Experimental Evaluation of Dual Fuel CI Engine Using Synthesized Biogas

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Abstract: The energy consumption rate of the world is increasing rapidly due to population sudden increase. The extensive use of energy sources has led to fossil fuel depletion and the rise in pollution. Renewable sources are the promising sources and key solutions to the energy shortage. Biogas, one such renewable fuel, can be used in a diesel engine under dual fuel mode for the power generation. This work attempts to unfold the effect of compression ratio on the performance, combustion and emission characteristics of a dual fuel diesel engine run on synthesized biogas. For this investigation, a Kirloskar made 3.5 kW single cylinder, direct injection, water cooled, variable compression ratio diesel engine is modified to run on biogas with diesel for dual fuel operation. Experiments were carried out for variations in compression ratio, pilot diesel fuel quantity and loads, at constant speed for diesel and dual fuel operation. Experimental results show that BSFC decreases as pilot fuel quantity increases. Brake thermal efficiency increases as pilot fuel quantity increases at all loads conditions. The peak cylinder pressure in dual fuel mode is lower than that of diesel mode and net heat release rate is lower in dual fuel mode than diesel mode. NOx emissions found lower in dual fuel operation as that of diesel. At low load conditions CO emission increased in dual fuel mode.

Keywords: Renewable source, Biogas, Dual fuel, Diesel engine, NOx emission

1. INTRODUCTION

The outburst of population gives rise for demand of energy. As petroleum resources are depleting due to this ever rising energy demand. Pollution also creates threats for bio-diversity. The identification and utilization of alternative fuels for power generation becomes prominent research area. With the increasing concern regarding diesel engine emissions, including nitrogen oxides (NOX) and particulate matter (PM), and the rising of energy demand as well, the utilization of alternative fuels in diesel engine has been found to be an attractive solution. Alternative fuels like biogas and biofuels founds more attractive in view of their friendly environmental nature. The gaseous fuels are getting more positive response from researchers and end-users compared to past because of current unfolding developments. Gas is clearly the fossil fuel of least environmental impact. When burnt, it produces virtually insignificant SOx and relatively little NOx, the main constituents of acid rain, and substantially less CO2, a key culprit in the greenhouse debate, than most oil products and coal (B. Sahoo *et al*, 2009; Wei *et al*, 2016).

The Diesel engines are the most reliable and efficient combustion device and has steadily grown with technological development over past few decades. They are appropriate due to their high thermal efficiency, and low emissions of unburned hydrocarbons (UHCs), carbon monoxide (CO) and carbon dioxide (CO2) compared to those of spark ignition engines. They can also operate at higher compression ratios which allow use low energy fuels like biogas (Yoon *et al*, 2011).

The use of biogas in diesel engines is environmentally favorable not only because it increases renewable fuel consumption in transport but also because methane is considerably lower in carbon than ordinary diesel fuel. Therefore, use of biogas can reduce pollutant levels in exhaust gases, including emissions of solid particles and NOx. However, biogas cannot be used separately from diesel, a dual-fuel supply system when biogas– biodiesel and biogas–mineral diesel are used as fuel is required (Makareviciene *et al*, 2013).

N. Mustafi *et al* (2013) conducted investigation for natural gas and biogas, and it is found that the peak cylinder pressure was similar to diesel at 75% of the rated output of the engine. Net heat release rates were 27% and 30% obtained for NG and biogas respectively compared to diesel. NOx emission under dual fuel mode was low. Deb et al, (2015) investigated the hydrogen-diesel dual fuel combustion in direct injection (DI) diesel engine. It is found that the improvement in brake thermal efficiency (BTHE) of the engine, reduction in brake specific energy consumption (BSEC) with an increasing hydrogen energy fraction. Also CO, CO_2 and smoke emissions decrease with an increasing percentage of hydrogen energy content but, NO_x emissions increases. In addition to that, it was also observed that there was a sharp increase in peak in-cylinder pressure and the peak heat release rate values with the increasing hydrogen rate.

