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Investigations on Performance and Emission Characteristics of Diesel Engine Fuelled with Biogas and ethanol-Biodiesel-Diesel Blend

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ABSTRACT: The current scenario of abating fossil fuels has imposed the experts to discover for a substitute fuel that can be used in diesel engines. At present, scientists and specialists have instigated that biodiesel along with alcohols can be a suitable substitute for the existing situations. This study attempts to utilize ethanol-biodiesel-diesel blend as pilot fuel engine. The engine performance and emissions parameters of dual fuel mode were investigated and related with conventional diesel fuel. It is inferred from the test outcomes that NO_x-smoke opacity exhalation were drastically reduced with bi-fuel mode in relation with conventional diesel. The higher HC exhalation level was observed with biogas-diesel with bi-fuel mode than natural diesel. The utilization of oxygenated additives such as ethanol and biodiesel improves the emissions characteristics from diesel engine. However, BTE was noticed to be inferior with bi-fuel mode as compared to diesel mode.

Keywords: Biogas, HC, bi-fuel, NO_x, CI engine, emission, ethanol, bio-diesel.

Abbreviations

ASTM	American society of testing & methods
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
SI	Spark ignition
CI	Compression ignition
CO_2	Carbon dioxide
HC	Hydrocarbons
CO	Carbon monoxide
KOH	Potassium hydroxide
NOx	Oxides of Nitrogen
rpm	revolutions per minute
E10B10D80	Ethanol-10%/Biodiesel 10%/Diesel 80% by volume
E20B20D60	Ethanol-20%/Biodiesel 20%/Diesel 60% by volume

I. INTRODUCTION

Diesel engines are extensively utilized in conveyance, agricultural appliances and building equipment because of the fact that they have extreme fuel effectiveness and permanence. Nevertheless, the major exhaust exhalations of a diesel engine are NO_x and smoke, and if NOx emissions decreases smoke emissions increases and vice-versa [1-3]. Further progressive and innovative approaches of combustion that utilize non-conventional and alternate fuels as energy sources are the principal selection of investigators these days owing to inflexible conservational guidelines, drop in subversive fossil fuel, accelerating amounts and augmented exigency for energy. There is incessant burden on emanation restraint by the means of occasionally constricted procedures throughout the world. In the contemporary state of affairs, there is a vital pre-requisite to encourage practice of unconventional fuels as replacements for diesel engine [4-6].

Bi-fuel diesel engines energized with biogas could be a solution to the crisis of critical scarcity of power predominantly in rustic parts of India. It is a preeminent fact that traditional diesel engine possesses the advantage of abundant advanced thermal effectiveness in comparison with SI engine at the disbursement of higher NO_x and soot exhalations. Therefore, the consumption of bio based fuel in CI engines will curtail the exhalations and continue high efficiency, which will endorse the relevance of bio based fuel [7-9]. Moreover, gaseous fuels are contemplated well for IC engines, as a result of their decent mingling features with air. The high self-ignition temperature empowers them to work with lean mixtures and higher compression ratios, consequential in an enhancement in the thermal efficiency and decrease in exhalations.

Biogas is a respect able unconventional gaseous fuel, and is procured by the anaerobic assimilation of cattle dung, non-consumable seed cakes, animal leftover, food surplus, agricultural excess, municipal remains, sewage mud etc. [10-12].

Abundant exploration on investigational and theoretic research regarding the bi-fuel diesel-gaseous fuel operational mode have been stated over the precedinger as but a very few work has been reported with biogas as primary fuel.

Bilgin *et al.* [13] reported the performance of an adaptable compression ratio CI engine operating on blends of ethanol and diesel. He operates the engine with blends of diesel and ethanolpar taking various percentages of ethanol on a volume basis in addition to diesel fuel alone. Compression ratios of 19, 21, and 23 were kept for these experiments. Investigational consequences specify that the accumulation of 4% ethanol to diesel fuel upsurges power output and effectiveness of the engine although it declines BSFC for numerous compression ratios. The superlative effectiveness was accomplished at the compression ratio of 21 with an augmentation ratio over 3.5%. Cheng *et al.* [14] studied the assessment of emanations of a direct injection diesel engine working on biodiesel with blended and decontaminated methanol. The researchers intended to associate the result of relating biodiesel with either 10% blended methanol or 10% fumigated methanol. The outcomes specify a decrease of CO_2, NO_x, and particulate matter exhalations and a lessening in mean particle diameter, in both circumstances, related with diesel fuel.

