Investigation on Performance and Emission Characteristics of Biogas- Diesel Dual Fuel Engine Based on AVL BOOST Simulation

Girish Rajendra Undale[1], Sana Salim Shaikh[2],

[1]Assistant professor Department of Mechanical Engineering, Walchand College of Engineering, Sangli (Maharastra).

[2]Assistant professor Department of Mechanical Engineering, Smt. Kashibai Navale College of Engineering, Pune.

ABSTRACT: The paper is to investigate the application of Biogas as a dual fuel with Diesel and its performance and emission effect in the diesel engine using AVL-BOOST computational simulation. Biogas as a dual fuel for four stroke single cylinder diesel engine modeling was developed from the real diesel engine using AVL BOOST computational model with measure all of engine component size. Semi-direct injection technique for the injection of biogas is used along with direct injection of the diesel fuel to simulate and investigate the engine performance and emission effect. Simulation is carried out at constant load and variable speed, constant speed and variable load for the different percentage of the biogas (Pure Diesel, B10, B20 and B40) on the weight basis along with diesel fuel. It has been found that NO and Soot emissions in dual fuel operations are found lower overall by 40% and 60%, compared to that of diesel.

KEYWORDS: Biogas, dual fuel, diesel engine, AVL BOOST, simulation

I. INTRODUCTION:

Petroleum resources are finite and, therefore, search for their alternative non-petroleum fuels for internal combustion engines is continuing all over the world. Moreover gases emitted by petroleum fuel driven vehicles have an adverse effect on the environment and human health. There is universal acceptance of the need to reduce such emissions. Towards this, scientists have proposed various solutions for diesel engines, one of which is the use of gaseous fuels as a supplement for liquid diesel fuel. These engines, which use conventional diesel fuel and gaseous fuel, are referred to as ‘dual-fuel engines’.

Gaseous fuels are attractive because of their wide ignition limits and capability to form homogeneous mixtures. Moreover gaseous fuels have high hydrogen to carbon ratio. Thus very low emissions are possible when they are used in IC engines. Biogas is one such a fuel and an attractive source of energy for rural areas. It can be produced from cow dung and other animal wastes and also from plant matter such as leaves and water hyacinth-all of which are renewable and available in the countryside. It is approximately two-thirds (by volume) methane (CH_4) and the rest CO_2. Biogas can be produced close to the consumption points in rural areas such as engines driving pump sets and generators. [2]

This paper is to explore the application of biogas as dual fuel along with diesel for the diesel engines using simulation. The investigation in this research is done on the performance and emission effect of diesel fuel partially substituted by biogas fuel for the same diesel engine specification. Simulation is carried in AVL BOOST for pure diesel, B10 (90% Diesel + 10% Biogas), B20 (80% Diesel + 20% Biogas), B40 (60% Diesel + 40% Biogas).

AVL BOOST model is based on one-dimensional gas dynamics, representing the flow and heat transfer in the piping and in the other component of an engine system. A four-stroke direct-injection diesel engine was modeled using AVL BOOST software and simulations are carried out to investigate the engine performance and emissions.

II. ENGINE SPECIFICATION:

In the present work, simulation is carried out on a single cylinder 4-stroke Ricardo E-6 diesel engine model to analyze the performance and exhaust emission. Entered engine components data is as shown in the Table 2.

Property	**Diesel**	**Biogas**
Carbon atoms per molecule	13.5	1
Hydrogen atoms/molecule	23.6	4
Lower calorific value (kJ/kg)	42800	30000
Density (kg/m3)	840	1.15
Boiling Point (° C)	210	-161.5
Stoichiometric Air-fuel ratio	14.5	17.2

Table 1: Fuel properties of diesel and biogas

Engine type	Four stroke, Water cooled, OHC
Bore x Stroke	76.2 mm x 111 mm
Fuel System	Direct Injection
Number of valves	2
Displacement Volume	507 cc
Compression Ratio	22
Speed	1000-3000

Table 2: Diesel engine specification

With these specifications and additional specifications such as boundary conditions such as pressure and temperature, connecting pipe parameters, fuel specifications such as chemical composition and properties, engine RPM models are created in the AVL BOOST, for both pure diesel fueled engine and Dual fuel engine. Models are shown in following figure 1 and 2.

