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Experimental Research on Biogas Utilization in CI Engines Using Biodiesel/Diesel Blends

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Abstract: The present study covers the utilization of a gaseous alternative fuel, raw biogas, in a diesel engine. Biogas alone cannot run a diesel engine, because gaseous fuel cannot burn by compression. It can be supplied to the CI engines in dual fuel mode by using an air-biogas mixer device. In this work, it is aimed to investigate the performance and emission characteristics of a biogas-biodiesel/diesel dual fuel mode diesel engine by employing a venturi gas mixer device for providing a homogeneous mixture.The performance and emission characteristics of the engine operated by dual-fuel mode were experimentally investigated, and compared to diesel. The results indicated that biogas inducted at a flow rate of 1L/min was found to have better performance and lower emission, than that of the other flow rates. On the other hand, dual-fuel mode with a biogas flow rate of BD10 BG@1L/min showed an average reduction in BTE of 9.94% and an average increment of 8.82% in BSFC as compared to diesel. Whereas an increment in CO and HC by 5.18% and 3.01% respectively and an average reduction in NOx emissions by 14.91% as compared to diesel.

Keywords: Alternative Fuel, Biogas, Biodiesel, Diesel Engine, Dual-fuel, Venturi Gas Mixer

I. INTRODUCTION

The objective of this study is to experimentally investigate performance, combustion and emission characteristics in a dual fuel CI engine using a B20 blend of algae biodiesel (AOME), as pilot fuel and to further replace biodiesel with biogas, which is also a renewable fuel. The suffix B with the numerical signature indicates the percentage of algae biodiesel by volume in the biodiesel blend. Experimentation was also conducted using diesel and AOME as fuel to serve as the baseline for comparison. Experiments were conducted at various loads at rated RPM for diesel and biodiesel in single fuel mode, and biodiesel and biogas in dual fuel mode of operation. The engine behavior with respect to combustion, performance, and emission characteristics are compared against a baseline of a standard diesel run.Feasibility studies on the use of different renewable liquid and gaseous fuels have been studied throughout the world. The oils that are extensively studied include Sunflower, Soya bean, Peanut, Rapeseed, Rice bran, Karanji etc.,[1,2]. One of the disadvantages of using these oils in diesel engines is nozzle deposits, which drastically affects the engine performance and emissions. The refining processes of vegetable oil gives better performance compared to crude vegetable oil[3,4,5,6]. Goering et al [7] studied the characteristic properties of eleven vegetable oils to determine which oils would be best suited for use as an alternative fuel source. Of the eleven oils tested, corn, rapeseed, sesame, cottonseed, and soyabean oils had the most favourable fuel properties. There is an improvement in the engine performance when these modified vegetable oils are used instead of base vegetable oils [8, 9, 11, 12]. This improvement in performance is attributed to good atomization of these modified fuels in the injector nozzle and a significant reduction in the viscosity. The performance of the non-edible oils like Rice bran oil [15] and cotton seed oil [14] was found satisfactory. The idea of using vegetable oils as fuel for diesel engines is not a new one. Rudolph Diesel used peanut oil as fuel in his engine at Paris Exposition of 1900.However, despite the technical feasibility, vegetable oil as fuel could not get acceptance, as it was more expensive compared to petroleum fuels. Later the various factors as stated earlier, created renewed interest of researchers in vegetable oil as substitute fuel for diesel engines. The density and viscosities of the blends increased with the increase of biodiesel concentration in the fuel blend. It also reduces the filter clogging and ensures smooth flow of oil. Some of the researchers [10, 13] conducted the experiments on diesel engine using non-edible vegetable oils used as alternate fuels and found maximum Brake thermal efficiency, BSFC and emissions like CO, HC also increased without any engine modification. The uses of biodiesel [16] in conventional diesel engines result in substantial reduction in the emission of unburned hydrocarbons, carbon monoxide and particulate. Neat oil is converted into Methyl ester of oil (biodiesel) using trans-esterification process. Methyl and ethyl ester of Karanja oil [17] can also be used as fuel in compression ignition engine without any engine modification.