Barik *et al.*, [15] investigated the influence of various flow rates of biogas with diesel as a pilot fuel. They inducted the biogas into the inlet manifold at various mass flow rates, i.e. 0.3 kg/h, 0.6 kg/h, 0.9 kg/h and 1.2 kg/h accompanied by the air. They analyse and compare the combustion, performance and exhalation features of the engine in the bi-fuel mode with that of diesel fuel mode. In their paper they have limit the extreme flow of biogas upto 1.2 kg/h, nonetheless in this paper we are limiting the biogas flow rate a maximum upto 3.2 kg/h to further extend scope of research. Mustafi *et al.*, [16] performed the combustion and emissions features of a bi-fuel engine operated on natural gas and biogas. The engine was operated at various engine loads i.e. at 10% and 85% correspondingly at 1800 rpm. They found extended ignition lags none the less shorter combustion durations for bi-fuelling modes. NO_x and PM emanations were less and UHC exhalations were more for biogas–diesel bi-fuel modes as related to diesel fuelling. Lu et al.[17] originate that soot and NO_x exhalations reduced though CO emanations augmented expressively. The presentation of biogas in CI engine with high thermal effectiveness is mostly understood in bi-fuel mode, in which primary fuel is biogas and pilot fuel is diesel. Agarwal [18] studies the applications of Bio fuels by way of fuels for IC engines. The researcher found the ethanol as an appealing substitute fuel since it is an unconventional biomass reserve and it is oxygenated, thus offering the probability to diminish PM emanations in CI engines.

Ethanol is a potential fuel additive for application in diesel engines and possesses numerous benefits for instance higher cetane number, high calorific value, inferior heat of vaporization and improved miscibility with diesel [19]. To attain promising circumstances for ignition, ethanol necessitates less heat and inferior intake air temperature as it has low heat of vaporization. Furthermore, its mixtures with biodiesel are to recover solubility and decrease viscidity to support flow ability [20]. Inclusively, ethanol has physical properties near enough to diesel, consequently, ethanol is a significant preservative or substitute fuel for use in CI engines [21].

From the reviewed writings, it was found that none of the investigational study has been done on utilizing ethanol/biodiesel-diesel blend combination as pilot fuel for biogas operated diesel engine. The authors are first to report the utilization of ethanol-biodiesel-diesel as potential pilot fuel for biogas operated bi-fuel engine. In conclusion, the outcomes attained from the bi-fuel mode were related with those of diesel only mode and accessible in this research work.

II. MATERIALS AND METHODS

The low sulphur diesel fuel was acquired from the native trade petrol pump of Indian oil Corporation Limited. The entire range of obligatory elements for instance methanol (Merck, 99.5%), ethanol (Merck, 98%) and potassium hydroxide of investigative rating were obtained from Lobachemie Pvt. Ltd. India. Methyl esters from used cooking oil were procured by transesterification reaction. Transesterification process was carried out by heating 1 litre of waste cooking oil to 65°C in a round bottom flask. Catalyst (NaOH-0.5% w/w_{oil}) was disbanded in methyl alcohol (270 ml), and this was dispensed into the round bottom flask comprising the excited waste cooking oil although moving the assortment incessantly for 1 hour in a biodiesel reactor.

A temperature of 55 ± 1°C was preserved for 1 hour, and the reaction products were permissible to settle down under severity for 6 hours in a separating funnel. The lower most deposit of glycerol was uninvolved, and the uppermost layer of biodiesel was assorted with hot distilled water (10% v/v) in mandate to eliminate the adulterations such as unreacted methanol, unreacted oil and catalyst. The assortment was yet again permitted to settle under gravity for 6 hours, and the subordinate deposit of water comprising adulterations was exhausted.

