Development And Testing Of Biogas-Petrol Blend As An Alternative Fuel For Spark Ignition Engine

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Abstract: This research is on the development and testing of a biogas-petrol blend to run a spark ignition engine. A20:80 ratio biogas:petrol blend was developed as an alternative fuel for spark ignition engine test bed. Petrol and biogas-petrol blend were comparatively tested on the test bed to determine the effectiveness of the fuels. The results of the tests showed that biogas– petrol blend generated higher torque, brake power, indicated power, brake thermal efficiency, and brake mean effective pressure but lower fuel consumption and exhaust temperature than petrol. The research concluded that a spark ignition engine powered by biogas-petrol blend was found to be economical, consumed less fuel, and contributes to sanitation and production of fertilizer.

Index Terms: Biogas, biogas-petrol blend, feedstock, fuel consumption, internal combustion engine, spark ignition engine, torque.

I INTRODUCTION

Society is today confronted with an increased demand for energy. The conventional energy sources appear not to be able to meet this ever increasing demand. This is due partly to the ever increasing population and the dwindling sources of fossil fuels, the high cost of tapping these energy sources and the effects of harnessing these energy sources on the environment. In recent times, attention has been shifted to the renewable energy sources. Internal combustion engines (ICE) are the plants that burn their fuels internally or within the chamber and later convert it to mechanical work. Internal combustion engines can either be Spark Ignition (SI) engines or Compression Ignition (CI) engines depending on their method of ignition [Fergusson 1986]. The petrol andgas engines are examples of spark ignition engine which mix atomized fuel and air in the carburettor and use spark plug for ignition. The diesel engines, on the other hand, are examples of compression ignition engines which compress only air to a high temperature and its combustion is by a spontaneous ignition of the atomized fuel injected into the compressed air [Fergusson 1986]. The present fuels for internal combustion engines include gasoline, diesel, alcohol, Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), electricity, solar, producer gas, and hydrogen. But these fuels have one limitation or the other [Adeyemo 2003, Awogbemi and Adeyemo 2013]. Nigeria, and indeed Africa today, still depends largely on petrol and diesel to run their internal combustion engines with its attendant problems of scarcity, pollution of the environment, contribution to global warming, agitations and militancy in the oil producing areas, and cost. Efforts are now on to develop other fuels as a substitute to petrol and diesel and a viable alternative is biogas. In Nigeria, the current scarcity in petroleum products occasioned by the inefficiency in the petroleum sector, militancy in the Niger Delta region, the poor state of the nation's refineries, and the current high price of refined petroleum products etc have all given rise to demand for other sources of fuels to power the nation's economy[Awogbemi and Adeyemo 2013]. Various researches have been conducted to develop alternative fuels, apart from Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), electricity, solar, producer gas, and hydrogen, to power internal combustion engines. Some of these efforts are in the developed world where researchers are exploring dual fueling and fuel blending. Various researchers [Klaus 1988, MdEhsan 2005, OmidRazbani et al 2011, and Hung Crookes 1998] worked on the use of biogas to run petrol engines with appreciable level of success while [Gupta199] and his colleagues worked on gas-fired spark ignition engine. The SI engines fuelled with pure methane instead of petrol suffer a reduction in peak power output of some 10-20%, poor combustion and harsh running, it was reported that the power loss can be offset by increasing the compression ratio of the engine [Klaus 1988, MdEhsan 2005, OmidRazbani et al 2011]. Also Pankhaniya et al 2011, Jose Ananth et al 2013, Jawurek 1987 and Ezeand Elijah 2010 worked on blending various fuels to run an internal combustion engines. For example, a study of performance and exhaust analysis of petrol engine using methanol-gasoline blends at 2000rpm and variable load condition at various blend condition produces promising brake power, brake specific fuel consumption, brake thermal efficiency and lower fuel consumption when compared with that runs on pure petrol. Carbon monoxide CO, Carbon dioxide CO_2 and Hydro carbon HC emissions also decrease when using a methanol-gasoline blend [Pankhaniya et al 2011]. In an effort to further develop an alternative fuel to reduce exhaust emission level and to increase the power output of an SI engine, petrol alcohol fuel blends was used with some engine modifications such as increasing the engine compression ratio and advancing the ignition timing,

