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Effect of Injection Pressure on Exhaust Emissions of Diesel Engine Fuelled with Biogas and Biodiesel

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Abstract

In the context of exhaustion of fossil fuels day by day due to heavy demand with the use of agriculture sector and transport sector, escalation of fuel prices in International Oil Market causing huge economic burden on developing countries like India and rise of pollution levels with fossil fuel, the exploration of alternative fuels has become pertinent. Gaseous fuels have many merits over liquid fuels, as the pollutants emitted by gaseous fuels are low due to clean combustion, high calorific value in comparison with liquid fuels. Vegetable oils are good substitutes for diesel, as they are renewable, comparable calorific value and cetane (meausre of combustion quality) number when compared with neat diesel operation. However, the disadvantages associated with vegetable oils such as high viscosity and low volatility cause combustion problems in diesel engines. They can be rectified to some extent by converting them into biodiesel. They are many methods to induct gaseous fuels such as port injection, carburetion technique, injection of gaseous fuel at the near end of compression stroke etc,. Investigations were carried out with biogas gas as primary fuel inducted by port injection and cottonseed biodiesel was injected into the engine in conventional manner. Particulate matter (PM), oxides of nitrogen (NOx), carbon mono oxide (CO) levels and un-burnt hydro carbons (UBHC) are the exhaust emissions from a diesel engine. They cause health hazards, once they are inhaled in. They also cause environmental effects like Green-house effect and Global Warming. Hence control of these emissions is an immediate effect and an urgent step. The pollutants of PM, NOx, CO and UBHC were determined at full load operation of the engine with varied injection pressure and compared with diesel operation on conventional engine. The maximum induction of biogas was 35% of total mass of biodiesel as full load operation. Particulate emissions were determined by AVL Smoke meter, while other emissions were measured by Netel Chromatograph multi-gas analyzer at full load operation. These pollutants were drastically reduced with induction of biogas and further reduced with an increase of injection pressure.

Keywords: Diesel, Biodiesel, CE, Exhaust Emissions

1. Introduction

The civilization of a particular country has come to be measured on the basis of the number of automotive vehicles being used by the public of the country. The tremendous rate at which population explosion is taking place imposes expansion of the cities to larger areas and common man is forced, these days to travel long distances even for their routine works. This in turn is causing an increase in vehicle population at an alarm rate thus bringing in pressure in Government to spend huge foreign currency for importing crude petroleum to meet the fuel needs of the automotive vehicles. The large amount of pollutants emitting out from the exhaust of the automotive vehicles run on fossil fuels is also increasing as this is proportional to number of vehicles. In view of heavy consumption of diesel fuel involved in not only transport sector but also in agricultural sector and also fast depletion of fossil fuels, the search for alternate fuels has become pertinent apart from effective fuel utilization which has been the concern of the engine manufacturers, users and researchers involved in combustion & alternate fuel research.

Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil [1].Several researchers conducted investigations on biodiesel with conventional engine (CE) and reported that the performance marginally improved, along with reduction of particulate emissions. [2-8]. However, they further reported that NO_x emissions were marginally higher with biodiesel operation in comparison with neat diesel operation on CE.

India is largest cattle breeding country; there is abundance of raw material for producing biogas. [9]. Also municipal sewage & kitchen wastes can be used for this purpose. The use of methane separated from biogas as a fuel will substantially reduce harmful engine emission and will help to keep the environment clean. Biogas consists of approximately 50-70 % methane. It is economical and slurry can be used as organic manure.

Biogas is produced by extracting chemical energy from organic materials in a sealed container called a digester. The generation of biogas is the concept of anaerobic digestion, also called biological gasification. It is a naturally occurring, microbial process that converts organic matter to methane and carbon dioxide. The chemical reaction takes place in the presence of methanogenic bacteria with water an essential medium. The anaerobic digestion process, as the name states, is one that functions without molecular oxygen. Ideally, in a biogas plant there should be no oxygen within the digester. Oxygen removal from the digester is important for two main reasons. First, the presence of oxygen leads to the creation of water, not methane. Second, oxygen is a contaminant in biogas and also a potential safety hazard. Due to presence of oxygen, calorific value of biogas becomes low. Table.1 shows composition of biogas

Table 1. Composition of Biogas

Components	**Amount (%)**
Methane (CH4)	50 – 70
Carbon Dioxide (CO2)	30 – 40
Hydrogen (H2)	5 – 10
Nitrogen (N2)	1 – 2
Water Vapour (H2O)	0.3
Hydrogen Sulphide (H2S)	Hydrogen Sulphide (H2S)

