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EXPERIMENTAL INVESTIGATION ON UTILIZATION OF RAW BIOGAS AS A FUEL FOR STATIONARY COMPRESSED IGNITION ENGINE

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ABSTRACT

In this work, an experimental investigation was carried out on a single cylinder, direct injection diesel engine, operating on different proportions of raw biogas with petroleum diesel. For this investigation, a Direct Injection Compression Ignition (DICI) diesel engine was modified into a dual fuel engine that can used raw biogas as the primary fuel and petroleum diesel as secondary (pilot fuels). The performance and emissions parameters were measured at constant speed and different loading conditions. The percentage saving of petroleum diesel was also measured with adding the different mass flow rate of raw biogas. The experimental test results show that the 8 gm/min adding the raw biogas with petroleum diesel produced maximum brake thermal efficiency of 23.14% with replacing 9.03% of petroleum diesel. On the other hand, NO_x emissions were reduced by 45.45%, 51.51, 58.58 and 66.67% with adding 2, 4, 6 and 8 gm/min raw biogas with petroleum diesel respectively. The HC emissions are observed to be higher for all combinations of raw biogas.

Keywords: Dual fuel, Biogas, petroleum diesel, performance, emissions

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1. INTRODUCTION

Energy demand will continue to increase as the population continues to grow, but the Energy resources consequently decrease. Especially fossil fuels as they are the lifelines of the modern age. The conventional Energy sources are getting depleted, resulting in increased fuel prices reduce the availability and dependency on foreign countries. Another drawback of the fossil fuels is the greenhouse gases emitted from the combustion. In view of these issues intensive search for alternative fuels for accomplish the need is going on. Biogas is an attractive alternative energy source because in view of energy crisis, it can act as an alternative fuel using for internal combustion engine and otherwise, it is renewable in nature, thereby not net contributors to the greenhouse gases emission.

Biogas is one of the best available energy sources to meet this requirement at both rural and urban areas. it is produced by anaerobic digestion of organic matters such as dry leaves of trees and crops, wood, agricultural residues, cow dung, kitchen waste, manure, sewage, municipal waste, green waste, etc. These organic matters decomposed by bacteria in absence of oxygen and forming gaseous by product known as biogas. it comprises of Methane (60-70%), Carbon Dioxide (30-40%), Nitrogen (1%) and Hydrogen Sulphide (10-2000 PPM). Biogas is about 20% lighter than air has an ignition temperature of 650 to 750^{o}C. Its calorific value is proportional to the methane concentration and found 20 to 22 MJ/m^{3}.

Biogas can be used as a fuel for internal combustion engines of both the spark ignition (SI) and the compression ignition (CI). It is octane based fuel so that can be directly used in SI engine, but required high compression ratio to maximize thermal efficiency. Due to its octane property, alone use in CI engine is quite complex, particularly for small high-speed engines subjected to variable loads. Easiest way to use in CI engine is the dual fuel mode, where both biogas and petroleum diesel are used simultaneously.

Dual fuel mode or dual fuel technique is newly developed method, in which both compression ignition and spark ignition concept is utilizing to burn the mixture of octane based (biogas) and cetane based (diesel) fuel. In the dual fuel mode, biogas is mixes with fresh air at intake manifold though a mixing device. This biogas-air mixture is drawn in to the cylinder just like to spark ignition engine and this mixture is compressed in order to increase the temperature and pressure. At the end of the compression stroke the mixture is ignited by the injection of small quantity of petroleum diesel. This pilot injection acts as a source of ignition. The biogas-air mixture in the area of the injected diesel spray ignites at number of places establishing a number of flame-fronts. Thus the combustion starts smoothly and rapidly. In this technique partial energy were added by the biogas and partial energy were added by the diesel. The quantity of diesel was controlled automatically according to load by the governor. It is interesting to note that in a dual-fuel engine the combustion starts in a fashion similar to the CI engine but it propagates by flame fronts, similar to the SI engine. The combustion process in a dual-fuel engine tends to exhibit combination features of both compression and spark ignition engines. It is concept of raw biogas diesel dual fuel engine, the subject of study of this work.