Higher viscosity is responsible for various undesirable combustion properties of Neat vegetable oils. Four well known techniques are proposed to reduce the viscosity levels of vegetable oil namely dilution, Pyrolysis, Micro emulsion and Trans esterification [18]. It also includes detailed reviews of different journals related to design parameters of a venturi gas mixer device, performance, combustion and emission characteristic of biogas-biodiesel dual fuel mode diesel engine. Attempts have been made in many developed countries of the world on the use of biogas and vegetable oils as diesel engine fuel. In most of the research work vegetable oil has been tried as pure, esterified or blended with diesel. Many researchers, engine manufacturers and users in different countries of the world have performed tests that demonstrated the potential and problems of this fuel source. However, there are several real problems that restrict the introduction of this source in to energy pool. Later in thispaper literature on economic assessment is reviewed. While the performance, combustion, and emission characteristics of a diesel-biogas dual fuel diesel engine mainly depend on two factors as seen from the literature above. These are the mixing device employed and engine operating parameters. As a venturi mixer provides a homogeneous charge into the engine cylinder, complete combustion will take place i.e. there is no chance for heterogeneous combustion. Therefore after go through from the existing literature the part including convergent angle and beta ratio associated with it of a venturi gas mixer is designed, for which differential pressure between the inlet and throat venturi sections is the least. This is part of an area understudied in the current research.

II. EXPERIMENTAL SETUP

A. Major Input Requirement

This section describes the equipment's will be utilize in this research along with detail of its characteristics and measurement capabilities. It also includes the experimental setup and procedure, device calibration and equations and measurements that will be use to obtain the performance and emission data. In any experimental study, instrumentation plays an important role, as it provides the required data for analysis.

Table 1 List of materials and equipment used for experimental test

1	CI engine, and
2	Biogas
3	gas mixer
4	Biodiesel
5	measurements apparatus.
6	Exhaust gas analyzer
7	Computer (desktop)

Table 2Engine Specifications

S.No	Component	Specification
1	Engine make	Kirloskar,Model TV1
2	Engine type	1 cylinder, 4stroke, water cooled
3	Rated Power	5.2 kW (7 BHP) @1500 rpm
4	Cylinder Volume	661cc
5	Compression Ratio	18
6	Injection timing (diesel)	23° bTDC
6	Dynamometer	Eddy current, water cooled
7	Piezo Sensors	Range 5000 PSI
8	Crank Sensor	Resolution 1^0, Speed 5500 RPM
9	Load Sensor	Load cell, type strain gauge,
10	Software	"Engine soft", Engine Performance analysis software

