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Investigation into Properties of Biogas as an Alternative Fuel for Internal Combustion Engines

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Abstract

In Nigeria, government has recently announced total removal of oil subsidies, which automatically translated into increase in petroleum products prices and coupled with the global concern on climate change resulting from burning of fossil fuel and depletion of world's crude oil reserve called for this study. Interest in biogas technology is growing and is gaining national attention with the abundant of animal, municipal and food wastes in Nigeria. This study investigated the characteristics of biogas as an alternative fuel in internal combustion engines. Cow dung, plantain peel, corn cobs and food wastes all were obtained from Bichi local Government Area of Kano state in Nigeria. The design was to combined feedstock with high caloric content and anaerobic microbes. The food wastes were crushed with mixer grinder while the fresh cow dung was mixed with water thoroughly by hand. The cow dung served also as inoculums as it contained the required microorganisms for anaerobic digestion. The waste samples were weighed and poured into the digester based on the experimental design. Biogas production was done in batch system, in which the slurry was added once in the digester for the whole duration of the process. The digester was connected to a calibrated measuring cylinder with paraffin oil displacement arrangement to measure the volume of biogas produced. Various blends of diesel and biogas were tested on diesel engine, and the performance of the engine was found to be almost equal to the performance using diesel fuel alone. Petrol engine was fully operated on biogas and natural gas; the exhaust gas sample gives 4.01% CO_2, 95.17%N_2 and 0.82% O_2 as against gasoline exhaust products of 98.7% C and 1.3% H_2. Hence, biogas gives lower CO emission and better volumetric efficiency and therefore, can replace the conventional gasoline.

Keywords— **Wastes, Biogas, internal combustion engine, gasoline, digester.**

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I. Introduction

Increase in energy need throughout the world and the fact that main energy sources such as crude oil, natural gas, coal and nuclear fuel are finite sources and are not renewable necessitated for the search for other alternative energy sources such as hydro energy, solar energy, energy of wind and biogas [1]. Furthermore, the global concern on climate change resulting from burning of fossil fuel and depletion of world's crude oil reserve called for this study. Biogas is particularly significant because of possibility of its use in Internal Combustion Engines (ICE).It is a renewable energy source with zero of greenhouse emissions [2], we will always be able to make biogas as long as the sun is shining and plants can grow. Biogas has zero net greenhouse emissions because the CO_2 that is released into the atmosphere when it burns is no more than what was drawn down from the atmosphere when the organic matter was first grown [3]. Biogas is produced when organic matter such as food waste, animal manure and agricultural byproducts biodegrade under anaerobic conditions (that is, in the absence of oxygen) [4]. This process produces a mixture of gases– primarily methane, some carbon dioxide and tiny portions of other gases such as hydrogen sulfide. When the biogas is filtered to remove the hydrogen sulfide, the resulting mixture can be burned as an energy source for cooking, lighting, or heating water or space, when compressed it can be used as fuel for vehicles [5]. On a commercial scale biogas can be used to generate electricity or even refined and fed into the gas grid. The organic matter used in biogas digesters is typically a waste product. By using biogas we can reduce the amount of food waste and other organic materials being sent to landfill [6]. Furthermore, biogas systems produce a nutrient-rich sludge that can be watered down into a fertilizer for gardens or farms. All of this can help to develop increased energy independence, build resilience and save money. In Nigeria, there are abundance of raw material for producing biogas such as cow dung, municipal sewage and kitchen wastes. The production of methane from biogas as a fuel will substantially reduce harmful engine emission and will help to keep clean environment. Hence, the main objective of this study is to investigate into properties of biogas as an alternative fuel for automobile engines.

II. Review of related works

[7] Converted diesel engine to spark ignition engine using biogas. He experienced 35% less power compared to diesel and 40% less compared to gasoline fuel, similarly, [8] used a spark ignition engine and ran it with simulated biogas in different compression ratio. They reached compression ratio of 15:1 for optimal solution. They found that lower heating value, corrosive composition and difficulties in transportation of the fuel were main challenges for biogas. They concluded that biogas would be attractive just where it is close to production site and they suggested converting gaseous fuels like biogas or natural gas to liquid fuels such as methanol and gasoline. Biogas contains 50% to 70% of CH_4, 2% of H_2 and up to 30% of CO_2[9].After being clean of carbon dioxide, the gas becomes a fairly homogeneous fuel containing up to 80% of methane with calorific capacity of over 25MJ/m^3 [10]. The other components are not involved in combustion of CH_4, as they leave the process at higher temperature than the one they had before the process.