A Dhole *et al*, (2014) found that producer gas is used as secondary fuel, maximum decrease in the brake thermal efficiency of 8% is obtained. Saleh *et al*, (2008) investigates the effect of variation in LPG composition on emissions and performance characteristics in a dual fuel engine run on diesel fuel and found that as higher butane content lead to lower NOx levels while a higher propane content reduces CO levels. M. Lapuerta *et al*, (2015) studied the effect on performance and pollutant emissions for biomass derived gaseous fuel with diesel and biodiesel with varying EGR ratios, found that as replacement of fuel increases particulate matter and hydrocarbon emission decreases. Bedoya *et al*, (2009) studied CI engine performance running on dual fuel mode at fixed engine speed and four loads, varying the mixing system and pilot fuel quality for synthesized biogas. It was found that full diesel substitution is attainable using palm oil biodiesel as pilot fuel on biogas dual fuel engine. Barik *et al*, (2014) conducted investigation diesel engine fueled with biogas-diesel in dual fuel mode and found that the cylinder peak pressure in the dual fuel operation was overall higher by about 11 bar than diesel operation. The NO and smoke emissions in the dual fuel operation was found lower overall by about 39% and 49%, compared to diesel operation. Saha *et al*, (2014) carried out experimentation on a dual fuel diesel engine running on raw biogas and carbon monoxide and hydrocarbon emissions under dual fuel mode are found to be more than the diesel mode. Pianthong *et al*, (2013) experimentally investigated performance of dual producer gas-diesel engine and found that increasing amount of pilot fuel improves thermal efficiency and reduces the CO emission at low engine load conditions. Luijten *et al*, (2011) investigates the CI engine performance with jetropha oil and biogas. It is found that at higher load thermal efficiency hardly got affected and at lower loads biogas addition results in a decrease up to 10% in thermal efficiency.

Hernández *et al*, (2015) studied the separate effect of hydrogen, methane and carbon monoxide addition on the performance, combustion efficiency and pollutant emissions of a diesel engine. The indicated thermal efficiency was reduced when increasing the diesel fuel replacement because of the unburnt gaseous fuel, as confirmed by an increase in HC and CO emissions when CH_4 and CO was used. However, a significant decrease in the PM mass and number concentration was achieved, while NOx emissions were not much affected by the diesel fuel replacement. Higher engine loads significantly improved the engine efficiency and the pollutant emissions.

2. Experimental Setup and Methodology

The experiments were performed at internal combustion engine laboratory at VPCOE, Baramati. A Kirloskar made 3.5 kW single cylinder, direct injection, water cooled, variable compression ratio diesel engine is used for experimentation. The diesel engine test rig specifications shown in Table 1. Test runs were conducted with the Diesel engine test rig for two modes, with diesel and diesel-biogas. Compression ratio varied from 15 to 18, while load varies from 0 to 100%. For diesel- biogas operation various composition were taken for varying load condition at constant speed. Synthesized biogas is used with composition of 65% CH4 and 35% CO2 (volume).

Table 1
Engine Specifications

Parameters	Specifications
Constructor	Kirloskar
Engine type	1 Cylinder, 4 Strokes, Water Cooled, Modified VCR Diesel Engine.
Bore (mm)	87.5
Stroke (mm)	110
Compression ratio	12:1 to 18:1
Speed (RPM)	1500
Power output(kW) 4.2	3.5
Volumetric capacity (cc)	661

Table 2
Fuel Properties

Properties	Diesel	Biogas
Chemical composition	$C_{12}H_{26}$	65% CH_4, 35% CO_2 (volume)
Density (kg/m^3)	840	1.17
Lower calorific value (kJ/kg)	46300	20500
Stoichiometric air fuel ratio	15.8	6.96
Auto-ignition temperature (K)	553	1087

The diesel engine setup was modified using air gas mixer for dual fuel operation. Manual reading was taken for performance evaluation.

