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Powering of a Spark Ignition Generator (4 Stroke) using a Locally made Propane Menturi mixer

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Abstract: *Exhaust emissions from portable generators is a major contributor to air pollution problem across the country. The energy crisis, which has engulfed Nigeria, has been enormous and has largely contributed to the increase dependence on this power source undermining the health hazards. In a bi-fuel engine, the carburetor plays a vital role in switching from fuel gas to petrol mode operation and vice versa. Accordingly, the main challenge is to design a device which mixes the supplied gas and the incoming air at an optimum ratio (near stoichiometric airfuel ratio). In this research, MATLAB was used to simulate different air inlet pipe diameters with fixed throat diameter of 19mm to determine best parameter combinations that would give the highest velocity of mixed gas and pressure drop in the throat of a venture mixer base on the Bernoulli's principle. The fabricated venture mixer was retrofitted into a 4 stroke spark ignition generator. The output voltage of the generator at varying load of 100 to 500watts using petrol and propane were recorded. Emission gasses and fuel consumption using both fuels were also determined. The results showed that the generator output voltage with both fuel gave 220volts when loaded less than 500watts but the voltage dropped more when the load was increased to 500watts, and above using propane as fuel. The generator lasted longer using propane as fuel and also produced less emisions*

Keywords: *Venturi,* Converging-Diverging *Nozzle, Bernoulli's Principle, Stoichiometric Air-Fuel Ratio*

Nomenclatures

Q = Air flow rate
D = Bore of engine= 0.05m
L = Stroke of engine= 0.49m
η_v =Volumetric efficiency of engine=70%

N = Speed of rotation of Engine =1500rpm
V_1 = Velocity of air at inlet
D_1 = Diameters of venturi inlet
V_2 = Velocity of air at throat
D_2 = Diameters of venturi throat =19mm which is the diameter of the carburettor
C_d = Discharge co-efficient of venturi = 0.9 (Considering compressibility effect) as found in Chandekar and Debnath (2018)
Z_1, Z_2 = Height level of venture pipe at inlet and throat respectively ($Z_1 = Z_2$)
P_1 = Pressure of air at inlet =101325Nm²
P_2 = Pressure at throat
P_{1g} = Pressure of gas at gas inlet =111305Nm²
P_{1g} = Pressure of gas at gas throat = P_2
ρ_g=Density of gas = 1.16kg/m3
m_a =Mass of air at throat
m_g = = Mass of gas
AFR = stoichiometric air fuel ratio for a propane gas in a spark ignition engine =15.67:1 (Danardono1, 2011)
d_g = Diameter of gas supply pipe n =
Number of holes for gas entrance =1
ρ_a =Density of air = 1.2629kg/m³
V_{2g} = Velocity of gas at throat
K_V = Velocity Coefficient (assume 0.8 for small holes as in, Baylar, 2007)

INTRODUCTION

A gas mixer plays a very important role in the performance of a gas engine according to Dominicus et al., (2011) and mixes air and fuel gas in the appropriate condition. A Venturi gas mixer is a device that uses the venturi effect, a particular case of Bernoulli's principle of a converging-diverging nozzle to convert the pressure energy of a motive fluid (air) to velocity energy at the throat to create a lowpressure zone. This low-pressure zone draws in and entrains the suction fluid (fuel) into the mixing chamber where it mixes with the motive fluid (Baylar *et al.*, 2007).

The air-fuel ratio (AFR) of the mixture generated must be within the range determined by the operating condition of the gas engine. An out of range air-fuel ratio will lead to an unstable gas engine operation and to the production of exhaust gas emission that will not meet the environmental standard. If there is no additional pressure at the air or fuel gas inlet, then the air-fuel ratio of the mixer will only depend on the mixer design. For this reason, the mixer design is very important. It should be designed to meet the air-fuel ratio requirement for various loads without using feedback control. Furthermore, to improve engine efficiency, the gas mixer design should produce a uniform air-fuel mixture and have small pressure loss (Baylar *et al.*, 2009).