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almost 12.5% increase in power output was reportedly achieved [Jose 2013, Muhamad and Atan 2012]. This research developed a biogas-petrol blend and used the resulting mixture to run a spark ignition test bed. Parameters such as torque, specific fuel consumption, brake power, brake thermal efficiency, brake mean effective pressure, mechanical efficiency, indicated thermal efficiency, and exhaust temperature at different speeds were compared with that run on petrol.Some of these parameters are:

(a) Brake Power

The power developed by an engine and measured at the output shaft is called the brake power (bp) and is given by

$$BrakePower, bp = \frac{2\pi NT}{60} \quad (1)$$

Where N = Rotational speed of the engine, rpm
T = Torque, Nm

(b) Indicated power

The Indicated Power is the power developed in the cylinders and thus, forms the basis of evaluation of combustion efficiency or the heat released in the cylinder [Eze and Elijah 2010].

$$IndicatedPower, IP = \frac{P_{im}LANK}{60} \quad (2)$$

Where
P_{im} = Indicated mean effective pressure, N/m^2
L = Length of the stroke, m
A = Area of the piston, m^2
K = Number of cylinders
The difference between Indicated Power (ip) and Brake Power (bp) is called the friction power (fp)
i.e$fp = ip - bp$ (3)

(c) Mechanical Efficiency

Mechanical Efficiency is a measure of how much of the indicated power is converted into brake power. The difference between them is due to the frictional losses between the moving parts and the energy taken to run the auxiliary equipment such as the fuel pump, water pump, oil pump, etc[TQ Equipment manual, Eastop and McConkey 1969]

$$MechanicalEfficiency = \frac{bp}{ip} \quad (4)$$

(d) Mean Effective Pressure and Torque

Mean Effective Pressure, P_m, is defined as a hypothetical/average pressure which is assumed to be acting on the piston throughout the power stroke.

$$Pm = \frac{ip \times 60}{LANk} \quad (5)$$

If the mean effective pressure is based on the brake power it is called the brake mean effective pressure (bmep), and if based on the indicated pressure it is called the indicated mean effective pressure (imep). Also, the friction mean effective pressure (fmep) can be defined as [Eastop and McConkey 1969].

$$fmep = imep - bmep \quad (6)$$

The torque is related to the mean effective pressure by [Eze and Elijah 2010].

$$Torque, T = \frac{(bmep \times A \times L \times k)}{2\pi} \quad (7)$$

(e) Brake Thermal Efficiency

Brake Thermal Efficiency is an indication of fuel power that is converted into brake power[Eastop and McConkey 1969]i.e$BrakeThermalEffeciency \frac{BrakePower}{EnergySupplied} = \frac{bp}{m_f \times Q_{net,v}}$ (8)

Where
m_f = mass of fuel consumed per unit time
$Q_{net,v}$= Lower calorific value of the fuel

(f) Indicated Thermal Efficiency

Indicated Thermal Efficiency is a measure of how much of the fuel power is converted into brake power[Eastop and McConkey 1969]i.e

$$IndicatedThermalEffeciency = \frac{IndicatedPower}{EnergySupplied} = \frac{ip}{m_f \times Q_{net,v}} \quad (9)$$

(g) Brake Specific Fuel Consumption

Brake Specific Fuel Consumption is defined as the amount of fuel consumed for each unit of brake power developed per hour. It is a clear indication of the efficiency with which the engine develops power from fuel [Eze and Elijah 2010].

$$BrakeSpecificFuelConsumption(bsfc) = \frac{Actualfuel-Airratio}{Stoichiometricfuel-Airratio} \quad (10)$$

