Evaluating the effect of DEE blending ratio in biogas-biodiesel fuelled dual-fuel engine

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Abstract: *Fossil fuels are depleting faster than being consumed. Fuels with higher efficiency, less consumability, and ecocity are very much desired for the present scenario. In this investigation, a conventional single-cylinder CI engine is utilized in dual-fuel mode, in which biogas is the primary fuel while biodiesel (palm oil) with different DEE blending ratios is used (5%, 10%, and 15%) as a secondary fuel. For each DEE blend, biogas flow rate and loads are varied and their effect on brake thermal efficiency, pilot fuel energy ratio, CO, NO_x, and HC emissions are estimated. Exhaust gas emissions were calculated using an AVL 5-gas emission analyser. The calorific value and density of each sample are calculated. It is witnessed from the experiments that 5% DEE used with lower biogas flow rate resulted in high brake thermal efficiency of 31.83%. Also, an increase in DEE is found to increase NO_x emission while an increase in biogas flow rate resulted in a reduction in NO_x emission. The addition of biogas is experimentally observed to have the potential in reducing pilot fuel consumption.*

Key Words: *Biogas, DEE, Performance, Dual fuel, emissions*

1. INTRODUCTION

Fuel has taken the predominant role in our regular life and it has been prevailing as an essential need since its inception. In the current scenario, researches are focussed on establishing alternatives to the conventional resources that are considered to be depleted soon. One of the few sectors that consume fuels to a large quantum is the transportation sector, where the increasing demand for vehicles poses an urgency to accelerate the research towards alternative fuels. In this line, Diethyl ether (DEE) is found to be one of the promising alternative fuels, which is considered in many engine studies [1, 2]. In the present study, the effects of the DEE blending ratio in biogas-biodiesel fuelled dual fuel mode of combustion are evaluated at various biogas flow rates. Brake Thermal Efficiency (BTE) was found to improve positively when DEE was utilized in dual fuel mode coupled with higher injection timing [3, 4]. Additionally, dual fuel mode and manifold heating reduce volumetric efficiency due to air displacement. Lowering of air density and the knocking index can be suppressed drastically in dual-fuel mode [5, 6]. Nitrogen Oxide (NO_x) emissions were found to be poor in biogas fuelled engines operating at low combustion temperatures [7]. Hydrocarbon (HC) emissions found in dual-fuel engines were detected to be more prominent than diesel, as a result of the lower flame velocity of biogas which leads to the fall in flame propagation speed, along with the ignition of lesser quantities of fuel [8]. A clean decline in the values of brake specific fuel consumption (BSFC) of about 2.2% using Karanja Methyl Ester (KME) at complete load was observed to be 13.3% greater than diesel at full load [9].

Experimental results conveyed that the inclusion of DEE in ethanol-biodiesel diesel (EBD) peaked the combustion duration, cylinder pressure, and BSFC, while reducing NO_x, particulate matter (PM), and smoke emissions. This was seen as a result of reduced ignition delay and higher latent heat evaporation [10].

On account of high notch properties like flammability, oxygen content, low self-ignition temperature, high miscibility, and high cetane number with diesel fuel, many studies revealed that DEE could be effectively used as a fuel additive along with diesel. From the literature studies, it is observed that no studies are the effect of varying DEE blends in a biogas-biodiesel dual-fuelled CI engine.

The present work aims at analysing the effect of various DEE blends at different loads and at different biogas flow rates in determining the performance and emission characteristics of a CI engine.

2. EXPERIMENTAL SETUP AND METHODOLOGY

Fig. 1 shows the schematic of the present experimental setup. The setup consists of a single-cylinder 4-stroke CI engine, a dynamometer, a mixing chamber, an emission analyser, a smoke sensor, CH_4, and CO_2 cylinders. An eddy current dynamometer served as a starter, as well as a load controller on the engine. The mixture of CH_4 and CO_2 gases in the ratio 3:2yield yields biogas for the present work and its flow rate is controlled using pressure regulators. Biogas and atmospheric air are introduced into the engine through the intake manifold whereas the modified fuel is introduced into the intake manifold through a separate pipeline. A smoke meter (AVL 437C) to analyse the smoke level and an emission analyser (AVL 444) to capture the quantity of CO, NO_x, and HC emissions are used. These devices are attached to the tailpipe of the engine's exhaust manifold while taking the exhaust emission readings.

