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Investigation on utilization of biogas & Karanja oil biodiesel in dual fuel mode in a single cylinder DI diesel engine

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Abstract
In this work, experiments were performed on a single cylinder DI diesel engine by using bio-gas as a primary fuel and Karanja oil biodiesel and diesel oil as secondary fuels in dual fuel operation. The experiments were performed to measure performance parameters i.e. (brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature) and emission parameters such as carbon monoxide, carbon dioxide, nitrogen oxide unburned hydro carbon and smoke etc. at different load conditions. For the dual-fuel system, the intake system of the test engine was modified to convert into biogas and biodiesel of a dual-fueled combustion engine. Biogas was injected during the intake process by gas injectors. The study showed that, the engine performance parameters like BP, BTE and EGT gradually increase with increase in engine load for all test conditions using both pilot fuels diesel and KOBD. However, the BSFC of the engine showed decreasing slope with increase in engine load for all test conditions. Above 40% engine load the BSFC values for all test fuels are very close to each other. The engine emission analysis showed that the CO_2, CO and NO_x emissions increase with increase in engine load for both single and dual fuel mode operation using both pilot fuels. The NO_x concentration of exhaust gases in dual fuel mode is superior than that of single mode.

Keywords: Biodiesel; Biogas; Dual fuel; Engine performance; Exhaust emission.

1. Introduction
Recently, Due to the rapid depletion, rising prices, uncertainty in supply and ever increasing demand of petroleum and most importantly stricter emission norms have triggered an intensive research for alternative fuels. Hence fuels which are renewable, clean burning and can be produced in a decentralized manner are being investigated as alternative fuels. Over few decades, lot of research has gone into use of alternative fuels in IC engines. Diesel fuel is largely consumed by the transportation sector, agriculture & electricity production. Thermodynamic tests based on the engine performance evaluations have established the feasibility of using different bio-fuels [1]. It is biodegradable, non-toxic and possesses low emission profiles. The term bio-fuel is referred to alternative fuel which is produced from biomass.
Bio-diesel is an environment friendly alternative liquid fuel for the diesel. Biodiesel is produced by a transesterification process of vegetable oils, animal fats and waste oils. Chemically, bio-diesel is referred to as the mono-alkyl-esters of long-chain-fatty acids derived from renewable liquid fuel. The advantages of biodiesel are that it reduces the formation of sulfur dioxide (SO_2), CO, HC and PM emissions during

the combustion process due to its low sulfur, low aromatic, and the presence of oxygen-containing compounds [2]. In addition to this, biodiesel has good ignition ability in engine due to its relatively high cetane number compared to that of conventional diesel fuel [2, 3].

Biogas is produced from anaerobic biodegradation of organic material in the absence of oxygen and the presence of anaerobic micro-organisms. It can be produced from animal manure waste, waste water and solid waste. It can be regarded as an alternative clean energy resource in view of its friendly environmental nature in CI engine because it has lower impact on pollution compared to fossil liquid fuels. In general, it is produced by the anaerobic fermentation of organic waste in landfills and the anaerobic digestion of sludge, crops, and agro-industrial byproducts and animal organic waste. The main composition of biogas is Methane (CH_4) (about over 65% by vol.). Due to its higher octane number and auto-ignition temperature it posses high knock resistance [3, 4]. Hence it is suitable for CI engines. In addition to this, the carbon content of methane is also relatively low compared to that of conventional diesel fuel, resulting in a significant decrease in pollutant exhaust emissions [4, 5].

Due to limited resources of fossil fuels, alternative solutions have been proposed by many researchers. The ‘‘dual-fuel concept’’ is one of them that use both conventional diesel and gaseous fuels. Diesel engines, with minor modification can be made to operate on gaseous fuels efficiently. Such engines usually have the gaseous fuel mixed with the air in the engine cylinders, either through direct mixing in the intake manifold with air or through injection directly into the cylinder [5]. Dual fuel CI engines introduce a premixed air–gaseous fuel mixture, which is ignited at the final stage of the compression stroke by a liquid fuel injection (pilot fuel) with good ignition properties. Induction of gaseous fuel, called primary fuel, reduces the consumption of diesel for power generation, which increases the premixed combustion and decreases NO_x and PM emissions compared to diesel engine operation [6].