III. Materials and Methods

The following raw materials were used in the production of biogas, Cow dung, plantain peel, corn cobs and food wastes, all were obtained from Bichi local Government Area of Kano state Nigeria. The design was to combined feedstock with high caloric content and anaerobic microbes. The food wastes were crushed with mixer grinder while the fresh cow dung was mixed with water thoroughly by hand. The cow dung served also as inoculums as it contained the required microorganisms for anaerobic digestion. The waste samples were weighed and poured into the digester based on the experimental design. After that digester was kept for that day and gas production was checked the next day.

A. Experimental Procedures

In this study, biogas production was done in batch system, in which the slurry was added once in the digester for the whole duration of the process. In the combined waste experiment, the digester was fed with 80 g of cow dung and 80 g of food wastes mixed with water at a ratio of 1:1 respectively [11]. In the single dung experiment 150g of the cow dung was introduced into the digester at the same ratio. The digester was provided with suitable arrangements for feeding, gas collection and draining residues. The digester was connected to a calibrated measuring cylinder with paraffin oil displacement arrangement to measure the volume of biogas produced. The slurry was allowed to ferment anaerobically for 15days at a pH range of 6.5 to 7.5 under mesophilic temperature of 26-35°C.

B. Digester Description

A biogas chamber of 25kg slurry capacity was constructed and used for this experiment. The diameter and height of the digester are 0.34m and 0.38m respectively. The biogas digester was built to maintain the anaerobic condition. The gas production was measured via the connection of a calibrated measuring cylinder with paraffin oil displacement arrangement. The digester was fed by opening the cover of the dome and remnant was evacuated through the outlet device at the bottom of the dome.

IV. Results and Discussion

A. *Results*

The sample of biogas obtained was investigated for physico-chemical properties and is presented in Table 1.

Table 1: Composition of **biogas**

1.0	Components	Amount (%)
2.0	Methane (CH_4)	65
3.0	Carbondioxide	35
4.0	Hydrogen	6
5.0	Nitrogen	2
6.0	Water vapour (H_2O)	0.3
7.0	Hydrogen sulphide (H_2S)	Traces

B. Discussion

1) *Properties of Biogas used as fuel in Internal Combustion Engines*

From Table 1, the biogas contains 65% of CH_4, 6% of H_2 and up to 35% of CO_2.After being cleaned of carbon dioxide, the gas becomes a fairly homogeneous fuel containing up to 75% of methane with calorific capacity of over 25MJ/m^3. The most important component of the biogas, from the calorific point of view is methane. The other components are not involved in combustion process, and rather absorb energy from combustion of CH_4 as they leave the process at higher temperature than the one they had before the process [12]. Requirements to remove gaseous components depending on the biogas utilization as shown in Table 2

Table 2: Requirements to remove gaseous components depending on the biogas utilization

Application	H_2S	CO_2	H_2O	Siloxane
CHP	<500	No	No condensation	Yes
Vehicle fuel	yes	Recommended	Yes	No

2) *Thermodynamic properties of CH_4 at S.T.P (273K, 101325Pa)*

Specific heat capacity Cp= 2.165Kj/kgK

Molar mass M = 16.04kg/kmol

Density þ = 0.72kg/m^3

Individual gas constant R= 0.518Kj/kgK

Lower calorific value H

u = 50000Kj/kg, Hu, n= 36000Kj/m^3n

3) *Properties of Biogas for engine performance*

The actual calorific value of biogas is function of the CH_4 percentage, the temperature and the absolute pressure, all of which differs from case to case. The actual calorific value of biogas is vital parameter for the performance of an engine. The fuel consumption of Internal Combustion (IC) engine using biogas is often specified in m^3n/h or m^3n/kWh. The standard cubic meter (m^3n) means a volume of 1cubic meter of gas under standard conditions (273K and 10132Pa). The consumption of biogas in actual volume will differ from these data according to the actual conditions of biogas fed to the engine in terms of temperature, pressure and CH_4 content. Determining of actual biogas consumption is vital for dimensioning the engine.

4) *Technical parameter of biogas*

Technical properties of biogas are essential because of their effect on the combustion process in Internal Combustion engines. Some of these properties are itemize below:

Ignitability of CH_4 in combustion: CH_4: 5…..15Vol. % Air: 95%...85%.

Mixtures with less than 5Vol. % and mixture with more than 15Vol. % of CH_4 are not properly ignitable with spark ignition.

Combustion velocity (cc) in a mixture with air at p = 1bar: cc=0.20m/s at 7% CH_4, cc= 0.38m/s at 10% CH_4.

The combustion velocity is a function the volume percentage of the burnable component (CH_4). The highest value of cc is near stoichiometric air/fuel ratio, mostly at an excess air ratio of 0.8 to 0.9. It increases drastically at higher temperatures and pressure.