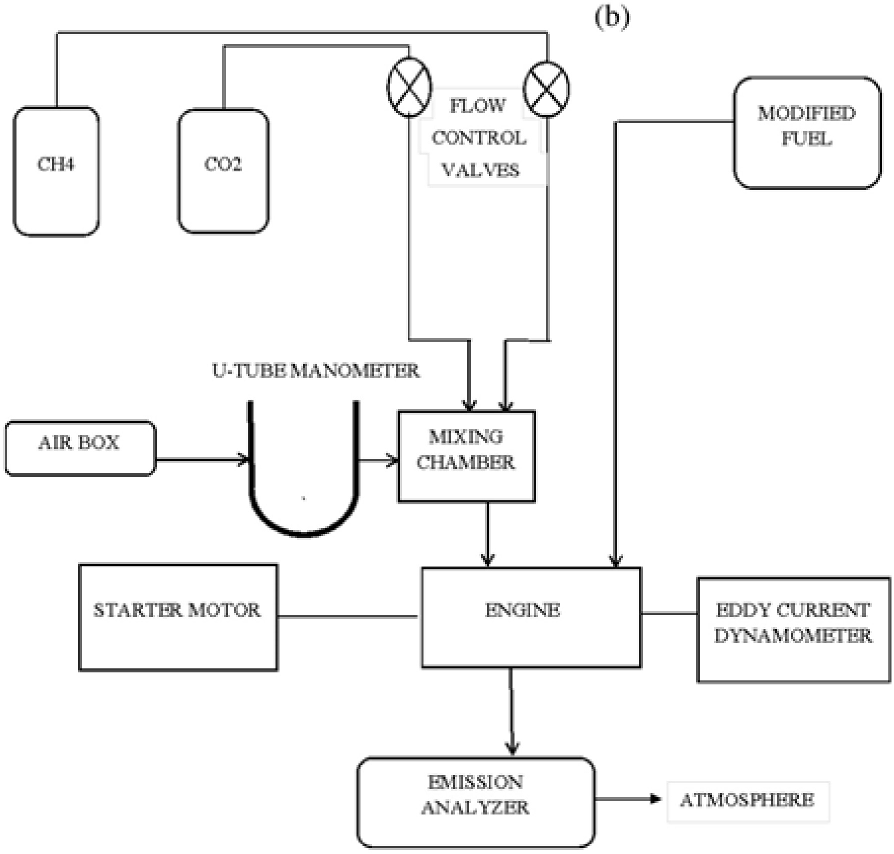


Fig. 1 – (a) photograph and (b) schematic of the experimental setup

The engine specifications are furnished in Table 1 and the input parameters are presented in Table 2.

At present, biogas is used as the primary fuel and the biodiesel (palm oil) containing DEE blend (three different fractions; 5%, 10%, and 15% by volume) is used as a secondary fuel. The effect of DEE blends is analyzed at four different engine loads (5, 10, 15, and 20 N-m) and two biogas flow rates (12 and 16 lpm).

The experimental results are utilized to map the influence of DEE blends on the performance and emission characteristics of the engine under dual-fuel mode.

Table 1. – Specifications of Engine

Parameters	Values
Working Principle	4 stroke, Compression Ignition
Compression ratio	17:1
Horsepower	8 hp
Bore & stroke	87.5 mm & 80 mm
Cubic Capacity	481 cm^3
Nozzle opening pressure	200 bar
Peak pressure	75 bar

Table 2. – Input parameters

Input parameter	Values
Load (N-m)	5, 10, 15 and 20
Biogas flow rate (lpm)	12 and 16
DEE blend ratio (% vol.)	5, 10 and 15
Methane fraction (%)	60
Intake temperature (°C)	30

The nomenclature of the fuel and the associated actual composition is explained as follows, which is referred to over the entire article.

