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Investigations on biogas fuelled Homogeneous Charged Compression Ignition engine with Di ethyl ether -Biodiesel-Butanol blend as Pilot fuel

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Investigations on biogas fuelled Homogeneous Charged Compression Ignition engine with Di ethyl ether -Biodiesel-Butanol blend as Pilot fuel

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Abstract. The continuous and increasing in volume of fossil fuels utilization leads to an alarming increase in green-house gases emissions. Consequentially, the release of toxic agents may cause detrimental health issues and aggravate global warming effects. Biofuels, due to its reduced emission effects, are found to be a potential alternate to fossil fuels, especially for their usage in internal combustion engines under certain loading conditions. The present research work aims at investigating the effects of butanol blending ratio at different biogas flow rates on the performance and emission characteristics of a single-cylinder CI (Compression ignition) engine under Homogenous Charge Compression Ignition (HCCI) mode. Flow rates of biogas taken in the present study are 12 lpm and 16 lpm whereas the butanol is blended in biodiesel – DEE (Diethyl-ether) mixture at 10, 20 & 30% concentration by volume. The engine parameters analysed in the present work are brake thermal efficiency, Brake Specific Energy Consumption (BSEC), Hydrocarbons (HC), Carbon monoxide (CO), Oxides of Nitrogen (NO_x) and Smoke emissions. Results showed that the butanol addition in the fuel reduced the NO_x emissions considerably at various loads between 0.1 N-m to 15 N-m. Further increase in load resulted in knocking conditions in the engine due to multipoint ignition. Based on the experiments, it is witnessed that 30% of butanol blend in biodiesel-DEE mixture high efficiency and low smoke emissions compared to all other blends. Simultaneous reduction of NO_x and smoke emissions is observed in HCCI mode.

1. INTRODUCTION

Being it any industrial sectors or areas of rural hamlets, the essential need becomes to produce and utilize the power effectively in a view to overcome the power scarcity. Renewable energy resources are believed to have possible ways to reduce the pertaining issue, together controlling the release of green-house gases to the atmosphere. In the transportation sector, it is witnessed that certain kind of fuels such as biogas, biodiesel, ether class fuels are emerging as a promising alternative to conventional fuel. Biogas, a mixture of carbon di-oxide (CO_2) and methane (CH_4), can easily be produced from animal waste or anaerobic bacterial decomposition. However, CO_2 affects the quality of combustion and also it reduces the overall heat content of the biogas. Consequently, the overall NO_x emissions will be controlled. Since gaseous fuels mix swiftly with air, it finds wide usage in internal combustion (IC) engines. Additionally, good flammability limits and high self-ignition temperature make them more compatible for spark ignition (SI) engines even at high compression ratios. Nevertheless, the biogas based IC engines results low thermal efficiency and high hydrocarbons (HC) emissions. The biogases possess relatively high auto-ignition temperature and hence its ignition through compression is arduous [1].

n-butanol, a class of alcoholic solvent, has been successfully proved as an alternative fuel for SI engines since its thermophysical properties resemble to that of gasoline and it is also witnessed as a possible blend with biodiesel. Interestingly, butanol blends are capable in saving the fossil energy up to 50%, which is more than with the gasoline. It is evidenced that the volume fraction of blended butanol influences the performance and emission indices of SI engines [2]. In case of CI engines, butanol has the following tendencies: it improves the thermal efficiency, it reduces the soot emissions (at higher loads), yet it increases the rate of fuel consumption [3]. Butanol provides good scope for further research towards improving the IC engines performance. The homogeneous charge compression ignition (HCCI) mode is emerging as a promising option over the conventional SI and CI modes of combustion. In this mode, a mixture of air and fuel are compressed until the auto ignition is achieved. Furthermore, HCCI mode produces extremely low levels NOx and soot emissions and results in better thermal efficiency which will be discussed explicitly in the paper further. Due to the fuel lean capabilities of these engines, they give 30% better efficiency than SI engine mode. The mixing of fuel with air leads to low amount of emissions and results in better and clean combustion. HCCI mode of engine has very low peak temperatures and hence they produce less emission. HCCI combustion is mostly controlled by the chemical kinetics. The engine's combustion parameters such as temperature, pressure and the chemical characteristics of fuel-air mixture inside the chamber at the moment of inlet valve close (IVC) are found to have good control over the HCCI combustion [2]. Similar approach is followed in the present experimental work.

