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Ethanol Fuel Production from Cassava as a Substitute for Gasoline

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The potential in alcohols as fuel had for long being recognized by the early inventors of machines and engines, even before gasoline and the hydrocarbons became popular. In fact, Henry Ford, one of the pioneers in automobile manufacture, designed his equipment to run on ethanol. But since then, time has seen gasoline and other conventional fuels take the front seat in engine application. This article is an insight into the experiment carried out to produce fuel from cassava starch and the characterization to determine some of the fuel properties in comparison to gasoline. The choice of cassava for the production was based on its availability and ability to grow in almost all geographical regions in Nigeria. Experimental production gave a sample concentration of 87% corresponding to a yield of 0.534 cm³ of ethanol per gram of starch hydrolyzed while the sample characteristics for the latent heat of vaporization, heat of combustion, flash point, and density are 950 kJ/kg, 22133.7 kJ/kg, 17–20°C, and 0.825, respectively. The results obtained compared favorably with those of gasoline that the sample concentration.

1.0   INTRODUCTION

The world's energy development has been one of mixed fortunes especially as the search for cheap, safe, efficient, and friendly energy sources led to the discovery of the fossil fuels, which, hitherto, were regarded as the ultimate solution to the complex energy problems. Cumulatively, the effect of the use of the fuels over time, manifested in the form of oil pollution, spillage and explosion, formation of ground-level ozone depletion compounds from gas flaring, and combustion of the hydrocarbon fuels. From the perspective of availability, the resources are not enough and are getting depleted by the day since they cannot be renewed.[1] In order to curtail the rate of environmental degradation due to the use of the fuels, the world again is forced to search for other energy sources that would encompass the benefits accruing from the conventional fuels and still remain free from some of their respective environmental setbacks. This big push is in the direction of clean fuels with a number of properties that distinguish them from the conventional gasoline and other fossil fuels. Of special interest is the recent re-emergence of alcohols, ethanol and methanol, in particular, as potential fuels.

Ethanol is composed of carbon, hydrogen, and oxygen atoms connected by bonds that contain energy stored when the bonds were formed. Ethanol belongs to the group of alkanols which are also oxygenates. They are remarkably similar to gasoline despite the fact that they are from different chemical classes. Gasoline is a mixture of hydrocarbons, which are compounds composed exclusively of carbon and hydrogen atoms. Mathewson[1] regards alcohols, based on their general formula, as hydrocarbons in which one of the hydrogen atoms has been replaced with an OH group. It can be produced from a range of materials and a number of processes but its production from biomass especially cassava, maize, and sugarcane will make the fuel renewable and its economy sustainable.

The aim of this article is to present the experiments carried out in producing the fuel from cassava and to compare the performance of the fuel with gasoline based on the characteristics obtained.

2.0   CASSAVA (*MANIHOT ESCULENTA*)

Cassava is a woody shrub of the family *Euphorbiacea*, possessing tall, thin, straight stems and when fully grown, attains an average height of 1–2 meters although some cultivars may reach a height of 4 meters.[2] Cassava (*Manihot esculenta*), also called manioc, tapioca, or yuca, is one of the most important food crops in the humid tropics, being particularly suited to conditions of low nutrient availability and able to survive drought.[2] Although cassava leaves are sometimes consumed, the major harvested organ is the tuber, which is actually a swollen root. The plant is propagated mostly from stem cuttings. A major limitation of cassava production is the rapid post-harvest

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deterioration of its roots that usually prevents their storage in the fresh state for more than a few days.[3] Cassava ranks very high among crops that convert the greatest amount of solar energy into soluble carbohydrates per unit of area. Among the starchy staples, cassava gives a carbohydrate production which is about 40% higher than rice and 25% more than maize, with the result that cassava is the cheapest source of calories for both human nutrition and animal feeding.[3]