The physio-chemical properties of the tested fuels were examined as per international ASTM specifications given in Table 1. Fuel blend having 20% by volume of biodiesel was designated as B20 and the fuel blends consisting of combination of waste cooking oil biodiesel-diesel/ethanol and biogas as primary fuel were represented as E10B10D80+BG and E20B20D60+BG. The pilot fuel assortments were attained by mixing on magnetic stirrer to ensure homogeneity of fuel blends. The biogas was procured from the School of Energy and Environment, Thapar University, Patiala. The biogas composition is shown in Table 2 and the test engine specifications are shown in Table 3. In the present investigation, the primary fuel used was biogas obtained by the anaerobic digestion of cow dung and kitchen waste in a fixed dome type biogas plant. A fixed dome type biogas digester comprises of a digester with a stable, non-portable gas compartment, which be situated on upper piece of the digester. Slurry was set by fraternization of water in cow's excrement in proportionate portion, and fractional amount of kitchen squander in blending supply. The slurry was then guided into the digester holder with the guide of delta compartment, where the composite carbon blends existing in the steers manure and kitchen waste breaks into easier issues by the demonstration of anaerobic organisms in the organization of water. This anaerobic breaking down of composite carbon mixes accessible in cow's fertilizer and kitchen waste secures biogas and a cycle is practiced in roughly 2 months. The biogas so shaped gathers in vault structured top of biogas generator and is provided to the motor with assistance of funnels. The devoured slurry is substituted every once in a while with new slurry to carry on the creation of biogas.

The premium diesel fuel:

Table 1: Fuel Properties.

Properties	Diesel	Test Method	Biogas	Test Method	WCO Biodiesel	Test Method
Chemical composition	$C_{12}H_{26}$	———	60% CH_4, 40% CO_2 (volume)	———	RCO_2R'	ASTM D 5291
Density (kg/m^3)	840	ASTM D 4052	1.1	ASTM D 3588	922	ASTM D 1298
Lower calorific value (MJ/kg)	42	ASTM D 4809	20.67	ASTM D 1945	40.3	ASTM D 3338
Cetane number	45-55	ASTM D 613	———	ASTM D 2699	63.8	ASTM D 613
Auto-ignition temperature (K)	553	ASTM D 93	1086	ASTM E 659	———	———
Stoichiometric air fuel ratio	14.92	———	10	ASTM D 4891	13.8	———

Table 2: Composition of biogas.

Components	Amount (%)
Methane (CH_4)	50-70
Carbon Dioxide (CO_2)	30-40
Hydrogen (H_2)	5-10
Nitrogen (N_2)	1-2
Water Vapour (H_2O)	0.3
Hydrogen Sulphide (H_2S)	Traces

Table 3: Technical specifications of the test engine.

Engine parameter	Specification
Engine model	Kirloskar DAF8
Number of cylinders	1
Cylinder bore/stroke	102/110 mm
Displacement volume	898.84 cc
Compression ratio	17.5 : 1
Maximum power	6 kW
Rated speed	1500 rpm
Fuel injection pressure	210 bars
Fuel injection system	Direct injection
Cooling system	Forced air cooled

III. RESULTS AND DISCUSSION

The subsequent segment exemplified the outcomes of performance and emanation characteristics of the diesel engine fuelled with the biogas and ethanol-biodiesel-diesel blend as pilot fuel under various load conditions. The influences of pilot fuel blends were analysed on the foundation of performance and emission characteristics at various engine loads at invariable speed of 1500 rpm.

A. Brake Thermal Efficiency (BTE)

Brake thermal efficiency can be explained as the ratio of brake power output to the power of the fuel expended. It expresses for the combustion quality of the engine [22]. It is used to evaluate how efficiently an engine converts the heat from a fuel to mechanical energy. It was observed in Fig. 1 that the BTE under different biogas-diesel bi-fuel mode of operation with both pilot fuels was lower than natural diesel fuel. The poor gaseous fuel utilization was due to a very rich air-fuel mixture, which sustains low combustion chamber temperature [23-26]. The enhanced ignition lag and low combustion temperature near to the point of fuel injection outcomes in slower flame propagation [27, 28]. This can be explained by the existence of biogas leftovers, more consumption of fuel and low combustion chamber temperature. At peak load the BTE of bi-fuel mode with E10B10D80 and E20B20D60 were 23.4% and 22.4% when related with diesel fuel (26.4%) and B20 (25.5%). As the percentage of ethanol increases in the blend from E10 to E20, there is a very slight increase in the brake thermal efficiency. This is because of the decrease of viscosity of the combinations with the accumulation of ethanol to biodiesel. This results in improved atomization and enhanced fuel-air mixing resulting in an upsurge in BTE. But the BTE of blended fuel from B20 to E10B10D80 to E20B20D60 decreases because of inferior energy content of biodiesel and biogas in relation with diesel.