Many researchers have studied the performance and emission characteristics of the dual-fuel engines fueled with gaseous-liquid fuels. It was experimentally reported that the use of CNG in a dual fuel mode reduces the noise level, specific fuel consumption, and NO_x emissions [6]. However, the hydrocarbon emission increased with a substitution of CNG for 75% of the diesel fuel. Investigations showed that by taking biogas diesel and biogas biodiesel of soybean oil in a dual fuel engine the BSFC and BTE of dual fuel mode are higher and lower respectively compared to single mode operation [7]. However, NO_x and CO_2 emission of biogas-biodiesel is more than biogas-diesel dual fuel mode, whereas CO and HC emission is lower. It was claimed that dual fuel operation results in higher output, better specific fuel consumption, superior emissions and quieter and smoother operation [8]. Experiments were conducted by considering diesel and coir-pith producer gas in dual fuel mode and it was found that BSFC is more and BTE is lower. CO and smoke emissions are higher in dual fuel mode compared to single mode operation [9].

2. Materials and methodology

2.1 The experimental setup

The apparatus used for this study was based on a vertical, 4- stroke, single cylinder, constant speed, direct injection, water cooled, and compression ignition engine. It has a bore of 80 mm, a stroke length of 110 mm, a displacement volume of 553 cm^3 and a compression ratio of 16.5:1.The rated maximum power was 3.78 kW at 1500 rpm. The engine was coupled with an electrical dynamometer rated at 10 kW and 43.5A. The detailed specifications and dimensions of the test engine are summarized in Table 1. The experimental apparatus for the dual-fuel engine consisted of the test engine, the dynamometer and control systems, the exhaust emission analyzer, and the gas fuel injection system as shown in Figure 1 and Figure 2.

The engine load and speed were controlled using an eddy current dynamometer system with a maximum braking power of 10 kW. The exhaust gas was analyzed by multi-gas analyzer made by NETEL India Pvt. Ltd. The smoke intensity was measured with a Bosch type smoke meter. The engine oil sump was filled with fresh lubricating oil before the start of experiment. The diesel and biodiesel fuels were pressurized by the high pressure injector system and the flow rate of the biodiesel and diesel fuels was measured by the fuel flow meter.

The intake system of the test engine was modified for a dual-fuel mode. Biogas was injected during the intake process by a gas injector which was installed in the intake pipe (Figure 3). The gas flow rate is controlled by a control valve. The consumption of biogas fuel was measured using a gas flow meter.

2.2 Test fuel

The pilot fuels injected into the combustion chamber which acts as the source of ignition, were conventional diesel fuel and neat biodiesel. Diesel fuel was used as the reference fuel. The biodiesel used in this study was 100% methyl ester of Karanja oil. The neat Karanja biodiesel is purchased from a commercial biodiesel supplier. The properties of Karanja oil biodiesel are tested according to ASTM standards in the laboratory and shown in Table 2.

The physical properties of biodiesel are somewhat different compared to diesel fuel. It has higher density, viscosity, cetane number and lower LHV (lower heating value) than diesel fuel.

Biogas is produced from anaerobic biodegradation of organic solid waste in the absence of oxygen and the presence of anaerobic micro-organisms. The above process is carried out in a biogas reactor within a specified time period. The process yields generally methane, carbon dioxide and a solid compost. The properties and composition of biogas depend on the nature and type of the anaerobic digestion reactor as well as on the nature of organic material use. Table 3 shows the properties of biogas.

Table 1. Test engine specification

Parameters	Description
Make	Kirloskar oil Engines Ltd, India
Engine type	4- stroke Single Cylinder Direct Injection Compression Ignition Engine
Model	AV-1
Rated power	3.78 kW at 1500 rpm
Compression ratio	16.5:1
Bore x stroke	80 mm x 110 mm
Displacement volume	553 cc
Injection pressure	220 bar
Injection Nozzle Opening	23^obTDC
Lubricating oil	SAE 20 W40
Cooling type	Water-cooled
Dynamometer	Eddy Current Type (10kW, 43.5 A)

