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Original Research Article

Performance and Emission Characteristics of a Spark Ignition Engine using Biobutanol Produced from Sugarcane Juice

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ABSTRACT

This work investigated the performance of biobutanol from sugarcane juice as a source of biofuel. Gasoline procured from the filling station (G100) was used as a baseline for comparison with the produced biobutanol (B100). The experiments were conducted at varying engine speed from 1000 rpm to 2800 rpm with an increment of 450 rpm. The performance of the engine was compared with the gasoline (G100), biobutanol (B100) and the biobutanol blend (70 % gasoline, mixed with 30 % biobutanol B30). The results showed an improved brake thermal efficiency with B100 and B30 of 12.12 % and 12.82 % respectively at 2800 rpm compared with the G100 (8.55 % at the peak).

1. INTRODUCTION

Given the impending energy crises and the continued increase in global population, meeting the demand for energy is becoming an ever more critical challenge for the world (Nathalie *et al.,* 2011). Development of the biofuel sector is a promising option for many developing countries and this has made governments to start looking for sustainable solutions that provide the most competitive energy supplies from secure sources, whilst at the same time trying to balance the long-term, and in some cases, short-term needs of the environment (Ahuja and Tatsutani 2009). Nowadays the common notion around the world is to reduce the consumption of fossil fuels and to bring down the effects of global warming. It will be an ideal state to live in a pollution-free world without cutting on power requirements.

Biofuels can be derived directly from plants, or indirectly from agricultural, commercial, domestic, and/or industrial wastes. The world production of bioethanol increased by 8% in 2005 to reach 33 billion liters (8.72

billion US gallons), with most of the increase in the United States, bringing it to level to the levels of consumption in Brazil (Renewable, Global Status Report 2006).

As a fuel, butanol has a number of advantages over ethanol. First, butanol has a higher caloric value of 29.2 MJ/L than ethanol of 21.2 MJ/L, although both are less than that of gasoline 32.5 MJ/L (Amanda, 2012). Secondly, butanol is less corrosive than ethanol, so no infrastructure modifications to tanks, pipelines, pumps, filling stations, etc. are necessary. butanol is less miscible in water and less volatile than ethanol (Amanda, 2012). According to Becerra *et al.* (2015), in the production of biobutanol, *Clostridium* species are natural producers of n-butanol through a biosynthetic pathway that depends on acetyl-CoA sources. Well-known species (*Clostridium acetobutylicum, Clostridium saccharoperbutylacetonicum, Clostridium beijerinckii, Clostridium saccharoacetobutylicum*) produced the highest yield (Huang et al., 2010).

Elfasakhany (2014) experimentally studied the behavior of n-butanol-gasoline on a single-cylinder spark-ignition engine. The engine performance was reduced by using n-butanol blends compared to gasoline. The emissions of carbon monoxide (CO), unburnt hydrocarbon (UHC), and carbon dioxide (CO_2) were found significantly lower than that of gasoline. At relatively low engine speed, the emissions of carbon monoxide, unburnt hydrocarbon, and carbon dioxide were lowered compared to gasoline while at high speed, the emission reduction difference was lower than gasoline. Elfasakhany (2016) investigated the performance and emission characteristics of single-cylinder, 4-stroke spark-ignition engine in between the range (2600-3400 rpm with an increment of 100 rpm) of the engine speed. In this study, dual fuel n-butanol and methanol were blended with gasoline (1.5, 3.5 and 5 percent by volume). The results showed that at the low rate of dual-fuel blends, the engine volumetric efficiency, brake power, engine torque, and exhaust gas temperature reduced. In-cylinder pressure and carbon dioxide emission were also found to be reduced. Emission of un-burnt hydrocarbon and carbon monoxide was found to increase compared to the n-butanol-gasoline blend and gasoline. At a higher rate of, dual fuel, blends showed improved in engine performance and exhaust emission to butanol-gasoline blend and gasoline.

The production of biobutanol from sugarcane juice as alternative fuel can replace gasoline completely due to its high energy content, high energy output and low/zero emissions namely hydrocarbons, carbon monoxide and oxides of nitrogen which prompt this present research work which aim to compare the performance and emission characteristic of the biobutanol and the conventional gasoline.