The venturi mixer design should be compact, with minimum pressure loss across the venturi-mixer, good suction pressure mainly in the throat due to the venturi effect from the pressure difference and homogeneous or good mixing quality as stated in Baert *et al.*, (1999). The air-fuel ratio and pressure loss of the venturi mixer are affected by several specifications: the venturi throat area, throat position, gas inlet area and gas inlet location as reported by Baylar *et al.*, (2010); Ozkan *et al.*, (2006).

Whereas the mixing effect of a venturi mixer is affected by venturi throat diameter, fuel nozzle position, number of fuel holes and impingement angle as reported by Luo *et al.,* (2007) and Gorjibandpy and Sangsereki (2010). The mixing process on the mixer is driven by the strong impingement of two fluid streams which produces high energy dissipation (Luo *et al.,* 2007). The mixing process depends directly on the momentum-transfer efficiency of the mean flow at different scales. At intermediate scale, mixing is governed by turbulent fluctuations that can be characterized by the turbulent kinetic energy (TKE) and at micro scale, mixing can be characterized by the turbulence energy dissipation rate. A higher TKE and turbulence energy dissipation rate lead to better mixing quality (Habchi *et al.,* 2010). However, better mixing quality is generally accompanied by an increase in pressure drop.

Air pollution by way of exhaust emissions from Spark Ignition engines has end up a prime challenge in most of the nations of the world seeing that it's miles answerable for inflicting respiration diseases and cancers. Air pollution is also responsible for critical phenomena consisting of acid rain and global warming. It is as a result of those unfavorable results of the emissions on human lifestyles and the environment that the regulations for emissions from Spark Ignition engines had been reinforced. This has led to research on alternative fuels for the Spark Ignition engines which would reduce dangerous exhaust emissions whilst maintaining high thermal performance. In addition to challenges of emissions from Spark Ignition engines due to use of fossil fuels, the price of the fossil fuels is constantly increasing due to increase in demand. All countries are at present heavily dependent on petroleum fuels for transportation and agricultural machinery. The fact that a few nations produce the bulk of petroleum and has led to high price fluctuation and uncertainties in supply for the consuming nations. Among alternatives being considered are methanol, ethanol, propane, synthesis biodiesel and biogas. In this paper, a 4stroke spark ignition generator engine will be operated using propane by designing and fitting in a venture mixer that will enable it to operate.

MATERIAL AND METHOD

2.1 Design of the Venturi Mixer

The fuel intake system basic design is shown in Fig. 1. Literature review has shown that a suitable mixture for the generator engine should be a venturi, with the accelerator cone being tapered as a curve of suitable radius and the diffuser cone angle. The fuel is fed into the venture through circular ports around the throat area.

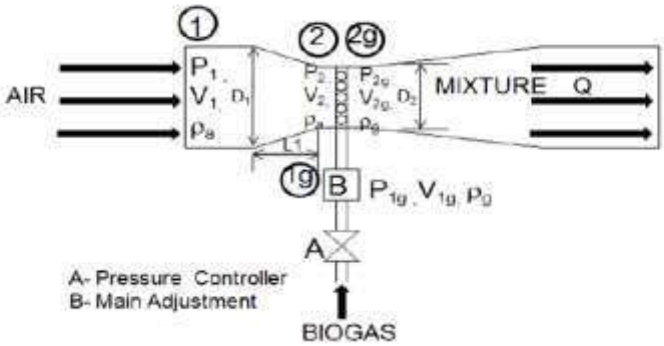

Fig.1 The base Venturi mixer

2.2 Air Flow Rate Requirement of Engine

The generator being retrofitted is a four stroke Spark Ignition generator. According to Dahake *et al.,* (2016) the equation for air flow rate of a four-stroke engine at any given speed is given by Equation (1).

$$Q = \frac{\pi D^2 L \eta v N}{4 \times 60} \quad (1)$$

2.3 Inlet Air velocity

The velocity of air at inlet is given by equation (2) as seen in Dahake *et al.,* (2016).

$$V_1 = \frac{Q}{A_{in}} \quad (2)$$

The inlet diameter was varied from 20mm to 100mm in order to determine the diameter that will give the highest velocity and lowest pressure at exit of the mixture.