Computerized data acquisition system is used to measure in cylinder pressure data. Kane Quintox 6 gas analyzer was used to measured the emission

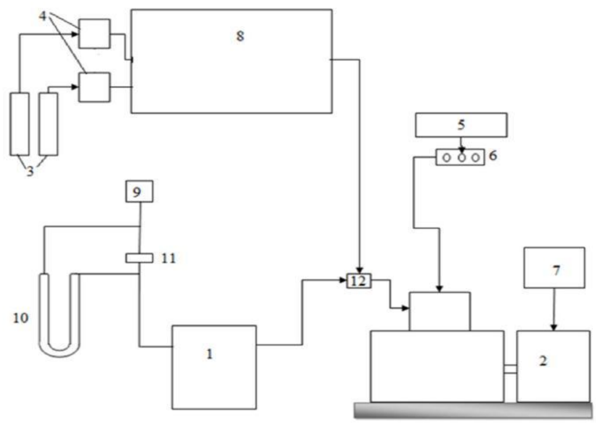

Fig. 1 Layout of Experimental setup

1. Air surge tank, 2. Test Engine, 3. Fuel gas cylinders, 4. Gas Flow meters, 5. Fuel tank, 6. Fuel consumption meter, 7. Computer interface of the control panel, 8. Damper to stabilize the gases, 9. Air filter, 10. Manometer to measure the pressure across orifice plate, 11. Orifice plate to measure the air flow rate, 12. Air-gas mixer.

3. Result and Discussion

The engine performance, combustion and emission characteristics were studied by experimentally with different operating modes. At diesel mode and diesel-biogas mode, experiments were carried out for 0% load to 100% load condition with variable compression ratio range of 15 to 18.

3.1. Performance Characteristics

I) Brake Thermal efficiency

Figures (2,3,4) shows that the brake thermal efficiency in the dual fuel mode operation is found to be lower than that of diesel operation. This is because of the lower calorific value of biogas. The brake thermal efficiency in the dual fuel mode improves as the CR is increased. This is because of the pressure and the temperature rise with increase in CR which increases the possibility of more amount of biogas to go through complete combustion.

Also the brake thermal efficiency increases as load increases, this is because at low and part load conditions there is poor utilization of biogas takes place which results in incomplete combustion of biogas. At all load condition as pilot diesel fuel quantity increases, brake thermal efficiency increases as compared of diesel operation this is because with higher pilot fuel the combustion of the biogas is better.

II) Brake Specific Fuel Consumption

Figures (5,6,7) shows that brake specific fuel consumption is higher in the dual fuel mode operation than that of the diesel operation. This is caused by the lower energy density of biogas, lower cylinder temperature, and also the presence of CO_2 in biogas limits faster burning.