B. Brake Specific Fuel Consumption (BSFC)

Brake Specific fuel consumption is an essential measure, to notice the effectiveness with which the fuel is being utilized in an engine [29]. It can be noted from the Fig. 2 that, a higher BSFC is observed in the bi-fuel operation with ethanol as compared to diesel at low engine loads. This is because of the lower calorific value of fuel (biogas, biodiesel and ethanol), inferior cylinder temperature, and the existence of CO_2 in biogas avoids rapid burning. At full and intermediate engine loads the variation in BSFC amid diesel and bi-fuel mode are not expressively dissimilar. At maximum engine load the bi-fuel mode has comparable fuel energy adaptation competence in relation with diesel. Since, low energy from the fuel is obligatory at maximum load of the engine in comparison with no engine load, because of the augmented temperature of the cylinder at maximum load. At maximum engine load, the BSFC for diesel is 0.35 kg/kWh, and in dual fuel operation, with E10B10D80 and E20B20D60, the BSFC is 0.77 kg/kWh, 0.83 kg/kWh respectively. In addition, the BSFC improved with the rise of ethanol percentage in the diesel-biodiesel-ethanol blends. It is because of the inferior energy content of biodiesel and ethanol vis-à-vis traditional diesel. The extremely oxygenated ethanol blending into the blends results in leaner combustion causing advanced BSFC.

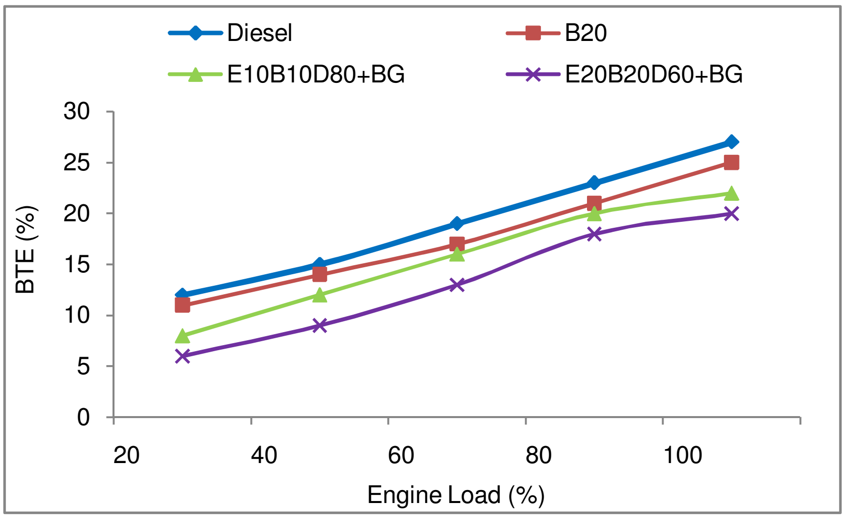

Fig. 1. Variation of brake thermal efficiency with engine load.

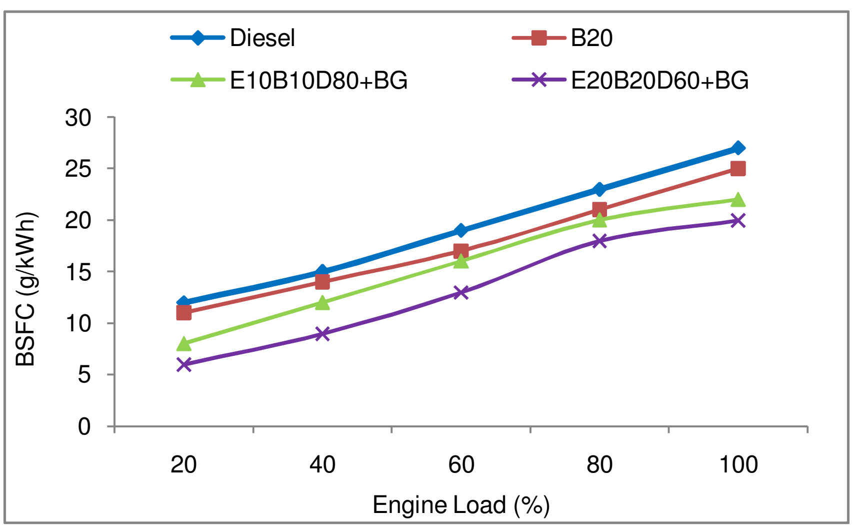

Fig. 2. Variation of brake specific fuel consumption with engine load.