In Nigeria, cassava is primarily produced for its roots and this is because the roots are quite high in carbohydrates, about 60–70% for Nigerian cultivars and a world average of about 39%. Traditionally, cassava tuberous roots are a major and cheap source of carbohydrates,[4] particularly starch, in human diets and are processed by various methods into numerous products utilized in diverse ways depending on local customs and preferences. The Food And Agricultural Organization (FAO) estimated that over 600 million people depend on cassava as staple food in Africa, Asia, and Latin America. Cassava starch, like other carbohydrates, is composed of the branched amylopectin and the straight amylose fractions with mean composition of 70 and 20%, respectively. It is an important source of energy with a calorific value of 250 kcal/ha/day as compared with 200 kcal/ha/day for maize, 173 kcal/ha/day for rice, 114 kcal/ha/day for sorghum, and 110 kcal/ha/day for wheat. The crop, however, is very poor in protein content, about 1.4–4.7% for Brazilian cultivars, 0.7–2.5% for Indonesian cultivars, 2.7–3.2% for Nigerian cultivars, and an average of 1–3%.[5]

3.0   EXPERIMENTAL PROCEDURE AND ANALYSIS

The peeled cassava tubers were soaked in water for some 24 hours to reduce the content of the poisonous hydrogen cyanide after which they were ruptured in the milling machine to expose the starch bearing cells. The pulp from the milling machine was then screened using the filter cloth to wash off the starch from the fibrous remnants. The extracted liquor containing the starch was allowed to stand undisturbed for another 24 hours to allow the heavier starch particles settle to the bottom of the vessel while leaving the clear liquor atop. Seven hundred grams of the condensed starch meal was added to the mashed still together with 79.6 g of malt and 1.4 liter of water. The still was heated to 55°C in the water bath and maintained at that temperature for 60 minutes to hydrolyze proteins to amino acids and to gelatinize the starch.

After the 60 minutes resting period, the temperature of the mash was raised to 93°C but in the process, at 75°C, 5 ml of termamyl enzyme was added. At the temperature of 93°C, it was maintained for 20 minutes. This rest period is called the saccharification rest, since it is during the temperature hold that the gelatinized starch is hydrolyzed into simple sugars. At the end of the 20-minute rest, the mash was cooled to 60°C by adding some quantity of cool water. Thereafter, 85.7 g of malt were added together with about 4 ml of the enzyme (fungamyl enzyme) while the temperature also was

maintained constant for 60 minutes. Throughout the mashing period, the sample was stirred continuously and the pH also was checked to ensure that it was within the range appropriate for the enzymes to function effectively. Calcium hydroxide and phosphoric acid were added whenever the sample pH deviated. At the end of 60 minutes, the mash was filtered to remove the spent materials from the liquid now called wort (yeast nutrient). The wort was heated to 78°C and maintained for 60 minute to destroy the unspent enzymes and to kill off unwanted microorganisms.

Fehling's solution test was carried out to determine the presence of the simple sugars in the sample. Yeast was added to some quantity of the nutrient now cooled to about 10°C. The mixture was maintained in the refrigerator for 24 hours. It was then added to the wort in a transparent plastic bucket. The bucket was made to be air tight while flexible tubing was connected to the bucket's top, and also to a plastic bottle containing water to collect the evolving CO_2 produced during fermentation by upward delivery.

At the end of a 16-day period, fermentation was stopped for distillation to be carried out.

The distillation was carried out to first separate the liquid from the spent materials and then to concentrate the alcohol produced. Some quantity of fermented wort was put in the conical flask of the distillation apparatus and then transferred to the electric burner. It was heated to 85°C (above the boiling point of ethanol) and the distillate received was measured (volume, relative density, and refractive index on an arbitrary scale). The distillation was carried out 4 more times and the temperature was successively decreased for each of the distillation runs until the boiling point of ethanol (78°C) was reached and maintained. The relative density of the fuel sample was measured using the hydrometer. The hydrometer was inserted into the sample until it attained a steady level in the sample. The reading on the hydrometer corresponding to the liquid level was noted.

The sulphur-in-oil tester was used to determine the amount of sulphur in the sample. The sample was placed in an x-ray beam and the intensity of the sulphur x-ray fluorescence was measured. The Cannon Fenske Viscometer was used to determine the viscosity of the sample. Some quantity of the sample was put in the viscometer up to the level of the upper mark. The time taken for the meniscus of the sample to fall from the upper meniscus of the bulb was noted and the viscosity was calculated.

The flash point was determined using the Pensky-Martens flash point Tester. The apparatus consists of a small cup into which the sample is put. The sample was cooled to about −20°C. Some quantity of the ethanol was put in the cup and the cup was closed so that no vapor was lost. The cup was gradually heated while being stirred continuously to distribute the heat uniformly in the cup. At regular intervals of 3–5°C, the cup was opened and an open flame was directed into it until when the vapor in the cup was able to produce a momentary flame. The temperature range that produced the flame was noted.

