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Performance and Emission Characteristics of Lime treated Biogas in Dual Fuel Mode in Single Cylinder Diesel Engine using Electronic Fuel Injector

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Abstract: This paper present the diesel engine characteristics operated with dual fuel mode (Diesel and Lime treated Biogas) injected through electronic fuel injection system. Biogas, composed principally of methane, has limited use in energy generation due to the presence of carbon-dioxide (CO_2).Biogas cannot be burned directly in the combustion chamber as CO_2 presence causes corrosion in the reaction chamber. There are various technologies to reduce CO_2 in the biogas, most of which are chemical based, expensive and are limited in use. Lime treatment is the one of the methods to enrich CH_4 in the biogas.

During experimentation the engine is made to run with diesel and lime treated biogas and the investigations are done. The engine performance is measured in terms of the brake thermal efficiency and exhaust emission is measured in terms of carbon di-oxide (CO_2), carbon mono-oxide (CO), and hydrocarbon (HC). It is found that the break thermal efficiency of electronic injection of lime treated biogas and diesel increases by 2% when compared with manifold injection of lime treated biogas and diesel. It is obtained that dual fuel engine with lime treated biogas injected through electronic injection system showed a reduction in emission of carbon mono-oxide by 9% on comparison with manifold injection of lime treated biogas and diesel and also the emissions of CO_2 were found to be reduced to 0.5%, the HC emission was found to be reduced by 10%, the smoke emissions were found to be reduced by 2% and the NO_X emissions were found to be increased by 15% with that of the manifold injection system. Thus the electronic injection of lime treated biogas and diesel improves the efficiency of the engine and reduces the various emissions from the vehicle.
Keywords: Electronic fuel injection, Manifold injection, Lime treated Biogas, Emission and Performance Characteristics.

I. Introduction:

The search for efficient alternate fuel is becoming more due to the increase in environmental pollution. Now different types of alternative fuels are used in various vehicles and engines. The alternative fuels in use today include ethanol, biogas, methanol, natural gas, propane and hydrogen. All the above alternate fuels can be used as fuel but only biogas can be used in IC engines.

Biogas typically refers to a gas produced by the breakdown of organic matter in the absence of oxygen. Biogas is produced by anaerobic digestion of bio-wastes. It is a clean and renewable fuel. Biogas comprises primarily of methane and carbon dioxide and may have small amounts of hydrogen Sulphide, moisture and Siloxanes.

Lime treated biogas is the one in which the biogas is made to fill, and the biogas is passed to the lime treatment process in which the amount of the flue gases are escaped, and the emission will be less in the lime treated biogas.

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. The electronic fuel injection is a system for directly admitting fuel into an internal combustion engine. It has become the primary injection system replacing a direct injection engine, fuel is injected into a separate pre-combustion chamber. Here piezoelectric injectors are used for injecting the fuels as it gives an increased precision of about 1800 bar or 26000 psi.

II. Literature Review:

Technologies recover biogas by harnessing anaerobic degradation pathways controlled by a suite of microorganisms. The biogas released acts as an environmentally sustainable energy source, while providing a method for disposal of various wastes. Biogas contains 50–70% methane and 30–50% carbon dioxide. Various appliances can be fueled by biogas, with stoves offering an application appropriate for deployment in developing countries[1].

A diesel vehicle fitted with a particulate filter showed substantial reduction of particulate matter with a number concentration equivalent to gasoline and LPG fuel. Moreover, bio-fuels and natural gas have the potential to reduce the particulate emissions with the help of clean combustion and low-carbon fuel quality compared to non-diesel particulate filter diesel-fueled vehicles[2].