2.4 Velocity of Air at Throat

The velocity of air at the throat is given by equation (3)

$$V_1 = \frac{Q}{C_d A_2} \quad (3)$$

Area of air at throat A_2 is given by;

$$A_2 = \frac{\pi D_2^2}{4}$$

2.5 Pressure at Throat

Assuming steady, one dimensional, incompressible, isentropic flow; the Bernoulli's theorem at section 1 and 2 of Fig. 2 is given by equation (4) (Dahake *et al.,* 2016)

$$\frac{P_1}{\rho_a} + \frac{V_1^2}{2} + Z_1 = \frac{P_2}{\rho_a} + \frac{V_2^2}{2} + Z_2 \quad (4)$$

$$P_2 = P_1 + \frac{\rho_a}{2}(V_1^2 - V_2^2) \quad (5)$$

2.6 Velocity of Gas at Throat

The gas velocity at throat at which it enters the engine is given by equation (6) as seen Chandekar and Debnath (2018).

$$V_{2g} = P_1 \times \sqrt{\frac{2}{\rho_g} \times (P_{1g} - P_{2g})} \quad (6)$$

2.7 Mass of Air at Throat

The mass of air at throat is given by equation (7) as seen in Baylar (2007)

$$m_a = \rho_a \times V_2 \times A_2 \quad (7)$$

2.8 Mass of Gas at Throat

The mass of fuel at throat is determined using equation (8)

$$m_g = \frac{m_a}{AFR} \tag{8}$$

2.9 Diameter of Gas Supply Pipe

The area of gas entrance at throat is given by equation (9)

$$d_g = \sqrt{\frac{4 \times m_g}{\rho_g \times \eta \times \pi \times V_{2g}}} \tag{9}$$

MATLAB code was developed using equations 1 to 9 to determine the design parameters for varying inlet air diameter from 0 to 0.08m.

2.10 Fabrication of the Venturi Mixer

Hollow mild steel pipe of length 200mm, diameter of 24.5mm (1 inch) and outlet diameter of 19mm were used for the fabrication of the venturi – mixer as seen in Table 2. The gas diameter of the gas inlet pipe is 10mm. The other specifications are also presented in Table 2. The fabrication processes are shown in Fig. 2. Fig. 3 shows the pictorial view of the fabricated venture mixer.

(a) Joining of the mixer chamber to the throat section

(b) Drilling of holes at the orifice section

(c)Welding of the gas inlet pipe to the chamber of the mixer device

Fig. 2 Fabrication processes

Fig. 3 The venture mixer

2.11 Engine Modification

The engine modification is necessary because the engine's original fueling system is configured for liquid gasoline. Therefore, there is need for modification for the usage of gaseous fuels such as propane. The following parts of the engine were modified

A. Disconnection of the Engine's Air – Filter

Disconnecting the air filter of the gasoline generator was very important to provide space to retrofit the venture mixer to the generator carburetor and also to ensure adequate control and monitoring of fuel/air intake.

B. Mounting the Venturi Mixer to the Carburettor Air Inlet with Extra Seals

The venturi – mixer ensures good mixture of propane and air. Therefore, the design and dimensioning was carefully fabricated to match the carburetor settings. The pictorial view of the mounted venturi – mixer is shown in Fig. 4.

Fig. 4 Mounting of the venturi – mixer to engine

Fig. 5 The assembled components the

The performance of the fabricated venture mixer was evaluated using the propane gas as fuel to run the generator as well as gasoline. All the fuels were tested under varying electrical load conditions. The engine was started using propane gas and it was also operated also using gasoline. After the engine maintained a steady state, the electric power output and emission parameters were measured using load board, voltage meter for the electric output measurement and gas analyzer for the exhaust emission parameters. Also, the fuel consumption for the propane gas and petrol were compared.

