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Experimental Investigation of Spark Ignition Engine Performance and Emission Characteristics Running with Gasoline – Biogas Blended Fuel

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Abstract— *The research deals with an experimental investigation of a biogas-gasoline blend fuel to run a spark-ignition engine. It studies the effect of engine loads and biogas flow rate on the performance and exhaust gas emissions of a spark-ignition engine run in biogas-gasoline blended fuel. Biogas was refined with a methane content of 45.5% by volume and 10.7% by volume of CO_2. The main objective of this finding was to explore the optimum operating condition of the spark-ignition engine run in blended fuel mode. The experiments are performed on a single-cylinder, four-stroke, air-cooled, and naturally aspirated gasoline engine with a rated output power of 3.31 kW. Both the engine load and the biogas flow rates varies from 0% to 80% and 2L/min, 4L/min, 6L/min, 8L/min, respectively. Based on the result, at 2L/min better performance and lower emission were obtained. On the other hand, for blended fuel mode with a biogas flow rate of 2L/min showed an average reduction in brake power, brake torque, and BTE by 2.81%, 3.65%, and 15.94%, respectively. And a Bsfc increased by 11.82% when it was compared to gasoline mode. Whereas, an increment in CO, CO_2, and HC was by 10.18%, 12.8%, and 6.01%, respectively. Similarly, an average reduction to, O_2 and NOx emissions by 7.01% and 19.91%, respectively were obtained for blended fuel mode.*

Keywords— *Alternative fuels, Biogas,Emission, gasoline fuel, Performance, SI Engine.*

I. Introduction

In the nineteenth century, the development of automobiles powered by an internal combustion engine (ICE) was the greatest satisfaction among automobile engineering achievements [1]. It was witnessed that the availability of low-cost fuel, ease of use, increased reliability, and long driving range had boosted the acceptance of these vehicles. The sources of energy for internal combustion engines are conventional fossil fuels (Gasoline and diesel) and alternative fuels. A gasoline engine, which is a class of ICEs**,** generates power by burning a volatile liquid fuel (gasoline or a gasoline mixture) being ignited by an electrical spark in the combustion chamber. The process of mining and using fossil fuels has become expensive, pollutant, and time taking [2]. So, researching alternative renewable energy sources has become necessitated. To this effect, Studies have shown that alternative renewable fuels, such as biofuel energy source biogas have become good solutions for problems resulted from deiseal and gasoline fuel [3]. Bioenergy, which is one of the renewable energy types, is derived from the conversion of biomass [4]. The types of bioenergy are identified as biodiesel, bio-oil, producer gas, and biogas [3]. Biogas is one of the extended biomass energy sources utilized for power generation. It is produced by the anaerobic decomposition of organic materials such as cow dung and other waste such as cornhusks, leaves, straw, garbage, the flesh of carcasses and any cellulosic organic material of animal or plant origin which are easily bio-degradable[5].

Different researchers have put much emphasis on the use of gaseous fuels to be used in internal combustion engines in fuel blending operation. T.O.kukoyi et al. [6] highlights the popular alternative fuels been utilized in a spark-ignition engine in terms of performance, renewability, ease of integration into existing infrastructure and cost and concluded that biogas is a suitable alternative gas for the petrol engine. A.Arul et al. [7] Investigated the effect of biogas blend with gasoline in specific fuel consumption, brake thermal efficiency and emission. A significant increase in specific fuel consumption and reduction in thermal efficiency of the engine was observed. Moreover, the concentration of CO, CO_2 and HC emission was found to be decreased and reversed for the case of NOx for biogas blends. Saiful Bari [8] carried out a study on the effect of carbon dioxide on the performance of biogas – diesel dual-fuel engine. It is found in this research that the presence of as high as 40% carbon dioxide in biogas did not deteriorate the engine performance much as compared to the performance of the engine with natural gas (96% methane), in dual – fuel mode. Eui-Chang et al. [9]Examine the effect of the biogas composition on engine performance and suggested that at the lowest carbon dioxide dilution maximum engine performance is obtained. Zuohua Huang et al. [10] Carried out an experimental investigation on the influence of different hydrogen fractions and Exhaust Gas Recirculation (EGR) on the performance and emission of a spark-ignition engine and found out that a large EGR rate with increasing hydrogen fraction increases thermal efficiency. Yassin Karagoz[11] Investigated the effect of the addition of hydrogen with biogas on emission and fuel consumption in the Worldwide Harmonized Light-Duty Test Cycle and European Driving Cycle. From the research, it is concluded that a low ratio of hydrogen added to biogas fuel have positive results on emission and fuel consumption. Bruno Vieira et al. [12] Analyze the emission of pollutants and the efficiency of conversion of fuel chemical energy using blends of hydrogen, biogas and methane on the spark-ignition engine. From the research, it is concluded that the addition of hydrogen allowed the combustion limits to be extended and carbon monoxide (CO) and oxides of nitrogen (NOx) values reduced.