Figure 1aKirloskar Diesel Engine Set-Up

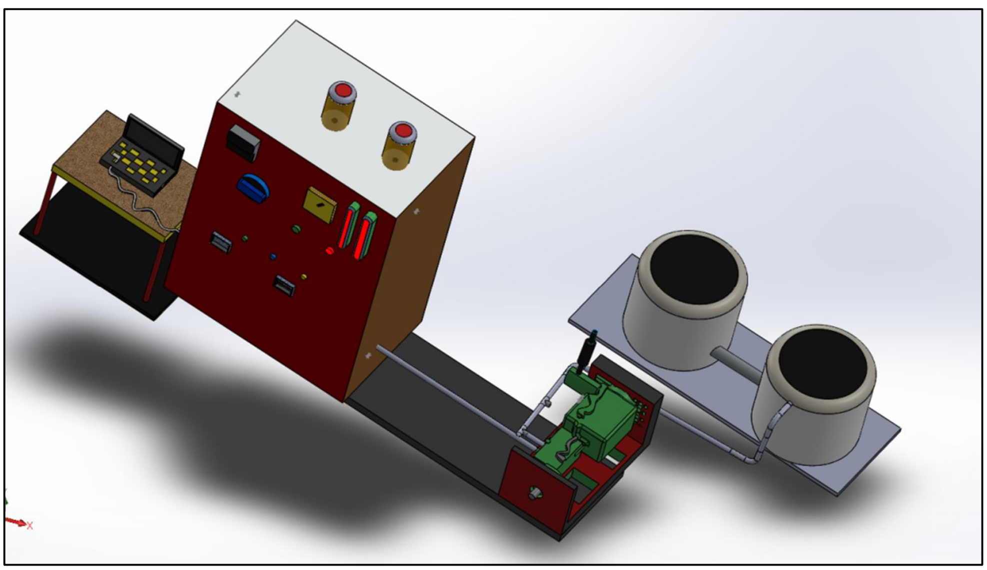

Figure 1b.Schematic diagram of Experimental setup

III. MATERIALS AND METHODS

This chapter comprises the computational and experimental analyses to study the effects of mass flow rates of raw biogas on diesel engine performance and emission parameters under certain operating conditions of diesel engine operate with biodiesel-biogas dual fuel mode by employing a gas mixing device. This also includes venturi type gas mixture models that can be use to study the flow characteristics. The numerical analysis for designing a gas mixer will be use for the computational methods that are described with the necessary illustrations. The experimental investigation will be carried out using a single-cylinder, direct-injection four-stroke diesel engine equipped with an eddy current dynamometer for loading the engine. The detailed research methodologies and required materials are explained below in the next sections.

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A. Test Fuels

Diesel was purchased from a retail station of Indian Oil Pvt. Ltd, located near the premises of our campus. Besides, biodiesel was produced by the transesterification of algae oil, which was purchased from retail pharmacy shop, located near by the campus. The production of biodiesel from vegetable oil is portrayed in Fig 3. The properties of biodiesel were measured and compared with the standard diesel fuel, presented in Table 3.

B. Biodiesel Production

There are different processes which can be applied to synthesize biodiesel such as direct use and blending, micro emulsion process, thermal cracking process and the most conventional way is
transesterification process.

Table 3 Composition of different feedstock's raw biogas (Wierzbicki, 2012).

Component	Composition		
	agricultural biogas	treatment plant biogas	landfill biogas
CH_4	45–75%	57–62%	37–67%
CO_2	25–55%	33–38%	24–40%
O_2	0.01–2.1%	0–0.5%	1–5%
N_2	0.01–5.0%	3.4–8.1%	10–25%
H_2S	10–30000 ppm	24–8000 ppm	15–427 ppm

Figure 3Some feedstock's for biogas production

C. Transesterification

This occurs in a multiple reaction process including threereversible steps in series, where triglycerides are converted todiglycerides, then diglycerides are converted to monoglycerides,and monoglycerides are converted to esters and glycerol. Thealgae oil obtained after this transesterification process is usuallyreferred to as algae oil methyl ester (AOME). Figureshows the chemical reaction of the transesterification of algaeoil. The algae biodiesel properties are evaluated andtabulated in Table4.

Table 4: Properties of fuels

Property	Algae Oil	AOME (Bio Diesel)
Density at 40 ºC (g/m3)	0.871	0.864
Specific Gravity at 40 ºC	0.916	0.894
Flash point (°C)	145	130
Kinematic Viscosity, 40 ºC(mm2/s)	5.76	5.2
Iodine Value (g/100g oil)	124	75
Acid Value (mg KOH/ g oil)	0.46	0.374
Calorific value (kJ/kg)	37200	

IV. EXPERIMENTAL PROCESS

A. Methodology

To address the general and specific objectives of this work a well-designed methodology will be followed. There are combinations of procedures that will be use to accomplish this study. These
are design, analysis and then manufacturing of the mixer device, preparing fuels (collecting biogas from digester outlets, producing biodiesel and purchasing diesel fuel), preparing the experimental setup of the test engine for experiment and analysis of experimental results. This thesis work will be based on the following procedures summarized as shown in Figure 5 below.