2. MATERIALS AND METHODS

2.1. Material Collection, Preparation and Analysis

Sugarcane (*Saccharum officenarum*) sample was obtained from the Papalanto Area of Ewekoro Ogun State, Nigeria. The sugar cane stalks are washed with hot water sprays to remove dirt and other field debris. The extraction of sugarcane juice was accomplished by crushing peeled sugar cane in the crushing chamber of sugarcane extraction machine, with the aid of sugarcane juice extracting machine to squeeze the juice out of the cane pulps. The extracted juice was clarified by adding milk of lime and carbon dioxide. The juice was piped into a decanter, heated and mixed with lime. The juice passed through carbon filters, producing a mud-like substance called carb juice, which was pumped through a heater and then to a clarifying machine. Here the mud settles to the bottom and the clear juice was piped to yet another heater and treated again with carbon dioxide. Once again, the mud was filtered out, leaving a pale-yellow liquid called thin juice (Kulkarni 1980; Dua and Bhagat 2000)

Clostridium acetobutylicum ATCC 824 strain was obtained from Microbiology and Parasitology Department, Sacred Heart hospital, Abeokuta, Nigeria and was cultured using sterile clostridia nutritive medium (CNM, from Fluka Analytical) in an anaerobic chamber at 37 °C for 20 – 24 hours. The cultivation medium was anaerobically inoculated with 10 % (v/v). The culturing of *Clostridium acetobutylicum* was performed in 50 ml falcon tubes containing 25 ml of semi-defined P2 medium containing of (g/l): xylose as control, 30; yeast extract, 1.0; ammonium acetate, 2.2;$KH_2PO_4.7H_2$, 0.5;K_2HPO_4, 0.5; $MgSO_4.7H_2O$, 0.2; $MnSO_4.7H_2O$, 0.01; $FeSO_4.7H_2O$, 0. 01; NaCl,0.01.

The sucrose of the juice was analyzed using a HPLC system (Perkin Elmer) equipped with an ion-exchange column (BioRad Aminex HPX-87P, 300mm x 7.8 mm) maintained at 80 °C by a column oven and refractive index (RI) detection after which 20 μL of sample was injected into the system with an auto-injector, using distilled water as the mobile phase with a flow rate of 0.6 ml/min during analysis.

The sugarcane juice was then fermented in a fermentation vessel where *Clostridium acetobutylicum* was added to work on the juice. The *Clostridium acetobutylicum* ferments the sucrose and produce Acetone, Butanol and Ethanol (ABE). The butanol produced after fermentation was quantified by a Gas chromatography (Varian 3400) system with an FID detector at 250 °C (Column type: 15QC 2.5/BP 30 - 0.25; injector temperature: 230 °C; column temperature: 80 °C; flow rate: 10 ml/min^{-1}) (Nofemele et al., 2012).

2.2. Engine Tests

Experiments were conducted with two strokes, single cylinder test engine coupled with a rope brake dynamometer. A GK-7 model dynamometer was used for obtaining the load on the engine. The internal combustion engine exhaust gas emission depends on the air-fuel ratio. The main exhaust gases in an internal combustion engine are hydrocarbon, carbon monoxide and nitrogen oxides and were measured by using an automatic exhaust gas analyzer (ALTAIR 2X exhaust analyzer). The exhaust temperature of the gases was measured with the aid of thermocouple that was inserted near the exhaust manifold of the engine.

Table 1: Parameters and designation

Parameter	Designation
Fuel type	100 % Biobutanol (B100) 100 % Gasoline (G100) 70 % Gasoline, 30 % Biobutanol (B30)
Engine speed	1000 rpm 1450 rpm 1900 rpm 2350 rpm 2800 rpm

The experiment was conducted at varying engine speed. The engine speed was varied from 1000 rpm to 2800 rpm with an increment of 450 rpm. The load was adjusted to maintain the minimum required speed of the engine. The throttle position was adjusted to maintain the same brake torque values at the given engine speed for all tested fuels. Initially, the engine was running for 15 minutes on gasoline for warming then the engine was allowed to run on the test fuel sample. The new fuel blends were used for the experiment when the earlier fuel blend was totally consumed. The performance of the engine was evaluated on three different fuel types and at five different levels of engine speed. The levels of different independent parameters studied are as shown in Table 1.

Table 2: Specification of engine

Description	Data
Type of engine	Spark ignition engine
No. of cylinder	Single (1) 2 stroke
Maximum brake power	3.6 kW
Maximum speed	4800 rpm
Maximum net torque	10.3 Nm
Direction of rotation	Clockwise
Bore diameter	74 mm
Stroke length	86 mm
Engine capacity	165.65 cc
Fuel type	Gasoline

2.3. Brake Specific Energy Consumption

Brake specific energy consumption signifies the total available energy of fuel consumed by the engine for generating engine power in an hour. (Pandey, 2016). The brake specific energy consumption of the engine operating at different conditions was calculated using Equation (1) (Pandey, 2016).

$$\text{BSEC} = \text{BSFC x GCV} \tag{1}$$

Where, BSEC is brake specific energy consumption, MJ/kWh, BSFC is brake specific fuel consumption, kg/kW-h, and GCV is gross calorific value, MJ/kg.