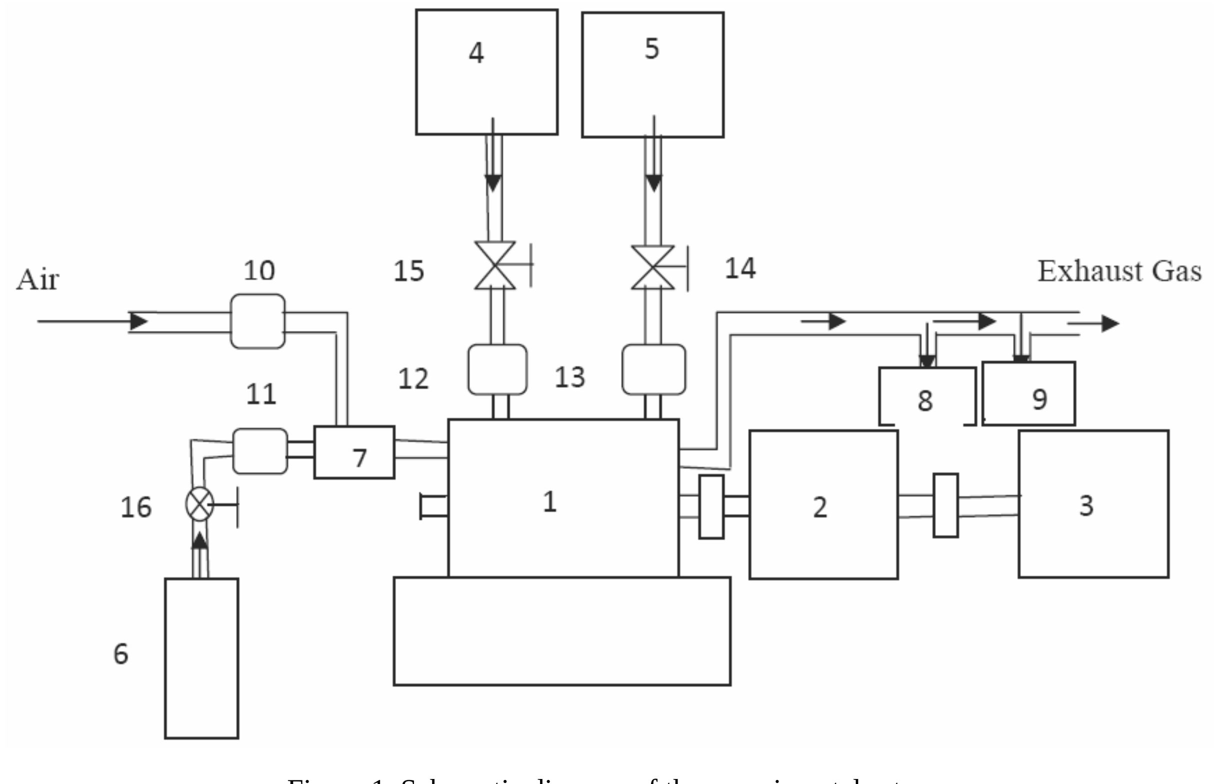

Figure 1. Schematic diagram of the experimental setup
1. Engine, 2. Dynamometer, 3. Loading unit, 4. Diesel Tank, 5. Biodiesel Tank, 6. Biogas Container, 7.Mixing Unit, 8.Exhaust Gas Analyzer, 9.Smoke Meter, 10-13. Flow Meters, 14-16. Control Valves