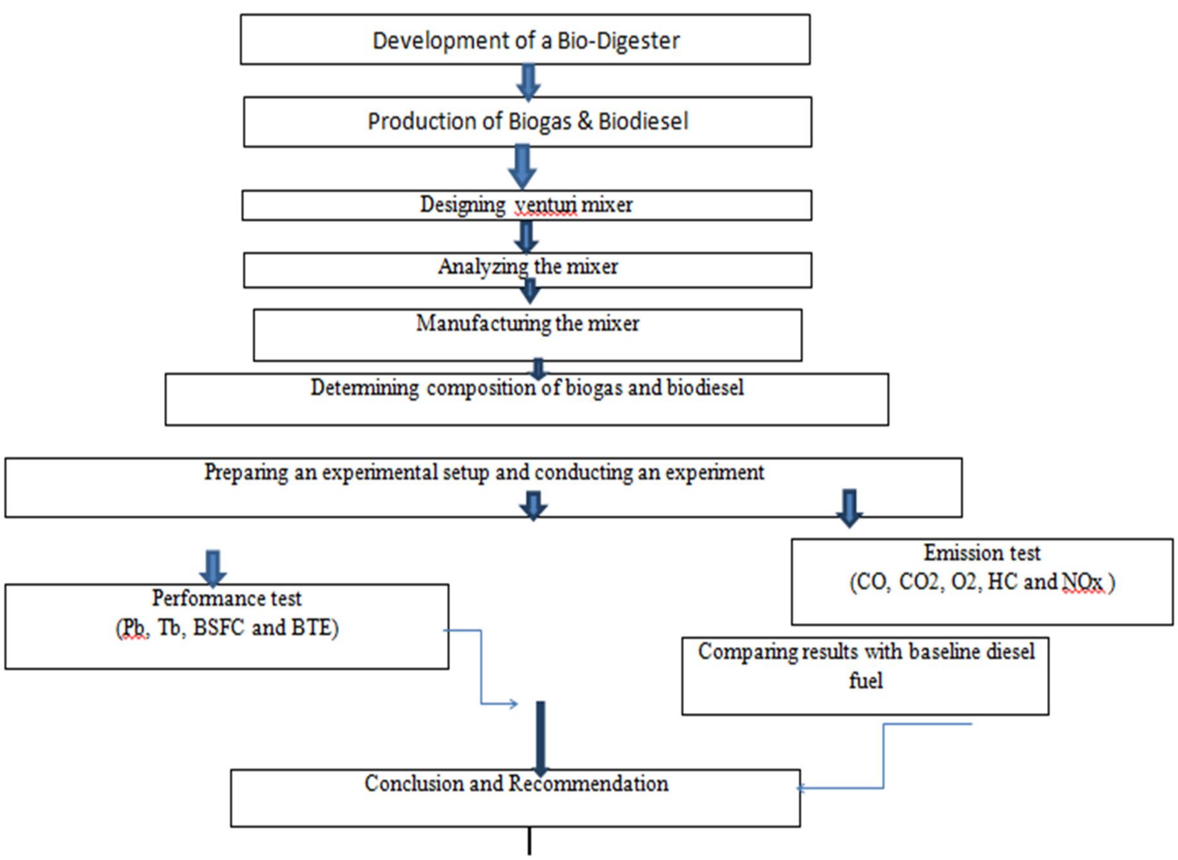

Figure 5 Flow diagram of the procedure of this thesis work

V. RESULT AND DISCUSSION

The experimental work analysis on the performance and emission characteristics of a dual fuel diesel engine are presented in this chapter This chapter also explains the effect of variation of load, and biogas flow rate/ percentage substitution of biogas in biogas-biodiesel dual fuel mode diesel engine performance and emission characteristics.

A. Engine Performance Characteristics

The performance characteristics such brake thermal efficiency and brake specific fuel consumption of a diesel engine when it operated in diesel fuel and diesel with biogas dual fuel mode at different engine loads are discussed in the following sections below.