The objective of this study is to experimentally investigate the performance and emission characteristics of CI engine in dual fuel mode using raw biogas in varying quantity i.e. 2, 4, 6 and 8 gm/min as a primary fuel and petroleum diesel as a pilot fuel. Experiments were conducted at various loads at 1500 RPM for diesel in single fuel and with biogas in dual fuel mode of operation. The engine behaviour with respect to performance and emission characteristics are compared against a baseline of a standard diesel run.

2. EXPERIMENTAL SETUP

The present investigation is to be carried out on a single cylinder, four strokes, direct injection, water cooled, diesel engine, shown in figure-1, of technical specifications given in Table-1. It contains a complete system for measuring the performance parameters such as engine load which is measured by rope brake dynamometer, diesel consumption by U-tube manometer, biogas consumption by hot wire anemometer and electronic weighing machine, temperature of inlet air, exhaust gas and cooling water by K-type thermocouples. For the analysis of the exhaust emission, an AVL DiGas 4000 Light exhaust gas analyser is used.

Table 1 Technical Specifications of Test Engine

Engine Company and Model	Kirloskar Oil Engine, SV1
No. of Cylinders	1
Bore X Stroke	80 X 110 mm
Cubic Capacity	553 cm^3
Compression Ratio	16.5: 1
Rated Output	3.7 kW/ 5 HP
Rated Speed	1500 RPM

2.1. Modification in test engine

For the dual fuel operation minor modification is required in to the existing CI engine. A convergent divergent nozzle was inserted in the air suction line of the engine, shown in figure-2. It has a very small hole at the throat to accommodate a biogas pipe. A gas welding torch tip was used for the induction of biogas in to the convergent divergent nozzle throat. due to the action of turbulence it was properly mix with the intake air. All other parameters and elements of CI engine remain unchanged. The supplementary components required for diesel biogas duel fuel operation are Biogas storage device, Biogas inlet pipe, flow measuring device, electronic weighing machine, Biogas mixing device, gas analyser for emission analysis etc. The schematic block diagram of experimental setup is shown in figure-2.