Bedoya et al. [4], from their experimental study on a 4-stroke diesel engine running under HCCI mode reported the significance of equivalence ratio on the combustion characteristics. The authors found with the combustion efficiency around 90% in the engine at the equivalence ratio of 0.4, however the inlet absolute pressure (2.2 bar) and the inlet charge temperature (483 K) caused engine damage at such high equivalence ratio. Nathan et al. [5] suggested that the diesel-HCCI mode is not suitable even at a charge temperature of 100 °C mainly due to high heat release rates. Also, the authors found that the thermal efficiency for biodiesel-HCCI mode is lower than with the CI mode. The high value of in-cylinder temperature resulted an increase in NO_x emissions, whereas increase in the bulk gas temperature significantly decreased HC and CO emissions at higher equivalence ratio. Kobayashi et al. [6], conducted experiments on a 4-cylinder gas engine of compression ratio (CR) 17, mounted with a turbocharger. The authors found the maximum values for brake mean effective pressure (BMEP) and efficiency as the inlet temperature of the engine reduced. By controlling the peak firing pressure in the cylinder, the maximum thermal efficiency and minimum NO_x emission can be achieved, according to the authors.

Park et al. [7] studied the effect of dimethyl ether (DME) on the combustion and emission characteristics of a CI engine. The authors observed a reduced emission in their experiments which might be due to the absence of carbon-carbon bonding in DME, according to the authors. Additionally, the DME mixes well with air and it easily atomizes to small droplets. As a result, the authors showed that the peak combustion was decreased with increase in amount of biogas rate at the same injection timing. Mustafi et al. [8] used a mixture of natural gas and biogas, by which it was showed that the proper mixing of the dual fuels, at specific loads, reduced the CO_2 emission. Also, NO_x concentration was found to be reduced up to 10% during the mixing of diesel and biogas fuel, but observed with a surge in CO_2 content. In general, the flow rates of biogas and methane fraction have control over the BTE of a CI engine that runs on dual fuel mode [9]. A high intake temperature could result in advancing the start of combustion (SOC), yet, reduction in the volumetric efficiency [10]. A CI engine with enhanced performance and better emission characteristics can be arrived with fuels like butanol, which is having higher heat of vaporization, good oxygen content and favourable flammability temperature [11]. HC and CO emissions are found high at low loads. Biodiesel combustion phasing is found to have less significant effects with the equivalence ratio, whereas pure diesel has strong effects. Henceforth, biodiesels combustion efficiency can be maintained even at lean mixtures [13].

In this study, Biogas and diethyl ether (DEE) mixed with butanol and biodiesel at different concentrations are used as primary and secondary fuel respectively in HCCI mode. Effects of butanol blending ratio and biogas flow rate at various load condition on performance and emission characteristics of HCCI engine are studied.

2. METHODOLOGY

Table 1 shows the various input parameters used in this study. Applied load is varied from 0 to 20 N-m at an interval of 5 N-m, using eddy current dynamometer. Knocking is noticed at the high load (20 N-m). Hence, 20 N-m represents 90% load of the engine. Two biogas flow rates say, 12 lpm and 16 lpm are taken in this study considering the misfiring and knocking conditions. 60% methane fraction is maintained. DEE is used as main port injection fuel due to its better ignitability and other properties. Palm oil based biodiesel and butanol are also added with DEE. 70% DEE is taken in all cases. Butanol blending ratio is varied from 10 to 30%. Biodiesel is taken for the remaining volume percentage. The main idea behind this study is to keep constant volume flow rate of DEE. So that effect of butanol blending ratio can be studied.