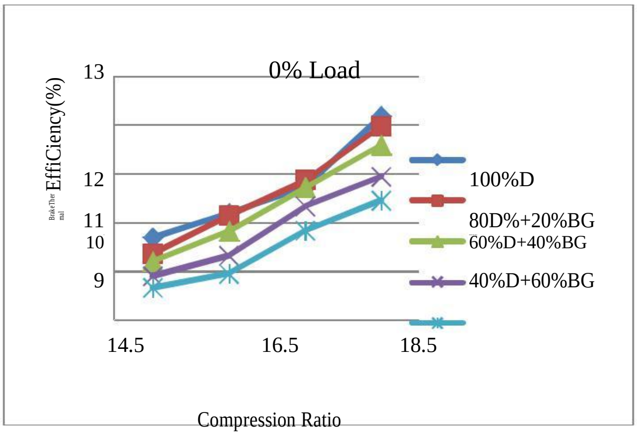

Fig. 2 Effect of Compression Ratio on Brake Thermal Efficiency at 0% Load

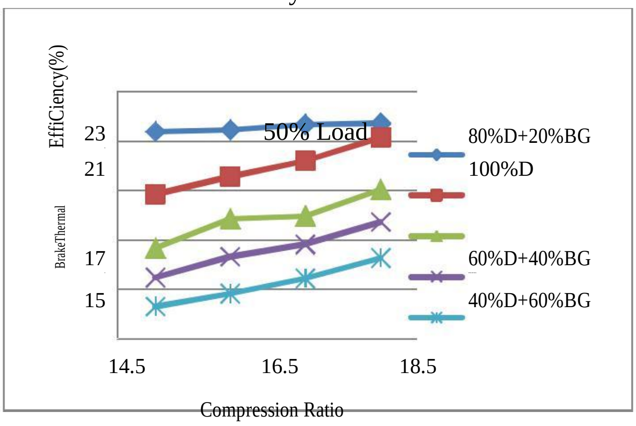

Fig. 3 Effect of Compression Ratio on Brake Thermal Efficiency at 50% Load

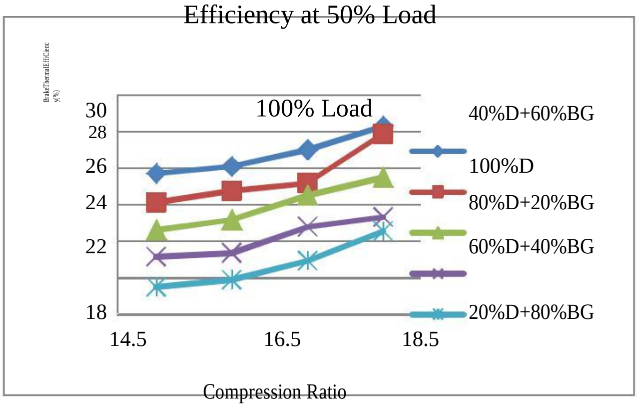

Fig. 4 Effect of Compression Ratio on Brake Thermal Efficiency at 100% Load

It is found that with increasing load, BSFC decreases. The increase in load causes cylinder pressure and temperature to increase, which improves the combustion process resulting in decrease in BSFC. The BSFC increases with increasing percentage of biogas substitution at part loads may be due to incomplete combustion of the gaseous fuel, while at higher loads BSFC improves with increase of biogas substitution.