A lot of research has been carried out for the last decade about dual-fuel engines and the blending of fuels using gasoline and biogas but most work has been focused on the performance and emission characteristics [13-14]. The results of the previous work have not given very conclusive results on the effect of raw biogas-gasoline blend with varying biogas volume flow rate and engine load on engine performance and emission characteristics of spark ignition engine. Most research work shows that biogas can be used as a substitute for gasoline engine but no optimum operating parameters have been suggested [15][16-18]. In this study effect of engine load and biogas volume flow rate to the performance and emission characteristics of spark ignition engine in using raw biogas blended with gasoline fuel were investigated. The main objective is to explore the optimum operational condition of a SI engine running in blended fuel mode.

II. Method

In order to carry out the study, a single cylinder, four-stroke, air-cooled, and naturally aspirated gasoline engine with a rated output power of 3.31 Kw were used. The specifications of the SI engine are presented in Table 1

TABLE 1. Specification of the engine used in this experiment

Engine Manufacture	Edibon
Engine model	TMC-3
Type of engine	spark ignition
Fuel type	Gasoline
Number of cylinders	1
Number of strokes	Four
Type of air intake	naturally aspirated
Type of cooling	Air cooled
Start	Computer controlled / manual
Compression ratio	8.5:1
Maximum power	4.2HP/3.13kW @ 3600 rpm
Cylinder bore	69mm
Stroke	60mm
Dynamometer	Asynchronous motor dynamometer

In order to measure the load, the engine is coupled with an eddy current dynamometer. The experimental setup is shown in Figure 1. To perform experiment, several additional equipment are installed to the experimental apparatus such as a biogas tank, exhaust gas analyzer and volume flow rate measurement apparatus (Rotameter). In pure gasoline fuel mode, the SI engine is tested without modification. In blended fuel mode, biogas is mixed with gasoline fuel in different flow rate ratio.

Fig. 2.1. Experimental setup

The experiments are performed in two modes. In the first mode, the spark ignition engine is operated with gasoline fuel. In this mode, the load is varied from 0% to 80% and engine speed is fixed at 1750 rpm. When the SI engine is stable, the measurement is carried out in 10% increment engine load variation. The second mode, the spark ignition engine is operated in the blended fuel mode, when the SI engine is operated, the biogas from the tank is mixed with the fresh air. The flow rate of the biogas is varied from 2L/min to 8L/min with 2L/min increment. For every load, the biogas flow rate is varied and the speed is adjusted to get constant speed. The same measurements with the pure gasoline are performed. Every test is replied for two times and the measurement is averaged. The characteristics of the exhaust gas are investigated using parameters CO, CO_2, HC, O_2, and NOx. These parameters are measured using automotive exhaust gas analyzer. The model of Gas Analyzer is SV-50. The specification of the Gas Analyzer is presented in Table 2.

TABLE 2. The technical specification of exhaust gas analyzer

S.N	**Measured Quantity**	**Measuring range**	**Resolution**	**Allowed error**	**Relative error**	**Accuracy**
1	CO	0 – 10.0 10^{-2}(%)	0.01 (%) vol.	± 0.06%	±5%	0.03% vol.
2	HC	0 – 10000 10^{-6} (ppm)	1ppm vol.	± 12ppm	±5%	10ppm vol.
3	CO_2	0-20 10^{-2} (%)	0.1 (%) vol.	± 0.5%	±5%	0.5% vol.
4	O2	0 – 25 10^{-2} (%)	0.01 (%) vol.	±0.1%	±5%	0.1 % vol.
5	NOx	0 –800 10^{-3} (ppm)	1ppm	± 10ppm	±5%	10ppm

Problem Formulation

The measured data is analyzed using several parameters. The performance of the engine was analyzed using brake power, brake torque, brake thermal efficiency and specific-fuel consumption. The brake power is of the SI engine is calculated using the following equation.

$$\text{Brake Power (kW)} = \frac{(2\pi NT)}{60\times1000}$$

Where N and T are speed of the engine and engine torque respectively.