Table 1. Input parameters

Load (N-m)	Biogas flow rate (lpm)	Butanol ratio in blended fuel (%)
5	12	10
10		20
15	16	30
20		

3. FUEL PREPERATION

Three samples consisting different volumetric ratios of diethyl Ether, butanol and biodiesel are prepared. First sample consists of DEE (70%), Butanol (10%) and Biodiesel (20%). The second sample consists of DEE (70%), Butanol (20%) and Biodiesel (10%). Finally, the third sample is prepared which consist of DEE (70%), Butanol (30%) and Biodiesel (0%). The measured properties for each sample are provided in Table 2.

Table 2. Fuel Properties

S.No.	Properties	B10 (Sample 1)	B20 (Sample 2)	B30 (Sample 3)

1	Flash point (°C)	75	80	89
2	Fire point (°C)	84	91	96
3	Pour point (°C)	-7	-6	-6
4	Cloud point (°C)	4	6	6
5	Density (kg/m^3)	848.2	845.4	842.6
6	Kinematic viscosity (mm^2/s)	4.26	4.32	4.38
7	Calorific value (kJ/kg)	40,611	39,312	36,013

4. EXPERIMENTAL SETUP

A single cylinder 4-stroke CI engine (8 HP, AV1XL model) is modified as HCCI engine. The schematic diagram of experimental setup used to conduct the present research work is shown in Figure 1. Simulated biogas constituting CO_2 and CH_4 is passed to the inlet manifold with air. A starter motor is used to start the engine in HCCI mode. Blended fuel is injected at inlet port during suction stroke. Thermal mass flow meter, weighing machine and manometer are used to measure the flow rate of biogas, blended fuel and air respectively. A separate home-made injection system is used to control injection timing and injection duration of blended fuel. AVL 5-gas emission analyser and AVL smoke meter are used to measure exhaust gas emissions