In determining the quantity of heat liberated during the combustion, an electric heater connected to a Joule meter was used to heat the calorimeter to the maximum temperature recorded during ethanol combustion. The heater was kept in the calorimeter setup until the temperature was attained. The reading on the Joule meter was noted while the amount of fuel burned was measured.

4.0 RESULTS

The results for the production of the ethanol after the 16-day fermentation period are summarized in Tables 1–4. The quantity of materials used is given in Table 1, while the samples analyses are given in Tables 3 and 4.

5.0 DISCUSSION OF RESULT

The pH of the starch solution was observed to be acidic before and during mashing (Table 2). The acidity was probably developed during the 5-day period that the cassava tubers were soaked both before and after milling, which was undertaken to reduce the content of the poisonous cyanides contained in it. Fermentation was carried out for 16 days and the pH measured before the fermentation started was 4.7. At the end of the 16-day period, the total volume was taken as 1.6 liters and the relative density (RD) measured with the hydrometer gave 0.927 which corresponded to a maximum concentration of 9% ethanol in the sample after the 16 days fermentation period.[1]

A total of 6 runs were carried out to concentrate the ethanol after fermentation and after each run (Table 3), the condensate was observed richer in ethanol than the initial starting material and the residue in the flask. It is important to note that ethanol forms an azeotropic mixture with water, which makes it difficult for the mixture to be completely separated by ordinary means. This was evident during the distillation. A careful look at Table 3 showed that the concentration increased significantly during the initial runs but during the last 3 distillation runs, the concentration change was slight, maintained at near 87%. Literatures gives the value for the maximum concentration of ethanol distilled from water as 90–95.[6]–[9] The 87% obtained in the experiment was close though the difference may have been due to:

TABLE 1
Quantity of materials used

Materials	Quantity
Cassava starch	700 g
Water	1.4 liters
Malt	265.3 g
Termamyl	5 ml
Fungamyl	5 ml
Yeast	160 g

TABLE 2
pH observation

pH	Observed	Expected
Mashing	4.3–4.7	5.4–5.6
Fermentation	4.6–4.8	5.9–6.1

1. Nonconsideration of the actual atmospheric pressure in the laboratory environment.
2. Error and unreliability in the method employed for reading the concentration of the sample.
3. Insufficient distillation runs.

Of the final 87% ethanol, 0.43 liters was collected at the end of distillation equivalent to 0.3741 liters of absolute ethanol and it gave a yield of $0.534 \ cm^3$ of ethanol per gram of cassava starch. In assessing the fuel potential of ethanol, it was necessary to carry out basic fuel tests on it, especially those more associated with gasoline, which has become the standard for Spark Ignition (SI) engines. The properties are shown in Table 4. The standard boiling point of ethanol is 78°C but the sample boiled at 76°C. The difference was due to deviation of laboratory conditions from that of that standard. Ambient pressure of the of the laboratory was 714 mmHg and the use of the boiling point correction index to obtain the corresponding temperature at normal atmospheric pressure gave the normal temperature value of 78°C.

The relative density of the sample at 25.5°C was obtained as 0.825, which deviated a little from the literature value of 0.799 at 25°C. The two values are quite close with the difference being accounted for by the concentration of the sample. Sulphur content in the sample was obtained as 0.0367 while the maximum required of all petroleum derivatives in Nigerian's Petroleum Companies are 0.5%. In earnest, the fuel is as good as being free of sulphur, which, on combustion, will not pose environmental problems of SO_2 emission and acid rain, a problem more commonly associated with petroleum products.[6–9]

The result of the Reid's vapor pressure of the sample at 13.2 kPa, suggests that it was volatile and could give off enough fuel vapor for carburetion although less than that of gasoline which has higher value. The experimental value was lower than the standard; this is attributed to the facts that the sample was not an anhydrous form of the compound but rather contained some quantity of water (13%) which were responsible for the reduction in the corresponding value of the Reid's vapour pressure.[8,10]

The flash point obtained for the ethanol was in the range of 17°C to 20°C. Although it is lower than room temperature, it would give off a smaller quantity of vapour compared to that of gasoline with flash point far below room temperature. It, thus, is going to be safer to handle than gasoline. The heat of combustion of the sample obtained was lower than that for