1) Brake Thermal Efficiency (BTE)

This affects the burning speed of biogas-air charge and causes a reduction in flame propagation which results lower in brake thermal efficiency of dual-fuel mode is expressed in Fig. 6. A similar trend was reported by (Rosha et al., 2018). On the other hand, in dual-fuel mode operations as biogas flow rate increases BTE decreases. This is due to an increase in the induction of biogas leads to further decreases the flame propagation speed and resulted in lower BTE. Generally, an average BTE reduction of BD10D90 + BG@1L/min, BD20D80 + BG@2L/min, and BD35D75 + BG@4L/min flow rate with respect to diesel mode were obtained 15.94%, 20.04% and 23.58% respectively.

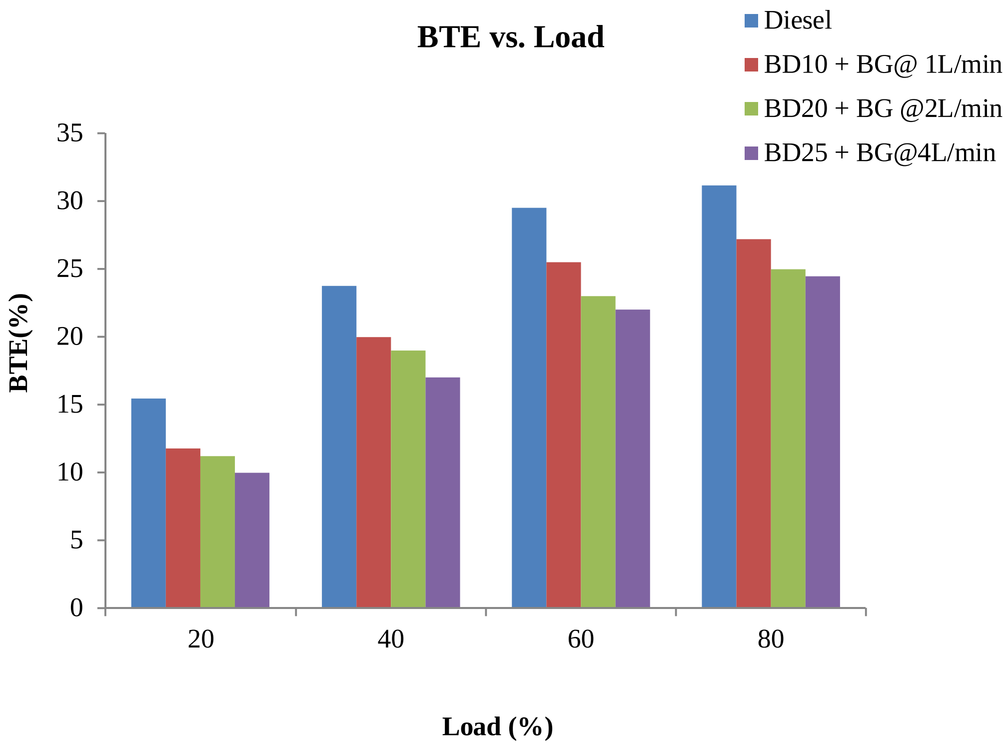

Fig. 6 Variation of brake thermal efficiency versus engine load

2) Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption depends on the heating value of the fuel (Sandalc et al., 2019). Figure 4.5 shows brake specific fuel consumption with respect to engine load for diesel fuel and all the biogas mixtures. Brake specific fuel consumption for both modes was found to be high at a low load of the engine. This is due to lower output power at a lower load. However, it was found to be lesser at high engine load for both modes of operations because of an increase in combustion rate due to high air-fuel ratio and high combustion temperature. Table 7 below shows the numerical value of brake specific fuel consumption for both neat diesel and dual-fuel operations. From Figure 7 it is observed that, supplying biogas leads to higher fuel consumption as compared to diesel mode throughout the load range. This is due to the low energy density of and slow-burning of biogas causes higher BSFC in dual fuel mode operation. Moreover, due to raw biogas contains more percentage of non-combustible components which reduces its fuel quality.