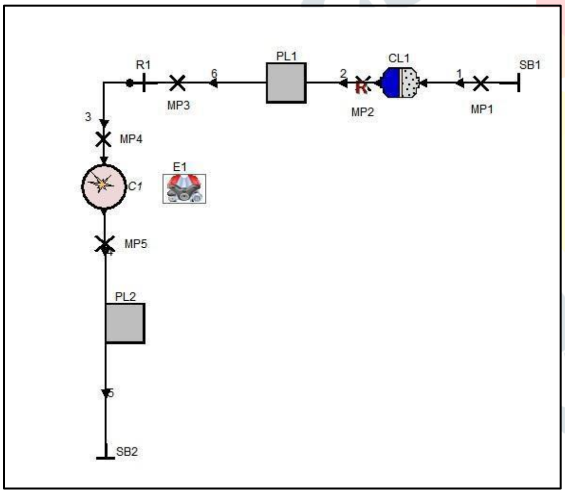


Figure 1. Pure Diesel Fuel model in AVL BOOST

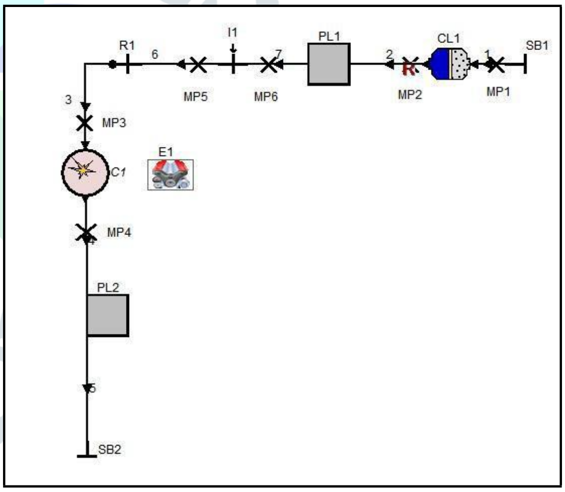


Figure 2. Dual Fuel model in AVL BOOST

In figures,
SB1 = system boundary at intake
SB2 = system boundary at exhaust
MP1 to MP6 = measuring points
CL1 = Air filter PL1, 2 = Plenum R1 = Restriction C1 = Cylinder
E1 = Engine
1 to 7 = Pipe numbers
I1 = Injector for Biogas injection

III. TEST CONDITIONS:

The present study concentrated on the performance and emission characteristics of the Diesel-Biogas dual fuel injection. The results are discussed into different subsections based on the various performance characteristics. The results are compared with the pure Diesel model results for the same engine and same engine parameters.

Simulation results are carried out for two different conditions

1. Constant load variable speed
2. Constant speed and variable load

With Pure Diesel and different Diesel-Biogas combinations Pure Diesel, B10, B20, B40.

Test simulations are carried out for the 100 number of cycles till we get the stabilized condition.

IV. RESULT AND DISCUSSION

1. Constant load variable speed

Results are obtained for the constant load and speed is varied from 1200 rpm to 2000 rpm. Parameters which compared are Brake specific fuel consumption (g/kWh), Thermal Efficiency (%), volumetric efficiency, Exhaust gas temperature (K), NOx emissions (ppm), soot emissions (g/kWh)

1.1 Performance Analysis

Variation of brake specific fuel consumption with engine speed at constant load is shown in figure 3. BSFC has first decreasing trend and later increasing trend. As shown in the figure, the BSFC increases as the percentage of the Biogas increases in the dual fuel mode. This can be attributed to the reduced calorific values of the biogas fuels with higher CO_2 contents. BSFC increases with the increase in biogas percentage increases. As the result shows, for B10 it increases by 3% to 4%, for B20 it increases by 7% to 8% while for B40 it increases by 15% to 19%.

Variation of Brake Thermal efficiency with engine speed at is shown in the figure 3. It has tendency to increase first with increasing speed and then decreases with increase in it. As the fuel replacement percentage increases percentage increases Brake thermal efficiency decreases due to decrease in the calorific value of the mixture. Calorific value for the pure Diesel is 42800 kJ/kg, while for B10, B20 and B40 mixture it is 41520 kJ/kg, 40240 kJ/kg and 37680 kJ/kg respectively. For B10 mixture it is decreased by 0.2% to 0.6%, for B20 it varied in between 0.7% to 1.6% while for B40 it shown maximum decrease it BTE than other two mixture and is in between 1.6% to 3.8%.