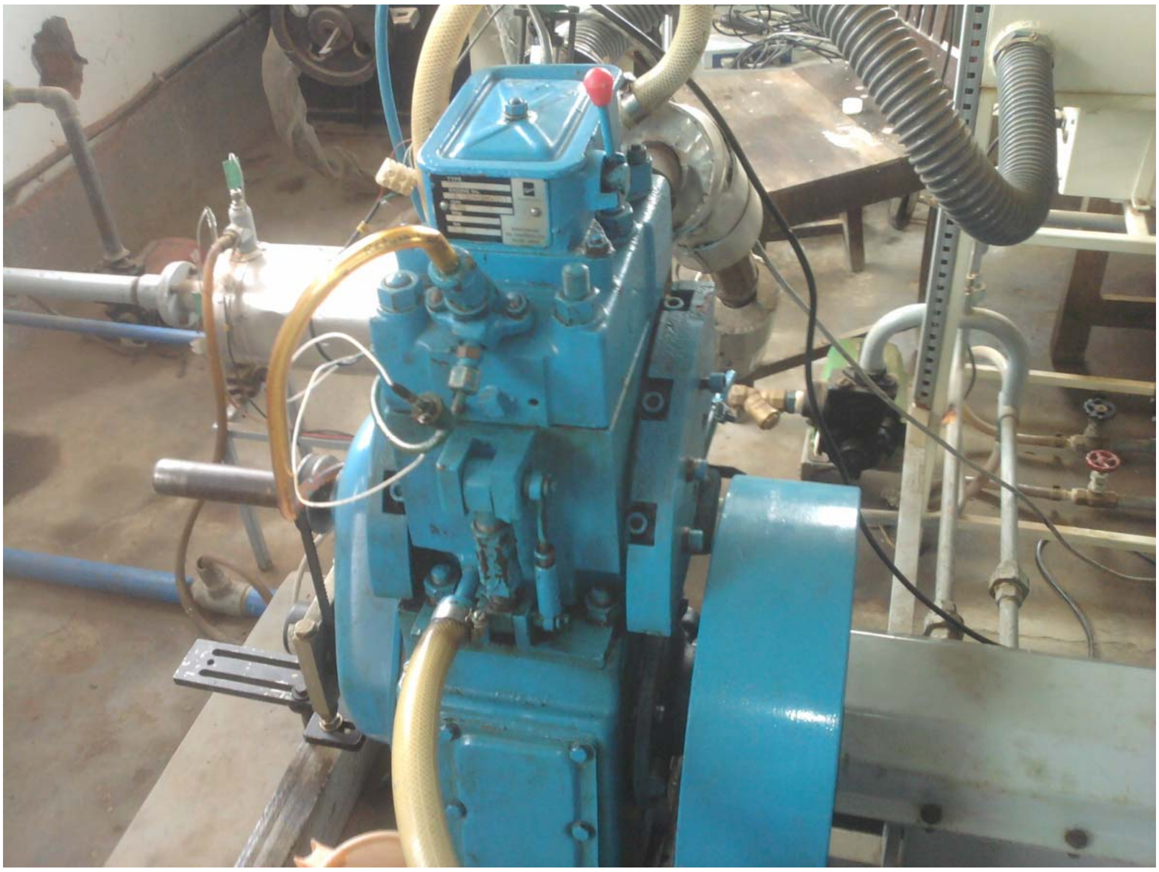

Figure 2. Photograph of the experimental set up

Figure 3. Photograph of biogas injection system

Table 2. Properties of diesel and KOBD

Sl.No.	Properties	Diesel	KOBD	Testing Method
1	Density at $20^oC(kg/m^3)$	850	886	ASTM D4052
2	Calorific Value (kJ/kg)	44000	41200	ASTM D240
3	Viscosity at 40^oC (cSt)	2.87	5.35	ASTM D445
4	Flash point (^oC)	76	172	ASTM D93
5	Cloud point (^oC)	6.5	14.2	ASTM D2500
6	Pour point (^oC)	3.1	5.2	ASTM D97
7	Iodine No. (g I_2/100gm)	-	86.5	ASTM D 1510
8	Acid Value (mg KOH/g)	-	0.43	ASTM D 974
9	Cetane Index	52	57.3	ASTM D 613
10	Moisture Content (mg/kg)	-	0.036	Metrohm 871

Table 3. Properties of biogas [10-13]

Sl. No.	Properties	Value
1	Methane (%, by vol.)	30–73
2	Carbon dioxide (%, by vol.)	20–40
3	Hydrogen (%, by vol.)	1–3
4	Oxygen (%, by vol.)	0–5
5	Nitrogen (%, by vol.)	5–40
6	Octane number	130
7	Auto-ignition temperature (°C)	632–813
8	Lower heating value (KJ/kg)	26170
9	A/F ratio (by vol.)	17.2
10	Density(kg/m^3)	0.65–0.91
11	Boiling point(°C)	(-)126–162

2.3 Experimental procedure

Initially, the engine was started with diesel oil for 15 minutes in single mode operation. Once the engine has warmed up, and stabilize then it was switched over to dual fuel mode in which biogas is supplied as the inducted fuel and diesel is supplied as an induction fuel. Readings were taken, when the engine was operated using an eddy current dynamometer at a constant engine speed of 1500 rpm with different engine loads. The engine loads were 20%, 40%, 60%, 80% and 100%. The performance of the engine was evaluated in terms of brake thermal efficiency, brake power, specific energy consumption, and emission characteristics like CO, HC, NO_x and smoke. Under biogas/diesel dual-fuel operation, an effort has been made to keep the pilot amount of diesel fuel constant, while the engine power output was adjusted through the amount of biogas.

After the end of first observations, the second observations were taken by considering biodiesel and biogas in dual fuel mode under same test conditions. The performance and emissions characteristics were also computed.

3. Results and discussion

3.1 Brake power

Figure 4 shows the variation in engine power output at different engine loads for single fuel mode and dual fuel mode operations of the engine. The figure explains that the power output of the engine is slightly higher during single fuel mode than that of dual fuel mode under all test conditions. This is because of higher heating value of diesel and KOBD as compared to biogas. The figure also indicates that with increase in engine load, the brake power increases linearly and this is due to the higher fuel consumption rate of the engine with increase in load.

3.2 Brake specific fuel consumption

Figure 5 shows that the BSFC obtained is the sum of the biogas and the liquid fuels i.e. KOBD and petro diesel. At low engine load conditions of 20% and 40%, the BSFCs for dual-fuel combustion for both fuels were higher than for single-fuel combustion. These results obtained indicate the lower rate of combustion of gaseous fuel due to the lower air–fuel ratio in the combustion chamber and a lower combustion temperature. Whereas the differences in the BSFCs between single and dual-fuel combustions are much lower at higher engine loads. It was seen that at engine loads over 60%, where a high thermal load was imposed on the engine, the increase in combustion rate of biogas led to a significant improvement in the BSFC with dual-fuel combustions.