The experimental results were analyzed for the selection of better blend of L.P.G and Biogas suitable for SI engine for better performance with reduced pollution. From the results, it is clear that at 50% blending of biogas the engine performance is found to be very appreciable. At this

50% blending trial particularly at full load the specific fuel consumption and brake thermal efficiency are high when compare to the petrol, LPG and the mechanical efficiency is high for the 50% blending with compared to the Petrol, L.P.G, and 40% Blending. And, also the emission values of CO, HC and NOx is minimum for the biogas when compared to the petrol, L.P.G. when the blending percentage increases the emission values are decreased. The petroleum fuel with its combustion products, pollute the air to great extent. In this case the intensity of pollution problem will be less because of blending this eco-friendly fuel biogas. Thus biogas may be the promising fuel for the future[3].

Depletion of petroleum derived fuel and environmental concern has promoted to look over the biofuel as an alternative fuel sources. But a complete substitution of petroleum derived fuels by biofuel is impossible from the production capacity and engine compatibility point of view. Yet, marginal replacement of diesel by biofuel can prolong the depletion of petroleum resources and abate the radical climate change caused by automotive pollution. But, severe corrosion, carbon deposition and wearing of engine parts of the fuel supply system components are also caused by biodiesel. Discussing all this advantages and disadvantages of biodiesel, it is comprehended that, a dedicated biodiesel engine is the ultimate solution for commercializing biodiesel. Minor modifications on the engine may not cost much; but continuous research and development is still needed[4].

A single cylinder vertical air-cooled diesel engine was modified to use LPG in dual fuel mode to study the performance, emission, and combustion characteristics. The primary fuel, liquefied petroleum gas (LPG), was mixed with air, compressed, and ignited by a small pilot spray of diesel. Dual fuel engine showed a reduction in oxides of Nitrogen and smoke in the entire load range. However, it suffers from the problem of poor brake thermal efficiency and high hydrocarbon and carbon monoxide emissions, particularly at lower loads due to poor ignition. In order to improve the performance at lower loads, a glow plug was introduced inside the combustion chamber[5].

An experimental investigation was performed to study the influence of dual-fuel combustion characteristics in a diesel engine fueled with biogas–biodiesel dual fuel. Biogas was injected during the intake process by two electronically controlled gas injectors, which were installed in the intake pipe. The results of this study showed that the combustion characteristics of single-fuel combustion for biodiesel and diesel indicated the similar patterns at various engine loads. Significantly lower NOx emissions were emitted under dual-fuel operation for both cases of pilot fuels compared to single-fuel mode at all engine load conditions. Also, biogas–biodiesel provided superior performance in reductions of soot emissions due to the absence of aromatics, the low sulfur, and oxygen contents for biodiesel[6].

The usage of lime treated biogas in addition to diesel improves the fuel consumption; thermal efficiency and emission specific fuel consumption is less for the lime treated biogas, whereas the thermal efficiency is improved for lime treated biogas. Emissions of NOx smoke and CO2 were found to be less for lime treated biogas on comparison with biogas[7].

It can be concluded that the combination of diesel and lime treated biogas of dual fuel engines can be applied to increase thermal efficiency as well as to reduce methane and carbon monoxide emissions. The exhaust emission decreased significantly with biogas and diesel compared to diesel alone. It is also found that the emission can be further decreased by using electronic fuel injectors instead of manifold injection thereby reducing environmental pollution. Normal compression ignition engines cannot run on biogas since the auto-ignition temperature is higher than diesel, so biogas is pre-heated.

2.1 Production of Biogas:

Biogas is also produced from the methanisation of farm waste. Anaerobic digestion is a biological process in which biodegradable organic matters are decomposed by bacteria forming gaseous by products. The gaseous by product consists of methane (CH4), carbon dioxide (CO_2), and tresses of other gases [8].

2.2 Pre-Heating of Biogas:

Biogas contains methane, carbon dioxide, Sulphur and other small constituents. In the composition of biogas methane is the only one needed during combustion to remove emission and corrosion of engine cylinder. So in order to remove one of such constituents, we need a process called pre-heating.