II MATERIALS AND METHODOLOGY

Biogas was produced using cow dung seeded with rice husk and banana peels as feedstock in a plastic digester at the Themofluid/Energy laboratory of the Ekiti State University, Ado Ekiti, Nigeria while petrol was obtained from the Nigerian National Petroleum Company (NNPC) mega station along Ekiti State University road, Ado Ekiti, Nigeria. The biogas and petrol were blended in ratio 20:80 using nozzle and an-air tight glass bottle. The chromatography test was carried out on the biogas used. Theperformance test was carried out on a 5hp single cylinder four stroke Spark ignition Honda GX 140 engine AC dynamometer. The technical specifications of the engine test rig and the dynamometer are presented in Tables 1 and 2 respectively. The engine performance characteristics were monitored within the speed range of 1000rpm and 3500rpm varied incrementally by 500rpm. The engine was run on petrol and then on a blend of biogas-petrol. The torque, exhaust temperature, and fuel consumption were read directly on the dynamometer control unit while the brake power, indicated power, specific fuel consumption, indicated thermal efficiency, brake thermal efficiency, and mechanical efficiency were calculated.

Table 1 : *Technical specification of the engine test rig*

S/N	Parameter	Specification
1.	Type	Honda GX 140, four stroke, single cylinder, spark ignition engine
2.	Bore	70mm
3.	Stroke	60mm

4.	Maximum Power	5hp @ 4000rpm
5.	DisplacementV_d	144cm^3
6.	Compression ratio	21:1
7.	Swept Volume	230cm^3

Table 2: *Specifications of the dynamometer*

S/N	Parameter	Specification
1.	Type	Honda GX 140
2.	Maximum operating capacity AC	Single phase, 220V, 50Hz
3.	Maximum operating Capacity DC	12V, 8.3A
4.	Maximum Speed	4000rpm
5.	Torque arm radius	25mm

A.Calibration of Torque Meter

Before the engine test, the torque meter was calibrated. The torque meter was set to zero and calibrated before use. To do the calibration [TQ Equipment manual]:

i. The span control was set to its maximum clockwise position
ii. I shook or rocked the engine vigorously to overcome the stiction of the bearing seals.
iii. The torque meter was set to read zero.
iv. A 8kg starting with 1kg with 1kg increments was hanged on the calibration arm.
v. I shook the engine until the torque meter reading settles down to a constant value.
vi. The span control was adjusted to give a torque reading of 8.6Nm
vii. The calibration load was removed and steps (ii) to (vi) repeated until satisfied that the zero and the span testing settings are correct.
viii. I recorded the indicated torque meter reading for each load and calculated the applied torque from the relationship$T = mga$(Nm)

Where
T = Applied torque (Nm)
m= Applied mass (kg),
g = Acceleration due to gravity, m/s^2
a= Distance from the centre of the dynamometer to the torque arm = 0.25m

B. Fuel Testing

Procedure for testing the fuels on the test bed

(i) The fuel tank was filled with Petrol.
(ii) I calibrated the torque meter, as described above.
(iii) The fuel was allowed to flow into the graduated pipette on the instrumentation unit.
(iv) I started the engine and recorded the time taken for the engine to consume 8ml of petrol. The exhaust temperature, torque, and RPM were also recorded.
(v) Steps (iii) and (iv) were repeated with a blend of petrol and biogas.

III RESULTS AND DISCUSSIONS

The chromatography result of the biogas is as shown in Table 3.

Table 3: *Chromatography result of biogas*

S/N	Constituent Gas	Percentage (%)
1	CH_4	65.250972
2	NH_3	0.647809
3	CO	1.629328
4	H_2S	1.760274
5	CO_2	30.711616
	Total (Biogas)	100.00000

The result showed that the biogas contains 65.25%, 0.65%, 1.63%, 1.76%, and 30.71% of methane CH_4, ammonia NH_3,carbon monoxide CO, hydrogen sulphide H_2S, and carbon dioxide CO_2 respectively.

A. Result of The Calibration of The Torque Meter

The result of the calibration of torque meter is as given in Table 4 and Fig. 1 below.