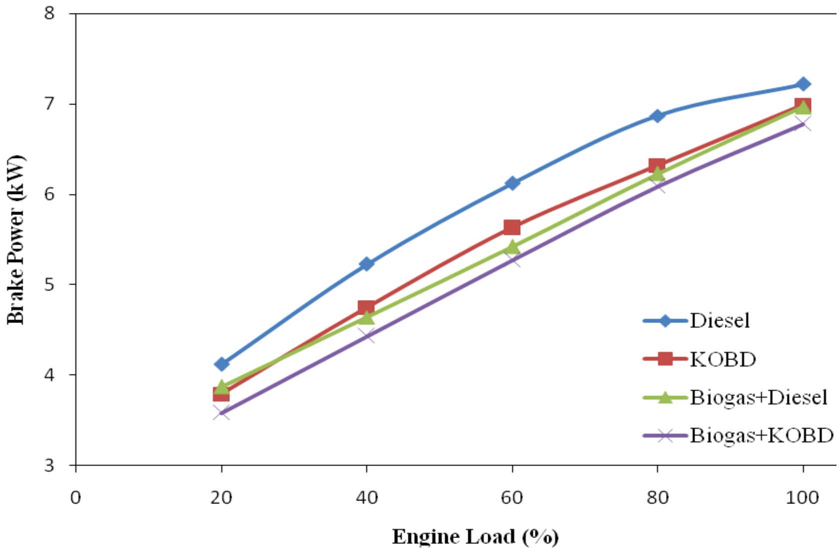

Figure 4. Variation of brake power with engine load

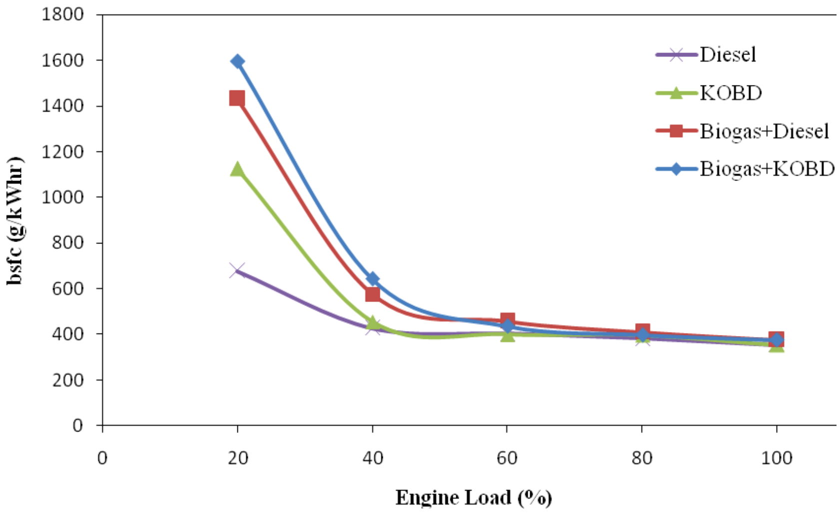

Figure 5. Variation of BSFC with engine load

3.3 Brake thermal efficiency

Figure 6 shows that the thermal efficiency of dual-fuel combustion for both pilot fuels was lower as compared to single-fuel mode at all engine loads. It has been reported that the lower thermal efficiency of the dual-fuel combustion is because of the effect of biogas residuals, combustion gas residuals and low combustion temperatures during the combustion process [14]. The figure also indicates that under high-load conditions, the brake thermal efficiency is higher in single fuel mode operation for diesel as that of KOBD, which is because the heating value of KOBD is relatively lower than that of diesel.

3.4 Exhaust gas temperature

Figure 7 shows the variation of the exhaust gas temperature with engine load for all the fuel modes. The exhaust temperature measurements were conducted using a thermocouple mounted at the end of the exhaust port. In this figure, the exhaust gas temperature increases linearly as the engine load is increased due to the increase of total energy input which is due to higher specific fuel consumption. However, the exhaust gas temperatures were found slightly lower for dual-fuel combustions compared to single-fuel modes and these differences increased at higher engine loads. The low gas temperature can be explained by the decreased charge temperature with induction of biogas in the engine which acts as a heat sink. It could also be due to that the flame propagation speed of the pilot fuel in intake charge is reduced and then the fuel in the combustion chamber was not burnt completely and therefore the combustion pressure and temperature are reduced.