As shown in figure 3, volumetric efficiency for Diesel fuel is more than that for the B10, B20 and B40. It is due to the introduction of the biogas replaces the air into the cylinder. Decrease in volumetric efficiency is 0.5 to 1% for B10, 0.5% to 1.5% for B20 and 3% to 4% for B40 combination.

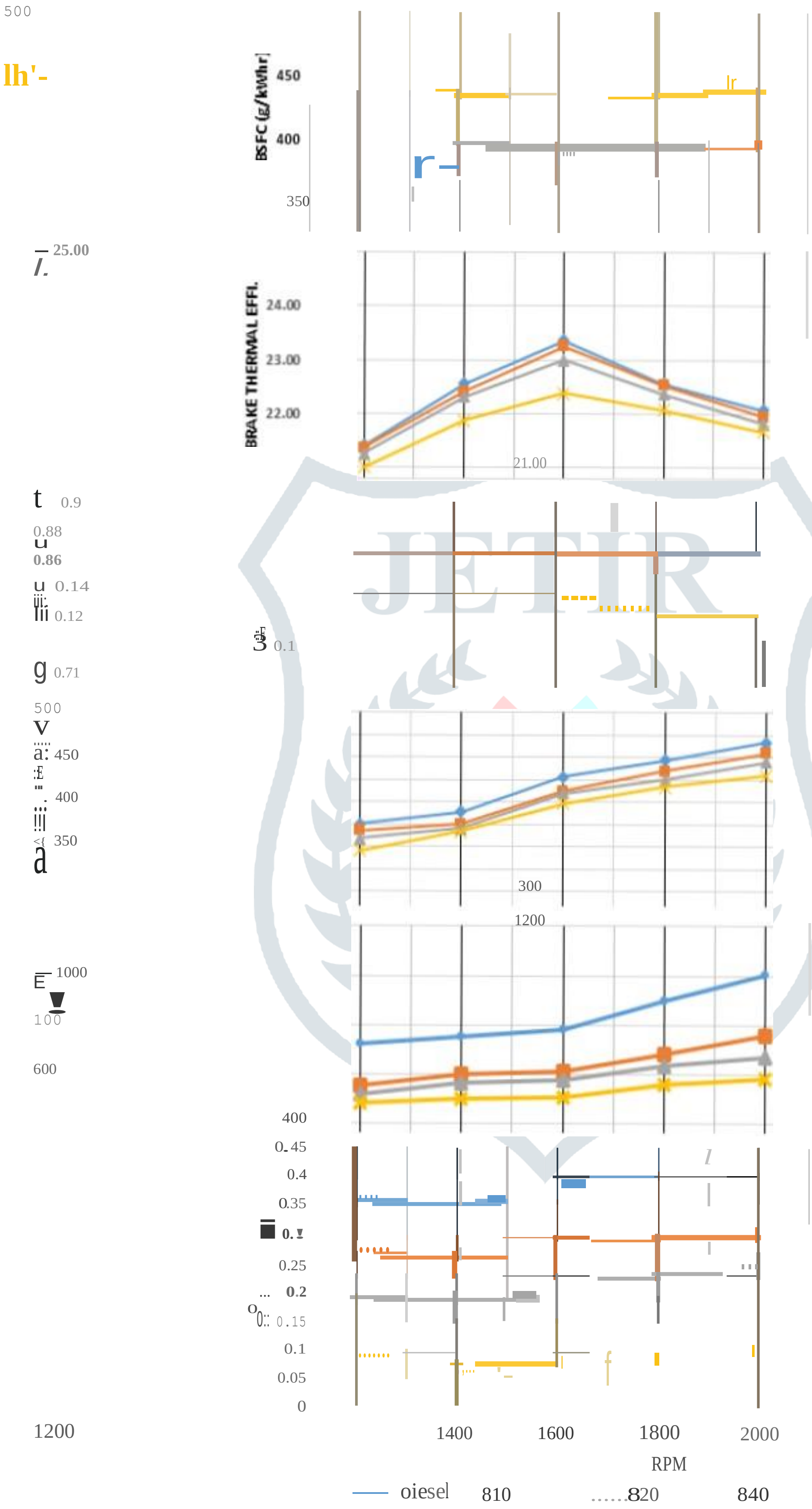


Figure 3. Variation of Performance and Ehlission parameters "Vith engine speed

1.2 Emission Analysis

From the figure 3, it can be observed that the exhaust gas temperature increases with the engine RPM. Exhaust gas temperature is marginally lower in the dual fuel operation compared to that of diesel, throughout the varying speed. This is due to the dilution of charge due to the presence of CO_2 in the biogas. In addition to this, the inducted biogas absorbs heat energy and get hot to auto ignite during the combustion process leading to a reduction in the exhaust gas temperature. Decrease in exhaust gas temperature is more significant with the B40 combination. Decrease in exhaust gas temperature is 4% to 6% for B40 combination.