Figure 1 Photographs of test engine test rig

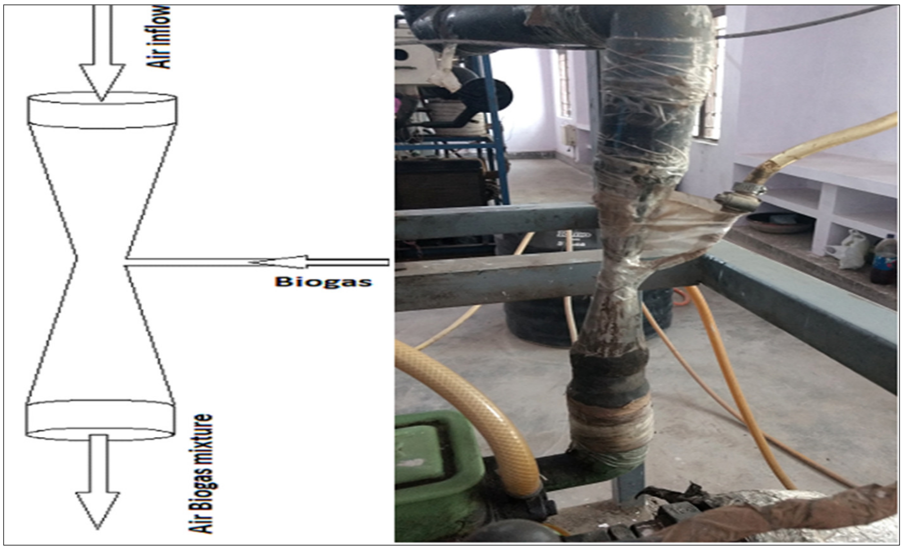


Figure 2 Schematic and Actual Photograph of Inspirator System

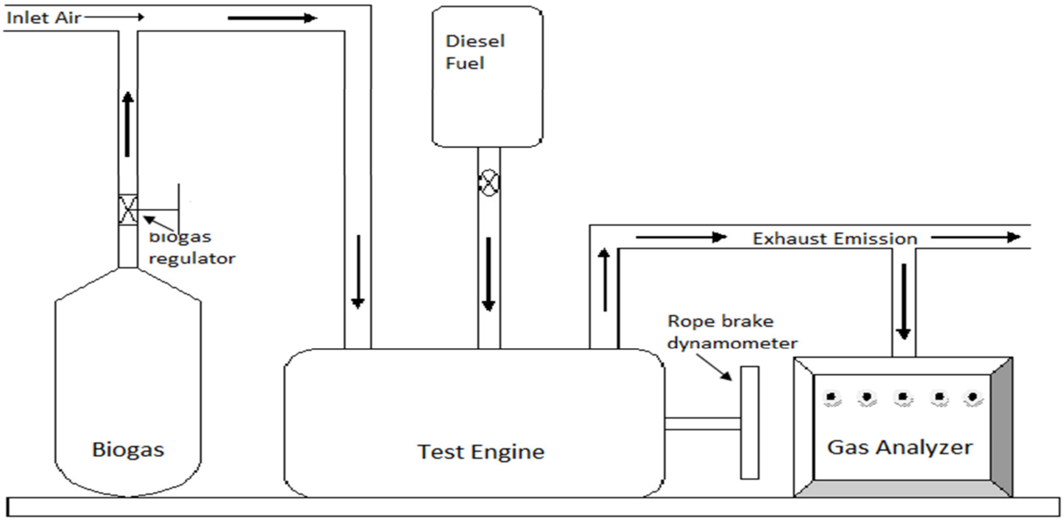


Figure 3 Schematic diagram of experimental set-up

3. EXPERIMENTAL PROCEDURE

First of all, engine was started and every accessory such as water supply, fuel supply, temperature indicators were switched-on and allowed the engine to run for 20 minutes so that it can achieve its steady state. In the first set, the engine was run with neat petroleum diesel fuel, which purchased from a local Petrol Pump. Initially engine was operated at zero load and readings were taken up for all the parameters those required for evaluating performance and emission. After noting down all the parameters, a load of 1 kg was applied on the engine and the engine was allowed to run for 15 minutes to achieve the steady state and then all the parameters were noted down again. In the same manner, the load now is increased gradually from 3 kg, to 12 kg in the steps of 3 kg. all the parameters were recorded as before. In the second set, biogas was introducing with the neat petroleum diesel and data was recorded in this set, one has to take reading of one additional parameter i.e. biogas consumption with the help of hot wire anemometer and electronic weighing machine. The biogas induction is regulated with the help of the regulator and flow meter. Four different mass flow rate of biogas is tested i.e. 2, 4, 6 and 8 gm/min.

3.1. BIOGAS PRODUCTION

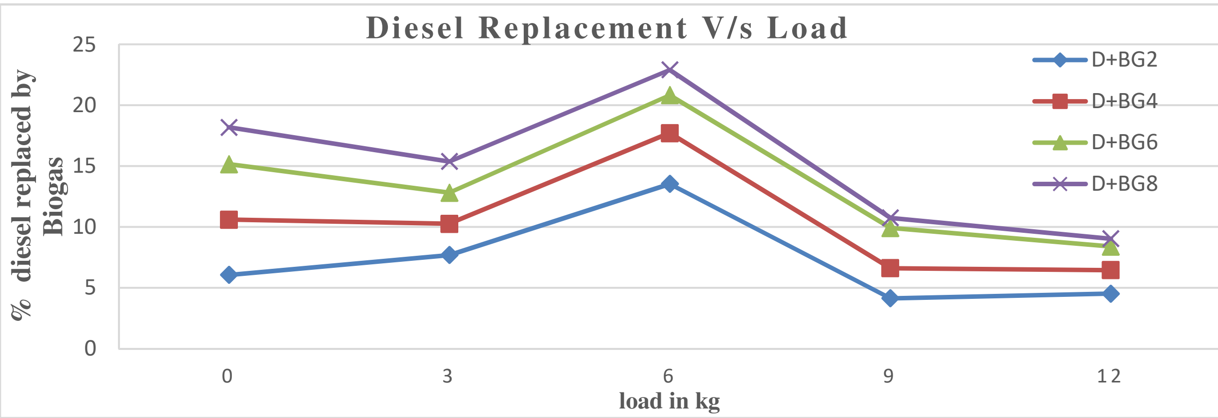
In this experimental work biogas was produced from the student's canteen waste, that operating at RGPV campus. A floating drum gas holder type biogas plant was installed in mechanical Engineering department of Rajiv Gandhi Proudyogiki Vishvavidhyalaya. This plant was made of fibre material, having an inverted drum resting over the digester of gas holding capacity 1m^3. This drum can move up and down and floating through water jacket over the digester, so that prevents the leakage of biogas from the digester. Initially 100 kg of cow dung and 500 litter water mixes together and form slurry then poured in to the digester. To maintain the pH value 1kg Calcium Hydroxide (CaOH) were also added with slurry. After one week of retention time 500 g of solid canteen waste and 20 L water were poured daily in to the digester during entire experimentation.