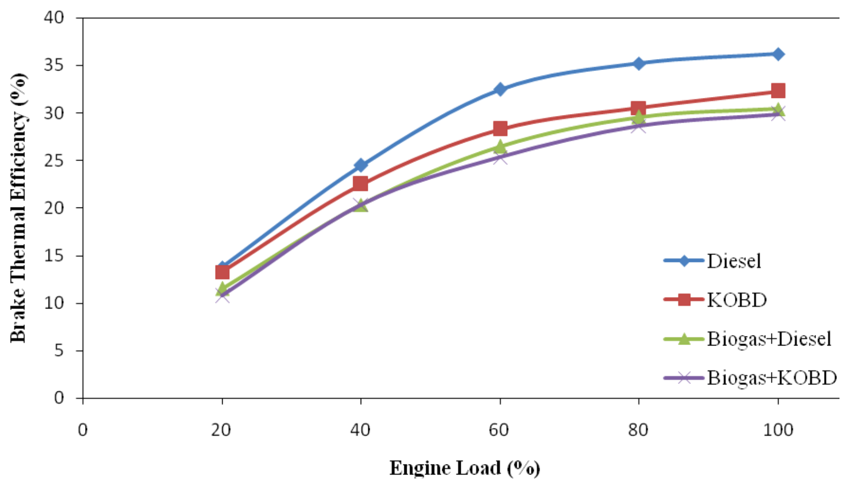

Figure 6. Variation of BTE with engine load

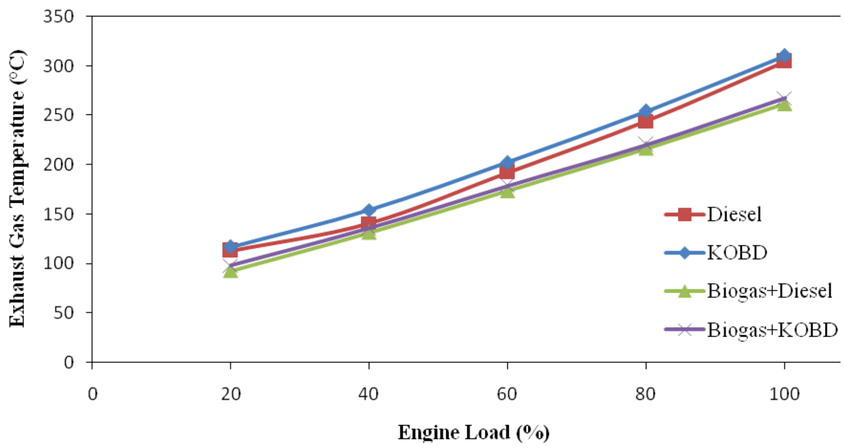

Figure 7. Variation of EGT with engine load

3.5 CO emissions

Figure 8 shows the CO emissions at various engine loads. As shown in the figure, the concentration of CO emissions for KOBD were lower than those of diesel fuel in both single and dual combustion modes. The reason for the lower concentrations of CO emissions is that biodiesel fuel contains about 11% oxygen by weight, which leads to a more complete combustion, and hence minimizes the chances of incomplete combustion. Also, the faster injection rate and higher cetane number of KOBD shorten the ignition delay, and this causes a decrease in the fuel-rich zone during the combustion process.

However, in comparison between single and dual-fuel combustions, the concentration of CO emissions for the dual-fuel mode with both pilot fuels were considerably higher than those of the single-fuel mode under all test conditions. With the induction of biogas, the CO_2 content increases in the mixture instead of fresh-air. It has been reported that the ignition is normally more delayed with dual-fueling compared to diesel fueling [15].

3.6 HC emissions

Figure 9 shows the HC emissions at different engine loads under different combustion modes. As shown in the figure, the HC emissions for biodiesel were lower than those of diesel fuel in both single and dual combustion modes. The lower HC emissions for KOBD is due to the fact that it has higher oxygen content by weight and high cetane value, which leads to better combustion in the combustion chamber. Whereas, comparing the single and dual-fuel combustions, the HC emissions for the dual-fuel mode with both pilot fuels were found to be higher than those of the single-fuel mode under all test conditions. With the induction of biogas into the engine, the CO_2 content in the mixture increases at the expense of fresh-air which in turn reduces the air–fuel ratio and combustion temperature. At higher engine loads the HC emissions were found to be reducing for dual fuel mode whereas the same was found to be slightly increasing for single fuel mode with both the pilot fuels. The reason towards this can be stated as the higher octane rating of biogas results in faster rate of combustion in the combustion chamber.