The brake torque is the available torque on the flywheel.

$$T = WR$$

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W= mg

Where R is the radius, m is mass in kg and g is the gravitational acceleration. Brake thermal efficiency is the ratio of its output power to the energy supplied by the fuel.

$$BTHE\ (\%) = \left(\frac{pb \times 3600}{m_f \times LHVf}\right) \times 100$$

Where pb is the brake power, mf is mass of fuel and LHV is lower heating value of fuel. Brake specific fuel consumption is the measure of the engine's ability to produce power by utilizing the energy content of the fuel.

$$Bsfc\ (Kg/Kw.hr) = \frac{m_f}{Pb}$$

III. RESULT AND DISCUSSIONS

Results of the experiments on the effect of engine load variation and biogas volume flow rate on engine performance and emission of blended fuel engine are presented. Moreover, the variation and trends of the results are discussed.

This chapter is divided in to two section to explain the effect of engine load and biogas flow rate variation in detail.

Effect of Engine Load and Biogas Volume Flow Rate Variation on Engine Performance

The performance of the engine (brake power, BSFC, BTHE) when using pure gasoline and gasoline-biogas blends under varying engine load (0%, to 80%) with a 10% increment results obtained were analyzed and discussed as follows.

Brake Power

According to Figure 3.1 shown below the brake power of the engine increases with the engine load (0% - 80%) both for pure gasoline and biogas blended with various volume flow rates (2lpm, 4lpm, 6lpm, and 8lpm). The average brake power reduction of biogas- gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 2.81%, 4.45%, 5.61% and 6.03 % respectively. To this effect it is indicated that at lower engine loads (0- 40%) with highest volume flow rates (6L/min and 8L/min) produced greater engine power as compared to other volume flow rates and engine load variation.

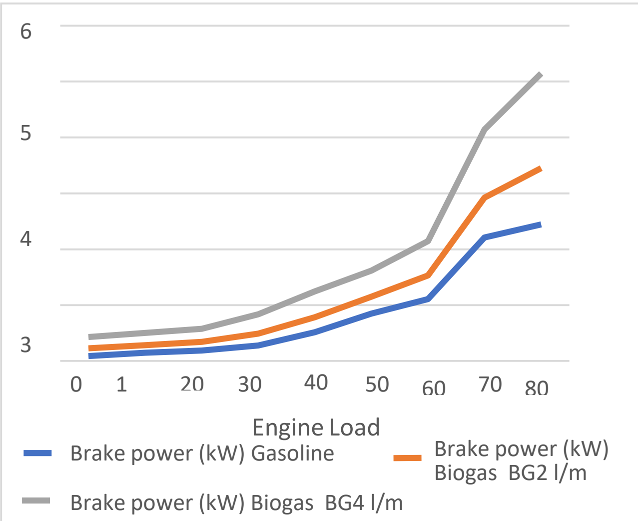

Fig. 3.1. Engine brake power under varying engine load and different volume flow rate of biogas-gasoline blend.

Engine Torque

According to Figure 3.2 shown below the brake power of the engine increases with the engine load (0% - 80%) both for pure gasoline and biogas blended with various volume flow rates (2lpm, 4lpm, 6lpm, and 8lpm). Generally, the average brake power reduction of biogas- gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 2.81%, 4.45%, 5.61% and 6.03 % respectively. Due to this reason it is indicated that at lower engine loads (0- 40%) with highest volume flow rates (6L/min and 8L/min) produced greater engine power as compared to other volume flow rates and engine load variation.