4. RESULTS AND DISCUSSION

The different values of performance and emission parameters are obtained by using various combination of these fuels. Neat petroleum diesel is represented by D+BG0, where biogas is 0 gm/min, similarly petroleum diesel with adding biogas of 2 gm/min is represented by D+BG2. other combination such as D+BG4, D+BG6 and D+BG8 are shows diesel with adding biogas of 4, 6 and 8 gm/min respectively

4.1. Diesel Replacement

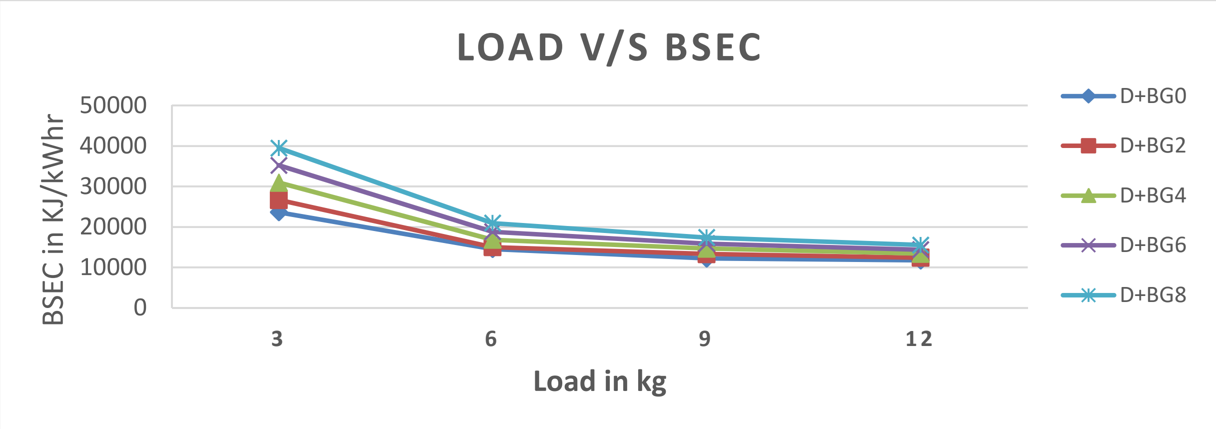
Graph-1 shows the variation of the percentage replacement of diesel by the biogas with the engine load for all combinations of fuel sets. The percentage diesel replacement was decreases with the increasing load from no load to 3 kg load and then increases at halfway load that is 6 kg and further decreases for higher load. The maximum percentage of diesel saving was found 22.91% with D+BG8 dual fuel mode at 6 kg engine load. Probable causes could be at lower and higher load; rich fuel mixture is supplied to the engine whereas at halfway load complete combustions is happens.