Main parameters to form NOx are peak temperature and availability of the Oxygen. It is apparent from the figure that, for the pure Diesel fuel NOx emissions slightly increases as the RPM increases. While for the dual fuel mode emission levels are decreased by nearly 20% to 42%. Increasing CO_2 content in the biogas is the most affecting parameter on the NOx emissions. CO_2 in the Biogas dilute the charge since it has the higher molar specific heat. The local concentrations of oxygen and nitrogen atoms, which are functions of local temperature and availability of oxygen molecules, as well as the time available for the oxygen nitrogen reactions to proceed to significant levels of completion, are the parameters that determine the reaction kinetics. [5] In dual fuel local temperature gets reduced. Both conditions causing reduced NOx formation. Increase in percentage of diesel re placement by Biogas causes slight decrease in the NOx emission by ppm. For B10 decrease in NOx ppm is by 20% to 15%, for B20 decrease is by 25% to 34% and it found more efficient for B40 by decreasing 33% to 42%.

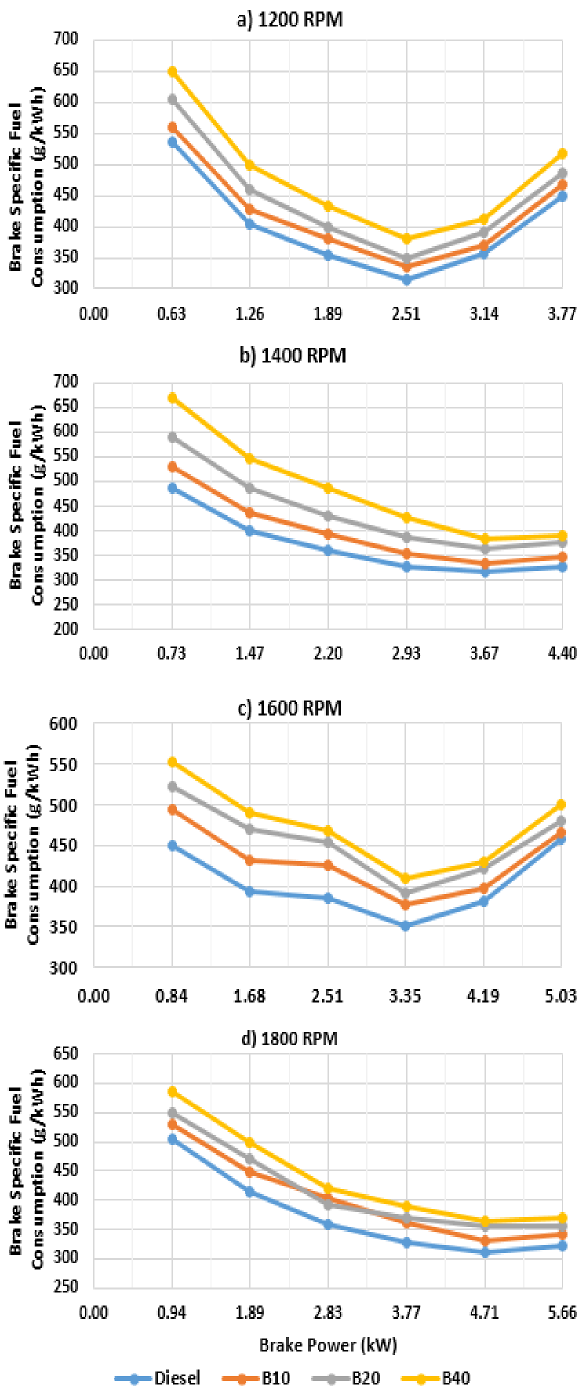
As the figure 3, depicts soot emissions decreases with the biogas substitution increases. It can be speculated that the formation of the majority of soot was caused by the quantity of diesel fuel injected which was minimized in the case of dual fuel. Also another affecting parameter is the chemical structure of the biogas. Unsaturated C=C bond causes the incomplete combustion of the diesel. While there is straight chain CH_4 present in biogas.