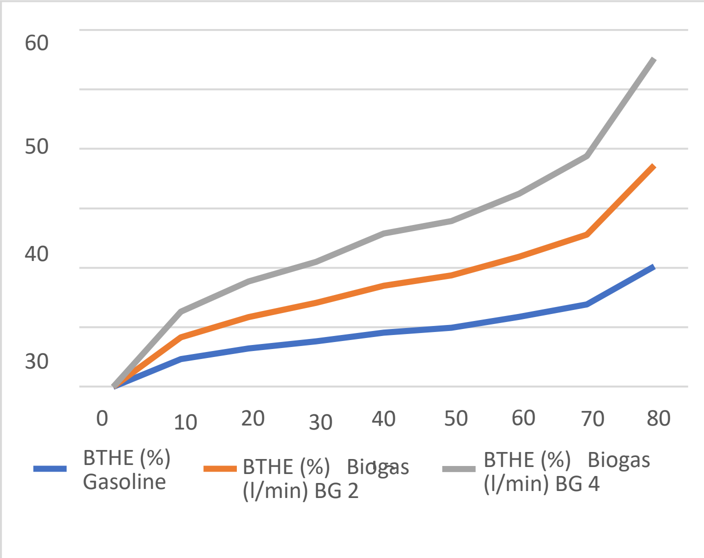

Fig. 3.2. Engine torque under varying engine load for different volume flow rates of biogas

Brake Thermal Efficiency

From figure 3.3, it is shown that brake thermal efficiency increases as the volume flow rate and engine load increases for both fuel modes but blended fuel were slightly lower than pure gasoline fuel mode.

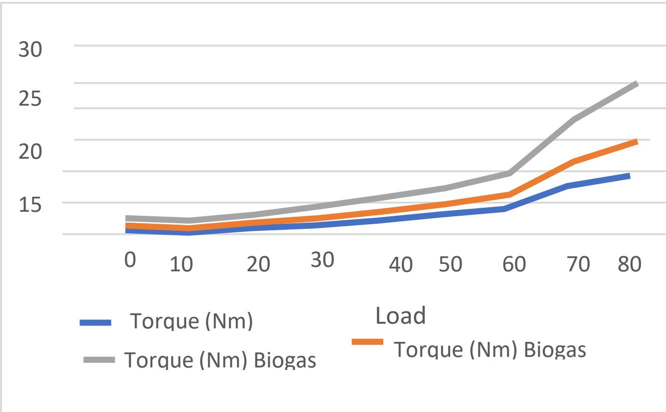

Fig. 3.3. BTHE under varying engine load for different volume flow rates of biogas.

Generally, the average brake thermal efficiency reduction of biogas- gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 3.65%, 5.47%, 6.61% and 6.87 respectively. To

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this effect it is indicated that at lower engine loads (0- 40%) with highest volume flow rates (6L/min and 8L/min) produced greater brake thermal efficiency as compared to other volume flow rates and engine load variation.

Brake Specific Fuel Consumption

From figure 3.4. It is shown that brake specific fuel consumption was found higher at lower engine loads for both fuel modes. This is due to lower output power at a lower load. Generally, the average brake specific fuel consumption increment of biogas- gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 3.65%, 5.47%, 6.61% and 6.87% respectively. To this effect it is indicated that at higher engine loads (40- 80%) with highest volume flow rates (6L/min and 8L/min) produced smaller brake specific fuel consumption as compared to other volume flow rates and engine load variation.

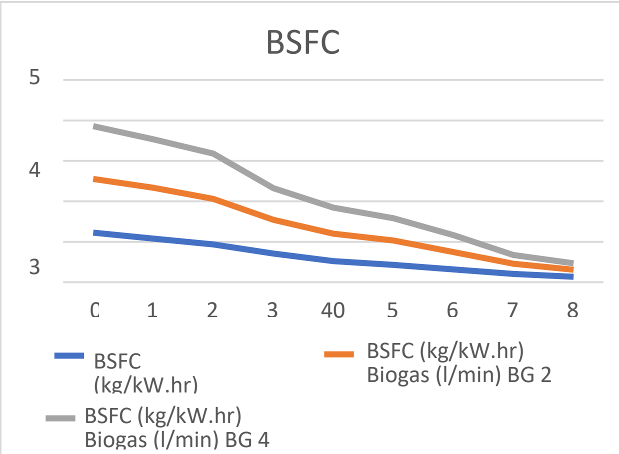

Fig. 3. 4 BSFC under varying engine load and different volume flow rate of biogas

Emission Characteristics Analysis

NOX Emission

NOx emission formation is mainly dependent on the in-cylinder temperatures, availability of oxygen and the retention time for the reaction for during combustion. The availability of oxygen is dependent on the air-biogas mixture ratios. Figure 3.5 illustrate the variation of NOx emission with the varying engine load for different biogas ratios.