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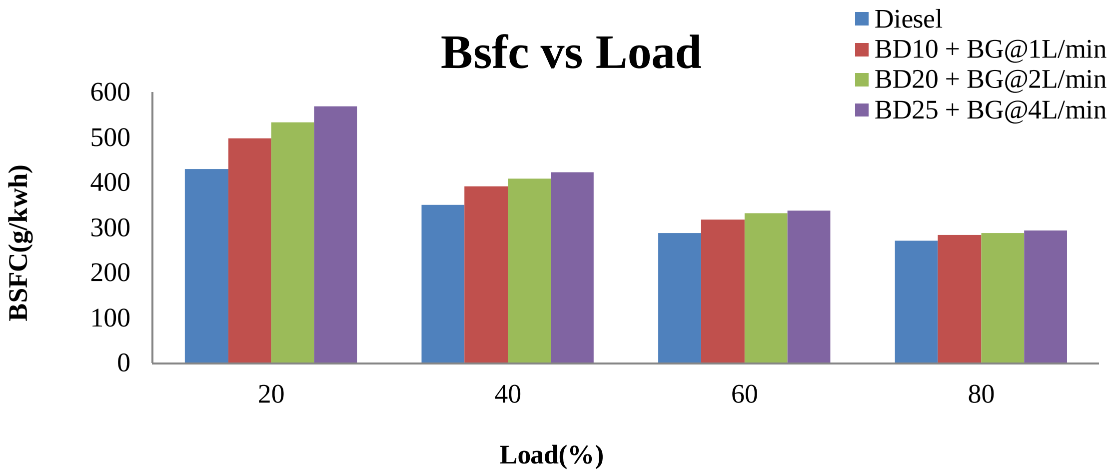

Fig.7 Variation of brake specific fuel consumption with respect to engine load

B. Exhaust Gas Emissions

Knowing the exhaust emissions of a specified fuel is an important issue for future controlling its emissions through different options, either searching alternative fuels which results in less emission or optimizing the engine operating parameters. This portion addresses the emissions of pure diesel and biogas-diesel dual fuel mode diesel engine. Now emissions of CO, CO2, HC, O2, and NOx which were measured by using Automobile Exhaust Gas Analyzer SV-50 when the engine run in dual fuel mode at each load with different biogas flow rate are briefly discussed in this section with comparison to neat diesel fuel emissions.

1) Exhaust Emissions of Carbon Monoxide (% Vol.)

Figure 8 shows the variation of CO emissions with respect to load for diesel fuel and diesel with biogas mixtures. In dual fuel mode operation, higher CO is observed than diesel. This is because of the lower flame speed of biogas due to the presence of CO2, reduction of oxygen caused by the induction of biogas and higher specific heat of biogas, as compared to diesel, requires high combustion temperature to burn completely. The above reasons cause some fuel undergoes incomplete combustion leads to high CO emission. It also increases as an increase in biogas flow rate. This is due to the high biogas flow rate further increases CO2 concentration and decreases the availability of O2 in the combustion chamber. The average CO emission increment of BD10D90 + BG@1L/min, BD20D80 + BG@2L/min, and BD25D75 + BG@4L/min flow rate from diesel mode was 10.18%, 19.91% and 31.86% respectively. Table 4.6 below shows the numerical value of carbon monoxide emissions.