The presence of higher CO_2 concentration in the fuel acts as a suppressant and causes a decrease in overall cycle temperature which might have an impact on oxidation processes. [23] Hence, the resultant soot emissions would be the balance between these two phenomena. Soot decrease by the percentage is varied as: for B10 it is 23% to 31%, for B20 it is 41% to 48% and for B40 it is 52% to 60%. As from the results it is seen that the decrease in the soot formation is increased as the biogas percentage is increased.

2. FOR CONSTANT SPEED AND VARIABLE LOAD

2.1 Performance Analysis

It can be observed from the figure 4 that, a higher BSFC (brake specific fuel consumption) is noticed in the dual fuel operation than that of diesel at part loads. This is due to the lower energy density of biogas, lower cylinder temperature, and the presence of CO_2 in biogas prevents faster burning. The difference in BSFC between diesel and dual fuel operation are not significantly different at high operating loads. At high loads the dual fuel operation has similar fuel energy conversion efficiency to that of diesel [21]. Because, less energy from the fuel is required at high load compared to low load, due to the increased cylinder temperature at high load. Hence the fuel consumption in dual fuel is more.



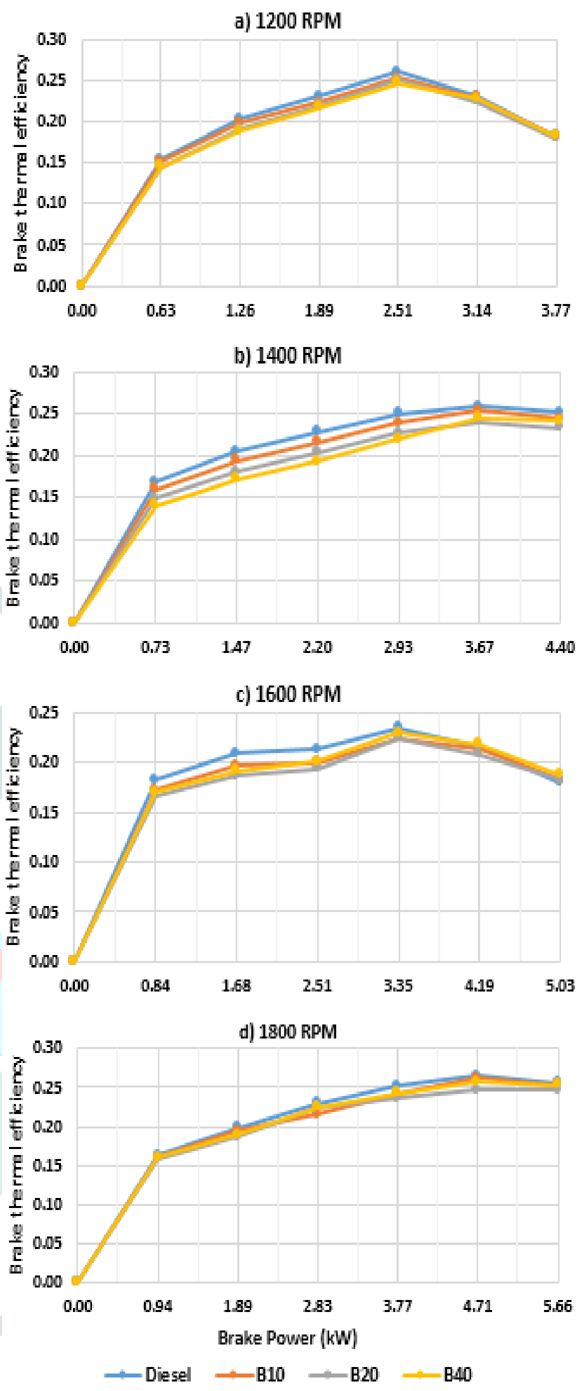


Figure 4. Variation of BSFC with load (kW) for constant RPM

Figure 5. Variation of Brake Thermal Efficiency with load (kW) for constant RPM

Figure 5 depicts that, the BTE (brake thermal efficiency) has tendency to increase first and at higher loads it decreases. In the dual fuel operation it is found BTE is lower than that of diesel operation at the low loads while for the higher loads brake thermal efficiency of dual fuels nearly matches the BTE of diesel fueled engines. The reason behind this is, deficiency of oxygen caused by induction of biogas through the intake manifold. Deficiency of oxygen causes incomplete combustion and subsequent decrease in converting the input fuel energy, results higher total fuel flow rate during the combustion process. Also, another reason may be the decreased flame propagation speed and increased negative compression work due to the gaseous biogas fuel intake, which in turn, are caused by the induction of a large quantity of air-biogas mixture. [21] But at the same time for the dual fuel operations energy conversion efficiency increases at the higher loads so brake thermal efficiency also nearly matches at the higher loads.