Graph 1 Variation in diesel replacement with the Engine Load

4.2. Brake-Specific Energy Consumption

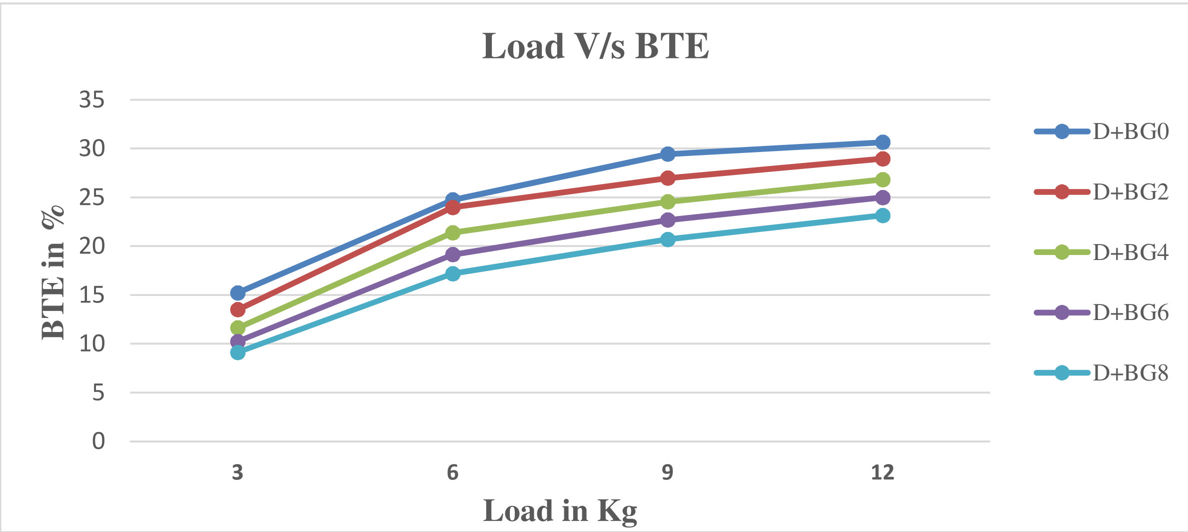
Graph-2 shows the Variation in BSEC with the Engine Load It was found that the brake specific energy consumption in dual fuel operation is higher in all combination of fuel sets than that of neat petroleum diesel in all operating conditions. The value of BSEC decreases with the increase in load. It may be because of reduction in losses at higher loads. The values of BSEC were found to increase with an increase the quantity of biogas. The possible reason of higher energy consumption for higher mass flow rate of biogas could be the lower calorific value of the biogas. Due to the low calorific value in biogas the BSEC increases as the quantity of biogas increases with diesel fuel at various load conditions. When the engine loads were increased from no load to 12 kg load, the reduction of specific fuel consumption was about 50.32% in case of diesel fuel mode. This Percentage reduction is increases with increasing the quantity of biogas and found 53.41%, 56.63%, 59.07% and 60.60% at 2, 4, 6 and 8 gm/min supplying of biogas respectively.