2.3 Lime Treatment of Biogas:

Lime treatment is one of the methods enriching the CH4 in biogas. During lime treatment, the reaction takes place is,

Ca(OH)2 (aq) + CO_2 CaCO3 (s) + H2O (l) [9].

The lime treatment of biogas is done by using an amount of one kg lime stone into the cylinder mixed with four liters of water. The entire setup is surrounded by ten liters capacity of a small tank to cool the cylinder.

2.4 Engine Specification:

Table 1.1

Product code	**PMVBB**
Bore	114.30 mm
Stroke	139.70 mm
Displacement	1432 cm3
No. of cylinders	1
Compression ratio	17:1
Rated RPM	660 RPM
Injection method	IDI
Fuel consumption	265 g/kwhr
Power	6.00/4.40 hp/kw
Maximum torque nm/rpm	63.6 /660
Method of starting	handle start
Engine cooling method	water cooled
Oil sump capacity	4.50 l

III. Experimental Setup:

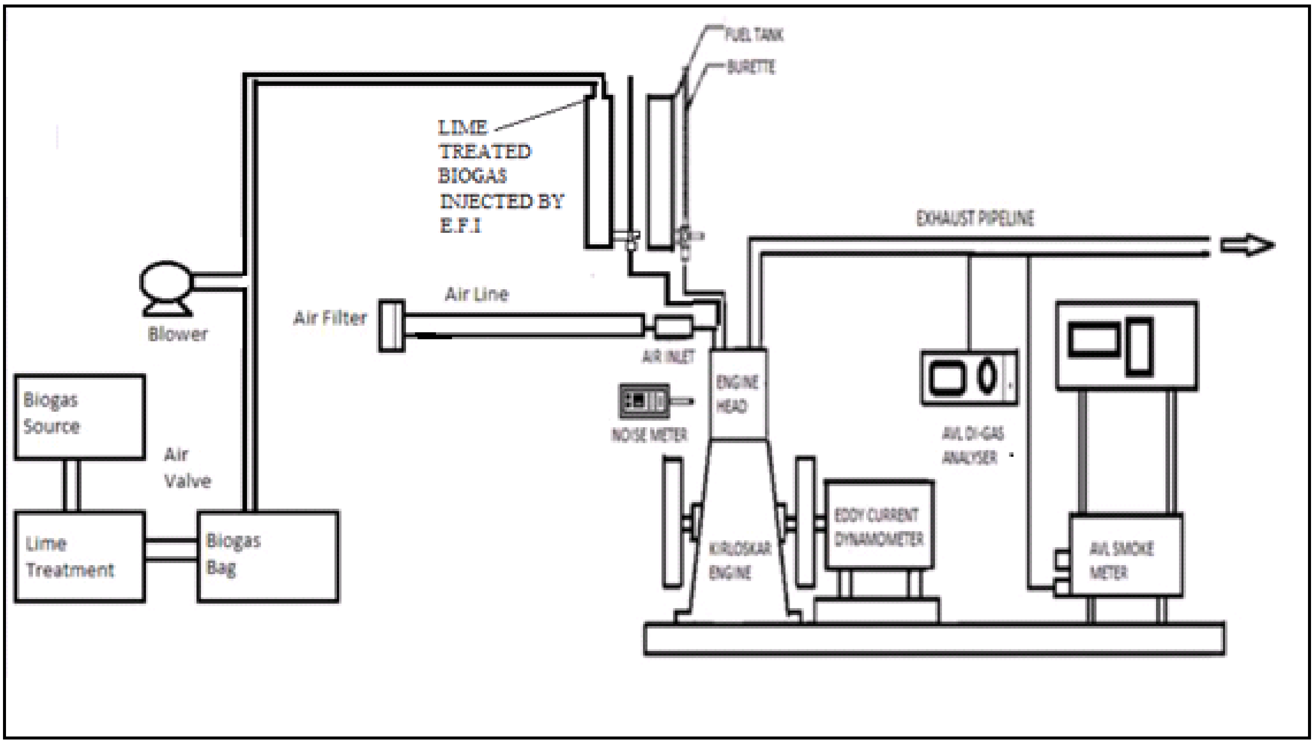

Figure 3.1

The setup of the project has a group of component which has electrical interface with each part, the proximity sensor detects the movement of rocker arm which has a displacement movement. Then the signal goes to the relay through a series connection of an electrical wire, where the impulse hits the armature of relay and passes an output to the solenoid valve.