2.4. Brake Thermal Efficiency

Brake thermal efficiency is the brake power of a heat engine as a function of the thermal input from the fuel. It is used to evaluate how effective an engine converts the heat from a fuel to mechanical energy. The brake thermal efficiency of the engine operating at different conditions was calculated using Equation (2) (Pandey, 2016).

$$\eta = \frac{K_s}{CV\ x\ bsfc}\ x\ 100\ \% \tag{2}$$

Where, η is Brake thermal efficiency, %, Ks is a constant (3600), GCV is gross calorific value (kJ/kg), and BSFC is brake specific fuel consumption (kg/kWh)

2.5. Brake Specific Fuel Consumption

This is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft power. It is typically used for comparing the efficiency of internal combustion engines with a shaft output. It is the rate of fuel consumption divided by the power produced. The brake specific fuel consumption was calculated using Equation (3) (Pandey, 2016).

$$bsfc = \frac{X\ x\ \rho\ x\ 3600}{t\ x\ 10^2\ x\ BP} \tag{3}$$

Where, volume of the fuel consumed is 20 cl, ρ is density of fuel, (kg/m^3), t is time taken to consume 20 cl and BP is brake power, (kW).

3. RESULTS AND DISCUSSION

Figure 1 shows the variation of the brake specific energy consumption (BSEC) with engine speed. The brake specific energy consumption of the biobutanol was 114.50 MJ/kWh from the investigation, while that of conventional gasoline fuel (G100) and the biobutanol blend (B30) were 125 MJ/kWh and 93.88 MJ/kW-h respectively at 1000 rpm. The G100 showed higher value compared to the B100 and B30 at the same engine speed and it was observed that the value of the BSEC decrease as the engine speed was increasing. The fuel tested with the least minimum value of brake specific energy consumption is B30, which was 28.07 MJ/kWh.

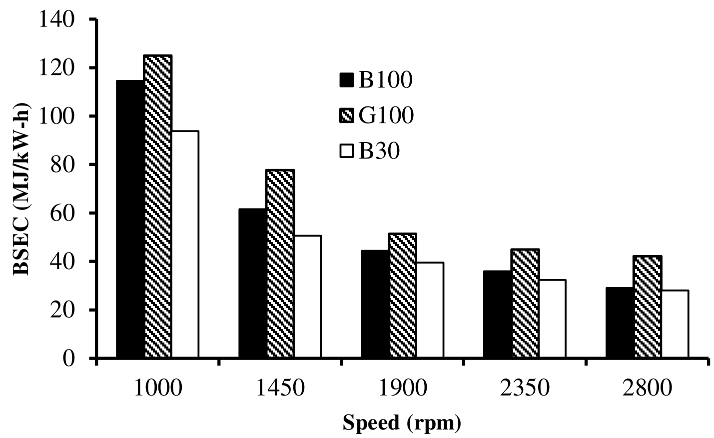

Figure 1: Variation of BSEC with speed of engine

The result shows that an improved brake thermal efficiency with B100 (12.12 %) and B30 (12.82 %) having higher values than G100 (8.55 %) at the same maximum speed of 2800 rpm (Figure 2). In Figure 2, the biobutanol blend (B30) has the highest value of 12.82 % while the gasoline fuel (G100) had the minimum value of the fuel types. This could be as a result that alcohol contains a certain amount of oxygen molecules that assist in proper combustion inside the cylinder (Pandey, 2016).

Figure 3 shows the BSFC of the different types of fuel used. BSFC decreased as the engine speed was increased and the biobutanol B100 has a high value of BSFC of 3.46 kg/kWh at 1000 rpm, compared with between G100 and B30 at the same engine speed of 1000 rpm (2.937 kg/kWh and 2.983 kg/kWh respectively). The variation in the brake specific fuel consumption shows that from all the results of BSFC for tested fuel, the minimum value for gasoline (G100) was 0.982 kg/kW-h at 2800 rpm because of the higher calorific value of gasoline (Varol *et al.,* 2014). BSFC will depend on the type of fuel, in which the B100 and B30 have a high content of oxygen molecules that help in the proper burning of the fuel compared to gasoline with low calorific value.