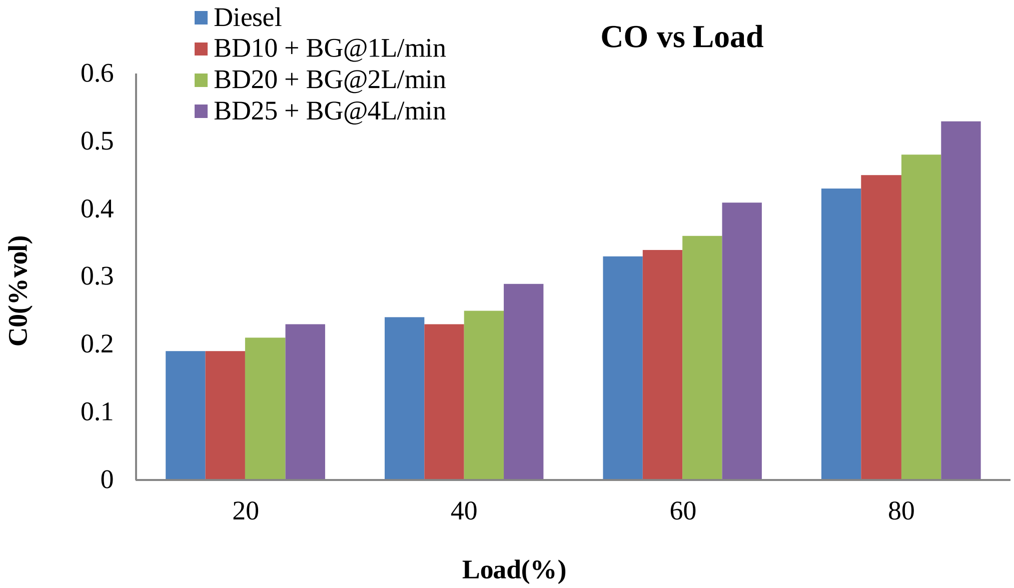

Figure 8 Variation of CO emissions with respect to load

2) Exhaust Emissions of Hydrocarbons (ppm Vol.)

Unburnt hydrocarbon emission for diesel and biogas-diesel fuel with respect to load is shown in Figure 9. The unburnt hydrocarbon (UHC) emission in dual fuel operation is higher than diesel, under all test conditions. The average unburnt HC emission increment of BD10D90 + BG@1L/min, BD20D80 + BG@2L/min, and BD + BG@4L/min flow rate from diesel mode were obtained 6.01%, 19.29% and 30.94% respectively. Table 4.9 below shows the numerical values of HC emissions.

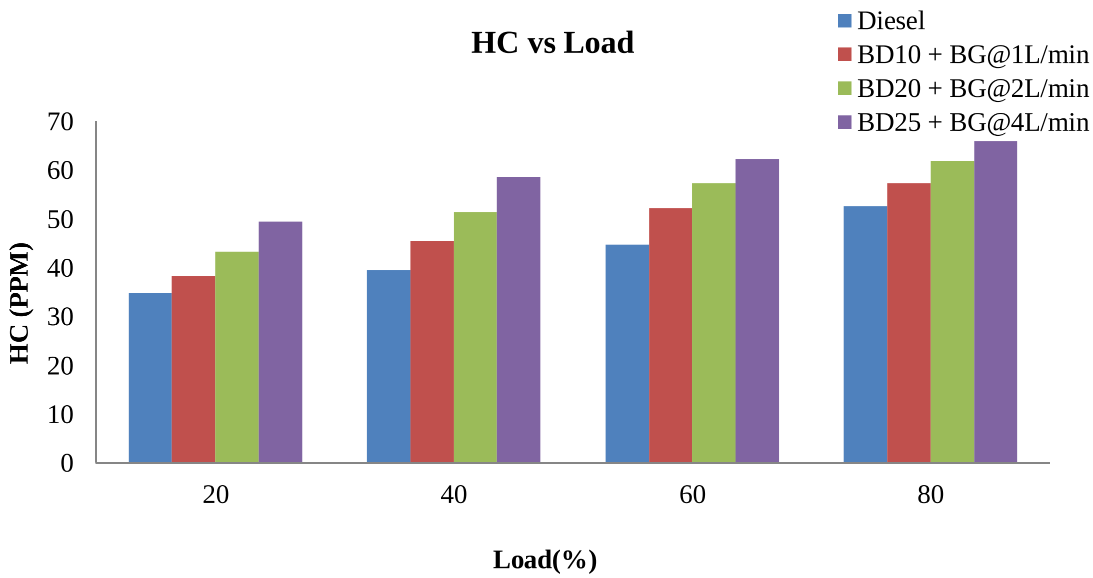

Figure 9 Variation of HC emissions with respect to load

3) Nitrogen Oxide Exhaust Emissions (ppm Vol.)