C. Installation Procedure

The installation of the propane venturi – mixer to the engine is carried out as follows;

i. Disconnect the air filter from the generator.

ii. Connect the mixture exit side of the venture mixer to the generator carburetor with gasket/seal. iii. Mount the gas control valve and connect it to the propane piping with pressure hose and hose clip.

iv. Check the various connections from the propane cylinder and to the venturi mixer

v. Open the air supply valve

vi. Turn on the propane gas cylinder

vii. Turn on the engine ignition switch

viii. Start the engine

ix. Turn on the bulbs on the load board

x. Some minutes were allowed to wave away so that steady state will be ascertained

xi. Connect a hose from the exhaust side of the generator to a cylinder to collect some exhaust emissions for analysis

xii. Turn off the bulbs at the load board and the propane gas cylinder.

xiii. Repeat the above relevant steps to test using gasoline for comparison.

D. Assembling of the Component System

The assembling involves piping the propane gas from the cylinder using a flexible rubber hose pipe to the venturi mixer. The rubber hose pipe was fastened at each point using a hose clip. The pictorial view of the assembled components is shown in figure 5.

E. Electric Power Output

The electric power and load bearing capacity was measured using 100 -500 watts electric bulbs mounted on a wooden board as variable load. The process for checking the output voltage for the propane gas and petrol is shown in figure 6. The output voltage was measured using wattsmeter to get the accurate output result.

Fig. 6 Output voltage measurement

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F. Exhaust Gas Emission Test

A gas analyzer was used to monitor the percentage composition of CO, CO_2 in the exhaust gas. NOX wasn't monitored because it is an inert gas therefore it is negligible. The analysis was carried out at Institute of Agricultural Research and Training, Ibadan.

G. Electrical Load Output Test

Six different 1kg of propane gas was purchased at the rate of two hundred and fifty naira (#250) each from a gas station in Benin City. Also, six different kegs of petrol were purchased at same amount which gave 1.72litters each. Each of the fuel was used to run the generator according to the Table 1 and the time for the generator to completely consume each fuel in the test condition was recorded.

Table-1 Fuel time test experiment

Gasoline		Propane	
Quantity	Load (W)	Quantity	Load (W)
1kg	No load	1.72litters	No load
1kg	No load	1.72litters	No load
1kg	300W	1.72litters	300W
1kg	300W	1.72litters	300W
1kg	500W	1.72litters	500W
1kg	500W	1.72litters	500W

RESULTS AND DISCUSSION

3.1 Determination of Diameter of Inlet Air Pipe

Fig. 7 shows the velocity and pressure drop of the venture mixer when the inlet air diameter is varied from 0 to 0.08m. It can be observed that increasing the inlet air diameter leads to a corresponding increase in the velocity and pressure drop at the outlet of the mixer. However, it can be seen that at about 0.0254m (1 inch) diameter of inlet pipe, the effect of velocity increase and pressure drop across the mixer becomes reduced drastically. Therefore, this diameter was chosen as the inlet diameter for the venture mixer.

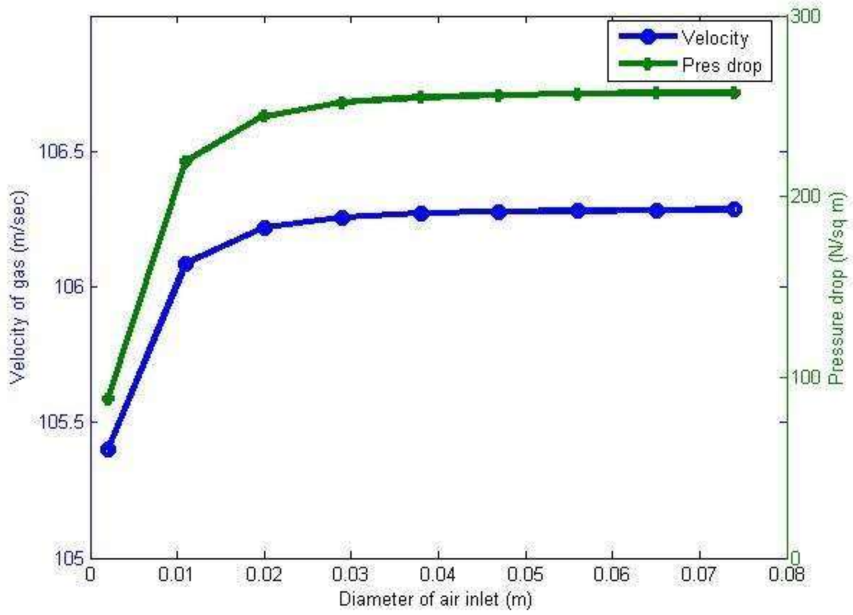

Fig. 7 Velocity and pressure drop at outlet with variation of inlet air pipe diameter

3.2 Determination of Diameter of Inlet Gas Pipe

Fig. 8 shows the diameter of gas supply pipe to the venture mixer when the inlet air diameter is varied from 0 to 0.08m.