CO_2 is high corrosive when wet and it has no combustion value so its removal is must to improve the biogas quality. The processes to remove CO_2 are as follows

a) Caustic solution, NAOH- 40% NAOH + CO_2 = $NAHCO_3$

b) Refined process, K_2CO_3 - 30 % K_2CO_3 + CO_2 = $2KCO_3$

Investigations were carried out with biogas in conventional engine. The dual fuel mode exhibited lower peak values of heat release rate and also they reported the application of exhaust gas recirculation (EGR) to dual-fuel mode additionally decreased the in-cylinder pressure and increased the ignition delay. [10]. Dual fuel mode displayed lower emissions of NO_x and smoke opacity while HC and CO concentrations were considerably higher as compared to other fuels. In dual fuel mode peak pressure and heat release rate were slightly higher compared to diesel and biodiesel mode of operation for all engine loads. [11].Investigations were carried out with biogas, diesel-methane, and neat diesel operation in conventional engine [12]. They observed higher brake thermal efficiencies compared to diesel mode at high loads. Though volumetric efficiency was almost identical in diesel and diesel-CH4 dual modes, exhaust gas temperatures were higher in diesel-biogas mode, followed by diesel-methane and diesel modes.[12] .NO_x is a strong function of local temperatures. They reported that in compression ignition engine at constant speed of 1500 r/min at full load both NO_x and soot missions were dropped, energy content rates in gas–fuel mixture compared to only diesel fuel[13].

However, little reports were available with the use of biogas and biodiesel. Hence authors have made work in this direction. It is attempted to determine the pollution levels of conventional engine with biogas and cottonseed biodiesel with varied injection pressure and compared the data with diesel operation on CE.

2. Materials and Methods

2.1 Experimental Set-up

Table.2 gives the details of the engine.

Table 2. Details of the Engine

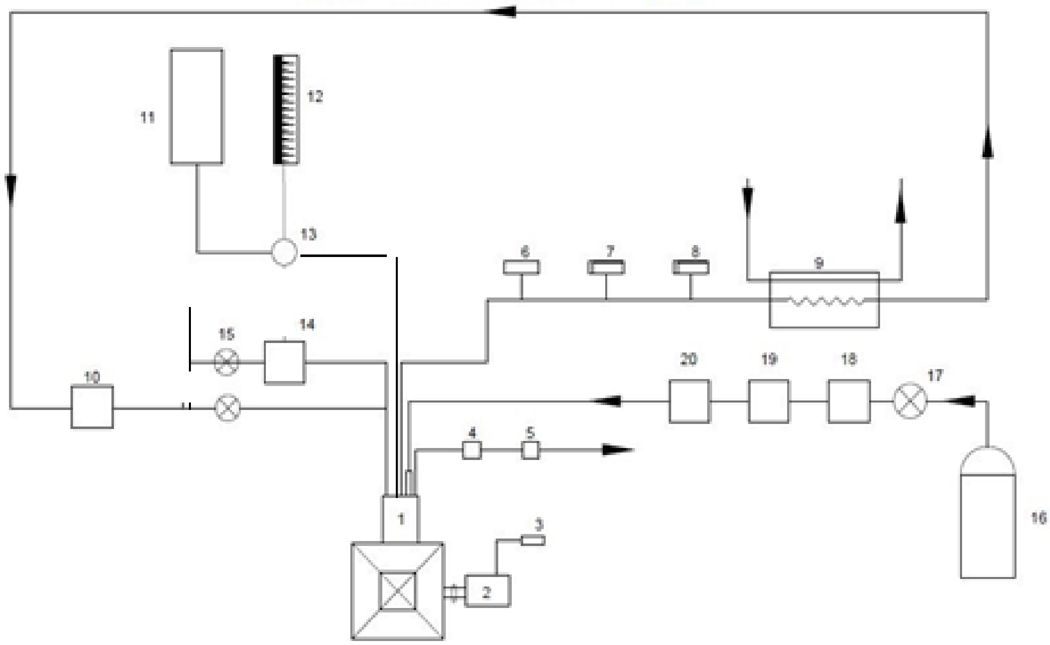
Description	**Specification**
Make	Mahindra & Mahindra
Number of cylinders	01
Number of Strokes	04
Ratio of bore to stroke	93 mm/92 mm
Power	6.6 kW (9 HP) at the rated speed of 3000rpm
Compression Ratio	18:1
Type of cooling Arrangement	Water cooling
Recommended Injection Pressure	190 bar
Recommended Injection Timing	27 degrees before top dead centre
Maximum Torque	30 Nm at 1800 rpm.