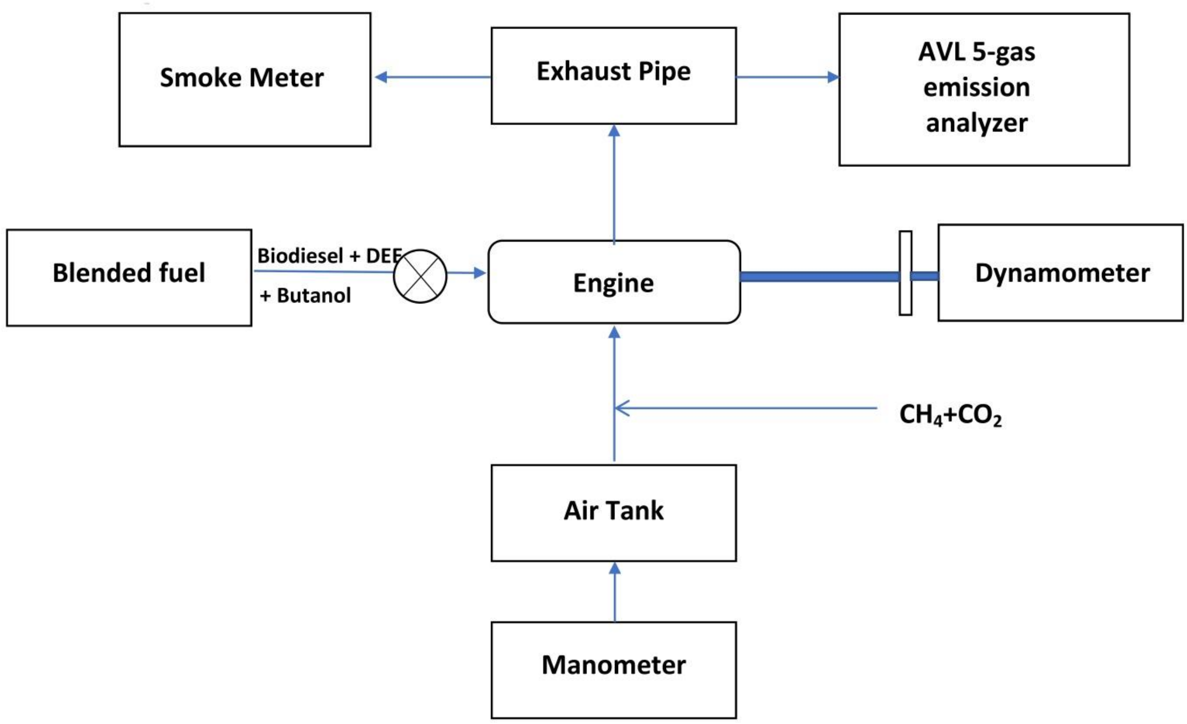

Figure 1: Experimental setup

5. RESULTS AND DISCUSSIONS

5.1. BRAKE THERMAL EFFICIENCY

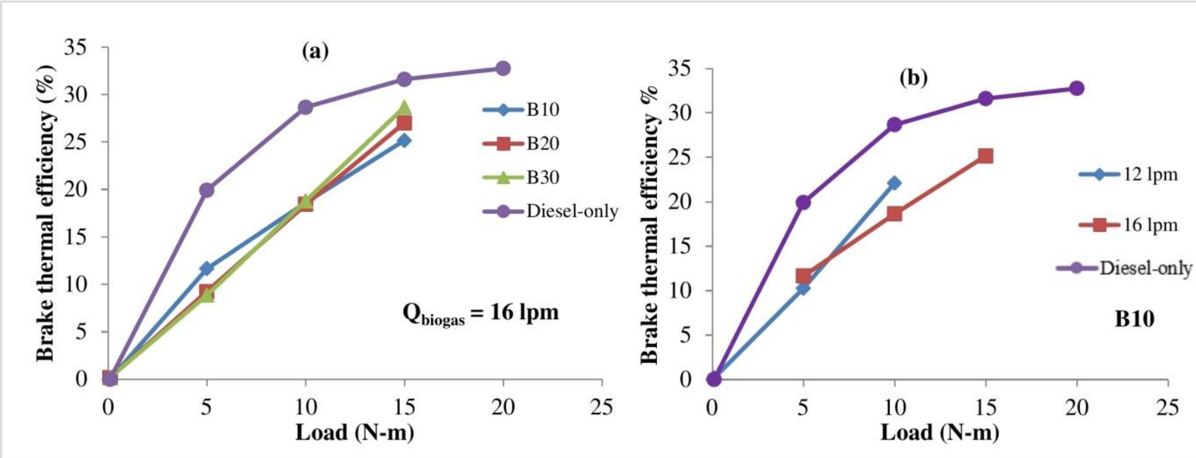

Figure 2: Effect of (a) butanol blending ratio and (b) biogas flow rate on brake thermal efficiency

Effect of butanol blending ratio at various applied load on brake thermal efficiency for 16 lpm biogas flow rate is provided in Figure 2(a). The trend in the figure shows an overall increase in brake thermal efficiency for all the three blend rates from a load 0.1 N-m up to 15 N-m. The rate of increase of brake thermal efficiency for B30 is observed to be constant resulting a near to linear line. The percentage of brake thermal efficiency is found to be 18.8% for all the three blends at 10 N-m loading. Maximum brake thermal efficiency is observed with B30 at 15 N-m load. BTE is comparatively higher for B30 sample which might be due to the fact that the increase in the available oxygen molecules helped for a complete combustion of the fuel. Butanol has a high latent heat of evaporation with a better cooling effect causing a relatively lower exhaust temperature of blended fuel compared to pure diesel fuel. This results in lower heat losses and henceforth greater brake thermal efficiency. An increase in the load after 15 N-m caused knocking while experimenting with all the three blend rates. Comparing to diesel-only mode, blended fuel shows comparable results at high load.