Generally, the average NOx increment of biogas- gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 19.3%, 29.33%, 40.61, 48.8% respectively. To this effect it is indicated that at lower engine loads (0- 40%) with highest volume flow rates (6L/min and 8L/min) produced smaller NOx emission as compared to other volume flow rates and engine load variation.

Unburned Hydrocarbon Emission (PPM VOL)

The unburned hydrocarbon variation with varying engine load at different biogas ratio is depicted in Figure 3.6. The unburned hydrocarbon (UHC) emission in blended fuel mode at highest volume flow rate is greater than pure gasoline fuel, under all engine loads. This is due to the reason that the presence of CO_2 reduces the flame velocity of biogas which intern leads to poor combustion. Unburned hydrocarbon increases as the biogas flow rate increases, this is because as the biogas flow rate increases the amount of air enters the combustion chamber decreases which results in a rich mixture as compared to a low biogas flow rate and causes incomplete combustion inside the cylinder. Generally, the average unburned hydrocarbon increment of biogas- gasoline blended fuel at 6L/min and 8L/min were 6.01%, 19.29% respectively. To this effect it is indicated that at lower engine loads (0- 40%) with lowest volume flow rates (2L/min and 4L/min) produced smaller unburned hydrocarbon emission as compared to other volume flow rates and engine load variation.

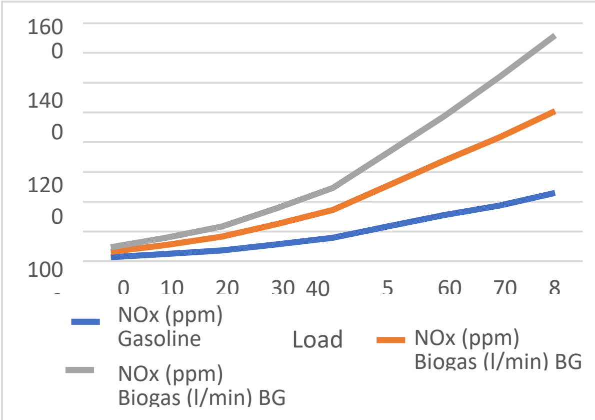

Fig. 3.5. Variation of NOx emission with the varying engine load for different biogas ratios.

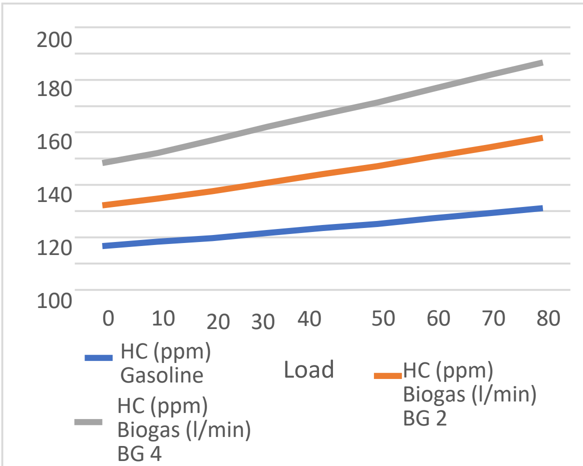

Fig. 3.6. HC emission under varying engine load for different volume flow rates of biogas.

Carbon Monoxide Emission (% VOL)

Carbon monoxide emission is produced to the incomplete oxidation of carbon atoms caused by the fuel-rich mixture in which oxygen availability is less. Emission of carbon monoxide at different flow rates is shown in Figure 3.7. It is observed that biogas- gasoline blended fuel produces higher CO than pure gasoline fuel mode. Generally, the average carbon dioxide increment of biogas- gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 3.65%, 5.47%, 6.61% and 6.87% respectively. To this effect it is indicated that at lower engine loads (0- 40%) with lowest volume flow rates (2L/min and 4L/min) produced smaller carbon dioxide emission as compared to other volume flow rates and engine load variation.