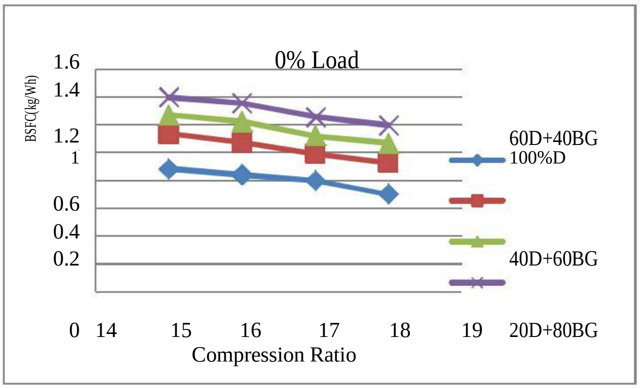

Fig. 5 Effect of Compression ratio on BSFC at 0% load

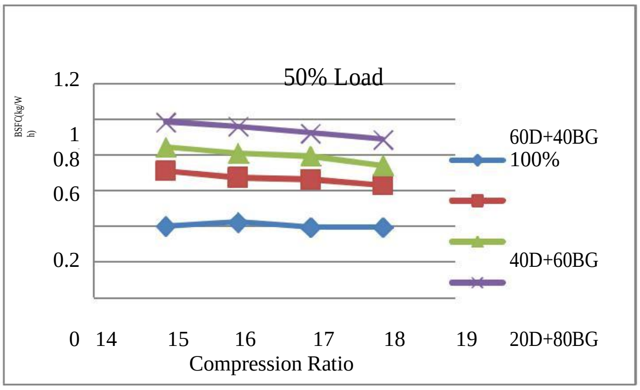

Fig. 6 Effect of Compression ratio on BSFC at 50% load

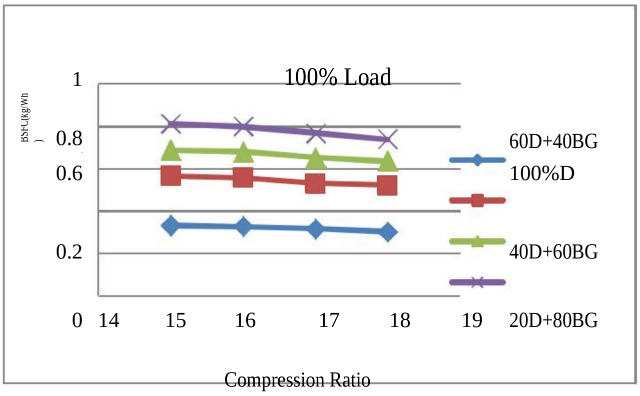

Fig. 7 Effect of Compression ratio on BSFC at 100% load

3.2. Combustion characteristics

Combustion characteristics of diesel operation and diesel-biogas operation are shown in figures (8,9,10). The cylinder pressure under dual fuel operation differs from the particular values under diesel operation. The peak cylinder pressure increases for both diesel mode and dual fuel mode as load is increased. This is because of increase of injected fuel mass with increase in load. But the peak cylinder pressure in dual fuel mode is lower than that of diesel mode for all CRs. The peak cylinder pressure rises as the CR is increased.

Figures (11,12) shows that the heat release is higher in diesel mode in comparison to duel fuel mode. This is due to high calorific value of diesel with respect to biogas. The heat release rate increases with increase in

CR normal diesel operation, revealing late combustion of the gaseous fuel.