Figure 2(b) shows the effect of biogas flow rate on brake thermal efficiency. Misfiring is observed at high biogas flow rate with low load while knocking is observed at low biogas flow rate with high load. At higher load of 10 N-m, sample with 12 lpm produced the highest brake thermal efficiency of 22.08%. The rate of increase of brake thermal efficiency of sample with 12 lpm biogas flow rate was constant with the slope of curve as 1.35. Comparing to diesel-only mode, HCCI mode shows low brake thermal efficiency due to lower consumption of high cetane number fuel.

5.2. BRAKE SPECIFIC ENERGY CONSUMPTION

The variations in brake specific energy consumption (BSEC) at various blended fuel ratio are shown in Figure 3(a). It shows a decline in BSEC with increase in load at 16 lpm biogas flow rate. The greatest decrease in BSEC was observed with B30 from 11.29 to 3.5 with an increase in load from 5 N-m to 15 N-m. This trend could be due to a result of better combustion at high load. HCCI mode shows same BSEC like diesel-only mode at high load. Figure 3(b) shows the effect of biogas flow rate on BSEC. Biogas combustion becomes easier at high load due to high combustion temperature.

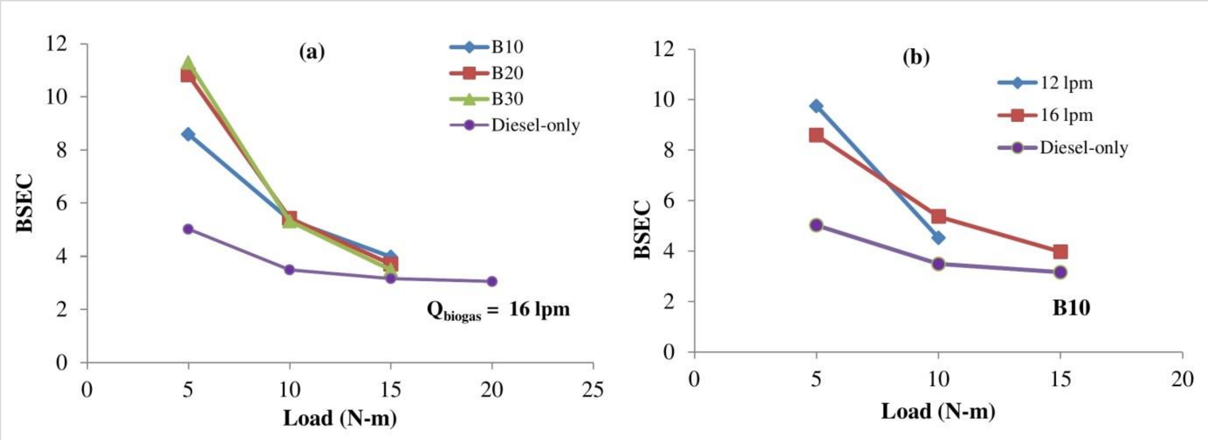

Figure 3: Effect of (a) butanol blending ratio and (b) biogas flow rate on BSEC

5.3. HC EMISSIONS