B20 Biodiesel – Prepared by mixing biodiesel (20% by volume of palm oil) with conventional diesel (80% by volume).

Three variants of the fuel (F1, F2, F3) - prepared by mixing DEE with B20 biodiesel as given below, whose density and calorific values are reported in Table 3. Density and calorific value of various samples are measured using ASTM D4052 and ASTM D4809 methods, respectively.

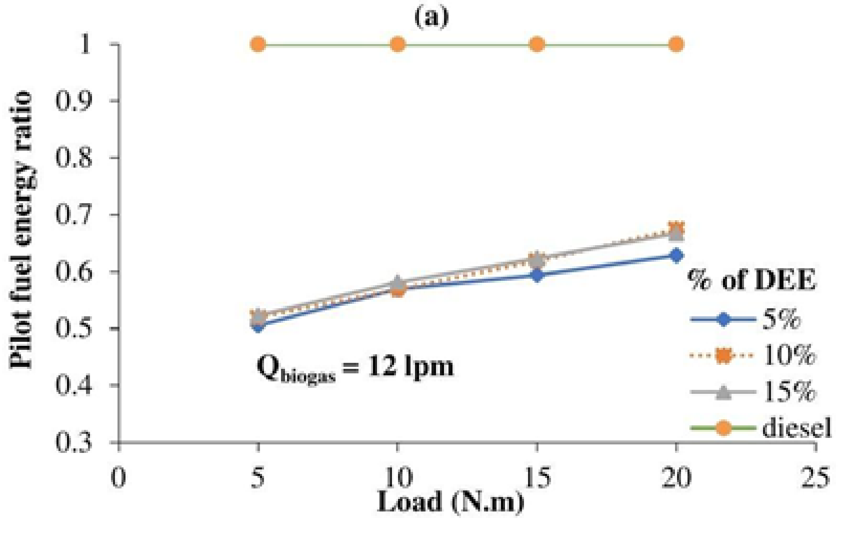
F1: 50 ml of pure DEE + 950 ml of B20 biodiesel.
F2: 100 ml of pure DEE + 900 ml of B20 biodiesel.
F3: 150 ml of pure DEE + 850 ml of B20 biodiesel.

Table 3. – Fuel properties

	B20	DEE	F1	F2	F3
Density (kg/m^3)	845.4	713.4	827.36	824.25	811.35
Calorific Value (MJ/kg)	39.312	33.9	38.127	37.933	37.739

3. RESULTS AND DISCUSSIONS

Pilot Fuel Energy Ratio



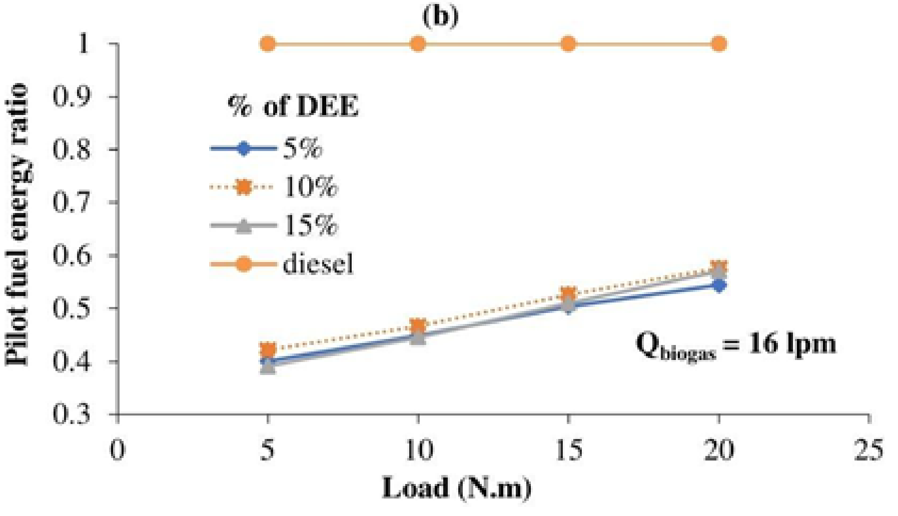


Fig. 2 – Effect of DEE blend ratio on the pilot fuel energy ratio

Pilot fuel energy ratio is the ratio of the energy supplied by biodiesel-DEE blends to the total fuel (biogas + biodiesel-DEE blends) energy.
The total fuel energy is expressed as:

$$\dot{E}_{total} = \dot{E}_{biodiesel-DEE\ blends} + \dot{E}_{biogas} \tag{1}$$

where, the energy released from each fuel is expressed as:

$$\dot{E} = \dot{m} \times LCV \tag{2}$$

where $\dot{m}$ is mass flow rate of the fuel and LCV is its lower calorific value.
Pilot Fuel Energy Ratio,

$$\text{Pilot Fuel Energy Ratio} = \frac{\dot{E}_{biodiesel-DEE\ blends}}{\dot{E}_{total}} \tag{3}$$

Fig. 2 demonstrates the variation of the pilot fuel energy ratio with the applied load. As it is shown from the figures (a & b), this trend in its variation differs with the biogas flow rates at all DEE blend fractions.

An increase in load increases the pilot fuel energy ratio to cause a rich mixture which in further provides high output power.

At 5 N-m, as the biogas flow rate increases from 12 lpm to 16 lpm, the pilot energy fuel ratio reduces from 0.5 to 0.39 due to biogas energy substitution.

Due to the quick start of ignition of pilot fuel, early fuel atomization takes place ensuring that the pilot energy fuel ratio increases as DEE blending ratios are increased.

The pilot fuel energy ratio reaches a maximum value of 0.674 at 20 N-m engine load, for 12 lpm biogas flow rate and 10% DEE blend.

Brake Thermal Efficiency (BTE)

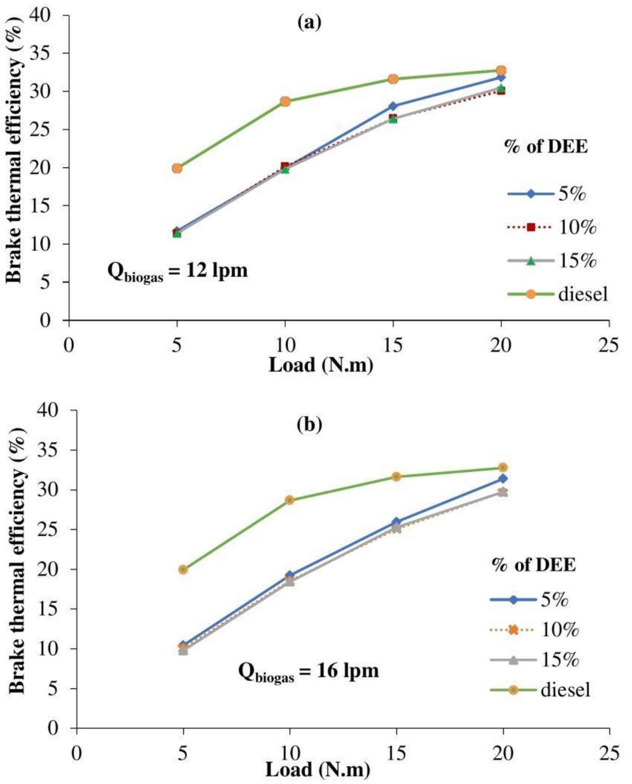


Fig. 3 – Effect of DEE blend ratio on brake thermal efficiency

Brake thermal efficiency is expressed as,

$$\eta_{bt} = \frac{P_b}{\dot{E}_{total}} \tag{4}$$

where $\dot{E}_{total}$ is the total energy supplied by the fuel (biogas+biodiesel-DEE blends) and P_b is the brake power.