Fig.1 shows that the test engine (1) and the details of the CRDi engine are given in Table.1 It was located at Applied Thermo Dynamics Laboratory of MED, CBIT, Hyderabad. The engine was connected to power measuring device (2). The engine had computerized test bed. There was facility of loading the engine by means of variable rheostat. (3). Outlet jacket water temperature was indicated with temperature sensor (4). The flow of the coolant was measured with flow meter (5). The temperature of the exhaust gas was indicated with exhaust gas temperature sensor (6). The particulate levels were determined with AVL Smoke meter (7) at full load operation. The pollutants of CO and UBHC were determined by Netel Chromatograph multi gas analyzer (8) at full load operation. The range and accuracy of the analyzers in multi gas analyzer are shown in Tabl.3. EGR (9) system was employed in the system to reduce NO_x emissions. Air flow was measured with air flow sensor (10). Biodiesel tank (11), burette (12) and three way valve (13) were used to induct biodiesel into the engine in conventional injection system. Bypass system was provided for EGR system. Air box arrangement (14) along with water manometer was employed to measure air flow rate from atmosphere. Directional valves (15) were provided for bypass system b p Biogas clean from CO2 was stored in a gas cylinder (16). Pressure regulator (17) was incorporated in the system. The pressure of the gas was noted in gas pressure sensor (18). The mass flow rate of the gas was noted by means of a rotometer (19). The flame arrestor (20) was employed in the gas circuit to ensure safety. Cam position senor was used to measure injection timing. Crank position sensor was used to determine the speed of the engine. Fuel temperature was determined with fuel temperature sensor. Gas was injected through gas injector.

Table 3. Range and Accuracy of Analyzers

S. No	**Name of the Analyzer**	**Principle adopted**	**Range**	**Accuracy**
1	AVL Smoke Analyzer	Opacity	0-100 HSU (Hartridge Smoke Unit)	±1 HSU
2	Netel Chromatograph CO analyzer	Infrared absorption spectrograph	0-10%	± 0.1%
3	Netel Chromatograph UBHC analyzer	NDIR	0-1000 ppm	±5 ppm
4	Netel Chromatograph NOx analyzer	Chemiluminiscence	0-5000pm	±5 ppm

Figure 1. Schematic Diagram of Experimental Set Up



1. Engine, 2. Electical Dynamometer, 3. Load Box, 4. Outlet jacket water temperature indicator, 5. Outlet-jacket water flow meter Orifice meter, 6. Exhaust gas temperature indicator, 7. AVL Smoke meter, 8. Netel Chromatograph multi-gas analyzer 9. Heat exchanger, 10. Air flow sensor, 11. Biodiesel tank, 12. Burette, 13. Three-way valve, 14. Air box with manometer arrangement, 15. Directional valve, 16. Gas cylinder, 17. Pressure regulator, 18. Gas pressure sensor, 19. Flame arrestor and 20. Rotometer

The engine was provided with gravity lubrication system. Biogas was inducted through port injection at the near end of compression stroke of the engine. There was facility to increase injection pressure by means of sensor.

The test fuels of the investigations were i) neat diesel and ii) biogas and biodiesel. The configurations or the versions of the engine were normal or base engine and insulated engine. Pollutants of CO and UBHC were determined at full load of the engine, at different injection pressures with test fuels.

3. Results and Discussion

Fig.2 shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with conventional engine (CE) with various percentages of biogas induction along with biodiesel operation. BTE increased with an increase of BMEP upto 80% of the full load and beyond that load, it decreased with different percentages of induction of biogas. This is due to increase of fuel conversion efficiency and mechanical efficiency up to 80% of the full load causing increase of BTE. However, beyond 80% of the full load, decrease of fuel conversion efficiency and oxygen-fuel ratio made reduction of BTE. At all load, BTE increased with increase of induction of biogas up to 35%. This is due to improved oxidation reaction of CH4 in biogas and O2 in the combustion chamber. However, beyond 35% induction of biogas, BTE decreased at all load when compared with neat diesel operation on CE. This is due to reduction of ignition delay with biogas causing to produce peak pressure at an early stage. Hence the optimum induction of biogas was limited up to 35% of total consumption of biodiesel by mass basis along with diesel operation