Table 4 : *Result of the calibration of the torque meter*

Load, m (kg)	Deflection (Ө)	Torque,$T = mga$ (Nm)
0.5	1	1.23
1	2	2.45
2	5	4.91
3	8	7.36
4	10	9.81
5	13	12.26
6	15	14.72
7	18	17.17

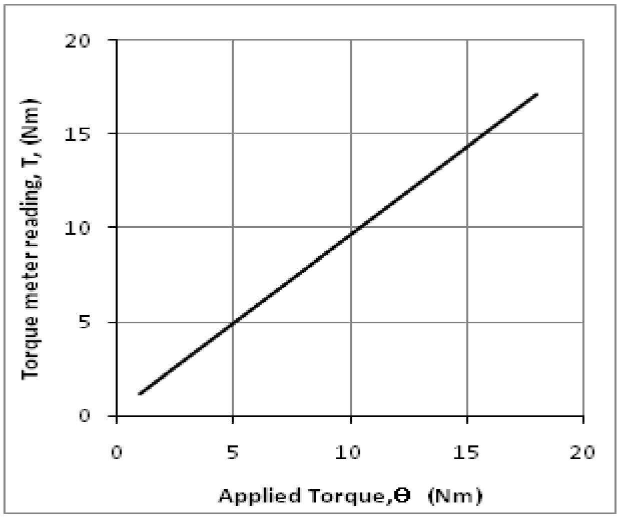

Fig. 1: *The graph of Torquemeter reading, T, (Nm) against Applied torque, Ө (Nm).*

B. Result of Engine Performance Tests

A four stroke Internal Combustion Engine test bed was run on the two fuels namely petrol and biogas-petrol blend. The results are presented in Tables 5 and 6 below while Fig.2 to Fig. 9 compare the performance of the two fuels.

Table 5: *Result of the Engine performance tests using Petrol fuel*

S/N	Speed, RPM	Torque, Nm	Fuel Mass flow rate, kg/hr	Brake Power, kW	Specific Fuel Consumption, g/kWh	Brake Thermal Efficiency, %	Brake Mean Effective Pressure, N/m^2	Friction Power kW	Mechanical Efficiency, %	Indicated Thermal Efficiency, %	Exhaust Temperature, ^oC
1	1000	6	1.07	62.84	16.96	4.81	0.00016	29.53	0.68	3.13	380
2	1500	7.5	1.18	117.83	10.05	8.11	0.00020	20.74	0.85	6.68	430
3	2000	7.9	1.52	165.48	9.20	8.86	0.00021	19.27	0.90	9.59	450
4	2500	8.1	1.78	212.09	8.37	9.73	0.00022	18.85	0.92	12.25	500
5	3000	8.4	1.94	263.93	7.34	11.10	0.00023	13.20	0.95	21.00	540
6	3500	8.5	2.66	311.58	8.55	9.53	0.00023	11.73	0.96	27.56	560

Table 6 : *Result of the Engine performance tests using Biogas-Petrol blend fuel*

S/N	Speed, RPM	Torque, Nm	Fuel Mass flow rate, kg/hr	Brake Power, kW	Specific Fuel Consumption, g/kWh	Brake Thermal Efficiency, %	Brake Mean Effective Pressure, N/m^2	Friction Power kW	Mechanical Efficiency, %	Indicated Thermal Efficiency, %	Exhaust Temperature, ^oC
1	1000	6.2	1.18	64.93	18.23	4.47	0.00017	27.44	0.70	3.37	350
2	1500	7.8	1.25	122.54	10.23	7.96	0.00021	16.02	0.88	8.65	410
3	2000	8	1.52	167.57	9.08	8.97	0.00022	17.18	0.91	10.76	440
4	2500	8.3	1.64	217.32	7.54	10.80	0.00023	13.62	0.94	16.96	460
5	3000	8.6	2.13	270.21	7.89	10.33	0.00023	6.91	0.98	40.09	530
6	3500	8.7	3.04	318.91	9.55	8.53	0.00024	4.40	0.99	73.50	570