The effect of DEE blends on brake thermal efficiency at various engine loads can be found in Fig. 3. Being a fuel with higher heat value, diesel provides the highest BTE all over the range of loads regardless of the DEE blends used in this study. From the graphs (Fig. 3(a) & 3(b)), it is observed that the increase in load escalates BTE. This trend is mainly due to the increased cylinder temperature and better combustion process at high loads; which in further resulted in exothermic reactions that release huge amounts of heat. BTE also increases steadily with load because of better conversion of fuel energy and coolant losses reduction on percentage basis [11]. Commencing with the biogas flow rate of 12 lpm, BTE reaches a maximum of 31.83% at full load, which is still lesser than diesel by 0.92%. The loaded biogas blends with the accessible surplus air and experiences combustion. The increase in BTE possibly contributes to the complete fuel combustion, owing to the inclination of volumetric efficiency, generated at the biogas introduction via the inlet manifold as reported in the previous work [1]. It is observed that as DEE blending ratio increases, BTE decreases since DEE evaporates quickly due to its low boiling point which mixes with air resulting in the formation of a homogeneous mixture. BTE of the engine goes down to 9.78% at the engine load of 5 N-m for 16 lpm biogas flow rate and 15% DEE blend. It reaches a maximum of 31.84% at 20 N-m engine load, 12 lpm biogas flow rate, and 5% DEE blend.

Hydrocarbon emissions (HC)

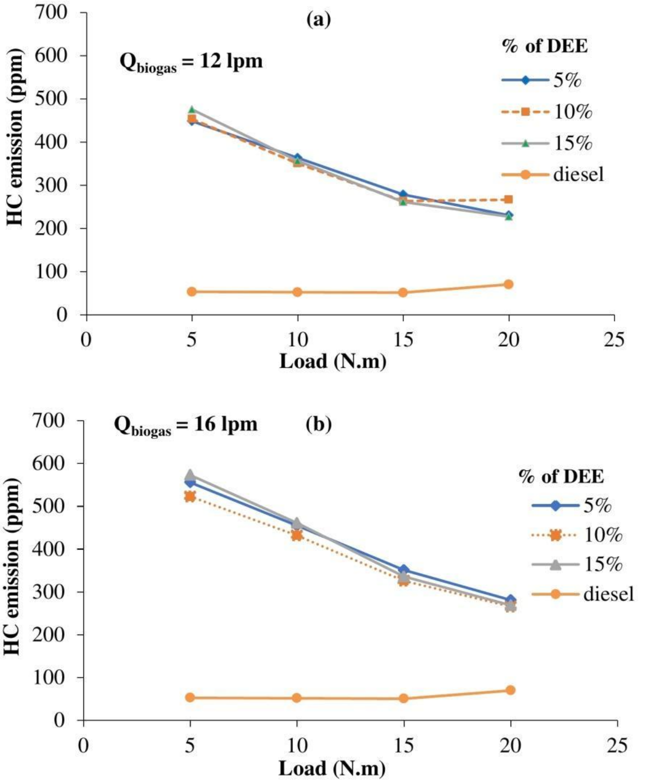


Fig. 4 – Effect of DEE blend ratio on HC emissions

Fig. 4 demonstrates the dissimilarity of HC emissions with the applied load at the two different biogas flow rates of 12 lpm and 16 lpm with different DEE blends. Thermophysical properties of diesel demand its injection to happen at high pressure, henceforth HC emission from diesel combustion is found to be lower across all range of loads compared to other fuels used in this study. It was spotted from the graphs [Fig. 4(a) & 4(b)] that the HC emission decreases with increase in load on account of the existence of oxygen molecules, which primarily yields carbon dioxide and water that helped in combustion. At 12 lpm, HC emission decreases drastically to 227 ppm for 20 N-m engine load, where the reduction with diesel is found to be 70 ppm. The less flame velocity at the biogas flow rate might have caused the absorption of inhibitor gases by the heat generated and hence resulting in low flame temperature. Also, biogas initiation through the inlet manifold dwindles the capacity of air induced, forming a rich fuel blend area which in turn increases the incomplete combustion [2 & 12]. As spotted from the figures, an increase in the DEE blending ratio decreases HC emission. It is due to the favourability of DEE improving oxidation because of its high volatility and low flashpoint. This is possibly due to the advance in combustion at the premature start of the engine, which in turn leads to the inclination of cylinder gas temperature. The results are found to fall in line with previously established reports [13 - 15].

A maximum of 573 ppm of HC emission is witnessed at 5 N-m loads with 16 lpm of biogas flow rate and 15% DEE blend.