Figure 2. Variation of BTE with BMEP in CE with Biogas and Biodiesel

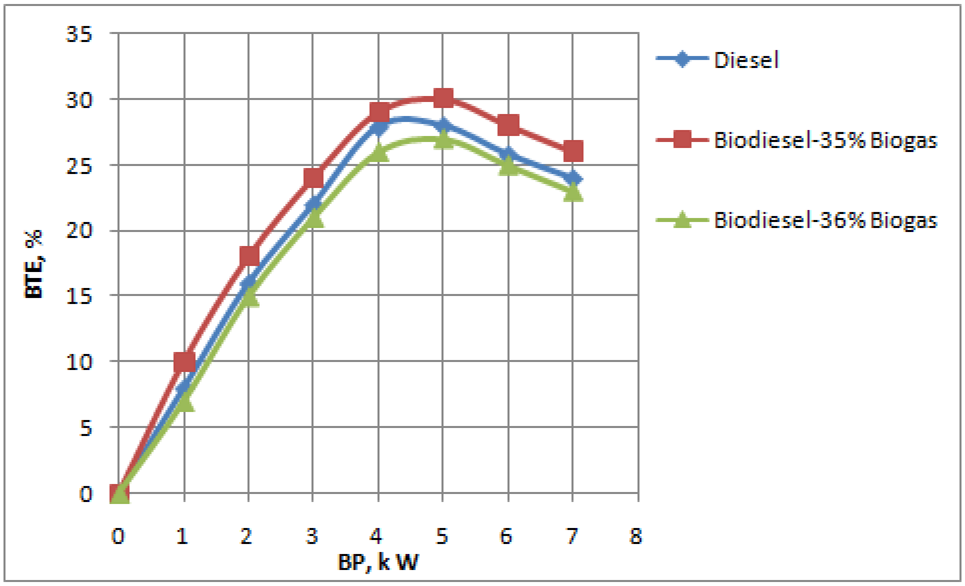
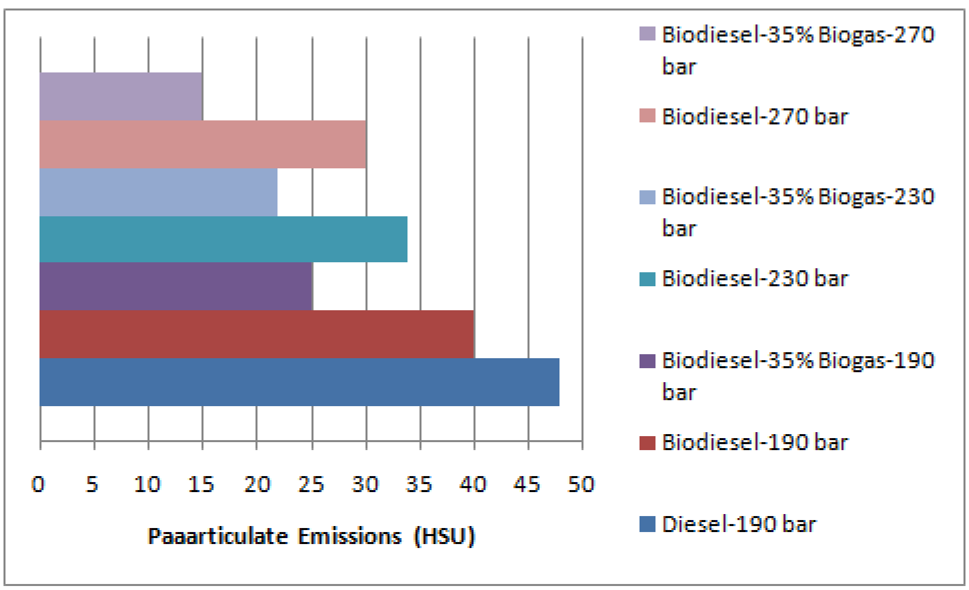


Fig.3 presents the bar chart showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with CE at maximum induction of biogas with varied injection pressure.

Figure 3. Variation of Particulate Emissions at Full Load with İnjection Pressure



Particulate emissions at full load decreased with increased injection pressure with different operating conditions of the engine. This is due to improved spray characteristics and atomization of the fuel spray which is penetrating through oxygen zone. Particulate emissions at full load decreased with increase of induction of biogas at different injection pressures. Improved oxidation reaction of CH4 present in the biogas and oxygen present in the biodiesel caused reduction of particulate emissions at full load.