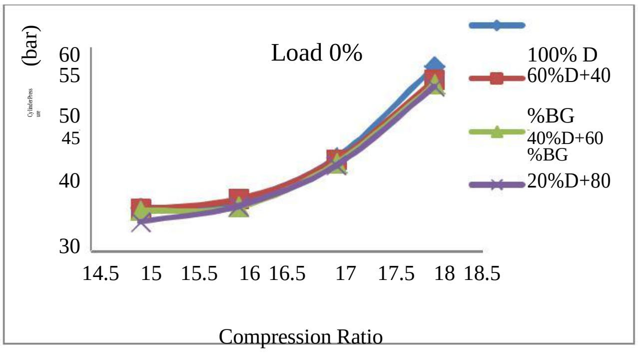

Fig. 8 Effect of Compression ratio on Cylinder pressure at 0% load

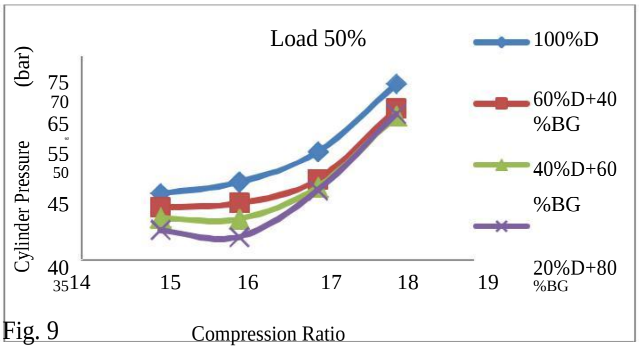

Fig. 9 Effect of Compression ratio on Cylinder pressure at 50% load

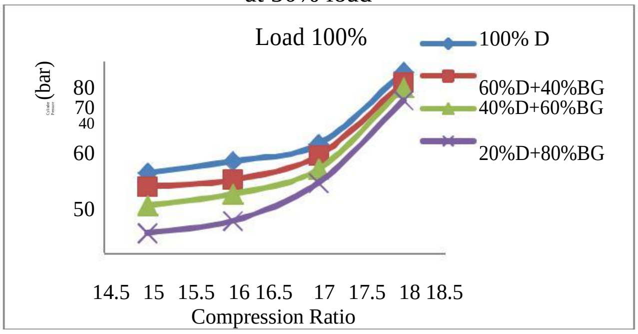

Fig.10 Effect of Compression ratio on Cylinder pressure at 100% load

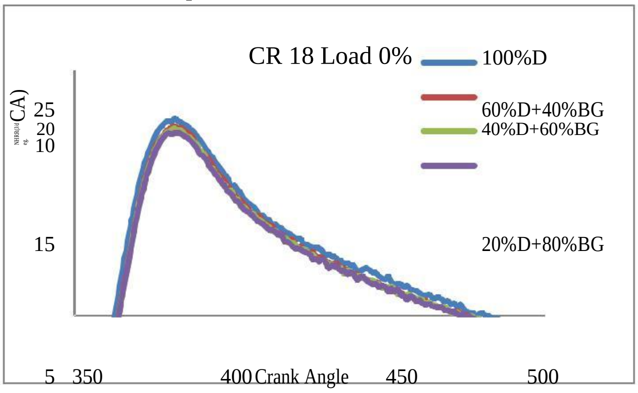

Fig. 11 Net heat release rate vs Crank angle of dual fuel engine at 18 CR and at 0% load.

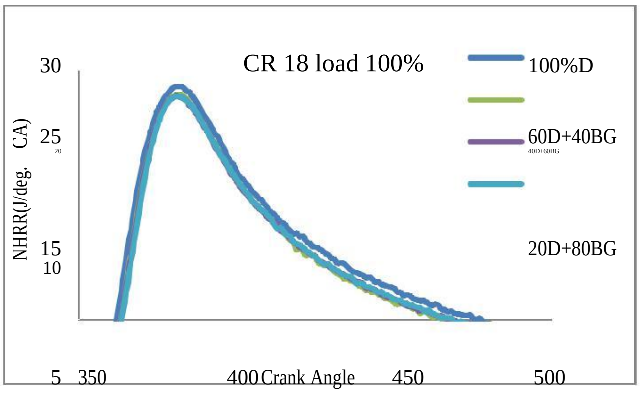

Fig. 11 Net heat release rate vs Crank angle of dual fuel engine at 18 CR and at 100% load.

3.3. Emission Characteristics

I) CO Emission

CO emission in the dual fuel mode operation is considerably higher than that of diesel under all test conditions. This is because of incomplete combustion caused by dilution of mixture by the CO2 present in biogas and lack of oxygen. Therefore, the flame formed in the ignition region of the pilot fuel is generally suppressed, and does not proceed until the biogas-air mixture reach a minimum limiting value for auto ignition. Primarily, at low load conditions, CO emissions are high which then decreases at part load conditions, and again increases at high load conditions. This is because initially, at low load condition, the cylinder temperature is low, and consequently the combustion of fuel is not appropriate. At higher load conditions, more quantity of fuel needs to be supplied. Hence after a particular load, the fuel-air mixture becomes too rich to go through complete combustion. CO emission decreases with increase of CR because higher CR consequences more growth of temperature during the compression stroke which results in improved combustion, which leads to lower formation of CO at higher CR.