TABLE 3
Concentrations of sample after distillation runs

Runs	1	2	3	4	5	6
Initial volume (liter)	1.6	1.28	0.98	0.76	0.64	0.51
Final volume (liter)	1.28	0.98	0.76	0.64	0.51	0.43
Temperature (°C)	85	82	79	78	78	78
Concentration (%)	38	52	64	75	83	87
Refractive index	11.5	13.7	15.9	18.8	19.1	20.1

TABLE 4
Sample characterization observations

Experiment	Experimental value (sample)	Standard value (ethanol)	Gasoline
Sulphur content (%)	0.0367	—	0.5
Relative density	0.8250	0.79	0.69
Vapor pressure (kPa)	13.2	16.0	48–108
Flash point (°C)	17–20	12.8	−42.8
Heat of combustion (kJ/kg)	22133.7	25120	43961
Latent heat of vaporization (kJ/kg)	950.8	921.4	349
Viscosity @20°C(cP)	1.32	1.20	0.503

6.0   CONCLUSION

From the experimental analysis, the yield of the ethanol produced shows that cassava is actually a viable source of ethanol fuel that can effectively serve as an alternative or substitute for the conventional fossil fuels. This was attested to by the good comparison of the sample characteristics with that of gasoline which in some instances, even measured more than the hydrocarbon. The closeness of the experimental and literature values of the characterization are an indication of the reliability of the whole experimental efforts. Furthermore, the correlation is a confirmation that the sample obtained was truly a solution of ethanol. It is hoped that this favorable comparison will be positively exploited to entrench the fuel as an alternative, blend, or substitute to the hydrocarbon in future.

gasoline but if used in SI engines, the value will be of little significance as other parameters like the latent heat of vaporization take prominence. The heat of vaporization is the property that is responsible for charge cooling. The value obtained for the sample was high compared to gasoline and the significance is that when used in an engine, the effect of charge cooling will be greater with an ethanol fuel than with gasoline. Extra thrust in engines is one of the effects of charge cooling in addition to better thermal efficiency.[1]

At the end of the experiment, the various properties of the ethanol obtained from the laboratory compared favorably with those in the literatures. For most of the characteristics, the values were not exactly the same but slight deviations of experimental readings from literature values are a proof of the reliability of the experimental results and the methods employed in carrying out the experiment. Most of the deviations from literature values were due to the composition of the sample with water. The highest sample concentration of 87% was used (Table 3) since ethanol up to that concentration can give good performance in engines with extra thrust generated from the conversion of the steam into a vapor of fine mist.

REFERENCES

[1] Mathewson, S.W. (1980) *The Manual for the Home and Farm Production of Alcohol Fuel*; Ten Speed Press, Diaz Publications: Moscow.

[2] Burrell, M.M. (2003) Cassava the need for improved quality or quantity: An overview. *J. Exp. Bot.*, 54 (382): 451–456.

[3] Okezie, B.O. and Kosikowski, F.V. (1982) Cassava as a food. *Crit. Rev. Food Sci. Nutr.*, 17: 259–275.

[4] Nwokoro, S.O., Orheruata, A.M., and Ordiah, O. (2002) P.I. Replacement of maize with cassava sievates in cockerel starter diets: Effect on performance and carcass characteristics. *Tropical Animal Health and Production*, 34: 163–167.

[5] Cock, J.H. (1982) Cassava: A basic energy source in the tropics. *Science*, 218 (4574): 755–762.

[6] Odigure, J.O. and Abdulkareem, A.S. (2000) Mathematical modelling of pollutants migration from gas flaring in the Niger Delta area. *J. AMSE*, 62 (3): 55.

[7] Gavriel, S. (1996) *Handbook of Industrial Engineering*; John Wiley and Sons: New York.

[8] Gwendolyn, H., Lewis, T., and Ben, B.S. (1993) *Handbook of Environmental Technology*; Interscience Publication: New York.

[9] Jackson, M.H., Morris, G.P., Smith, P.G., and Crawford, J.F. (1989) *Environmental Health Reference Book*: Butterworth-Heinemann: London.

[10] Perry, R.H. and Green, D.W. (1997) *Perry Chemical Engineers' Handbook*, 7th ed; McGraw Hill, New York.