Unstable and incomplete combustion with poor efficiencies in HCCI engines attributes an increase in HC and CO emissions [4]. Figure 4(a) depicts the relationship between blended fuel ratio and HC emissions at various loads. Butanol addition reduces ignitability of the fuel and increases HC emissions. For example, the HC emission of B10 is 578 (ppm) which is lower than B20 blend by 23.33%. Compared to diesel-only mode, higher rate of HC emission is observed in HCCI mode. The reason behind this effect is due to the fact that a higher butanol ratio results a higher-Octane number since butanol has a low calorific value and high heat of evaporation. It has a leading influence, against the contrasting effect of the lower Cetane number which means a longer ignition delay. Henceforth, the flame velocity is expected to reduce along with combustion temperature and leads to a greater emission with B30 sample. Increase in load improves combustion and reduces HC emission. Figure 4(b) shows variation in HC emissions for different biogas flow rates. The HC emission for B10 is lower at the flow rate of 12 lpm than that of 16 lpm for every load from 5 N-m to 10 N-m. At a particular load of 10 N-m, the HC emission at flow rate of 12 lpm was lower by 40.14%. This trend is possibly due to the fact of the incomplete combustion and insufficient ignition temperature prevails at low loads for the biogas. Due to high combustion temperature, improvement in HC emission is observed at high load.

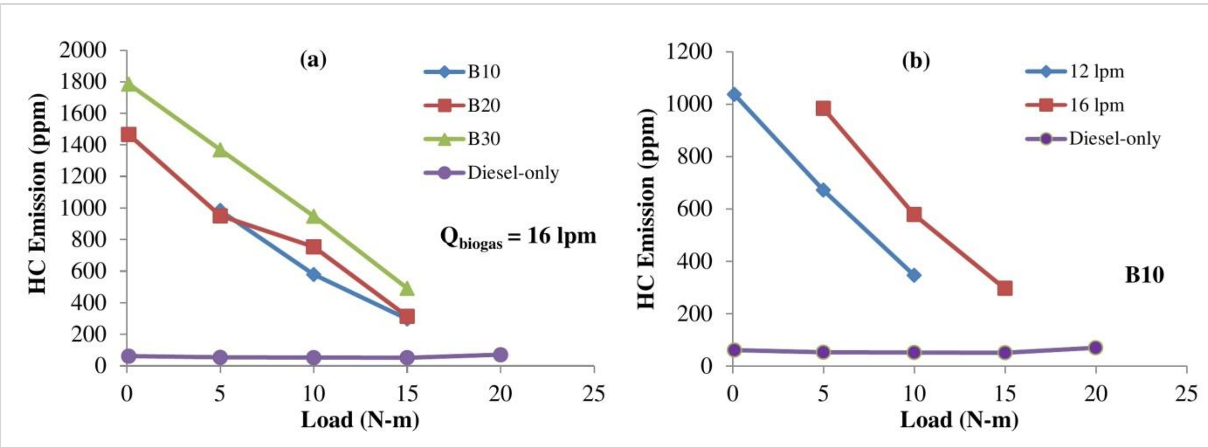

Figure 4: Effect of (a) butanol blending ratio and (b) biogas flow rate on HC emissions