CO emissions

Fig. 5 shows the CO emission variation with the applied load at the experimental biogas flow rates and DEE blends. Under diesel combustion, lean mixture results with lower CO emission, and the emission moderately decreases with an increase in load. This trend is attributed to the presence of lean mixture and low engine temperature at part loads, incomplete combustion of the total air-fuel mixture and hardly any of it goes into the exhaust. This may also boost the rate of combustion due to the high cylinder gas temperature [16]. Observation from the graphs shows that an increase in biogas flow rate from 12 to 16 lpm, raised the CO emission to 0.29% at 5 N-m load, which is 0.18% higher than diesel at such load.

The reason behind this rise could be due to depletion in natural oxygen leading to the fuel mixture undergoing partial oxidation. As the DEE blend proportion increases, CO emission decreases to 0.13% which is 0.03% lower than full load conditions at diesel-only operation. This might be owing to the existence of excess oxygen in blends in contrast to proper oxidation of the blends in neat diesel fuel. DEE multi-point injection aids in the proper mixing of the main–biogas mixture and provides the combustion chamber with numerous ignition centers resulting in lower CO emissions [13, 14 & 17]. The lowest and highest value of CO emissions was found to be 0.13% and 0.29% at varying loads, varied biogas flow rate with varied DEE blend ratio.