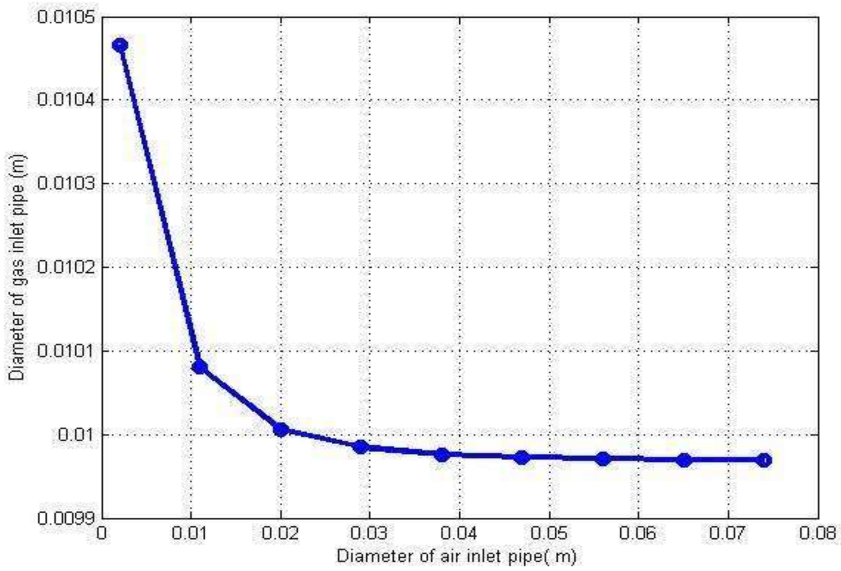

Fig. 8 Determination of diameter of the gas inlet pipe

From Fig. 8, it can be seen that the diameter of the gas supply pipe that corresponds with the 0.0254m air inlet pipe diameter to give the most desired pressure drop and velocity at inlet of the mixer is 0.01m. Therefore, this value was chosen as the diameter of the gas supply pipe.

3.3 Results of Detailed Design

Table 2 show the results of the detail designs of the venture mixer obtained from the MATLAB simulation code.

Table-2 Results of detailed design of the venture mixer

Specifications	Size
Diameter of air inlet pipe	25.4mm (1 Inch)
Length of air inlet pipe	200mm
Diameter of biogas inlet pipe	10mm
Length of biogas inlet pipe	20mm
Diameter of outlet throat pipe(manifold)	19mm
Number of holes for gas entrance	1
Thickness of mild steel sheet and pipe	2mm

3.4 Performance Test Analysis Results

A. Voltage Output Capacity Test

The voltage output was measure using voltmeter and a wooden load bearing board. The load board was connected to the retrofitted propane electricity generator. In this test, the term load is used to measure the electric power produced by the electric generator. A board of three several bulbs were used to vary the electric load produced by the retrofitted 4–stroke generator. This load board was wired in parallel consisting of different watts bulbs controlled by a switch for flexible texting. The load bearing test was conducted using petrol as source of fuel with 100 – 500 watts bulbs and twice each with 100500 watts bulb using propane as source of fuel. Table 3 shows the results obtained using the petrol and propane as fuel while varying load output.

Table-3 Load bearing capacity and voltage output

Range of Loads (watts)			
	Petrol	Propane	
		First test	Second test
100			
200			
300	220V	220V	220V
400	220V	220V	220V
500	220V	220V	220V
	220V	220V	220V
	190V	180V	180V

From Table 3, it was discovered that the retrofitted electricity generator operated smoothly with propane producing output voltage of 220v just like the petrol fuel when the load output of the generator was between 100 to 400 watts but dropped more than the petrol when the load was increased to 500watts.