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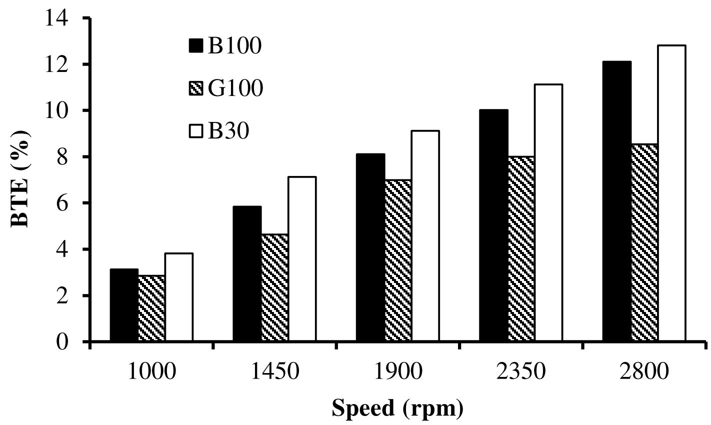

Figure 2: Variation brake thermal efficiency with speed of engine

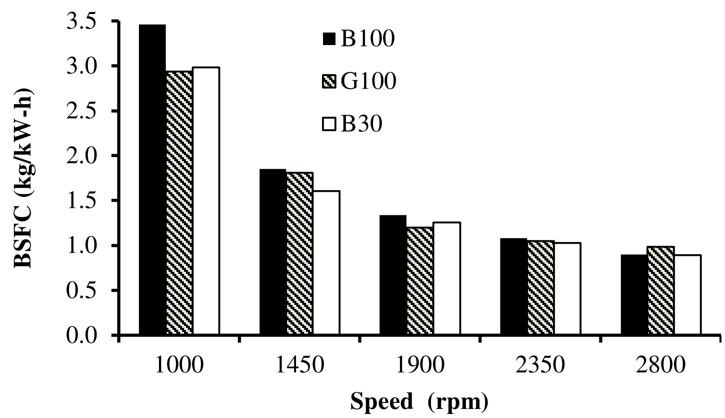

Figure 3: Variation of brake specific fuel consumption with speed of engine

Figure 4 shows the variation of the brake power with speed ranging from 1000 rpm to 2800 rpm. The brake power of the engine for the different types of fuel used increased as the speed of the engine was increased. The G100 and B30 are almost similar with a little variance of 0.01 kW.

Figure 5 shows variation of hydrocarbon emission for the type of the fuel used with respect to different engine speeds ranging from 1000 rpm to 2800 rpm. Hydrocarbon (HC) is a product of incomplete combustion of fuel, and forms due to lack of complete supply of air in the combustion chamber. The emission of hydrocarbon is an indication of loss of power in the engine and the higher the hydrocarbon emission the higher the power loss which will results into less brake thermal efficiency. The Figure shows that with the increase in the speed of the engine the hydrocarbon emission tends to decrease which leads to an increase in turbulence in the engine combustion chamber which increases the rate of combustion in the combustion chamber (Pandey, 2016). The biobutanol (B100) shows better quality than other fuel i.e. biobutanol blend (B30) and gasoline (G100) due to its low value (26 ppm) which experiences less incomplete combustion and low power loss that will occur in the combustion chamber.

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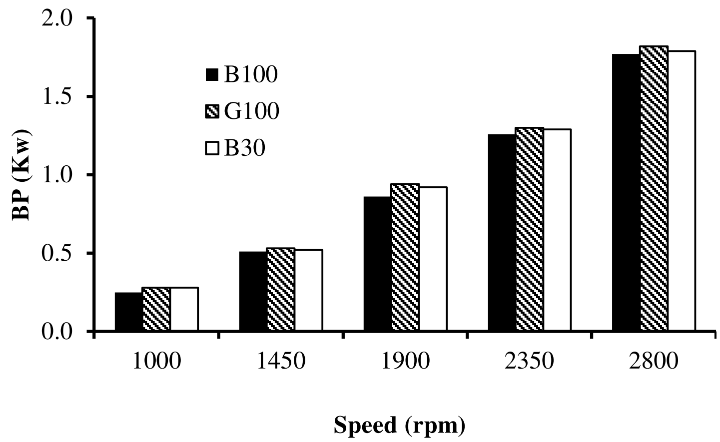