A battery of 12V power having a suitable ampere rating measure to the solenoid valve which act as fuel injection device directly to the head of engine. This solenoid is only used for the flow of lime treated biogas directly injected to the engine head. This solenoid gets a triggering pulse from relay from a 12V battery also this power system is regulated to proximity sensor. This signal is sent to the system through a digital terminal (data) of the proximity sensor and other two terminals is for power, where one terminal is ground and other is positive 5 V. The armature terminal of solenoid valve sends the electrical signal pulse to the solenoids 12V positive supply and the ground as the common.

IV. Results and Discussions:

4.1. Comparison of Performance Characteristics of Diesel, Lime Treated Biogas on Manifold and Direct Injection

4.1.1 Brake Thermal Efficiency

The Figure 4.1 shows the variation of Brake thermal efficiency with brake power for Diesel, Lime treated biogas on manifold and direct injection. In general break thermal efficiency indicates ability of the combustion system that how efficiently energy of the fuel can be converted into mechanical productivity. The variation of Brake thermal efficiency with brake power for Diesel, Biogas and Lime treated biogas. If we use lime treated biogas as a secondary fuel, then the break thermal efficiency will be greater when compared to diesel because due to carbon content present in the biogas, lower energy contents in diesel fuel with biogas. Brake thermal efficiency increases when using electronic injection of lime treated biogas compared to manifold injection of lime treated biogas and diesel.

BP VS BTE

- BG - Biogas
- LBG - Lime treated Biogas

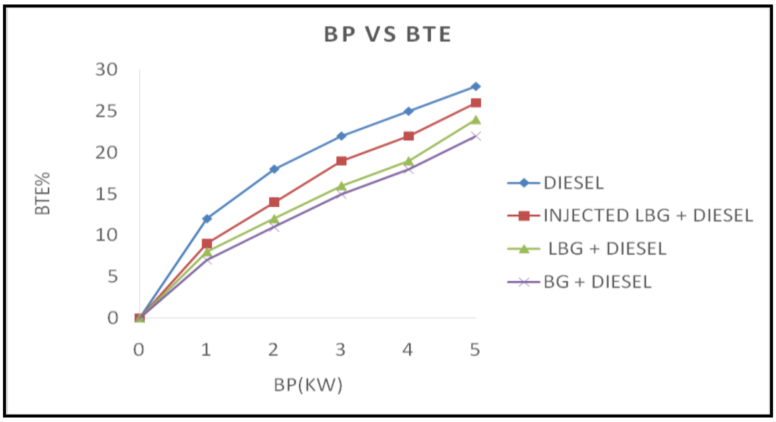

Figure.4.1.BP vs. BTE

4.2 Comparison of Emission Characteristics of Diesel, Lime Treated Biogas on Manifold and Direct Injection

4.2.1. Carbon monoxide Emission

Figure 4.2 shows the variation of carbon monoxide emission in percentage with brake power of Diesel, Lime Treated Biogas on Manifold and Direct Injection. In general Carbon monoxide is a product of incomplete combustion due to insufficient amount of air in the air fuel mixture or insufficient time in the cycle for completion of combustion.

The CO emission for MI. LBG increase with increase in load for all fuels, this is because of insufficient time to complete combustion process. But in DI- LBG at first CO emission is high due to rich fuel mixture and it is decreased on loading. The CO emission is high for normal biogas due to high carbon content that adversely affects the combustion efficiency. But in all LBG the amount of carbon content is reduced and it makes CO emission is near to Diesel. Thus, DI-LBG have good combustion rate and calorific valves which required for good flame rate in the combustion cylinder.