Graph 2 Variation in BSEC with the Engine Load

4.3. Brake Thermal Efficiency

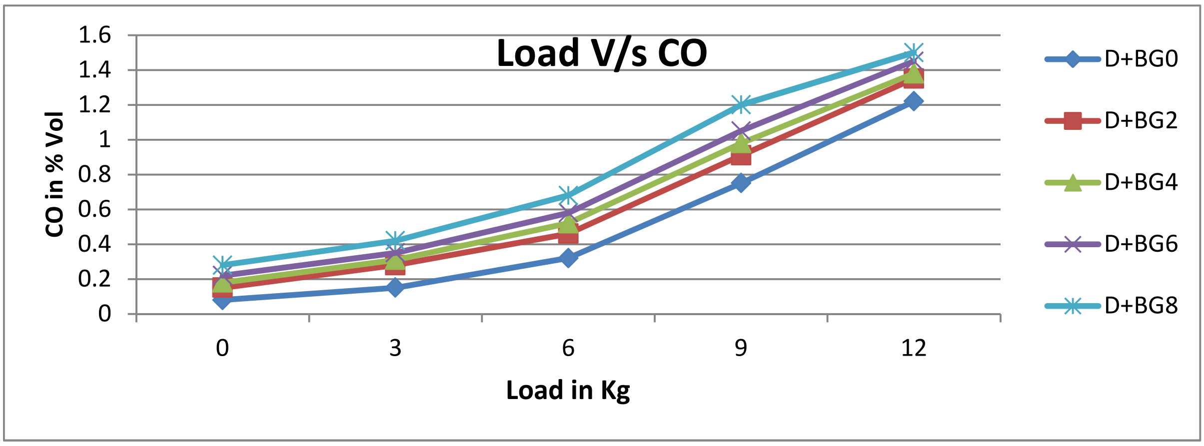
Graph-3 shows the variation in BTE with the Load for neat diesel and different combination of fuel sets. BTE increases with increasing the load which can be due to reduction in heat losses at higher load. The values of BTE were found to increase with an increasing the load in all combination of fuel sets and higher in case of neat diesel than the other fuel combination and goes continuously decreases with increasing the quantity of biogas. When the engine load is increases from no load to 12 kg load, the increments of BTE is about 50.32% in case of neat petroleum diesel. this percentage increments are increases with increasing the quantity of biogas and found 53.42%, 56.63%, 59.07% and 60.60% at 2, 4, 6 and 8 gm/min supplying of biogas respectively. Maximum BTE (30.63%) is found with neat petroleum diesel. It is continuously decreases with adding the biogas i.e. 28.94%, 26.81%, 24.97% and 23.14% at 2, 4, 6 and 8 gm/min respectively.



Graph 3 Variation in BTE with the Engine Load

4.4. Carbon Monoxide Emissions

Graph-6.4 shows the variation of CO emission in percentage volume with the load. Result shows CO emissions increases with the increasing load and found slightly lower in case of neat diesel than the other fuel combination and increases with increasing the quantity of biogas, on an average 48.96% rise in CO emission was observed in dual fuel mode at 8 gm/min supply of biogas.

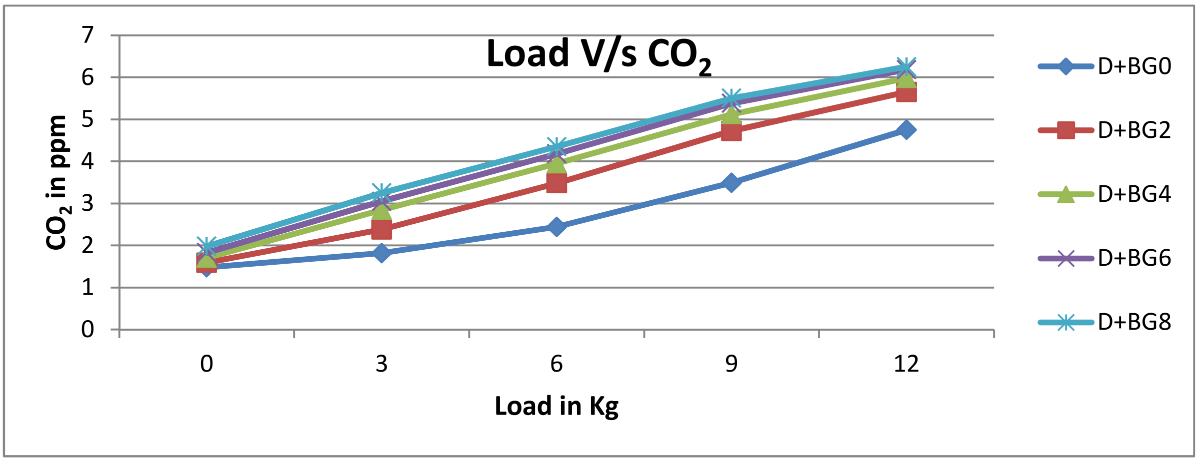


Graph 6.4 Variation in CO emission with the Engine Load

The CO emission depends on the air fuel ratio while adding the biogas, BSEC increases and air fuel ratio decreases, which in turn increases CO emission. Other probable causes for higher CO emission are due to high carbon content that adversely affects the combustion efficiency. In incomplete combustion CO_2 is not converted in to CO.

