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Combined effect of compression ratio and diethyl ether (DEE) port injection on performance and emission characteristics of a DI diesel engine fueled with upgraded biogas (UBG)-biodiesel dual fuel

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ABSTRACT

In this present investigation, a single cylinder, four stroke, direct injection (DI) diesel engine was modified to operate on dual fuel mode with upgraded biogas (UBG)-Karanja methyl ester (KME). In dual fuel mode, diethyl ether (DEE) was injected as an ignition improver through the air intake manifold of the engine to initiate early combustion of biogas in the combustion chamber. During UBG-KME-DEE operation the compression ratio (CR) of the engine was varied from 16.5 to 18.5 in steps of 1. During investigation, the engine load was varied from 0% to 100% in steps of 25. The DEE injection quantity and the KME injection timing was kept constant at 6% (vol%) and 24.5 °CA bTDC (found to be optimum from previous study by the authors) respectively. The results indicated that UBG-KME-DEE operation with CR 18.5 gave optimum result than those of other CRs. For UBG-KME-DEE-CR18.5 the BTE increased and BSFC decreased by about 7% and 2.2% respectively, than that of KME. A reduction in the specific CO, specific HC, and smoke emissions of 42.2%, 39.5%, and 42.8% was observed for UBG-KME-DEE-CR18.5 in comparison to diesel at full load respectively. However, the specific NO emission for UBG-KME-DEE-CR18.5 was 7.6% higher than that of diesel, but it was 1.2% lower than that of KME, at full load.

1. Introduction

In the recent decades, denser volumes of harmful pollutant are being released to the atmosphere due to the excessive consumption of fossil fuels in automobiles, process industries, and power plants. The environmental degradation caused due to the consumption of fossil fuels can be declined by the use of biomass-based fuels. The renewable energy technologies have gained international recognition for research, development, and dissemination because of its environment and eco-friendly nature. However, due to the complexity of renewable energy extraction process, inadequate technology, and diminutive quantity production drags its growth. The replacement of fossil fuels by alternative renewable liquid and gaseous fuels in the transportation sector could be a significant contributor to the sustainable development. The application of biomass-based gaseous fuels in automotive and power sector is considered to be superior, in comparison with that of liquid biofuels, due to their easy mixing characteristics with intake air before combustion.

Gaseous fuels such as compressed natural gas (CNG), methane (CH_4), producer gas, furnace gas, pyrolysis gas, and biogas are emerged as potential alternative fuels and can be used in a diesel engine in dual fuel mode. The use of CNG in diesel and gasoline engine is extensive in the present decade [1]. However, the CNG reservoirs have decreased drastically in the past few years and may result crisis of CNG availability in future by 2030 [2,3]. Among gaseous fuels the use of biogas in the diesel engine offers certain advantage on waste to energy, waste minimization and waste to bio-fertilizer. Biogas is environmental friendly and can be produced from easily available waste by-products of biomass, by-products of agricultural industries, food processing industries, municipal solid waste and waste water [4–7]. Biogas is a carbon neutral fuel and it offers zero addition of greenhouse gas to the atmosphere. Biogas is a colorless gas, which is lighter than air. The concentration of CH_4 in biogas signifies its energy content. The main constituents in biogas are methane (CH_4), carbon dioxide (CO_2), traces of hydrogen sulfide (H_2S), and nitrogen (N_2) [8,9]. The presence of CO_2 in biogas decreases its combustion quality, when used in engines. The CO_2 from the biogas can be separated by purifying biogas in a scrubber. The purified biogas property is almost similar to CNG, and can be used in CNG operated vehicles without any modification to the engine. Also the purified biogas can be used for decentralized power generation

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applications. Biogas is a highly apposite fuel for SI engines, but it can be efficiently used in CI engines in dual fuel mode because of its very high antiknock property compared to diesel [10,11].

Biogas has a high auto ignition temperature because of its low cetane rating. Hence, for efficient utilization of biogas in diesel engines it is essential to increase the compression ratio of the engine. High compression ratios (CRs) in biogas fueled dual fuel diesel engines gives higher thermal efficiency [12–14]. The ignition delay in a biogas operated diesel engine can be minimized by using a fuel with a high cetane index. For this purpose diethyl ether (DEE) is a promising choice, because DEE is renewable in nature and can be produced easily from ethanol at acceptable price [15–18].

Research reports are available on the use of DEE in diesel engines operated in a dual fuel mode with biodiesel or diesel as pilot fuels, and compressed natural gas (CNG), liquefied petroleum gas (LPG), and biogas as primary fuels [14,15,18–20]. The DEE injection in the dual fuel engine gave a shorter ignition delay and shorter combustion duration [14,16,17,21]. The peak cylinder pressure and the heat release rate increased with the DEE injection [14,17,22]. The part load performance and the BTE of the engine were increased [11,16]. The HC, CO, and smoke emissions were decreased [16,23], but the NO emission was reportedly higher [14,24].

Edwin et al. [16] and Hariharan et al. [19] reported that the injection of DEE into the inlet manifold increases the latent heat of vaporization, and hence increases the heat release rate (HRR) and cylinder pressure. Kapilan et al. [25] reported that 5% DEE blend with diesel, improved engine efficiency significantly and minimized the emission of CO and HC drastically in comparison to diesel. Sivalaksmi and Balusamy [26] evaluated that 5–15% DEE addition in neat Neem biodiesel resulted in an increase in BTE and reduction in BSFC. Qi et al. [23] observed that 5% addition of DEE with soybean biodiesel-diesel blend significantly lowered the CO emission and improved BSFC. However, it was reported that very high quantity of DEE injection (more than 40%) leads to an abnormal increase in knock tendencies of the engine [14,16].