i. Torque
The torque generated by the engine increased as the speed increases for the two fuels as shown in Tables 5 and 6. The torque achieved ranged from 6Nm to 8.5Nm for the petrol fuel and between 6.2Nm and 8.7Nm for the biogas-petrol blend fuel. This is due to the fact that the biogas-petrol blend generated more energy when burnt compared with petrol owing to its slightly higher heating value. The highest values of torque of 8.5Nm and 8.7Nm were recorded for petrol and biogas-petrol blend respectively was recorded at a speed of 3500rpm. Also, as the speed increases, the generated torque also increases but with less fuel consumption per unit time. Judging from the shape of the curves in Fig.2, further increase in speed will produce an increase in torque.

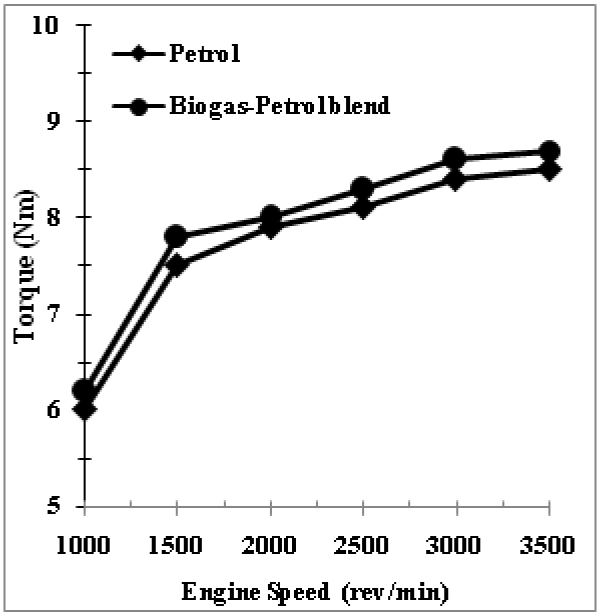

Fig. 2: *The Graph of Torque (Nm) against Engine Speed (rev/min)*

ii. Fuel Mass Flow Rate
The Fuel Mass Flow Rate of the two fuels increases as the engine speed increases. There are no significant differences in the parameter for the two fuels until after a speed of 3000rpm when the fuel mass flow rate for biogas-petrol blend increased more than that of petrol as shown in Fig. 3. This might be due to the fact that biogas-petrol blend (density of 739.2 kg/m^3) has a slightly lower density than petrol (density of 740.5 kg/m^3) and as such flows more easily than petrol.

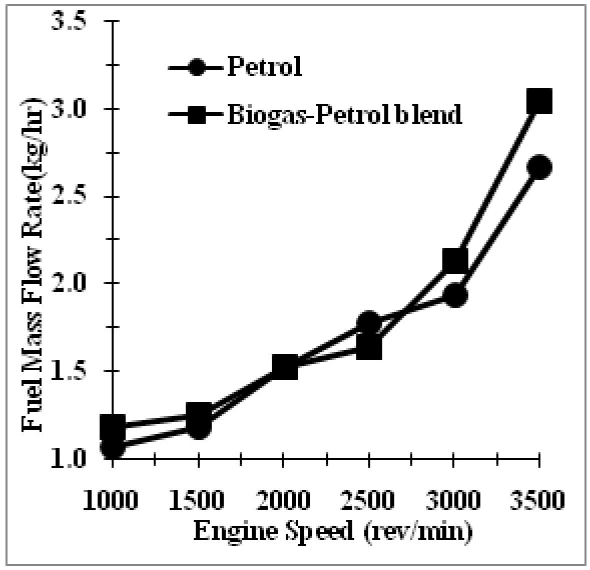

Fig. 3: *The Graph of Fuel Mass Flow Rate (kg/hr) against Engine Speed (rev/min)*

iii. Brake Power
The Engine performance with respect to brake power when run on petrol and biogas-petrol blend is shown in Fig. 4. Biogas-petrol blend produced slightly greater brake power when compared with petrol fuel. This can be attributed to the fact that biogas-petrol blend has a slightly higher heating value than petrol[Awogbemi 2014] and therefore produced more energy aftercombustion at a given speed. From Fig. 4, brake power increases with an increase in engine speed. The highest brake power of 311.58kW and 318.91kW was recorded at the maximum speed of 3500rpm for the biogas-petrol blend and petrol respectively.