Figure 4: Variation of the brake power with speed of the engine

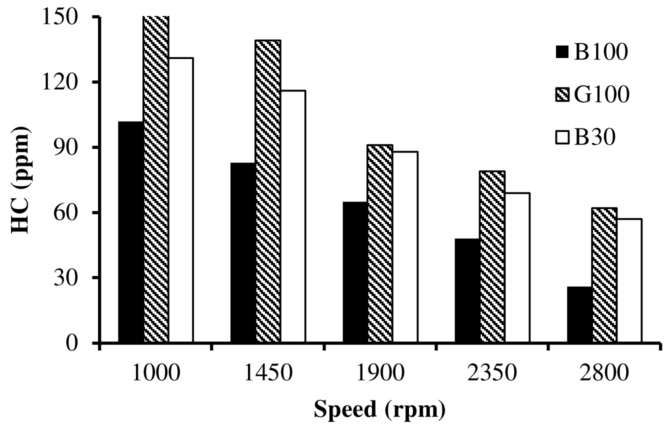

Figure 5: Variation of hydrocarbon with the speed of the engine

Figure 6 shows variation of carbon monoxide emission from engine, Carbon monoxide (CO) is another product of incomplete combustion of fuel in an engine. The formation of carbon monoxide in the engine indicates loss of power, which is as a result of oxygen deficiency in the combustion chamber of the engine (Farkade and Pathre 2012). The variation of carbon monoxide shows an increasing trend as the speed of the engine increases. The value of the carbon monoxide of gasoline (G100) was the highest value out of the different types of fuel used followed by biobutanol blend (B30) and biobutanol (B100) having the least minimum value. Biobutanol (B100) shows better quality than other fuel i.e. biobutanol blend (B30) and gasoline (G100) and the B100 will give out less poisonous gas emission to the atmosphere.

Figure 7 shows that exhaust gas temperature increase as the engine speed increases which could be as a result of the increase of turbulence inside the cylinder which will improve the rate of heat transfer (Pandey, 2016). The gasoline (G100) has a high exhaust temperature than the other fuel used. This is because the B100 and B30 have high latent heat of vaporization compared with gasoline (Pandey, 2016).

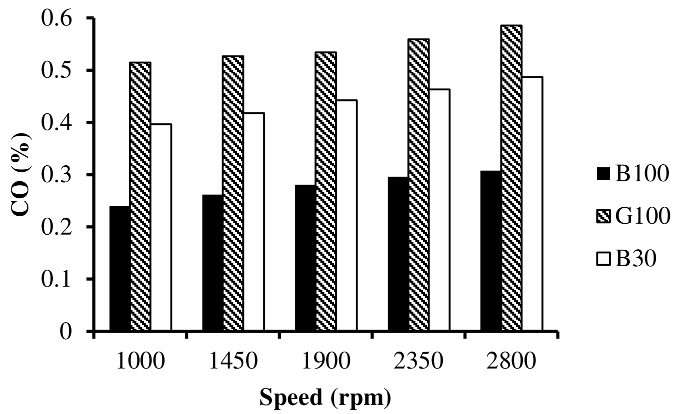

Figure 6: Variation of carbon monoxide emission with speed of engine

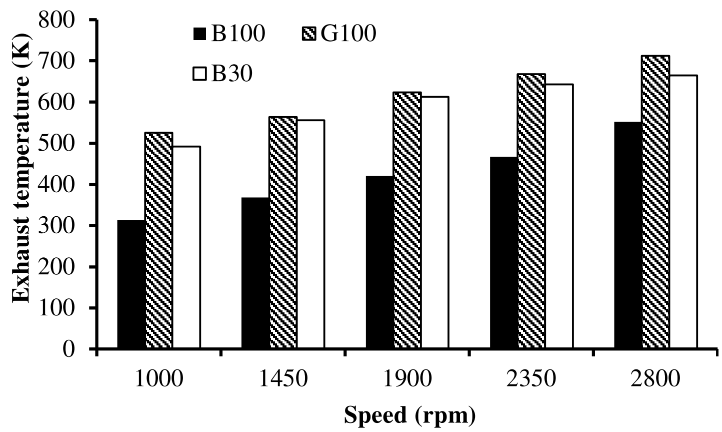

Figure 7: Variation of exhaust temperature emission with speed of engine

4. CONCLUSION

The result shows that brake specific energy consumption (BSEC) of the fuel decreasing for B100 and B30 when the speed of the engine is increased compared with the G100, It is expected that the production of biobutanol from sugarcane juice will reduce environmental degradation associated with the use of fossil fuel in the emission of harmful gases into the atmosphere, due to the low level of hydrocarbon, carbon monoxide, nitrogen oxide, and exhaust temperature.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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