Apart from the use of DEE in a biogas-fueled dual fuel diesel engine, varying the compression ratio is also one of the important parameter that significantly affects a wide range of engine outputs like BTE, BSFC, ignition delay, rate of heat release, CO, HC, smoke, and NO_x emissions. Bora et al. [27] studied the influence of CRs of 18, 17, 17.5 and 16 on the performance and emission characteristics of a raw biogas-diesel run dual fuel diesel engine. The investigation indicated that CR of 18 gave a maximum BTE of about 20.04% and pilot fuel saving of 79.46%. For the same CR the CO and HC emission were lower by about 26.22% and 41.97%. However, there was an increase in NO_x as well as CO_2 emission by 66.65% and 27.18% respectively, when CR increased from 16 to 18. Another study carried out by Bora and Saha [28] on the effect of CR in a DI diesel engine run on rice bran biodiesel-biogas dual fuel. The investigation indicated superior engine performance parameters, when operated at CR of 18. A maximum 80% replacement in rice bran biodiesel and a maximum reduction in CO and HC emissions of about 17.67% and 17.18% obtained when the CR increased from 17 to 18. However, they also observed that for the same setting of CRs, NO_x as well as CO_2 emission increased by about 42.85% and 14.13%, respectively. Laguitton et al. [29] studied the effect of CR on emission characteristics of a Premixed Charge Compression Ignition (PCCI) diesel engine. They reported that reducing the CR the NO_x and soot emission could significantly reduce with a small penalty in increased HC and CO emission.

Tangoz et al. [30] studied the effects of CR on performance and emissions characteristics of a diesel engine fueled with blends hydrogen enriched compression natural gas (HCNG). The experimental investigation carried out for CRs of 9.6, 12.5 and 15. The results indicate that highest brake torque and lowest BSFC values were obtained at CR of 12.5 for all blends. At CR of 15 the in cylinder pressure and the rate of heat release (ROHR) values became close to TDC. Fu et al. [31] experimentally investigated the effects of CR on in-cylinder combustion process and the performance of liquefied methane fueled six-cylinder diesel engine. The results showed that, with the rise of CR, ignition delay period reduced and SOC advanced. Also, the BSFC reduced by a maximum of 10.9% at CR of 15.6. The NO_x emissions increased with increase in CR and the engine smoothly operated at CR of 15.6 without knocking. Hosmath et al. [32] examined the effect of compression ratio on the performance, emission and combustion characteristics of a diesel engine operated on dual fuel mode with CNG and Honge oil methyl ester. Their investigation indicated that CR of 17.5 helped to improve the BTE and reduced smoke, CO, and HC. The ignition delay and combustion duration decreased for CR 17.5, but the peak pressure and HRR increased.

In the present investigation raw biogas (RBG) was purified to remove the dissolved CO_2 and H_2S, by using a vertical two stage scrubber. Because, CO_2 is a combustion arrester and H_2S is corrosive to metal. Further, the UBG extracted from the scrubber was used as fuel in a DI diesel engine on dual fuel mode. During experiment an attempt was also made to study the effect of CR on the combustion performance and emission characteristics of the engine modified to operate on UBG-KME dual fuel. In dual fuel mode 6% DEE was injected through the intake manifold to improve the ignition of UBG. The combined effect of fuel and engine modification at different CRs of 16.5, 17.5, and 18.5 has been analyzed carefully, and the optimum CR was identified. The combustion, performance and emission characteristics of the modified dual fuel engine were analyzed and compared with those of diesel and presented in this paper.

2. Materials and method

2.1. Fuels used

The fuels used in the present investigation are diesel, Karanja methyl ester (KME), biogas and diethyl ether (DEE). A complete description of the production methods of KME and biogas have already been documented by the authors [6,7,14,33]. The DEE was collected from fuel and chemical supplier located near to National Institute of Technology (NIT), Rourkela campus. The important physical and chemical properties of diesel, KME, and DEE are given in Table 1. In the present investigation, biogas was produced from the mixed inoculum of Karanja de-oiled seed cake (SCK) and cattle dung (CD) mixture (25%:75%). A non-dispersive infrared biogas analyzer was used to measure the gas constituents in biogas. The main drawbacks in the composition of biogas were the presence of carbon dioxide (CO_2) and hydrogen sulphide (H_2S), which affect the long life of storage devices.

It was observed that, the raw biogas contained about 17.3% CO_2 and 0.23% of H_2S. In nature, CO_2 is a combustion arrester, and H_2S is corrosive to metal. Hence, for a long-term use of biogas in diesel engine, it is essential to remove the CO_2 and H_2S. So, the raw biogas was purified using a vertical packed bed two-stage scrubber.

Table 1
Properties of diesel, KME and DEE.

Properties	Test method, ASTM	Diesel	KME	DEE
Density, kg/m^3	D 4052	830	880	713
Calorific value, MJ/kg	D 4809	43.8	40.96	33.90
Auto-ignition temperature, °C	E 659	210–350	170–320	150–160
Flash point, °C	D 93	50	230	-40
Fire point, °C	D 93	56	258	44
Cetane number	D 613	50	57.6	125
Oxygen, wt.%	E 385	Nil	24.01	28.2