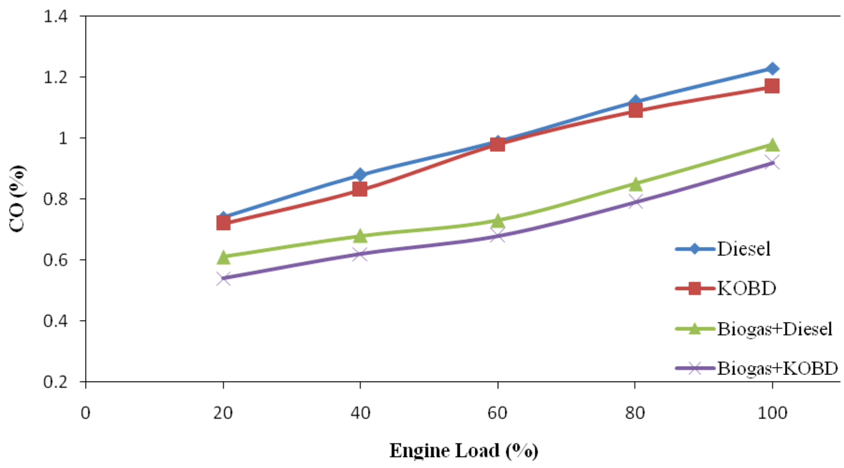

Figure 8. Variation of CO emission with engine load

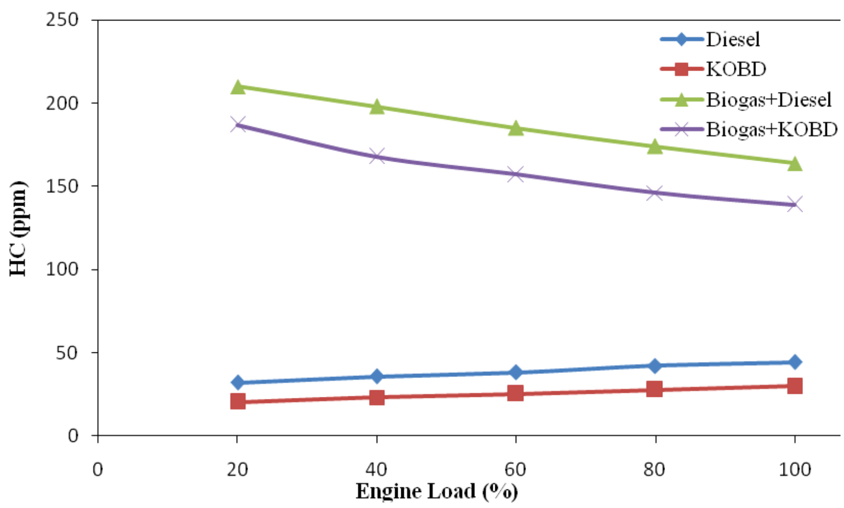

Figure 9. Variation of HC emission with engine load

3.7 CO_2 emissions

Figure 10 shows the concentrations of CO_2 emissions at different engine loads for two pilot fuels in both single and dual-fuel combustion modes. In this figure, the highest CO_2 emissions were produced by single-fuel combustion of biodiesel due to low C/H ratio, where as biogas- diesel dual-fuel combustion produced the lowest CO_2 emissions. For the comparison of test fuels, Figure 10 indicates biodiesel combustion with both combustion modes generated higher concentrations of CO_2 emissions. This is because of presence of oxygen in biodiesel allowing more CO emissions to be oxidized into CO_2. However, analysis of closed carbon life-cycle of biodiesel, the CO_2 emissions exhausted from the diesel engine fueled with biodiesel are absorbed and recycled by growing plants. Therefore, biodiesel combustion can be considered as definitely causing lower net CO_2 emissions than diesel fuel.

3.8 NO_x emissions

Figure 11 indicates the concentrations of NOx emissions for the engine operated with single mode and dual-fuel combustion modes. In Figure 11, with increase in engine load, the NOx concentrations of all test conditions are increased steeply. However, the NOx emissions emitted under the dual-fuel operation for both pilot fuels were lower compared to the single mode at all test ranges, In the case of the single mode, biodiesel combustion produced higher concentrations of NOx emissions at all engine loads, compared to diesel fuel. This is due to oxygen content, faster injection and early ignition characteristics of biodiesel. This resulted in a slightly higher maximum combustion pressure and temperature, which enhance the formation of NOx emissions. Again in case of dual-fuel operations, the concentrations of NOx emissions were significantly lower at all engine loads, on average about 60% below the levels measured in single mode combustion. This is because of low combustion rate of the gaseous fuel in the presence of CO_2 in biogas. The CO_2 of biogas dilutes the oxygen concentration of the intake fluid. It has been reported that [16-19] the induction of biogas increases the specific heat capacity of the working fluid which causes the slowing of the flame propagation and the lowering of the combustion temperature during the combustion process compared to the single-fuel mode.