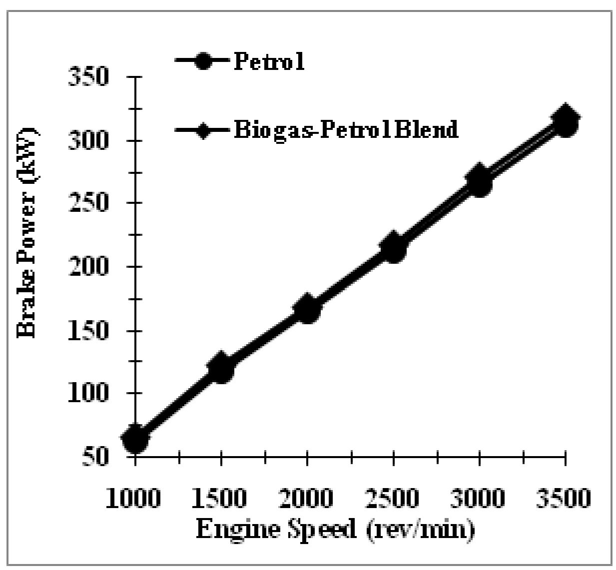

Fig. 4: *The Graph of Brake Power (kW) against Engine Speed (rev/min)*

iv. Specific Fuel Consumption

The engine performance with respect to Specific Fuel Consumption is shown in Fig.5. The Specific Fuel Consumption decreased as the engine speed increased. At an engine speed greater than 2750rpm, the specific fuel consumption for biogas-petrol blend was higher than that of petrol the same way as the fuel mass flow rate speed is greater than that of petrol fuel at those speeds. This can be explained from the fact that the power required at the speed above 2750rpm necessitated an increase in the flow rate and the fuel consumption. The appreciably higher specific fuel consumption of biogas-petrol blend could also be explained in terms of higher specific gravity, and higher viscosity of petrol which led to higher fuel consumption per unit of power produced. Also, higher fuel viscosity reduces the quality of fuel atomisation and could result in higher gas emission and fuel consumption [Eze and Elijah 2010].

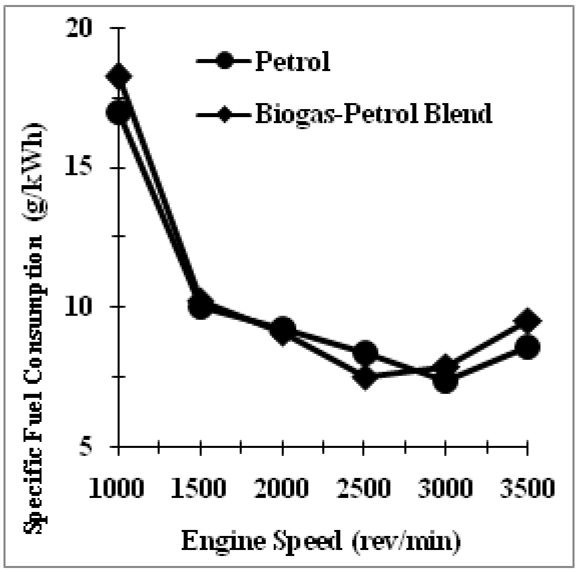

Fig. 5: *The Graph of Specific Fuel Consumption (g/kWh) against Engine Speed (rev/min)*