4.5. Carbon Dioxide Emissions

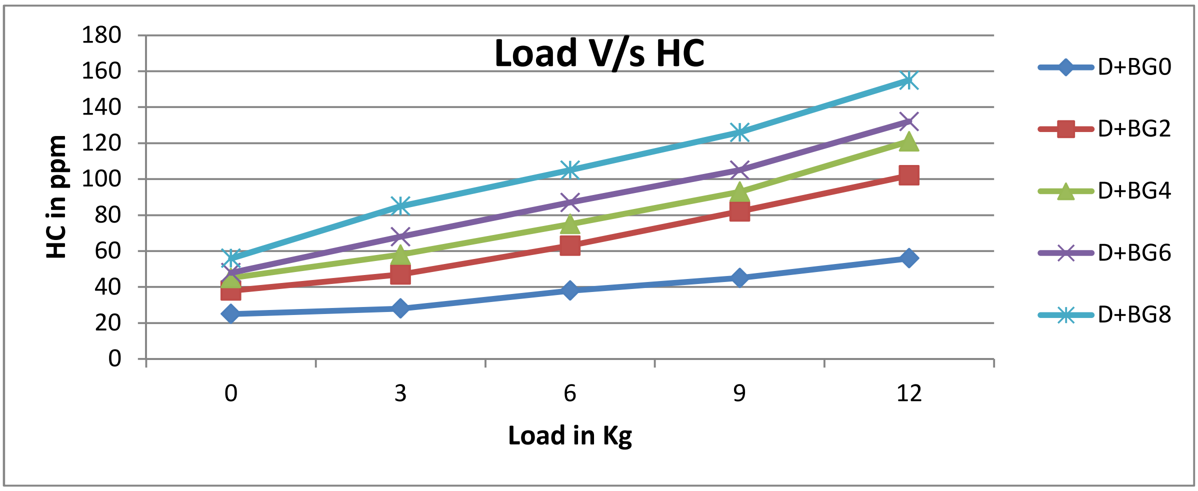
Graph-4.5 shows the variation of Carbon dioxide (CO_2) emission in % volume with the load. Result showed CO_2 emissions increases linearly with the increasing load and found lower in case of neat diesel than the other fuel combination and decreases with increasing the quantity of biogas. At no load condition CO_2 emissions were almost same for all combinations of fuel sets and increases with increasing the load at different rate, on an average 34.74 % CO_2 emission were increased in dual fuel mode at 8 gm/min supply of biogas This is due to the fact that the amount of fuel consumption increases with for high loading conditions and biogas contains large amount around 40% by volume of CO_2.



Graph 4.5 Variation in CO_2 emission with the Engine Load

4.6. Unburnt-Hydrocarbon Emissions

Graph-4.6 shows the variations of unburnt hydrocarbons emission in parts per million (ppm) with engine Load for neat diesel and diesel with various quantity of biogas.