Temperature at which CH_4 ignites in a mixture with air Ti= 918K…1023K.

Compression ratio of an engine at which temperatures reach values high enough for self-ignition in mixture with air (CO_2 content increases possible compression ratio) e= 15….20

Methane number which is a standard value to specify fuel tendency to knocking (uneven combustion and pressure development between TDC and BDC) methane and biogas are very stable against knocking and therefore can be used in engines of higher compression ratios than petrol engines.

Stoichiometric air/fuel ratio on a mass basis at which the combustion of CH_4 with air is complete but without unutilized air.

5) *Challenges of biogas as fuel in Internal Combustion Engines and their remedies*

The high content of CO_2 reduces the power output, making it uneconomical as a transport fuel. The CO_2 content was removed by washing the gas with water i.e Caustic solution, NAOH-40% NAOH + CO_2 =$NAHCO_3$. The solution produced from washing out the CO_2 is acidic and needs careful disposal.

H_2S is acidic and if not remove can cause corrosion of engine parts within a matter of hours. It is easy to remove H_2S, by passing the gas through iron oxide (Fe_2O_3) or (ZnO). These materials can be re-generated on exposure to the air, although the smell of H_2S is unpleasant.

6) *Fuels used in I.C. Engines and their limitations*

There are many fuels used in I.C.Engines. but they have certain physical and chemical properties. In other words, fuels used in I.C.Engine re-designed to satisfy performance requirements of engine system, in which they are used. The limitations of fuels that are used presently are as follows:

- Gasoline contains many impurities. It has low octane number. All petroleum fuels oxidize slowly in presence of air. The oxidation of unsaturated hydrocarbons result in formation of resinous materials called gum and reduces its lubricating quality and tends to form sludge and warmish on piston and rings. It has less knock resistance as well as energy per unit mass. It has less efficiency compared to other fuels. It has high cost
- In alcohol, higher latent heat of vaporization reduced charge temperatures before combustion. Alcohols suffer disadvantages of water absorption, corrosive and lubricant incompatibility
- In LPG, it reduces volumetric efficiency due to its high heat of vaporization. The road sensitivity is very high. It is very corrosive. Response to blending is very poor. It has high cost of transportation.
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7) *Modification of Internal Combustion Engines*

Diesel engine can be modified to operate on biogas into the following ways:

- Dual fuel operation with ignition by pilot fuel ignition
- Operation on gas alone with spark ignition

8) *Dual fuel operation with ignition by pilot fuel ignition*

In this case, the normal diesel fuel injection system still supplies a certain amount of diesel fuel. The engine however sucks and compresses a mixture of air and biogas fuel which has been prepared in external mixing device. The mixture is then ignited by and together with the diesel fuel sprayed in. The amount of diesel fuel needed for sufficient ignition is between 10% and 20% of the amount needed for operation on diesel fuel alone [13] . Operation of the engine at partial load requires reduction of the biogas supply by means of a gas control valve. A simultaneous reduction of airflow would reduce power and efficiency because of reduction of compression pressure and mean effective pressure. So, the air/fuel ratio is changed by different amounts of injected biogas. All other parameters and elements of diesel engine remain unchanged.

9) ***Advantages of modification of diesel engine into dual fuel engine***

- Operation on diesel fuel alone is possible when biogas is not available
- Any contribution of biogas from 0% to 85% can substitute a corresponding part of diesel fuel while performance remains as in 100% diesel fuel operations
- Because of existence of a governor at most diesel engines automatic control of speed/power can be done by changing the amount of diesel fuel injection while the biogas flow remains uncontrolled. Diesel fuel substations by biogas are less substantial in this case

10) ***Disadvantages of modification of diesel engine into dual fuel engine***

- The dual fuel engine cannot operate without the supply of diesel fuel for ignition
- The fuel injection jets may overheat when the diesel fuel flow is reduced to 10% or 15% of its normal flow
- Larger dual fuel engines circulate extra diesel fuel through the injector for cooling.
- A check of the injector nozzle after 500hours of operation in dual fuel is recommended.

11) ***Performance characteristics on automobile engines operating on biogas***

The performance of Internal Combustion engine operation on dual fuel (biogas and diesel) has been found to be almost equal to the performance using diesel fuel alone as long as the calorific value of biogas is not too low. The inlet channel and manifold of diesel engine are dimensioned in such a way that at the maximum speed and power output of the engine sufficient air can be sucked in to obtain an air/diesel fuel ratio, which is optimal for operation at this point. When the diesel fuel is reduced and an air/biogas mixture is sucked instead of air alone, part of the air is replaced by biogas. With less air fed to the engine and excess air ratio is maintained, the total fuel input will be less than the fuel input in diesel operation [14]. As result of this reduction in both air and fuel, the maximum power output at high speed in dual fuel mode may be less than in diesel fuel operation. This decrease is less significantly than in modified petrol engines.