BP VS CO

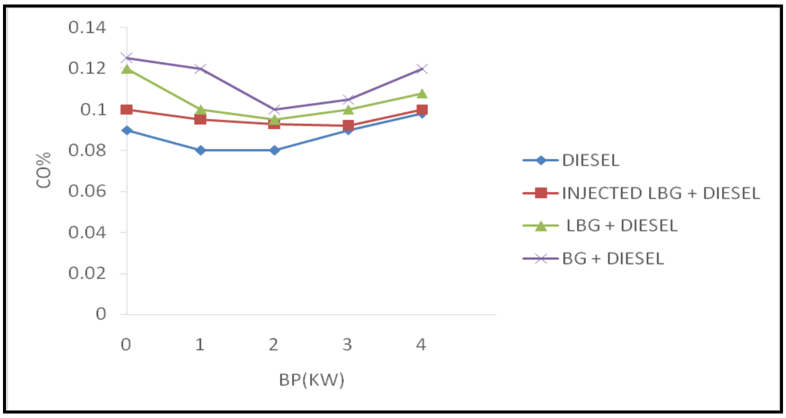

Figure.4.2.BP vs.CO

4.2.2. Carbon dioxide Emission

This figure shows 4.3 the variation of carbon dioxide (CO_2) emission in percentage by volume with brake power for biogas and lime treated biogas with diesel in different injection mode. The CO_2 emissions increase with an increasing brake power; it indicates the efficiency of the combustion chamber. The lower percentage of LBG with Diesel emits almost same amount of CO_2 in comparison with diesel. The CO_2 increases gradually as the brake power increases this is due to the increase of carbon content in the biogas. But the CO_2 emission in the biogas is high as compared to the diesel and the bio gas and LBG, also the content of carbon in the biogas increased, so the CO_2 level in the exhaust is increased. The oxygen content in the exhaust gas will decrease gradually, this is due to the complete combustion is occurred as the load is increased. This is because of the residual content in the biogas. But from the fig 4.3 it is clear that the CO_2 emission was less for lime treated biogas than the non-treated biogas. Biogas and diesel mixture has high CO_2 emission and as the temperature of biogas increases while it is treated with the lime the CO_2 emission also increases. The increase in CO_2 was due to oxidation of the CO. The late burning of the mixture of diesel and biogas has caused more fuel to remain partially unburned. This increases the formation of carbon monoxide and decreases the proportion of the carbon dioxide level. The above graph also shows that the manifold injection of LBG with diesel shows a increased CO_2 emission than the electronic injection of the fuel mixture.

BP VS CO_2

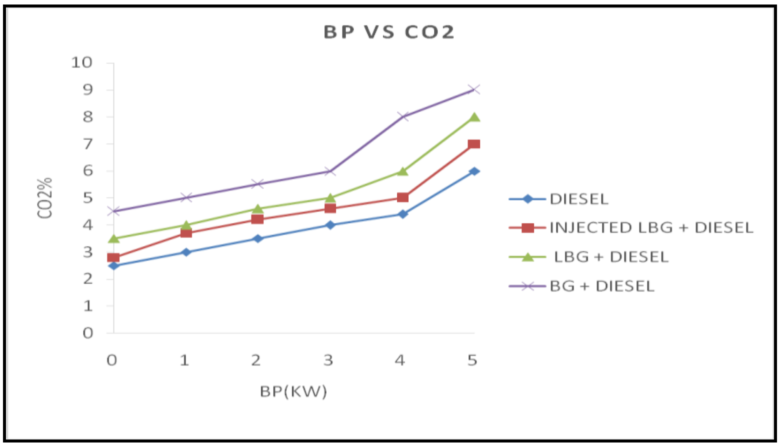

Figure.4.3.BP vs.CO_2

4.2.3 Hydrocarbons Emission

The Figure.4.4 shows the variations of un-burnt hydrocarbons (HC) emission in parts per million (ppm) with brake power of Diesel, Lime Treated Biogas on Manifold and Direct Injection.