5.4. CO EMISSIONS

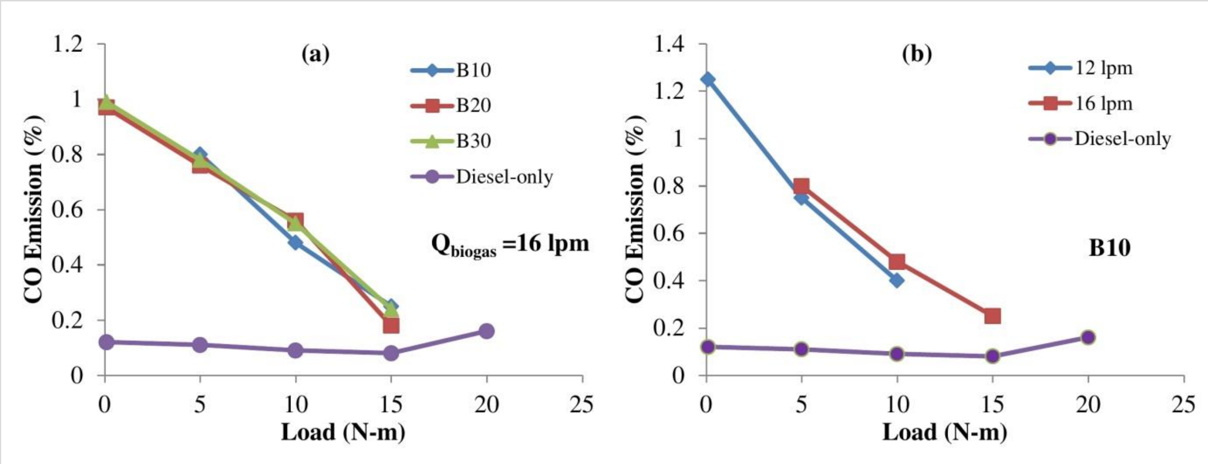

Figure 5: Effect of (a) butanol blending ratio and (b) biogas flow rate on CO emission

The influence of butanol blending ratio on CO emission at various loads, for 16 lpm biogas flow rate is provided in Figure 5(a). The percentage of CO emission is reduced significantly to 0.2% from a value of 1% for the three blends with the increase in load value from 0.1 N-m to 15 N-m. High combustion temperature at high load burns low octane number fuels and improves combustion. There is no clear trend for various butanol blends. Compared to HCCI mode, CO emission is observed to be significantly lower with diesel-only mode. It is due to the lower cetane number fuel, which resulted an increase in CO emissions for the blend fuel.

Figure 5(b) shows effect of biogas flow rate on CO emission. The least CO emission is observed with biogas flow rate of 12 lpm by 6.25% at 5 N-m and by 16.67% at 10 N-m. Knocking is observed with further increase in the load at the flow rate. As the biogas flow rate increases, the Octane number increases and the Cetane number reduces, which in further decreases the combustion temperature. This effect would leads to incomplete combustion causing the CO content to rise.

5.5. NO_x EMISSIONS

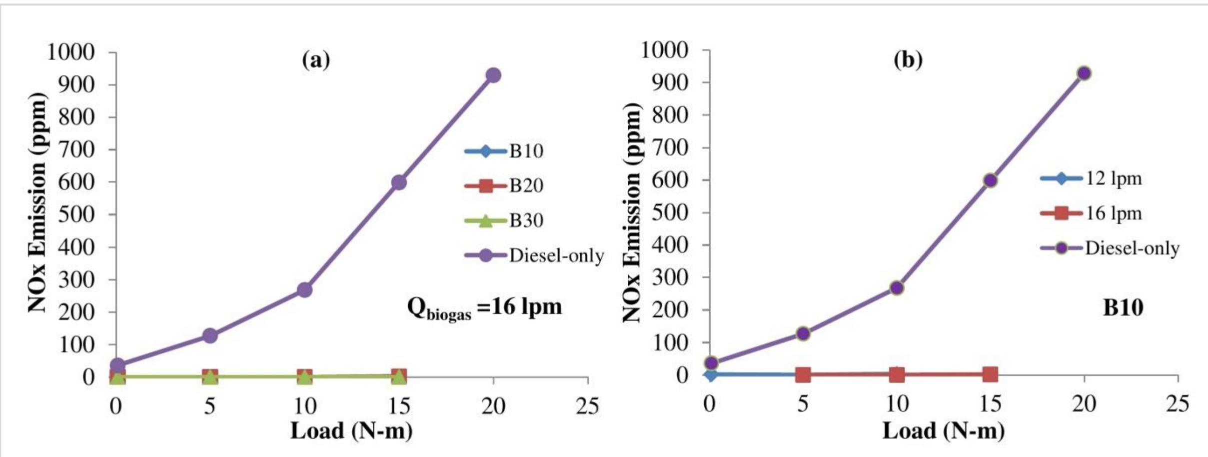

Figure 6: Effect of (a) butanol blending ratio and (b) biogas flow rate on NO_x emission

