreatment method.

Sugarcane bagasse was chipped and grind 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 introduce into a water bath while shaking and stirring for two hours at 60^oC. The pretreated bagasse was collected and wash thoroughly with distilled water to reduce the pH level (Efe *et al.,* 2011). The treated sugarcane bagasse was then be prepared for hydrolysis.

Since lignocellulosic materials contain molecules which are primarily made up of long chains of glucose, it was important 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 solution will then be introduce into the broth and allow to remain for 24 hours before fermentation.

The pH level was adjust to 4.5 by adding KOH, which is suitable for enzymatic activity (Verma and Kumar, 2011). 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 (Verma and Kumar, 2011). The production of bioethanol from the hydrolysate that was obtained from hydrolysis of sugarcane bagasse comprised the fermentation of the hydrolysate with the aid of a catalyst under anaerobic condition (absence of oxygen). Fermentation was expected to take place for a period of time in which weighed amount of hydrolysate was put in conical flasks with which was properly seal with foil paper and left to ferment. After fermentation, CO_2 is evolved from the mixture which bioethanol was then be distilled out from it at 78^oC.Concentration of Bioethanol bioethanol, glucose and xylose was determined using high performance liquid chromatography (HPLC) analysis (HPLC) as described by (Khattab *et al.* 2013 and 2015).

An experimental design software was employed to optimize the process of production of bioethanol from the sugarcane bagasse. Variables such as was temperature, time, amount of yeast used and the effect of the amount of *momordica chrantia* seed oil on the bioethanol fuel efficiency.

All the experimental analyses was conducted in triplicate and results that was presented was as the average values with average deviation of ±0.00125. The bioethanol that was produced will then be characterize 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.

Extraction of the *Mormodica Charantia* Seeds Oil Its Characterization

Extraction of Oil

The *Mormodica Charantia* seeds collected was dried at ambient temperature after which was grinded and weigh. Soxhlet apparatus was use fat was extracted by petroleum ether at maximum temperature of 60 ^{o}C for about 8 h (Yoshime *et al.,* 2016).

The seeds was extracted using the soxhlet extraction methods and then was characterize by gas chromatography. Other parameters were analyze such as the acidity and peroxides values was evaluated by the standard methods of the American Oil chemists' society (AOCS), (Yoshime *et al.,* 2016).

Sugarcane Bagasse and Analytical Methods

The maximum sugar that was produced was then determined using HPLC as described by (Khattab *et al.,* 2013). Liquid hydrolyzates of hemicellulose was collected by filtration, using glass microfiber filter paper GF/A 110 mm diameter. The percent of digestibility was calculated by the following fomula:

Digestibility % = [Total sugar(s) concentration g/l × volume] / [sugar cane bagasse weight (g)] × 100 (Sadat, 2015)

Blend of Bioethanol and *Mormodica Charantia* seeds oil of various composition

From the solution of the bioethanol that was produced 100/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20/80 volume by volume (in cm^3) was prepared as described by (Shuaibu and Okibe, 2013).

The absorbance of each was taken at 315 nm using the ultra violet spectrophotometrer, this measurement was done in triplicate in each composition and results was taken and calculated as averages. The experiment was repeated for optimal time, amount of catalyst used during the production of bioethanol, acid concentration to determine the best conditions for hydrolysis of hemicellulose (bagasse/sulfuric acid), amount of *Mormodica Charantia* seeds oil blended with the bioethanol, pH, and temperature and graph was plotted accordingly.

Fourier-transform infrared spectroscopy analysis

The solution of the Bioethanol that was produced and the *Mormodica Charantia* seeds oil that was extracted from the *Mormodica Charantia* seeds was subjected to FTIR analysis to find out the functional group (s) present in them.

Results and Discussion

Bioethanol's potential as substitute for conventional petroleum based fuels has been the issue at the tip of everyone's tongue. The focus of this research is to produce and characterize bioethanol blended with *Mormodica charantia* oil extracted from *Mormodica charantia* seeds 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 II as below.

Table II: Variation of Parameters of the Factorial Designs

Level	Time (Hrs)	Temp (^oC)	Catalyst conc.(w/w)	Mass of stock
Low	48	48	1	20
High	72	72	2	30

As presented in Table 2 the optimum bioethanol yield of 14.5% was obtained under the operating conditions of 35^oC (operating temperature), 72 hours (fermentation time), 2g 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. From the experimental results, it was noticed that the highest ethanol yields were recorded at temperature values of 35^oC.

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.

The results as presented in Table III Indicate that the viscosity of the produced bioethanol is 1.30 which is high compared to the set limit of 1.18.

Table III: Properties of Bioethanol Produced

Properties	Units	Experimental values	ASTM Standards
Moisture content	%	0.48	20
Density	g/cm^3	0.965	0.99
Refractive Index		1.299	1.33
Flash Point	^0C	19.20	17.89
Viscosity		1.30	1.18
Ash Content	%	0.5	29
Cloud Point	%	20.01	24
Pour Point	%	4.68	5.01

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 20.01^oC which is lower than the set limit of 24^oC 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 4.68°C which is also lower than the set limit of 5.01°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°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.

Conclusion

The quest for alternative energy to either substitute or complement the existing fossil fuel led energy source to the discovery and acceptance of biofuels as a renewable and environmentally friendly energy source. The technology of biofuels recently have been developed to partially substitute the use of conventional fossil fuels for the effect of the later on our climate. Climate change and its effect have become the problem of many developed and developing countries, as the whole is working towards adapting and mitigating the effect of climate change to the Environment. Today the energy crisis becomes one of the global issues confronting us. Fuels are of great importance because they can be burned to produce significant amounts of energy. Many aspects of everyday life rely on fuels in particular the transport of goods and people. Production of Bioethanol/*Mormodica charantia* oil blends of varying compositions was expected to be given out a vital way and open up a window for the research and development of producing a biodiesel oil with excellent engine performance with a no or minimal environmental risk having profitable, feasible and achievable end-used applications. The results obtained from this research study it can be concluded that sugarcane bagasse is a good and sustainable feedstock for production of bioethanol since it is an inedible material.

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