In general, HC emission is due to relatively less oxygen the reaction when more fuel is injected into the cylinder at higher loads. When compared to the diesel, HC emission is more in MI.PH LBG. The HC emission of DI LBG is almost equal to Diesel this is because of timed injection of LBG in air suction Stroke of Cylinder. There is also another reason behind increase in HC emission that is over lapping of Inlet and Exhaust Valve but it does not affect in Timed Injection setup.

Since during the MI injection the fuel entering the combustion chamber does not provide good turbulence, the combustion becomes incomplete and leaves a lot of unburnt gas in the exhaust. But during the DI injection the fuel gets mixed with air inside the chamber giving a good turbulence and thus it leaves considerably low unburnt gas in the exhaust compared to MI injection.

BP VS HC

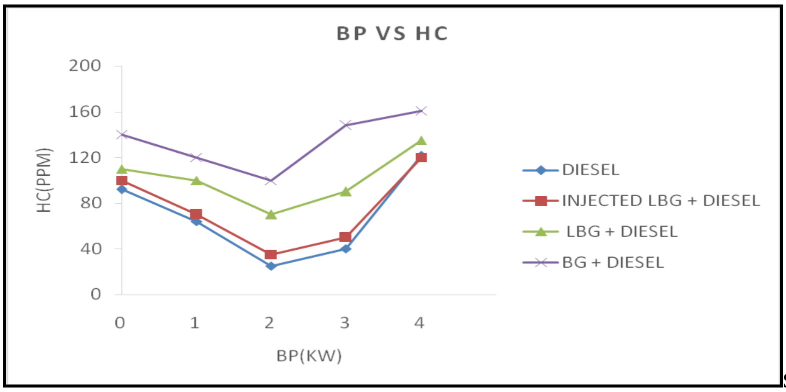

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Figure.4.4.BP vs. HC

4.2.4. Oxides of Nitrogen Emission

The Figure 5.4 shows the variation in NOx emission with brake power of Diesel, Lime Treated Biogas on Manifold and Direct Injection. The oxides of nitrogen in the exhaust emission are nitric oxide (NO) and nitrogen dioxide (NO2). In general the formation of NOx is highly depends on oxygen concentration in the cylinder.

The NOx is very low in both MI. LBG and DI.LBG on comparing with diesel. This is due to high availability of oxygen in both LBG injections and thus low NOx emission produced.

Presence of lot oxygen in the inlet during both MI and DI injection enables the reduction of NOx emission but NOx emission is lower in MI compared to DI since we reduced the air-biogas ratio to reduce CO and HC emission.