v. Brake Thermal Efficiency

Fig. 6 presents the performance of the fuels on an ICE test bed with respect to brake thermal efficiency. Petrol presented a higher brake thermal efficiency than biogas-petrol fuel particularly at a speed above 2750rpm. According to the second law of thermodynamics, the engine thermal efficiency increases due to the reduced heat loss from the engine through heat transfer to the coolant and to atmosphere [Fergusson 1986]. Moreover, the efficiency is inversely proportional to the brake specific fuel consumption [Pankhaniya et al 2011, Jose et al 2013], biogas-petrol blend has a lower ignition temperature, which may hasten engine combustion process and thus makes it have higher thermal efficiency than petrol. It has been observed [Plint and Patners 1987] that the fall in brake thermal efficiency, particularly at higher speed, reveals that specific fuel consumption relates conversely with thermal efficiency. This however emphasised the desirability of running engines at near their maximum power output or speed to expect good return for the burnt fuel. The decrease in thermal efficiency was due to increased mechanical losses in engine relative to useful power output, throttling losses, and deterioration in combustion efficiency [Eze and Elijah 2010]. Generally, it was observed that the two fuels behaved in the same way on the test bed.

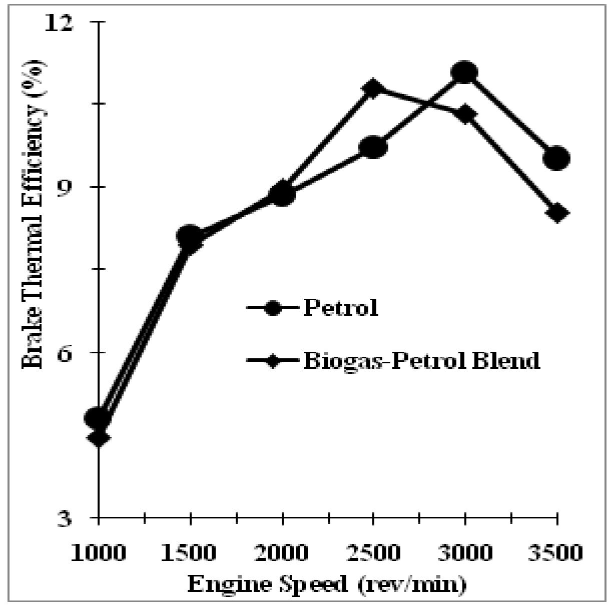

Fig. 6: *The Graph of Brake Thermal Efficiency (%) against Engine Speed (rev/min)*

vi. Brake Mean Effective Pressure

The engine performance with respect to the brake mean effective pressure is presented in Fig.7. The brake mean effective pressure is the calculated mean pressure that would act upon observed power output, when no mechanical losses occur. This parameter behaved in similar way as torque and brake power [Fergusson 1986, Eze and Elijah 2010]. The brake mean effective pressure increased with increase in speed with the biogas-petrol blend having higher values at all speeds than petrol.

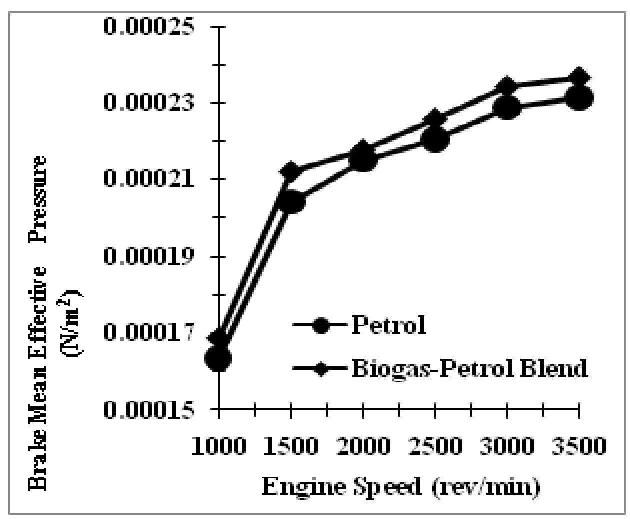

Fig. 7: *The Graph of Brake Mean Effective Pressure (N/m^2) against Engine Speed (rev/min)*

vii.Mechanical Efficiency

The biogas-petrol blend produced higher mechanical efficiency than petrol at a given speed when used on test bed. This can be attributed to the fact that more power is generated by biogas-petrol blend than petrol fuel. The mechanical efficiency increases sharply at lower speed of 1000rpm – 1500rpm but gently thereafter as shown in Fig.8.