12) ***Emission characteristics of engines operating on gasoline***

Automobile engine running on gasoline is the greatest polluter, as emissions from a million vehicles on the road add up to a planet – wide problem and climate change [15]. Exhaust gas can contain unburnt fuel Hydrocarbon (HC) partially burnt fuel Carbon Monoxide (CO), dangerous nitrogen oxides (NOx) from combustion, and lead (Pd) from petrol additives. Table 3 showed the sample of exhaust gas obtained from internal combustion engine operating on gasoline

.Table 3: Emission characteristics of engine operating on gasoline.

S/No	Dry Exhaust gas from (ICE)	Percentage of dry Product
1	CO_2	12
2	CO	5
3	0_2	6.5

Nitrogenous oxide and other gases = 100 – (12+5+6.5) = 76.5.

From table 3, the proportion by mass of carbon content to hydrogen in the fuel and also A/F ratio can be determined for the analysis as follows:-

Let the unknown mass fraction of carbon in the fuel be Xkg per kilogram of fuel, then the combustion equation can be written as follows:-

$$\frac{X}{12}C + (1-X)\,H + A\left(\frac{0.233}{32}\,0_2 + \frac{0.767}{28}N_2\right)$$

$$\longrightarrow B\,[0.12CO_2 + 0.05CO + 0.01H_2 + 0.0450_2 + 0.765N_2] + AH0_2$$

Where A = The A/F ratio on a mass basis.

B = the amount of substance of dry exhaust gas per kilogram of fuel, Kmol/kg.

a = the fraction by volume of oxygen in the dry exhaust gas.

Carbon balance:

x/12 = B [0.12 + 0.05]

x = 2.04B -------- (1)

Hydrogen balance:

(1 – x) = (2 x 0.01) B + 2a

a = 0.5 – 0.5x – 0.01B ----- (2)

Oxygen balance:

0.233A/32 = B (0.12 + 0.02 X 2 + 0.045) + 2a

a = 0.0364A – 0.15B ----- (3)

Nitrogen balance:

0.767A/28 = 0.765B

a = 27.927B ----- (4)

Equating [2] and [3] we have

0.5 – 0.5x – 0.01B = 0.0364A – 0.15B.

a = 137.36 – 137.368 + 24.362B

From equation (4)

27.927B – 24.362B = 137.36 – 137.36x

From equation (1)

0.490x = 38.530 – 38.530x

X = 0.987.

Therefore, the fuel composition is 98.7% Carbon and 1.3% Hydrogen.

Also, B = 38.350 38.530 (0.987) = 0.5000

Then equation (4) becomes.

A = 27.927 X 0.5000 = 13.98

A/F = 13.98

13) *Emission characteristics of I C E operating on biogas/ natural gas*

A gas engine is supplied with natural gas of the following composition: CH_4 93%; C_2H_6 3%; CO1%, the air/fuel ratio is 30 by volume. The exhaust gas sample obtained was analyzed as follows:

Combustion equation:

$0.93CH_4 + 0.03C_2H_6 + 0.01CO + 0.03N_2 + (0.21x30)\ O_2 + (0.79x30)\ N_2 \longrightarrow aCO_2 + bH_2O + cO_2 + dN_2$

Carbon balance: 0.93+ (2x0.03) + 0.01= a or a = 1

Hydrogen balance: (4x0.93) + (6x0.03) = 2b or b = 1.95

Oxygen balance: 0.01+ (0.21x30) = 2a + b + c

Therefore, c = 6.31- 2-(2x1.95)/2 = 0.205

Nitrogen balance: 0.03 + (0.79x30) = d or d = 23.73

Total amount of substance of dry products = 1+ 0.205+ 23.73 =24.935Kmol

Analysis by volume gives:

$\frac{1}{24.935}$ x 100 = 4.01 CO_2

$\frac{23.73}{24.935}$x 100 = 95.17%N_2

$\frac{0.205}{24.935}$x 100 = 0.82% O_2

Hence, the dry analysis showed that internal combustion engines operating on biogas have lower CO emission than the conventional gasoline engines.

IV. Conclusion:

It has been established that both heavy duty and light duty vehicles can operate on biogas, in diesel engines combination of biogas and diesel is required while petrol engines can operate fully on biogas. Methane and biogas are very stable against knocking and therefore can be used in engine of higher compression ratio than petrol engine. The stoichiometric air/fuel ratio on a mass basis at which the combustion of CH_4 with air is complete but without unutilized excess air while gasoline has low octane number and it oxidizes slowly in presence of air

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