BP VS NOX

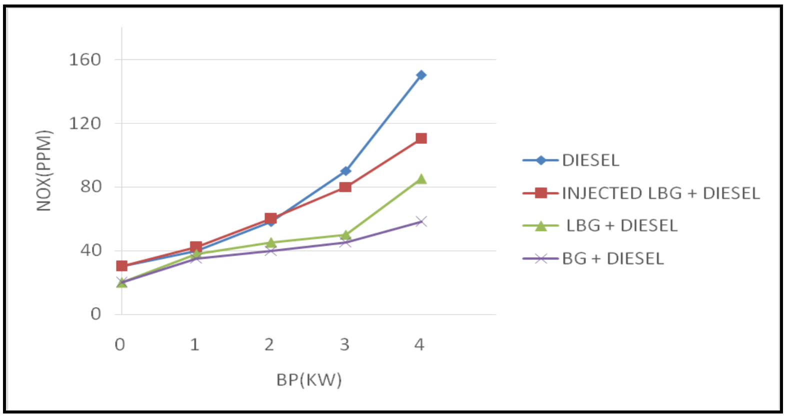

Figure.4.4 BP vs. NOx

4.2.5 Smoke Emission:

The figure 4.5 shows the variation of smoke in HSU with the brake power for biogas and LBG with diesel. For all the percentage of biogas the smoke increases with the increase in brake power. The high emission formed is indicative of incomplete combustion. The smoke emission is higher due to high viscosity and low volatility, which can result in poor mixture formation that leads to less fuel air mixing rates & large mean fuel spray droplet size. The smoke emission is higher for the biogas and LBG than the diesel due to low oxygen borne fuel combusted in the diffusion combustion stages. The amount of smoke present in the exhaust gas is measured to quantify the particulates matter present in the exhaust gas. The increase in ignition delay time improves the mixing process which leads to better combustion reaction and hence reduction of smoke capacity.

Emission of smoke in biogas is less when compared to all the previous fuels. When using lime treated biogas, smoke emission is very low. Smoke of the engine was found to be less as that of NO_x on using diesel with biogas. With the increase in load, smoke also get increased but by using the lime treated gas in which the CO_2 content is reduced smoke was found to be reduced to the larger extent. The reduction of diesel oil in the engine would reduce the smoke in the engine exhaust.

The smoke density is more in duel fuel mode than in diesel. Smoke emission is high in biogas due to high oxygen content. In duel fuel mode operation, with the increase in the gas flow rate, there is an increase in smoke density.

BP VS SMOKE

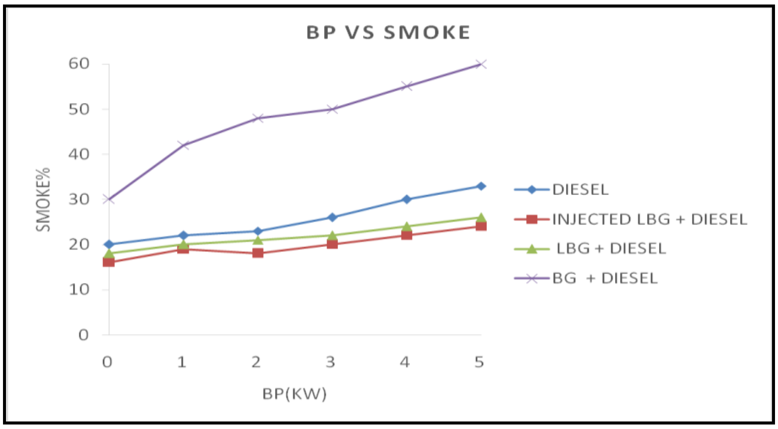

Figure.4.5 BP vs. SMOKE

V. Conculsion:

The biogas is a renewable fuel that can be used as dual-fuel in diesel engine with minimum modification in engine. In spite of being cheap, renewable and its easy availability, biogas can make a good substitute for diesel fuel. It is observed that the type of injection also play a major role in the reduction of various emissions by the fuel. The various injection modes are manifold injection and electronic fuel injection. The fuels used are lime treated biogas and diesel. It is found that the break thermal efficiency of electronic injection of lime treated biogas and diesel increases by 2% when compared with manifold injection of lime treated biogas and diesel. It is obtained that dual fuel engine with lime treated biogas injected through electronic injection system showed a reduction in emission of carbon mono-oxide by 9% on comparison with manifold injection of lime treated biogas and diesel and also the emissions of CO_2 were found to be reduced to 0.5%, the HC emission was found to be reduced by 10%, the smoke emissions were found to be reduced by 2% and the NO_X emissions were found to be increased by 15% with that of the manifold injection system. Thus the electronic injection of lime treated biogas and diesel improves the efficiency of the engine and reduces the various emissions from the vehicle thereby reducing the pollution when compared to the manifold injection of the fuels. It is concluded that the electronic fuel injection is more efficient than the manifold injection system.

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