From the figure 6, it can be observed that, the volumetric efficiency has slightly increasing trend. For diesel operation it is found to be higher than that of the dual fuel operation. The volumetric efficiency decrease for mixture B10, B20 and B40 is 1% to 1.6%, 2% to 2.5%, 4% to 5% respectively, for all speeds than pure diesel. This reduction in volumetric efficiency in dual fuel operation is due to the induction of biogas with air through the intake manifold, replaces some amount of fresh air. Also, another reason may be the increase in the inducted air temperature, as a result of the hot cylinder wall, that reduces air density. [21]

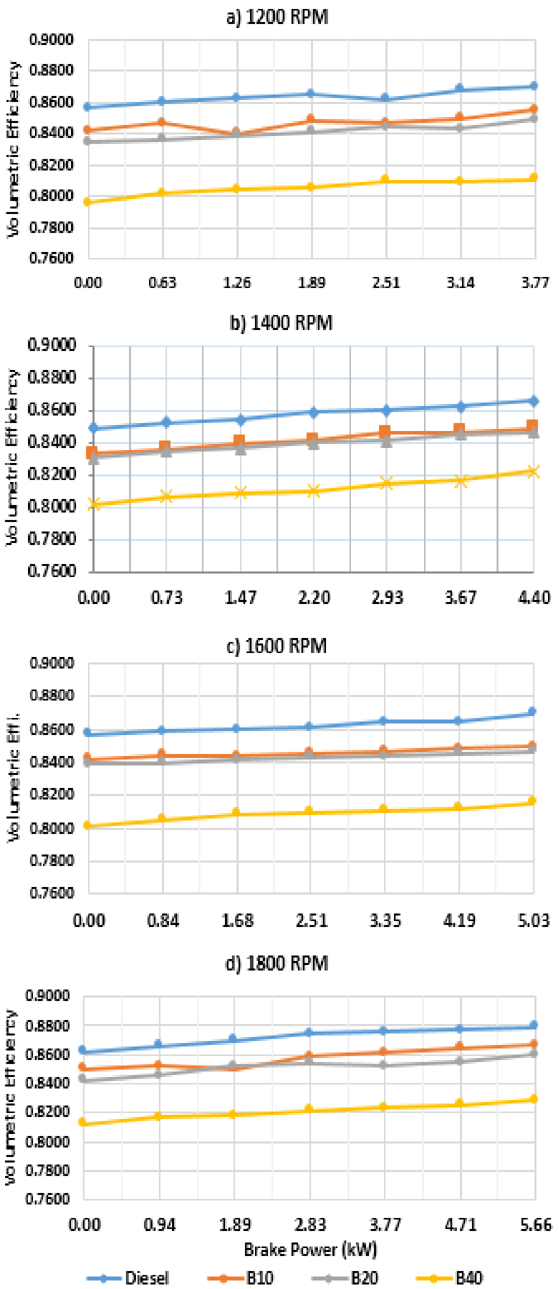


Figure 6. Variation of Volumetric Efficiency with load (kW) for constant RPM

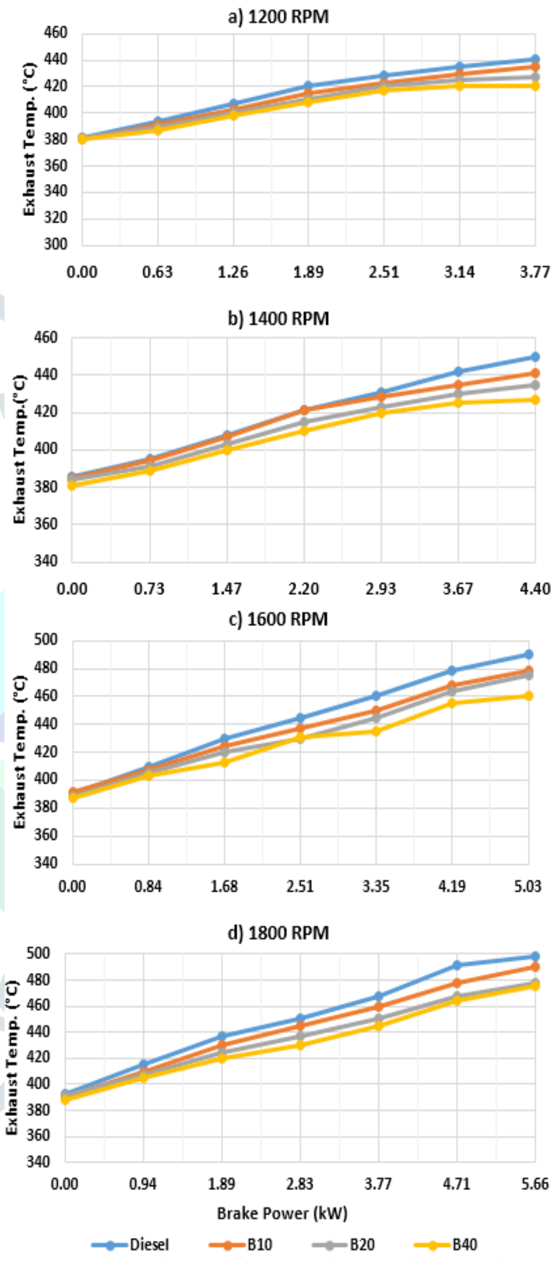


Figure 7. Variation of Exhaust Gas Temperature with load (kW) for constant RPM

2.2 Emission Analysis

The variation of engine exhaust gas temperature with engine load is illustrated in above figure 7. It is observed that, diesel shows the highest value of exhaust gas temperature among all the dual fuel combinations tested in this experiment, throughout the load variations. CO_2 present in the biogas dilutes the charge, and absorbs heat energy to auto ignite causing reduction in the exhaust gas temperature. [21] Reduction in exhaust gas temperature is observed maximum at high load and B40 mixture. It is ranged from 3% to 6%.