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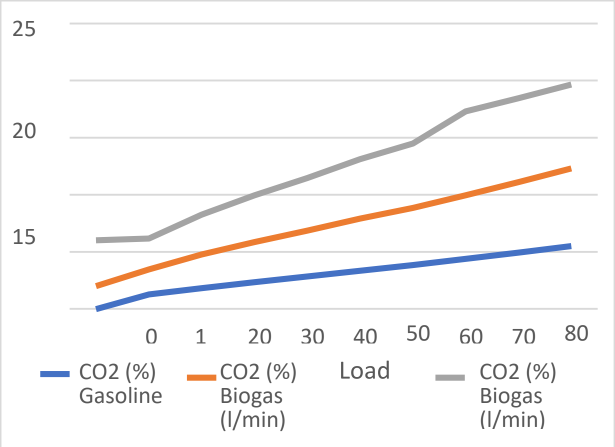

Fig. 3. 7. CO emission under varying engine load and different volume flow rates of biogas.

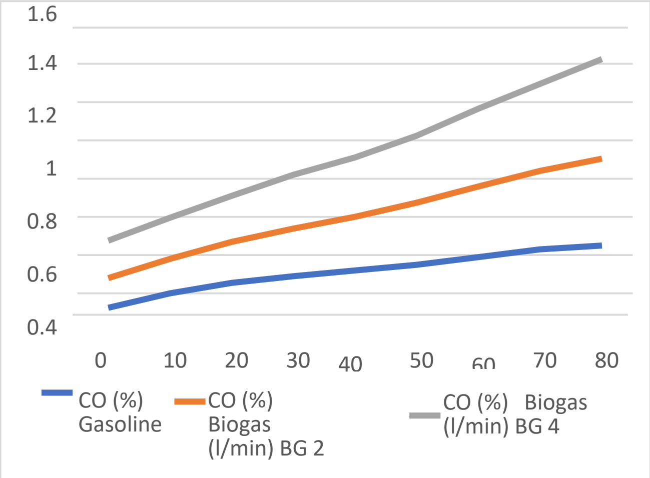

Fig. 3.8. CO_2 emission under varying engine load and different volume flow rates of biogas.

Carbon Dioxide (CO_2)

The carbon dioxide emission increases with increase in load and volume flow rate for both fuel types. This is because of an increase in combustion rate fuel to high combustion temperature as compared to low loads. It can be seen from figure 3.8 that CO2 emission is lowest at lower engine load and volume flow rate. Carbon monoxide emission increased as the engine load and flow rates increased. In blended fuel mode due to the existence of carbon dioxide in biogas, carbon dioxide emission is noticed higher as compared to pure gasoline mode. Generally, the average carbon dioxide increment of biogas-gasoline blended fuel at 2L/min, 4L/min, 6L/min and 8L/min were 12.8%, 25.98%, 47.33% and 50.87 respectively. To this effect it is indicated that at lower engine loads (0- 40%) with lowest volume flow rates (2L/min and 4L/min) produced smaller carbon dioxide emission as compared to other volume flow rates and engine load variation.

IV. Conclusion and Recommendation

Experimental study was done on the effects of volume flow rate and engine load variation parameters on performance and emission characteristics of a blended fuel engine running on biogas. The experiments were conducted in a single cylinder, four stroke, and air-cooled naturally aspirated gasoline engine at a constant compression ratio of 8.5:1. The following conclusions were deduced from the results that were obtained from the experiments:

1. The output power of the spark ignition run in blended fuel mode is better than pure gasoline mode.
2. Brake thermal efficiency of the spark ignition engine run in dual-fuel mode is better than pure gasoline mode if the biogas flow rates are 2 L/min and 4 L/min.
3. The output brake torque of the spark ignition run in blended fuel mode is better than pure gasoline fuel mode.
4. The exhaust gas analysis shows biogas reducing capacity of the exhaust gas.
5. The carbon monoxide number of the engine run in blended fuel mode is very high in comparison with pure gasoline mode.
6. The hydrocarbon emissions reduced at lower volume flow rate 2L/min, 4L/min.
7. Oxides of Nitrogen reduced when the biogas volume flow rate increases.
8. From the analysis of results, it can be concluded that a 3.31 Kw single cylinder, air-cooled, four stroke, naturally aspirated in a blended fuel mode has optimum performance and emission characteristics at compression ratio of 8.5:1, 4L/min biogas flow rate, engine load 40% and engine speed of 1760. It is recommended to use biogas-gasoline blended fuel as: an alternative fuel source, medium speed range engine such as generators, pumps, 2 stroke engines with modification. Moreover, regarding in increasing engine performance and reducing exhaust emission it is recommended to purify the biogas or use with a lower volume substitution.