Effect of butanol blending ratio on NO_x emission at various loads, for 16 lpm biogas flow rate is provided in Figure 6(a). It is witnessed that increasing the engine load increased NO_x emission for diesel-only mode. Since more fuel is burnt at higher loads, the combustion temperature raises to a large value. Combustion in HCCI mode is a multi-ignition combustion and the developed combustion temperature in the combustion chamber is considered not to be sufficient for NOx formation, under such mode [14]. Ultra-low NO_x emission is observed in HCCI mode due to low combustion temperature mechanism. Same trend is observed for various biogas flow rates in Figure 6(b). Traces of NO_x are observed to be a maximum of 2 ppm for the B10 sample, compared with the NO_x emission of diesel-only mode which is more than 900 ppm.

5.6. SMOKE EMISSIONS

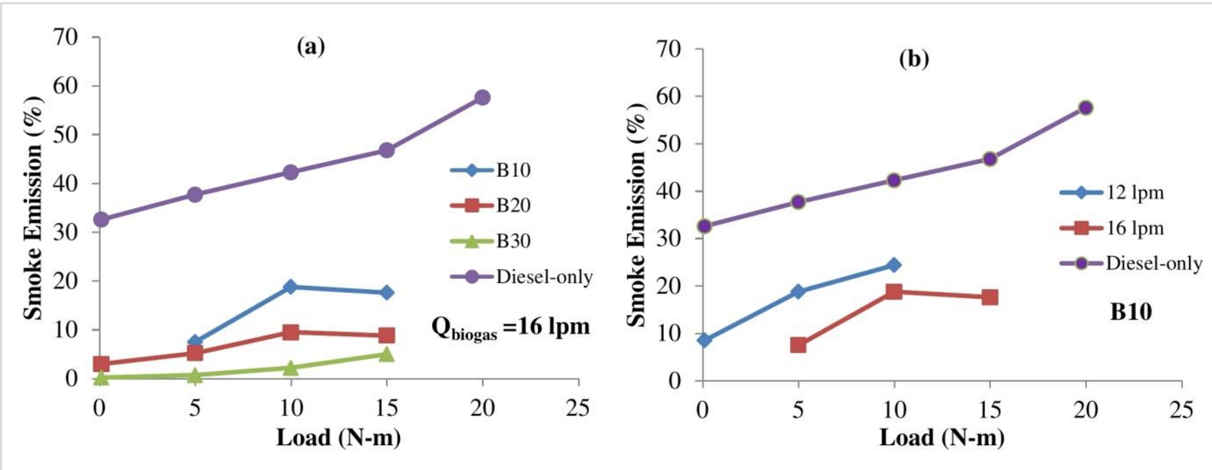

Figure 7: Effect of (a) butanol blending ratio and (b) biogas flow rate on smoke emission

Figure 7(a) depicts the relationship between blended fuel ratio and smoke emissions at various loads. Due to high homogeneity factor, HCCI mode reduces smoke emission compared to diesel-only mode. Addition butanol reduces biodiesel addition in blended fuel. It reduces smoke emissions. B30 shows better smoke emissions due to above mentioned reasons. Figure 7(b) shows variation in smoke emissions for different biogas flow rate. Increase in biogas flow rate reduces blended fuel consumption and reduces smoke emission. Interestingly, under HCCI mode a simultaneous reduction of both NO_x and Smoke is witnessed. The multi-point ignition in HCCI mode reduces the temperature which reduces NO_x. The homogeneity of the fuel is also one of the reasons for low smoke emissions.

6. CONCLUSION

In this study, effect of butanol addition in blended fuel and biogas flow rate on performance and emission of HCCI engine is analysed and compared with baseline (diesel-only) mode. The following conclusions are arrived through the recorded experimental outputs,

- B30 provides better efficiency and BSEC at high load.
- Addition of biogas reduces NO_x and smoke emissions.
- Simultaneous reduction of NO_x and smoke emissions is possible in HCCI mode.
- B30 reduces smoke emission compared to all others blends and diesel-only mode.

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