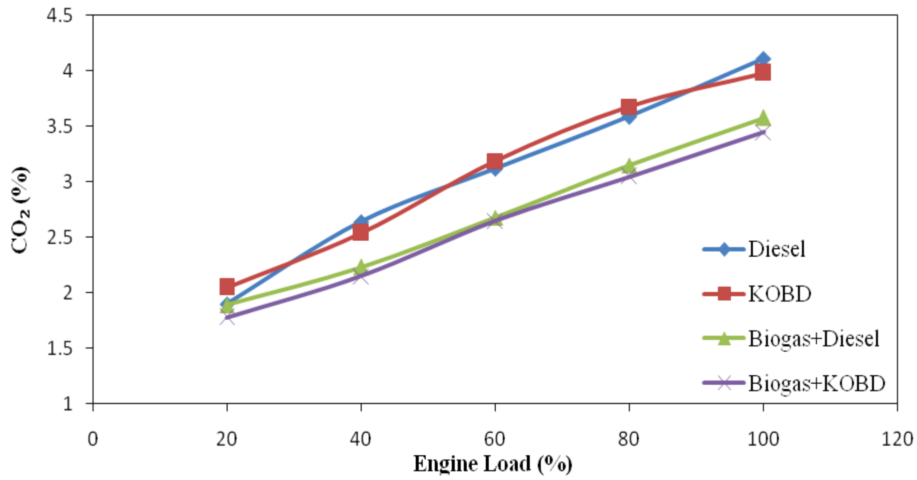

Figure 10. Variation of CO_2 emission with engine load

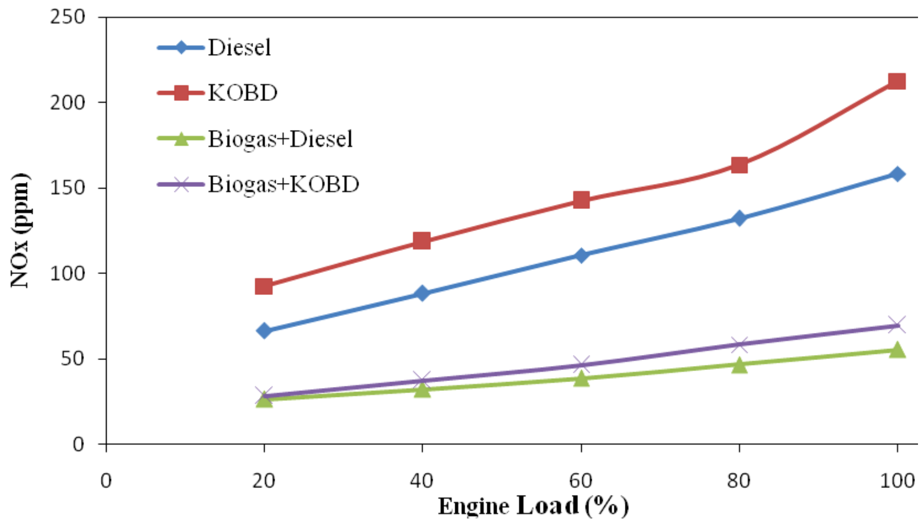

Figure 11. Variation of NO_x emission with engine load

4. Conclusion

To investigate about various effects of dual-fuel combustion of KOBD and biogas along with diesel on the performance and exhaust emission characteristics of a single cylinder four stroke DI diesel engine under various experimental conditions. The following conclusions were drawn from the analysis:

1. The test results showed higher brake specific fuel consumption of the engine at 20% and 40% load and comparatively much lower BSFC at higher engine loads. Also the BSFC in dual fuel mode was higher than that of single fuel mode operation at 20% and 40% loads but it is almost equal for both modes at higher engine loads.
2. The brake thermal efficiency of the test engine in dual-fuel combustion mode for both pilot fuels was lower as compared to that in single-fuel combustion mode at all engine loads. It was also found that under high load conditions i.e. above 60% engine load, the BTE was higher in single fuel combustion mode than that of dual fuel combustion mode.
3. The CO emissions of the test engine were found higher for both diesel and KOBD in single fuel combustion mode as compared to dual fuel combustion mode. The results also indicate almost linear increase in the CO emissions with increase in engine load in case of both single and dual combustion modes. On the other hand the results showed a linear decrease in HC emissions for dual combustion mode and a linear increase in the same in single fuel combustion mode with increase in engine load.
4. The NO_x emissions from the engine linearly increases with increase in engine load for both single and dual fuel mode combustion. In particular the NO_x emissions were found higher for single fuel mode operation as compared to the dual fuel mode. In single fuel mode operation the concentration of NO_x emissions for KOBD is more as compared to that of diesel.

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Nomenclature

CI	Compression Ignition
DI	Direct Injection
KOBD	Karanja Oil Biodiesel
KOME	Karanja Oil Methyl Ester
KOH	Potassium Hydroxide
BP	Brake Power
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
EGT	Exhaust Gas Temperature
PM	Particulate Matter
CO	Carbon Monoxide
CO_2	Carbon Dioxide
SO_2	Sulphur Dioxide
HC	Hydro Carbons
NO_x	Oxides of Nitrogen
LHV	Lower Heating Value
CNG	Compressed Natural Gas
ASTM	American Society for Testing of Materials

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