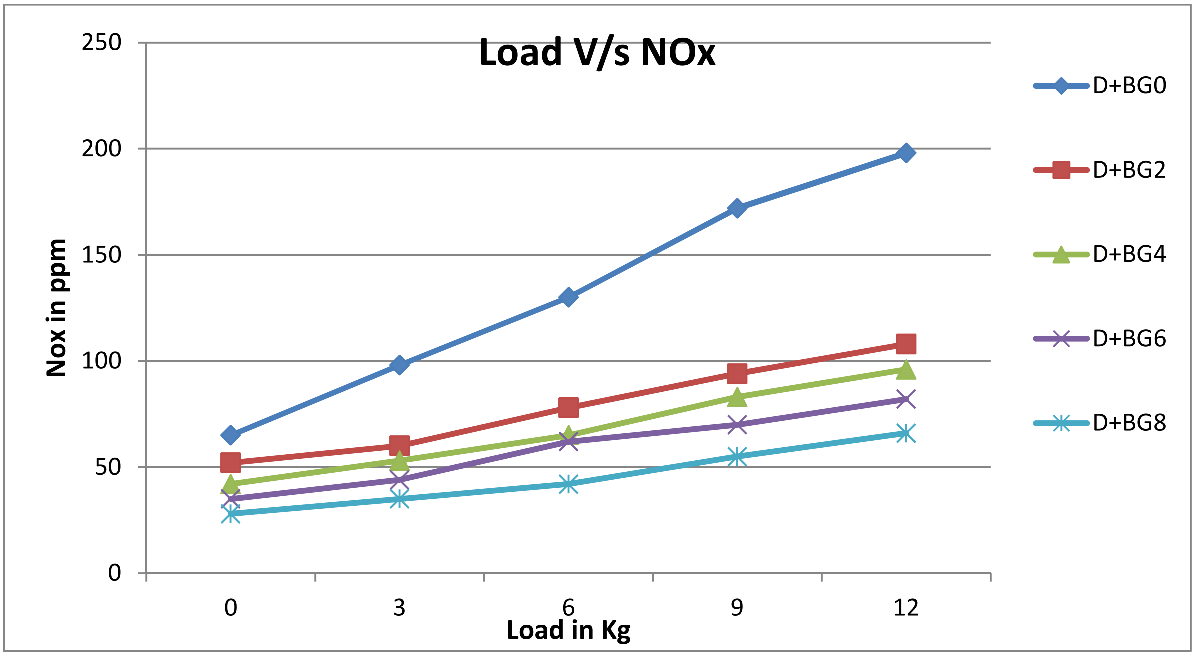


Graph 4.6 Variation in HC emission with the Engine Load

The HC emissions increases as increasing the engine load and found lower in case of neat diesel than the other fuel combination and increases with increasing the quantity of biogas, on an average 62.87% HC emission was more in dual fuel mode at 8 gm/min supply of biogas. It may be because of more induction of biogas into the engine, the CO_2 content in the mixture increases which reduces the air–fuel ratio and combustion temperature therefore incomplete combustion takes place and HC emissions increases.

4.7. Oxides of Nitrogen Emissions

Graph-4.7 shows the variation of NO_x emissions in parts per million (ppm) with engine Load for neat diesel and diesel with various quantity of biogas. Result shows NO_x emissions increases linearly with increasing the engine load. It may be happened due to need of more fuel at higher loads, which results in slightly higher maximum combustion pressure and temperature, therefore increases the formation of NOx emission. However, the NO_X emission in the neat diesel is much higher in comparison to other combination of fuel sets and found higher in case of neat diesel than the other fuel combination and decreases with increasing the quantity of biogas, on an average a drop of 64.71% NO_x emission was found in dual fuel mode at 8 gm/min supply of biogas. This is because of calorific value, diesel has a high calorific value as compared to biogas which generates much more temperature in the engine cylinder another reasons are the presence of CO_2 in the biogas, CO_2 of biogas dilutes the oxygen concentration of the intake mixture which reduced the engine cylinder temperature therefore lowering the formation of NOx.



Graph 4.7 Variation in NO_X emission with the Engine Load

5. CONCLUSION

In this experimental work, a single cylinder four stroke direct injection diesel engine was modified into a dual fuel engine that can be operated petroleum diesel with biogas. It was experimentally proved that direct injection compression ignition engines can be modified into dual fuel engines and be used in stationary applications such as electricity generation, cultivating the fields, irrigation and harvesting the crops. hoisting in construction sites and as a prime mover for water pumps, flour mills among other applications.

The maximum petroleum diesel saving with biogas was possible up to 22.91%, The engine operation on biogas alone was not possible, this was due to the high auto ignition temperature of biogas which made it difficult to ignite without considerable amount of pilot fuel. Utilization of raw biogas will reduce dependence on petroleum fuels and save Indian currency. Other benefit was achieved in oxides of nitrogen (NO_x) emissions, 66.66% NO_x reduction was obtained in diesel biogas dual fuel operation

The quantity of biogas was varying in dual fuel operation, but optimum quantity does not define yet, hence further studies are required to investigate optimum quantity as well as purification of raw biogas to improve combustion efficiency at low and intermediate engine loads.

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