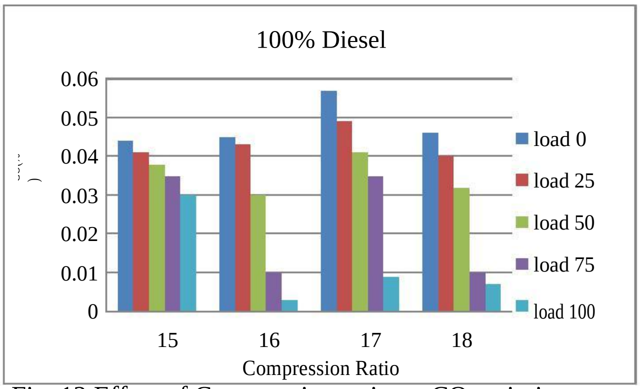

Fig. 12 Effect of Compression ratio on CO emission at 100% Diesel

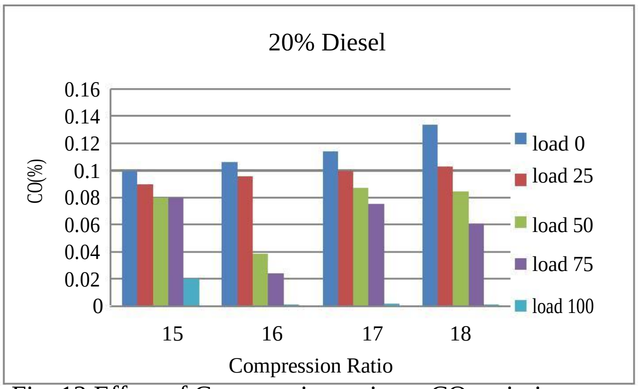

Fig. 13 Effect of Compression ratio on CO emission at 20% Diesel

II) CO_2 Emission

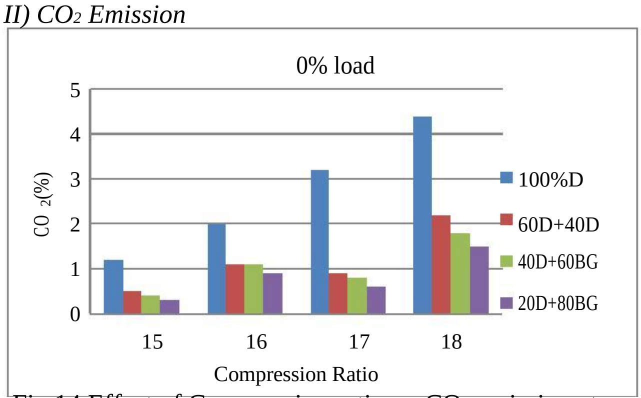

Fig.14 Effect of Compression ratio on CO_2 emission at 0% load

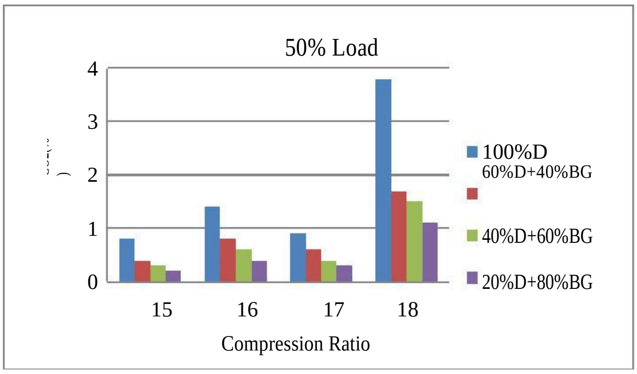

Fig.15 Effect of Compression ratio on CO_2 emission at 50% load

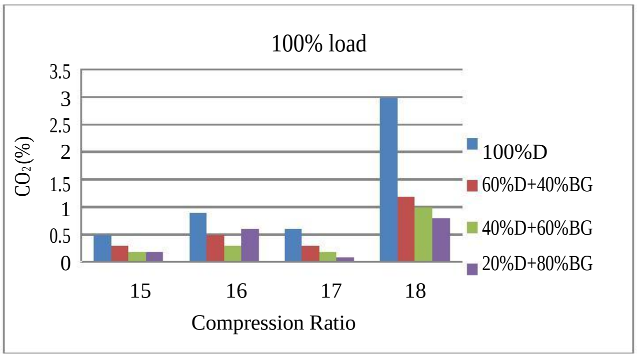

Fig.15 Effect of Compression ratio on CO_2 emission at 100% load

The CO2 emission is an sign of complete combustion of fuel in the combustion chamber with the presence of excess oxygen. The CO2 emission shows a decreasing trend from no load to full load. Since, at no load the fuel consumption of the engine is found to be lower, as compared to full load and the availability of air in the combustion chamber is enough to achieve complete combustion. The dual fuel operation shows a lower CO2 emission compared to diesel. This is because of the deficiency of oxygen, lower combustion chamber temperature, and less instance for combustion, which leads to incomplete combustion, causing less CO2 emission.