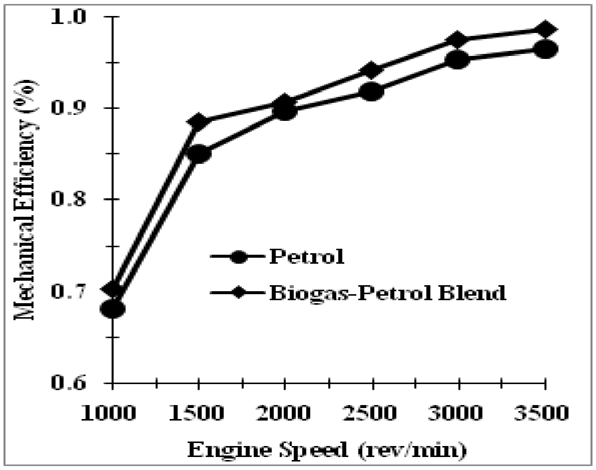

Fig. 8: *The Graph of Mechanical Efficiency (%) against Engine Speed (rev/min)*

viii. Exhaust gas Temperature

Fig. 9 presents the effect of the fuels on the exhaust gas temperature. As shown in the figure, exhaust gas temperature increased with increase in engine speed. Because heating value of petrol is slightly lower than that of biogas-petrol blend, petrol presented slightly higher exhaust gas temperature in some speeds than biogas-petrol blend. Also, ignition temperature of petrol is higher than biogas-petrol blend so the temperature required for burning petrol is also higher [Pankhaniya et al 2011].

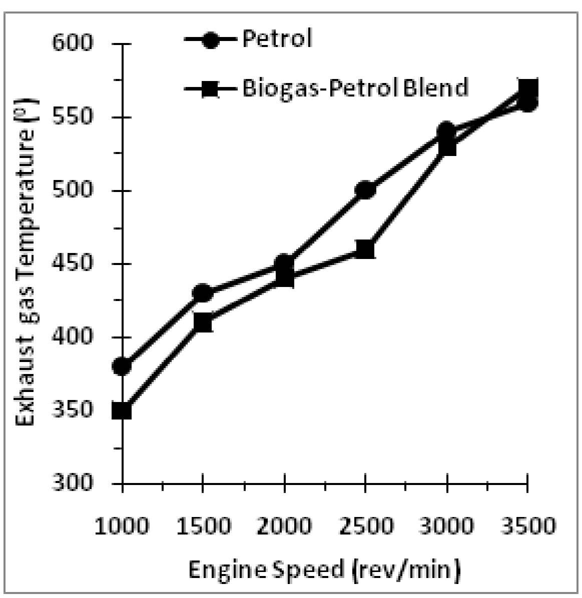

Fig. 9: *The Graph of Exhaust Temperature (^{0}) against Engine Speed (rev/min)*

IV CONCLUSION

The use of biogas as an internal combustion fuel comes with its own difficulties which include modification of some parts of the engine and some engine specifications. The technology to achieve running an IC engine on biogas is not presently available in Nigeria. However, blending of biogas with petrol is not as problematic as using only biogas to run spark ignition engine. It can therefore be concluded that biogas-petrol blend is a veritable and viable alternative for standalone spark ignition engine. A spark ignition engine fuelled with biogas-petrol fuel of proportion 20:80 generates more torque, brake power, indicated power, brake thermal efficiency and more brake mean effective pressure but with less fuel consumption and exhaust temperature. A biogas-petrol blend run on spark ignition engine is more economical, environmental friendly, and contributes to waste disposal and production of fertilizer.

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