The formation of NOx emission mainly depends on the availability of oxygen, higher temperature developed during the combustion, and the residence time for which oxygen-nitrogen reactions occurring to a significant completion level (Bouguessa et al., 2020). Variations of NOx emission for both diesel and dual-fuel at all loads are shown in Figure 10 below.

The average NOx emission reduction of BD10D90 + BG@1L/min, BD10D90 + BG@2L/min, and BD25D75 + BG@4L/min flow rate from diesel mode were obtained 19.91%, 27.33% and 39.16% respectively. Table 4.10 below shows the numerical values of NOx emissions.

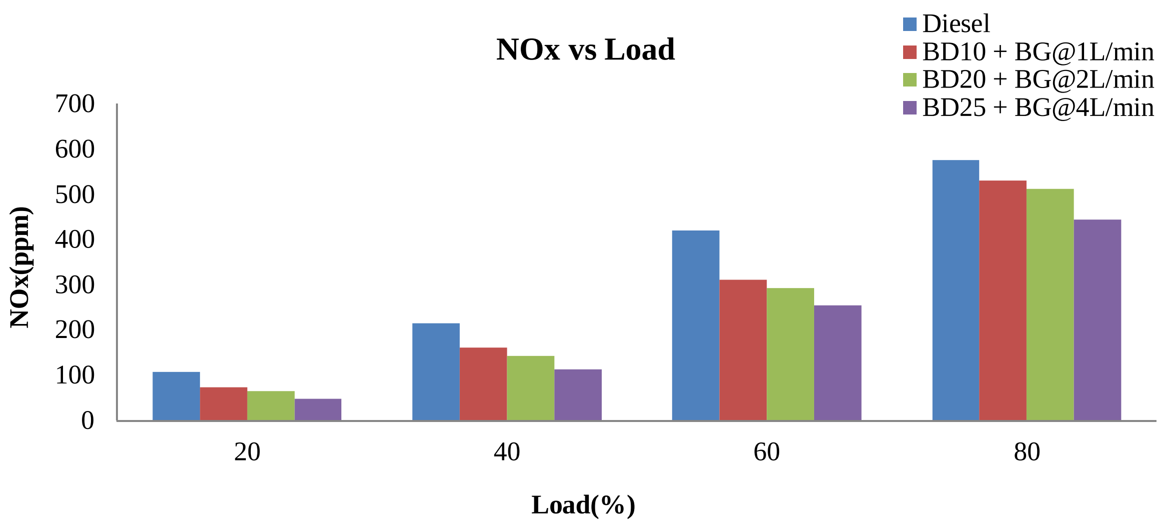

Fig.10 Variation of NOx emissions with respect to load

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusion

Based on the experiments conducted in the biogas-biodiesel dual-fuel mode diesel engine under various load condition with different biogas flow rate at constant engine speed, and thereby from the results obtained, the following conclusions are drawn:

As biogas flow rate increases from 1L/min to 4L/min with an increasing of load from 20% to 80%:

1) Relatively reduction in BTE from 15.94% to 23.58% and an increment of BSFC from 11.82% to 20.87%.
2) Increment in emissions like CO by 10.18% to 31.86% and HC by 6.01% to 30.94%.
3) There is a reduction in NOx emission from 19.91% to 39.16% respectively.

Generally, among different DF mode operations, due to small percentage of methane in a given biogas, with a biogas flow rate of 1L/min yields relatively same performance and emission characteristics and allows extremely low levels of NOx as compared to diesel fuel operation.

B. Scope for Future Work

The following points are suggested for future work, for the use of biogas in diesel engines.

1) CFD models can be used to predict the temperature distribution in the combustion chamber and flame propagation dynamics for in-depth analysis of dual fuel combustion reaction.
2) An improvement in the lubricity property of the engine oil for the biogas operated engine needs to be carried out for its long term use.
3) An improvement for the compression and storage stability of biogas can be carried out for its off-site application for heat and power generation.

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