III) NO_x Emissions

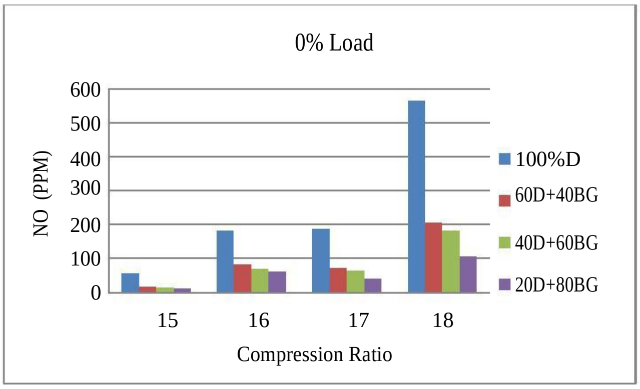

Fig.16 Effect of Compression ratio on NO_x emission at 0% load

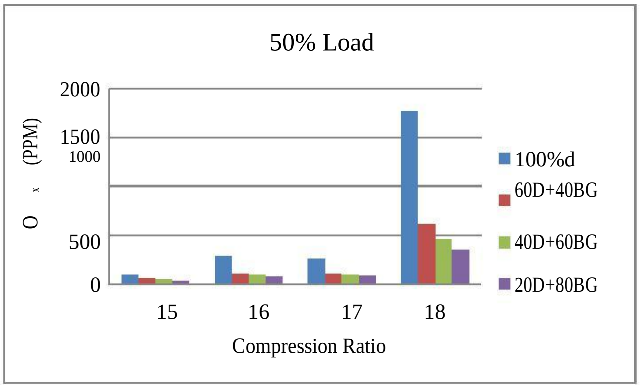

Fig.17 Effect of Compression ratio on NO_x emission at 50% load

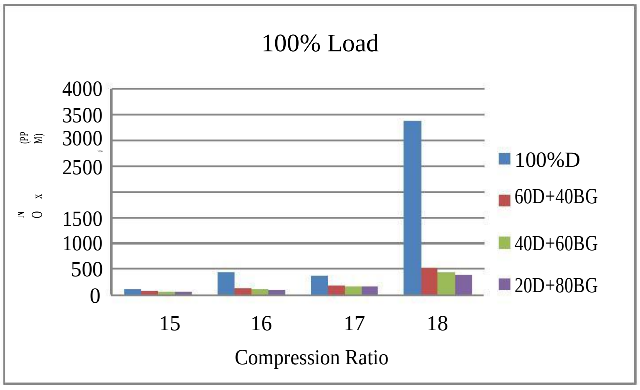

Fig.18 Effect of Compression ratio on NO_x emission at 50% load

NOx are generally composed of mainly NO and smaller amount of NO2. NOx is usually formed in the high temperature combustion gases inside the cylinder and mostly through oxidation of nitrogen present in the atmospheric air. The figures (16,17,18) show that the NOx emission in the diesel mode operation is much higher as compared to dual fuel mode operation. This is due to the formation of NOx mainly depends on the temperature of the combustion chamber. The combustion chamber temperature in diesel operation is much higher as diesel has a higher calorific value as compared to biogas. Also, the presence of inert CO2 in biogas lowers the temperature of combustion chamber. The NOx emission increases with load because more quantity of fuel needs to be supplied with increase of load which consequently increases the temperature of combustion chamber.

CONCLUSIONS

An experimental investigation was carried out for evaluation of the effect of variable compression ratio on the performance, combustion and emission characteristics of a synthesized biogas-diesel dual fuel operation, at variable load condition and constant speed and following conclusion were made:

1) The brake thermal efficiency in the dual fuel mode improves with increase in load and compression ratio.
2) Brake specific fuel consumption decreases with increase in load and compression ratio.
3) The peak cylinder pressure in dual fuel mode is lower than that of diesel mode for all CRs.
4) The net heat release was higher in diesel mode in comparison to duel fuel mode.
5) CO emission in the dual fuel mode operation was higher than that of diesel mode and at higher CRs CO formation is lower.
6) NOx emission found decreased in dual fuel mode as compared to diesel mode.

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