C. Oxides of Nitrogen (NO_x)

The NO_x exhalation under biogas energized bi-fuel mode is lesser in relation with fossil diesel. With enhancing ethanol concentration, the NO_x emanations slightly increase at all engine load conditions. This can be ascribed to the enhancement in level of oxygen value of the ethanol-biodiesel blended fuel. In the biogas energized bi- fuel mode the existence of inert gases such as CO_2, having advanced specific heat dilutes the cylinder charge and expressively dropping the highest combustion temperature and accessibility of oxygen [30-33]. The existence of oxygen content in the biodiesel fuel aids in enhancing NO_x emission from biodiesel operated diesel engine [34].

D. Smoke opacity

It is revealed from the Fig. 4 that biogas fuelled diesel engine gives lower smoke emissions due to reduction in flame temperature because of the accessible CO_2 in biogas [35]. An additional cause can be the existence of methane as primary essential of biogas, which is a lower member of the paraffin family and have a low propensity to generate smoke [36, 37]. The addition of ethanol in the pilot fuel blend under biogas energized bi-fuel mode is very effectual in restricting smoke emanations in the exhaust of the engine. The most significant feature is that with increasing ethanol concentration, the smoke exhalations decreases at all engine loads. The smoke is mainly associated with burning of pilot liquid fuel. The reduction of smoke emanations with biogas fuelling is primarily produced by abridged smoke formation and higher smoke oxidation [38]. The presence of oxygen in ethanol and biodiesel blended fuel plays vital role in enhanced oxidation of the fuel.

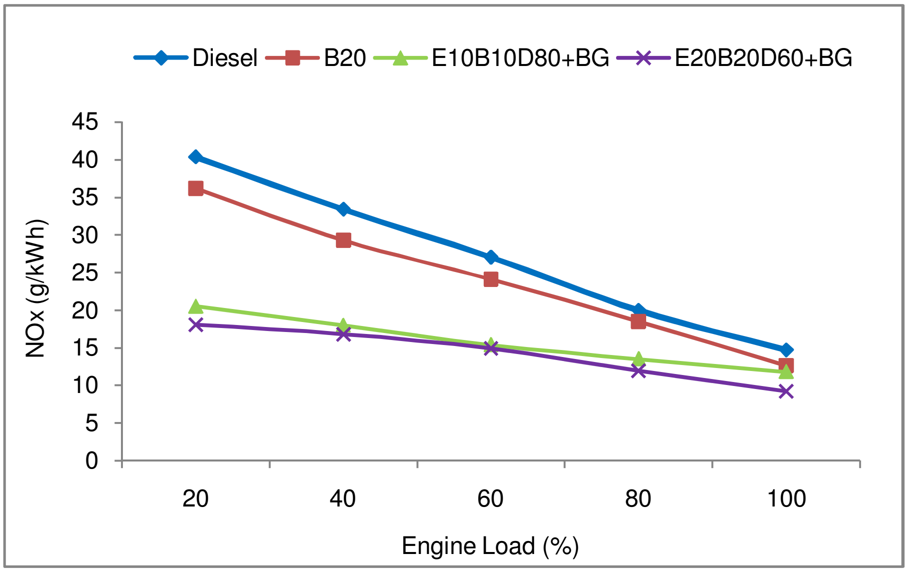

Fig. 3. Variation of NO_x emission with engine load.