References

[1] S. A. Stern, B. Krishnakumar, S. G. Charati, W. S. Amato, A. A. Friedman, and D. J. Fuess, "Performance of a bench-scale membrane pilot plant for the upgrading of biogas in a wastewater treatment plant," vol. 151, pp. 63–74, 1998.
[2] G. J. Amador, P. G. Juan, A. Adolfo, and A. Arrieta, "ScienceDirect Effect of equivalence ratio on knocking tendency in spark ignition engines fueled with fuel blends of biogas , natural gas , propane and hydrogen," no. xxxx, 2018.
[3] H. G. Chaudhari, T. M. Patel, and P. P. R. Patel, "Effect of Supercharging & Injection Pressure on Engine Performance Characteristic of Jatropha Biodiesel Blend," vol. 14, no. 2, pp. 21–32, 2017.
[4] *23rd Transport and Air Pollution (TAP) conference – Part II*, no. May. 2019.
[5] A. Rimkus, G. Przybyła, and P. Dro, "applied sciences Effect of Hydrogen Addition on the Energetic and Ecologic Parameters of an SI Engine Fueled by Biogas," pp. 1–16, 2021.
[6] P. G. Aleiferis and D. Richardson, "An Analysis of the Combustion Behavior of Ethanol , Butanol , Iso -Octane , Gasoline , and Methane in a Direct-Injection Spark-Ignition Research Engine," vol. 2202, 2013.
[7] M. Y. E. Selim, "Sensitivity of dual fuel engine combustion and knocking limits to gaseous fuel composition," vol. 45, pp. 411–425, 2004.
[8] T. Engineering and S. Issue, "Effect Of Hydrogen Addition At Different Levels On Emissions," vol. 4, no. 2, pp. 1780–1790, 2018.

[9] V. Gnanamoorthi and N. M. Mohandoss, “Environmental Effects Combustion , performance and emission analysis of dual fuel engine using tsrb biogas,” *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 00, no. 00, pp. 1–13, 2018.
[10] Y. Zhou *et al.*, “The impact of population urbanization lag on eco-efficiency : A panel quantile approach,” 2019.
[11] H. G. Chaudhari, T. M. Patel, and P. P. R. Patel, “Effect of Supercharging & Injection Pressure on Engine Combustion Characteristic of Jatropha Biodiesel Blend Effect of Supercharging & Injection Pressure on Engine Combustion Characteristic of Jatropha Biodiesel Blend,” no. September, 2019.
[12] S. Kumar, V. G. Srinivas, K. Murthy, and M. S. Sudheer, “Simulation and Experimental Validation of Combustion Characteristics of Dual Fuel LPG- Diesel Engine,” vol. 39, no. 6, pp. 1937–1944, 2021.
[13] T. Patel, A. Dubey, and M. Feroskhan, “Environmental Effects Investigation on the effect of intake air pressure in a biogas-diesel fueled dual-fuel engine,” *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 00, no. 00, pp. 1–17, 2020.
[14] T. Zhang, “Possibilities of Alternative Vehicle Fuels – A literature review,” 2015.
[15] K. Senthilkumar, S. Vivekanandan, A. Nagar, T. Nadu, A. Nagar, and T. Nadu, “Investigating the Biogas as Secondary Fuel for Ci Engine,” vol. 11, no. 1, pp. 155–163, 2016.
[16] M. M. Musthafa, “Production of Biogas from Multiple Feedstocks and its Application as a Fuel for Spark Ignition Engines - A Review,” vol. 4, no. 3, pp. 4–9, 2020.
[17] A. Katijan, “The Effect of Compression Ratio by Different Piston Head Shape on the Performance of Motorcycle Engine,” no. February, 2021.