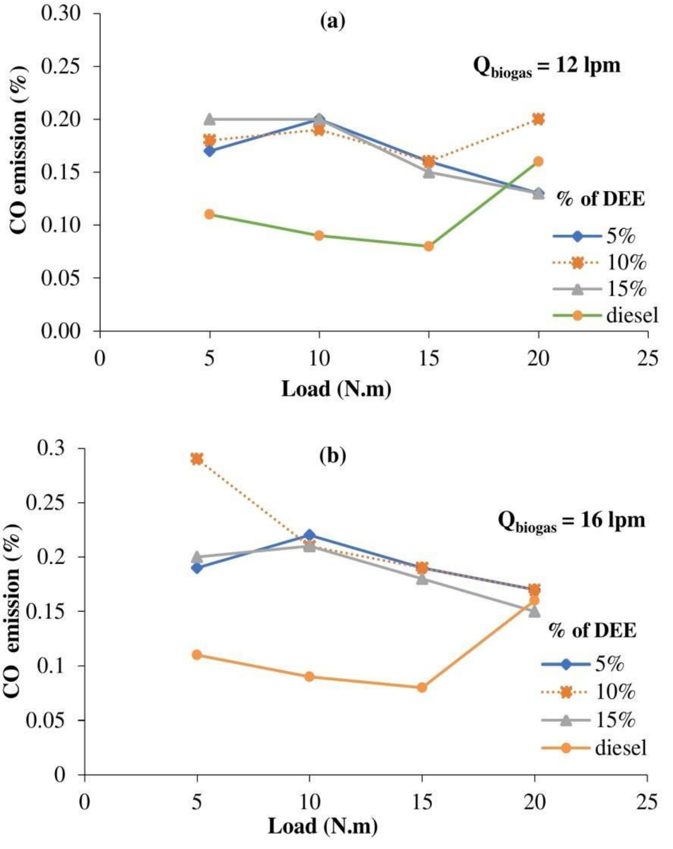


Fig. 5 – Effect of DEE blend ratio on CO emissions

NO$_x$ emissions

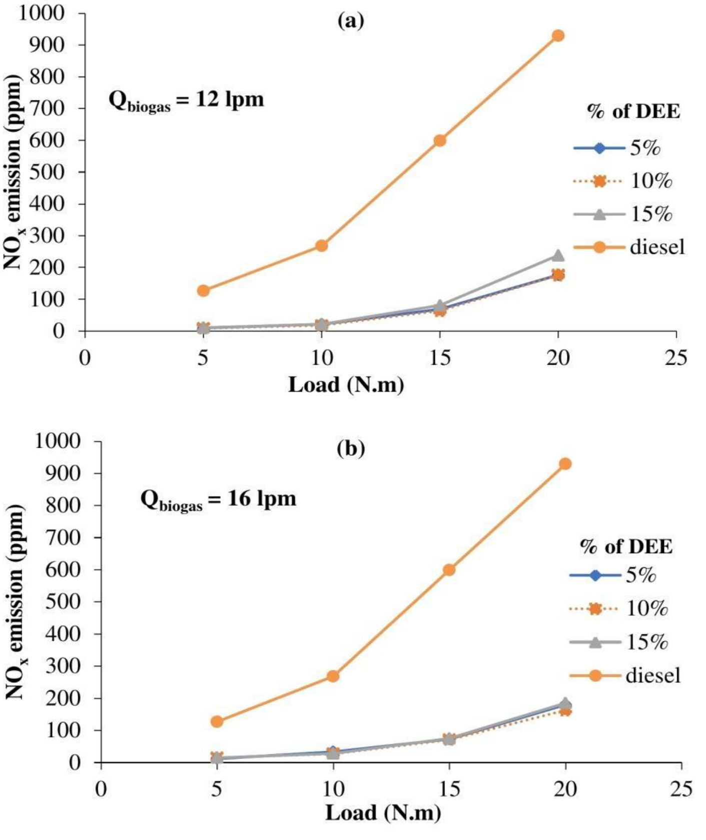


Fig. 6 – Effect of DEE blend ratio on NO$_x$ emissions

Fig. 6 [(a)-(b)] demonstrates the dissimilarity of NO$_x$ emissions with the applied load at two different biogas flow rates of 12 and 16 lpm at different DEE blends. NO$_x$ emissions are found to be higher with diesel operation at all engine loads. As it can be witnessed from the figures, the NO$_x$ emissions increase with the engine load at both the flow rates of biogas. At full load for the engine, a maximum of 238 ppm is witnessed from 15% DEE blended fuel whereas 929 ppm is found with diesel operation. At high load, as additional gaseous fuel is ignited, and as extra energy is liberated, the rise in combustion temperature and the consequence of enrichment of extra oxygen in combustion resulting in the production of more NO$_x$. The advanced injection takes place because of an increase in this NO$_x$ emission, which escalates the temperature, and cylinder pressure rises because excess fuel burns close to TDC [18 & 19]. NO$_x$ emissions reduce when biogas flowrate increases to 16 lpm, because of the inadequate quantity of oxygen in biogas due to anaerobic digestion of organic matter and hence prohibits the reaction of nitrogen with enough oxygen at high temperature. The gain in NO$_x$ concentrations with the increase in the injection of DEE is the reason for the enrichment of higher oxygen leading to the engine running overall in a richer mixture. It may also be due to further complete combustion which may result in high combustion temperature due to the production of high thermal NO [17 & 20].

With blended fuel, the lowest recorded NO$_x$ emission is 9 ppm at 5 N-m engine load with 12 lpm of biogas flow rate. The lowest NO$_x$ emission in the case of diesel operation is found to be 127 ppm at the same operating conditions.

4. CONCLUSIONS

The present study has been carried out to analyze the performance and emission characteristics of a CI engine that undergoes a dual fuel mode of combustion. The following observations arrive through the experimental investigations,

- Brake thermal efficiency (BTE) boosts to 32% at high loads owing to the injection of DEE blends with 12 lpm of biogas in the fuel mixture in decreasing order, hence reducing the overall pollution.
- Varying the DEE blends in increasing order there was a substantial increase in pilot fuel energy ratio in the engine having a maximum output of 0.67 at 12 lpm and 15% DEE blend.
- A drastic decrease was seen in HC and CO emissions, 227 ppm and 0.13% respectively both at 20N-m, 12lpm due to combustion enhancement by DEE blends.
- Increment of DEE blends showed a momentous increase in the NO_x concentrations of 238 ppm at 20N-m, 12lpm having a 15% DEE blend because of inclination in combustion temperature.
- Based on the results acquired through our study, it is concluded that the execution of the engine and emission is enhanced which is a result of DEE addition. The optimum experimental results for better performance and emission characteristics obtained are at 5% DEE having a load of 20N-m with a biogas flow rate of 12 lpm.

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