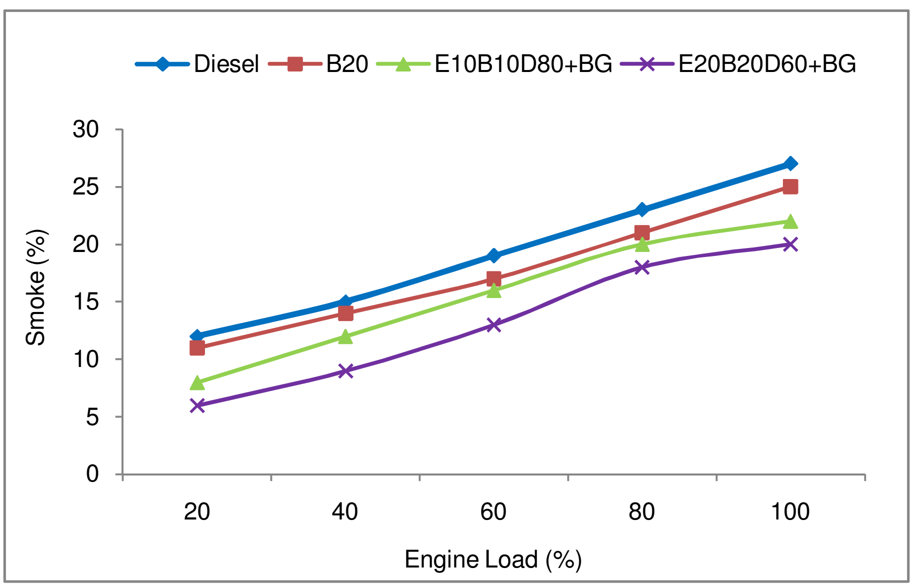

Fig. 4. Variation of smoke opacity emission with engine load.

E. Hydrocarbon (HC)

The biogas fuelled bi-fuel operation with both pilot fuels was higher in relation with diesel fuel at all loads. At low to intermediate load condition, the higher hydrocarbon emanations in the bi- fuel mode are due to the very lean premixed charge, lower combustion temperature and slower flame propagation leads to the higher amount of hydrocarbons emitted in exhaust [39].

At advanced loading conditions, because of higher combustion chamber temperature, more complete oxidation takes place which subsequently reduces the formation of hydrocarbon exhalations than lower loading conditions with bi-fuel operation [40]. The addition of ethanol concentration helps in improving the enhanced oxidation of fuel under bi-fuel operation.

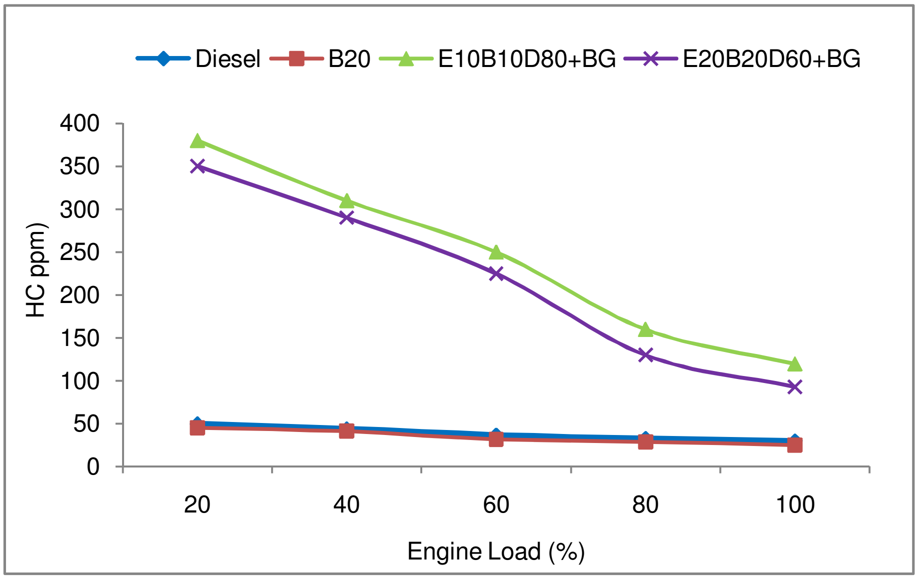

Fig. 5. Variation of HC emission with engine load.

IV. CONCLUSIONS

The present experimental investigation explores the potential of ethanol-biodiesel-diesel blended fuel as pilot fuel for biogas operated bi-fuel diesel engine. The oxygenated feature of ethanol and biodiesel improves the emission characteristics by drastically reducing the well-known trade-off of NO_x-smoke opacity from biogas bi- fuel diesel engine. The BTE was inferior with bi-fuel operation as compared to diesel at all engine load patterns whereas BSFC follows the opposite trend. The emission of unburned hydrocarbon is higher with biogas bi-fuel operation in relation with diesel. In spite of inferior performance characteristics, the trade-off of NOx and smoke was managed by utilizing biodiesel, ethanol and biogas as fuel, which is a remarkable accomplishment. Hence, the usage of oxygenated pilot fuel under biogas bi-fuel operation is a promising alternative fuel for diesel engine.

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