Fig.4 presents the bar chart showing the variation of NO_x levels at full load with CE at maximum induction of biogas with varied injection pressure. NO_x levels increased with increased injection pressure with test fuels. Increase of combustion temperatures increased NO_x levels with test fuels. NO_x levels decreased with induction of biogas. This is due to presence of oxygen in biodiesel improved combustion, due to enrichment of oxygen with oxidation reaction of CH4 present in biogas with oxygen present with biodiesel.

Figure 4. Variation of Nitrogen Oxide Emissions at Full Load with Injection Pressure

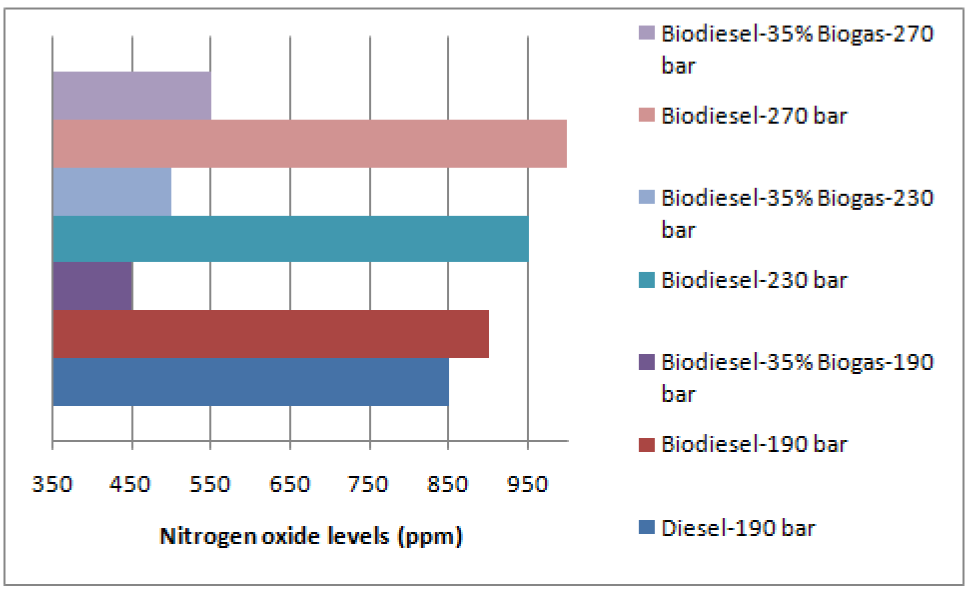


Fig.5 presents the bar chart showing the variation of carbon monoxide (CO) emissions at full load with CE at maximum induction of biogas with varied injection pressure. CO emissions decreased with an increase of injection pressure with test fuels at different operating conditions of the engine. This is due to improved spray characteristics of the fuel. When the injection pressure increased, the depth of penetration of the fuel increased in oxygen zone leading to improve oxidation reaction of the fuel with oxygen with not only in the environment but also available with biodiesel causing improved combustion and reduced CO emissions. CO emissions decreased with biodiesel operation. This is due to improved combustion with presence of oxygen in biodiesel molecular composition. This is also due to improved cetane number of biodiesel causing improved combustion leading to reduce CO emissions. CO emissions reduced with biogas induction. This is due to improved oxidation reaction of CH4 with oxygen available with biodiesel. Improved cetane (a measure of ignition quality of the fuel in diesel engine) number of biodiesel also improved combustion and thus reduced CO emissions.