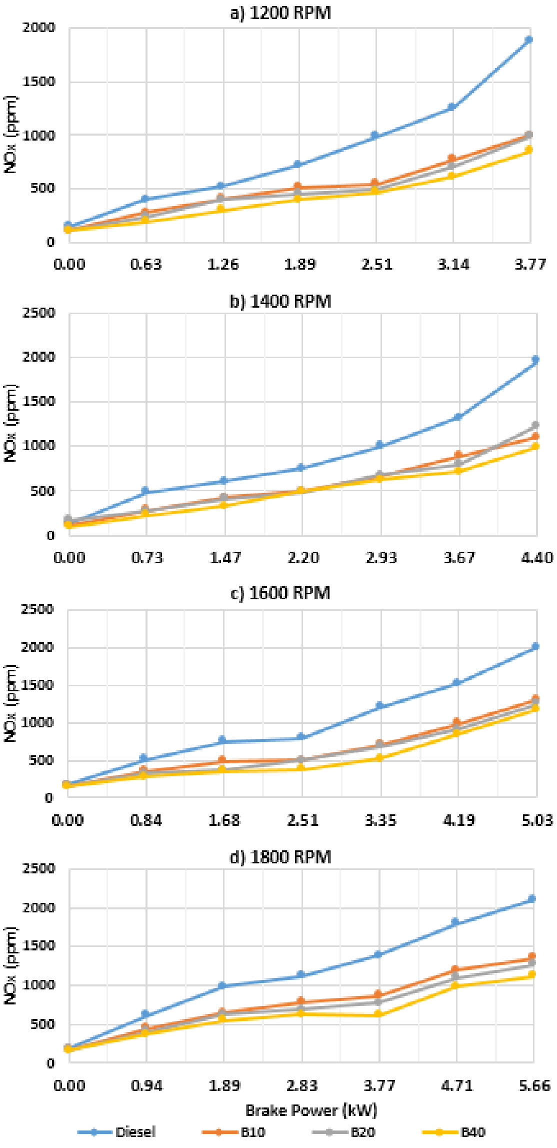


Figure 8. Variation of NOx with load (kW) for constant RPM

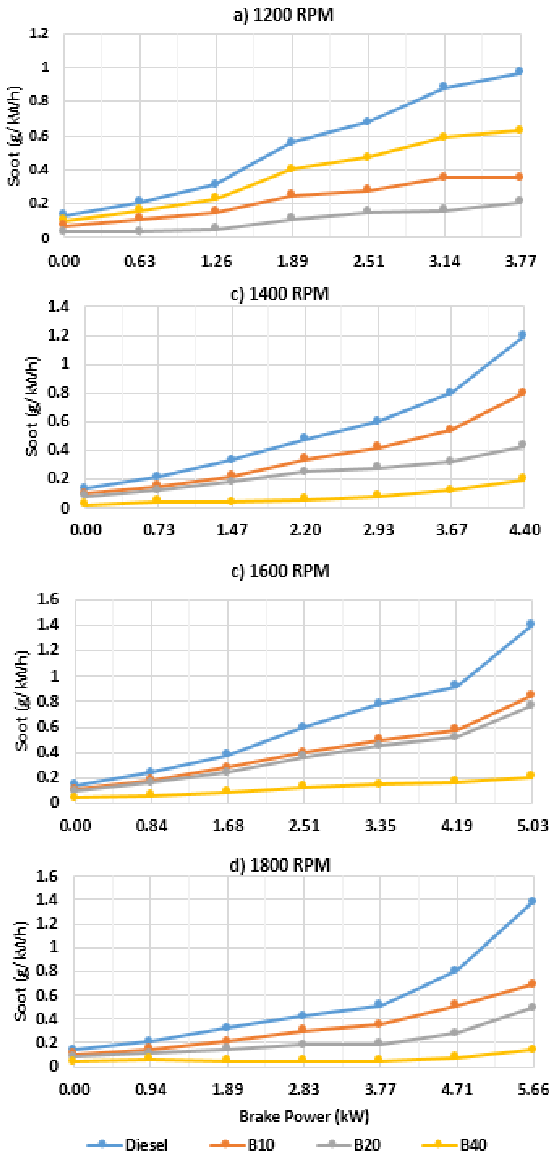


Figure 9. Variation of soot with load (kW) for constant RPM

Figure 8 depicts, NOx emission comparison. The NO formation is highly dependent on the combustion temperature, availability of oxygen, compression ratio and the retention time for the reaction. Lower NO emissions are found in the dual fuel operation compared to that of diesel throughout the load variation. CO_2 having high molar specific heat, dilutes the charge and lowers the cycle temperature significantly. In addition, CO_2 in biogas lowers the oxygen concentration of the charge followed by overall decrease in cycle temperature. [18] Hence, the NO formation is suppressed with the combined effect of these phenomena. Reduction in NOx is significant with the increase in the biogas percent. For B40 mixture reduction in NOx emission is up to 40% to 45%.

Soot emission comparison for the diesel and dual fuel operations is shown in figure 9. Figure depicts that, soot emission in the case of dual fuel operations is found to be less than that of diesel operation. This is due to the absence of aromatic compounds in the biogas. Also, the amount of smoke produced is strongly dependent on the amount of air in the cylinder, as well as on the amount of oxygen in the fuel. In dual fuel operation, some amount of diesel is replaced by the biogas resulting in less smoke emission.

V. CONCLUSION:

1. Introduction biogas in the diesel engine shows increase in BSFC due to the lower CV. But at the higher loads difference in the difference in BSFC reduces.
2. While for the comparison of Brake thermal efficiency shows that, as the percentage of the biogas increases brake thermal efficiency decreases at the partial loads. It nearly matches the BTE of diesel at the higher loads. Variation in the brake thermal efficiency is in between 1% to 15%. At 1600 rpm at the high loads it has shown improvement in BTE by 1%.
3. Volumetric efficiency is reduced by 1% to 4% in all cases due to replacement of the air by the biogas. Decrease in the volumetric efficiency is higher for B40 mixture.
4. There is decrease in the exhaust gas temperature 1% to 4%. At the higher loads decrease in temperature is maximum than other cases and nearly up to 4%. For the constant load it is nearly constant.
5. For constant RPM and varying load oxides of Nitrogen formation is suppressed with the effect of CO_2 presence in biogas. Reduction in NOx increases with the increase in the biogas percent for both, constant load and variable speed and constant speed and variable load. For B40 mixture reduction in NOx emission is up to 40% to 45%.
6. Soot emission is decreased significantly as the percentage of the biogas increases. It is found that at higher load and high biogas percentage has ability to reduce the soot by 40% to 60%.
7. From overall results it is observed that B40 mixture is effective in dual fuel injection for better performance and emission reduction purpose.

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