B. Exhaust Emission

The emission analysis was conducted at at Institute of Agricultural Research and Training, Ibadan (IAR&T) laboratory with an ENERAC 700 gas analyzer. The device probe was fixed into the gas tube outlet. A pump located inside the device was used to draw small amount of sample of the exhaust. The sample was conditioned before entering the analyzer, via a water trap. A series of sensors in the ENRAC 700 analyzed the compositions of the dual fuel gas. The model was used to derive the compositions of CO, and CO_2 which are for the exhaust gas (petrol and propane).

The exhaust emission constituent compositions test results are shown in Table 4 for CO and CO_2. NOX was not considered because it is an inert gas. Therefore, it is negligible.

Table-4 Composition of retrofitted engine exhaust emission

Emission	Petrol 1(%)	Petrol 2(%)	Propane 1(%)	Propane 2(%)
CO	0.35	0.34	0.15	0.14
CO_2	29.90	28.99	18.01	18.59

The analysis of the exhaust composition gave %CO for propane to be 0.145%, %CO for petrol to be 0.345%, %CO_2 for propane to be 18.3% and %CO_2 for petrol to be 29.445%., It can be seen that the exhaust gas of propane when used as fuel has less adverse effect on our environment than petrol. The result analysis also depicted a low amount of CO which is more poisonous gas than CO_2.

C. Fuel Consumption Rate Test

Fuel consumption rate was determined by three different load conditions; No load, 300watt and 500 watts using petrol and propane as fuel respectively. A wrist watch was used for the timing. The start and stop time for each set of test load and fuel were recorded. The durations were obtained by subtracting the stop time from the start time of each test. Table 5 show the result obtained for propane and petrol gas consumption rate with varying load condition.

Table-5 Fuel consumption rate test result

Gasoline					Propane				
Quantity (Litters)	Cost (#)	Load (Watts)	Time(min)	Mean time (min)	Quantity (kg)	Cost (#)	Load (Watts)	Time(min)	Mean time (min)
1.72	250	0	300	306	1	250	0	412	421.5
		0	312				0	431	
1.72	250	300	254	244.5	1	250	300	388	381
		300	235				300	374	
1.72	250	500	215	210	1	250	500	306	312.5
		500	205				500	319	

From Table 5, it can be seen that for each load condition tested, using propane as fuel gave a greater number of usage time. The main cause of higher fuel consumption rate of gasoline is due to improper or incomplete combustion of gasoline resulting from poor mixing of fuel with air leading to higher fuel consumption and greater environmental pollution.

CONCLUSION

Most Nigerians depend on the use of fossil fuel due to the epileptic power situation of the country. These fossil fuels when used to run generators have very high adverse effect on our environment. In this project, a venture mixer was designed and fabricated to enable to use of propane as fuel in place of petrol. A MATLAB code was developed base on the models derived from Bernoulli's principle of flow in pipes to simulate the best inlet pipe diameters of air and gas that will give the highest pressure drop and velocity at the throat of the mixer not neglecting the stoichiometric ratio of the fuel used. Performance test was carried out using the fabricated venture mixer to determine the Load bearing capacity base on voltage output using voltmeter readings, exhaust emission and fuel consumption rate tests using petrol and propane as fuel. From the results analysis, it can be concluded that using propane as fuel with the help of the fabricated venture meter gave very good results compared to petrol. The generator output voltage readings with both fuels gave 220volts.

However, when the load was increased 500watts and above, petrol voltage was better than that of the propane by 10 volts. The amount of CO and CO_2 in the exhaust gas of petrol were higher than that with propane. CO composition in petrol gave0.345% as compared to 0.145% using propane. The CO_2 value was 29.44% as compared to 18.3% with propane. For the fuel consumption rate, using propane as fuel with the aid of the venture mixer had very noticeable performance than with petrol. It is therefore recommended that the venture mixer be retrofitted to household's generators to enable the use of propane as fuel which is not only cleaner energy, but also last longer than petrol of same cost.

CONFLICT OF INTEREST

We hereby state that no conflict of interest will arise in any form from the publication of this research work.

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