Figure 5. Variation of CO emissions at Full Load with Injection Pressure

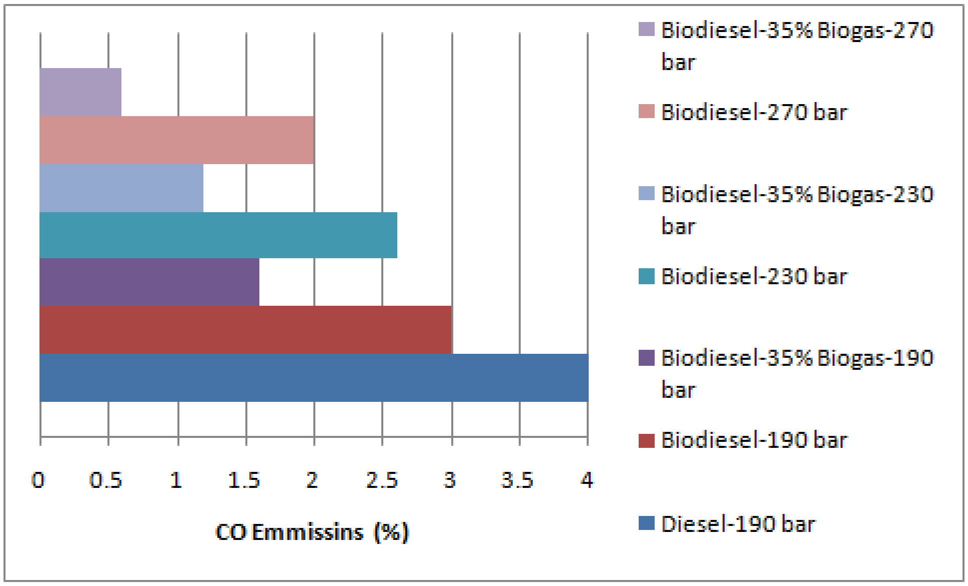
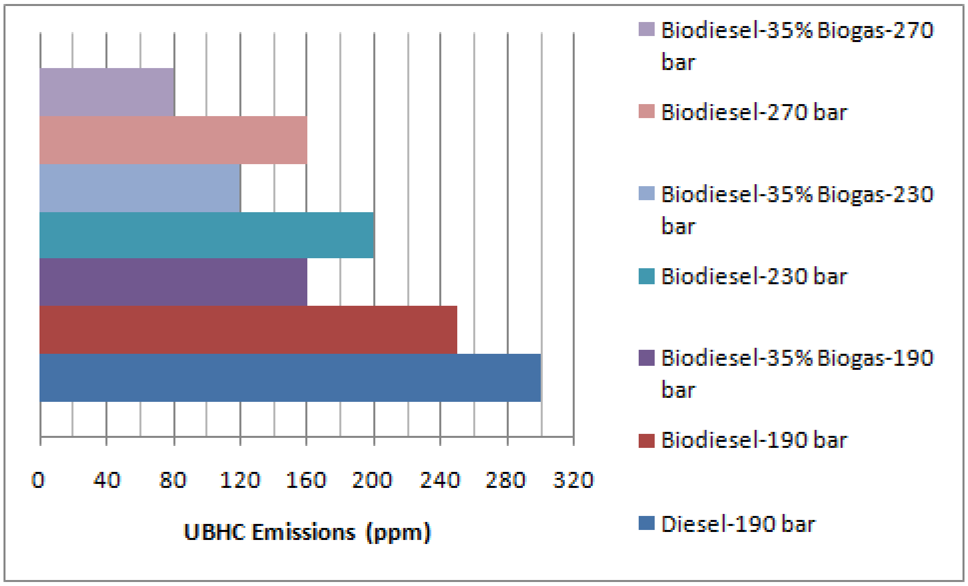


Fig.6 presents the bar chart showing the variation of un-burnt hydro carbon (UBHC) emissions at full load with CE at maximum induction of biogas with varied injection pressure.

Figure 6. Variation of UBHC Emissions at Full Load with Injection Pressure



The UBHC emissions at full load followed similar trends with CO emissions. CO is formed due to incomplete combustion of the fuel, while UBHC emissions are formed due to accumulation of the fuel in the crevice volume. UBHC emissions decreased with increased injection pressure at different operating conditions of the engine with test fuels. This is due to improved oxidation reaction of the fuel with increased fuel spray characteristic of the fuel along with atomization characteristics of the fuel. When the fuel injection pressure increased, number of fuel particles will increase along with reduction of mass, having good exposure of the fuel with oxygen particles due to improved surface to volume ratio. UBHC emission decreased with biodiesel operation. Presence of oxygen in its molecular composition and high cetane number of biodiesel improved combustion and hence reduced the un-burnt fuel in the crevice volume, thus reducing UBHC emissions. UBHC emissions at full load decreased with induction of biogas. High cetane number and presence of oxygen in the molecular structure of biodiesel caused improved oxidation reaction of CH4 present in biogas and thus reduced accumulation of the fuel in the crevice volume leading to reduce UBHC emissions at full load with induction of biogas.

4. Conclusions

The maximum induction of biogas in conventional engine was 35% of total mass of diesel at full load operation. Particulate emissions, nitrogen oxide levels, carbon monoxide levels and un-burnt hydro carbons drastically decreased drastically with dual fuel operation in comparison with neat diesel operation on conventional engine. Increased injection pressure from 190 bar to 270 bar marginally decreased pollutants with test fuels.

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