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Performance and Emission Analysis of Bioethanol Diethyl Ether Fuelled Compression Ignition Diesel Engines

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ABSTRACT:

Experimental investigations were carried out in a single cylinder, four stroke, air cooled direct injection (DI) diesel engine, fuelled with bioethanol diethyl ether blend, adopting the fumigation technique. Bioethanol produced by the fermentation of cooked rice blended with 25%, 50% and 75% of diethyl ether was used as an alternative fuel in this investigation. With the help of a fuel vaporiser and a microprocessor controlled injector, bioethanol was fumigated at 0.20, 0.40, 0.60 and 1.2 kg/h flow rate in the suction. The results of the combustion, performance and emissions of the engine, running with the bioethanol fumigation, were compared with those from the diesel fuelled operation. The results indicated that, at full load, the bioethanol fumigation exhibited an overall longer ignition delay of 2–3 CA for all the flow rates in comparison with diesel. Bioethanol fumigation at the flow rate of 0.48 kg/h gave a better performance and lower emissions than that of other flow rates. The maximum brake specific nitric oxide and smoke emissions were found to be lower, by about 24.2% and 25% in the bioethanol fumigation, compared to that of diesel operation at full load.

KEYWORDS:

Rubber; Bioethanol; Homogeneous charge; Combustion; Emissions; Performance

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1. Introduction

Internal combustion (IC) engines continue to dominate many fields like transportation, agriculture and power generation. Though diesel engines offer advantages of high thermal efficiency they exhibit problems of high nitrogen oxides and smoke emissions[8]. Simultaneous control of these emissions continues to be a challenge[9]. Thus there is a need to find suitable alternatives to conventional hydrocarbon (HC) fuels and combustion techniques, which can reduce pollution levels, especially for compression ignition engines. Promising alternative fuels for IC engines are natural gas, liquefied petroleum gas, hydrogen, biogas, alcohols and vegetable oils[10]. Even very lean mixture of these fuels can be burned in air and in addition they have low hydrogen to carbon ratio[2]. Thus very low emissions are possible when they are used in IC engines. One of the major alternative sources especially for transport sector is ethanol which is produced in large quantities in some of the developing countries.

Commercially two manufacturing methods of ethanol are available, namely natural and synthetic. The natural method involves the fermentation of carbohydrates i.e., sugarcane molasses at controlled temperature by addition of selected yeasts[4]. The ethanol produced by this natural method is simply referred as Bioethanol. The synthetic method generally involves the hydration of ethylene to ethanol. If bioethanol is used as an alternative to diesel the cetane rating needs to be improved with additives to initiate combustion[6]. Since major power plant used in the transport sector is diesel engine, large quantities of diesel can be saved by operating the engine on bioethanol, as there is already shortage of diesel. One of the major challenges of diesel engine development is simultaneous reduction of nitrogen oxides (NOx) and particulate emissions[8]. In order to overcome these problems investigations are in progress for new combustion process namely Homogeneous Charge Compression Ignition (HCCI) to achieve lower NOx and particulate emissions[8] [5] [6]. A wide range of alternative fuels can be used in diesel engines using HCCI concept. In the HCCI engine premixed charge of fuel and air is compressed and allowed to self ignite[8]. This has advantages in terms of NOx and smoke emissions in comparison to diesel engines. In order to broaden the HCCI operating range of these high octane fuels an ignition promoter such as diethyl ether (DEE) can be added to the fuels[5]. Amongst other things to control ignition timing, the motivation for using fuel blends is to lengthen combustion duration and to lower the intake temperature, thereby expanding the operating window[9].

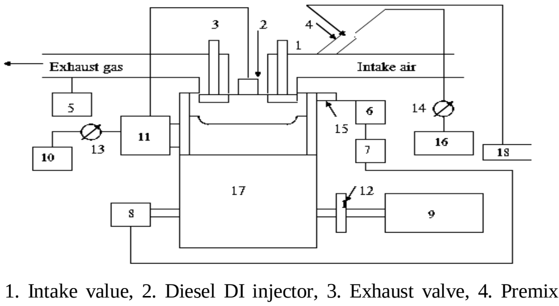
In this work, a single cylinder, direct injection (DI), air cooled, diesel engine was modified to work in the HCCI mode with Bioethanol-DEE blend as the inducted primary fuel and diesel as the secondary injected fuel for ignition[9]. An electronically controlled inlet port injection system was employed to inject bioethanol-DEE in to the intake port. This system includes a sensing arrangement for detecting the intake valve opening, and control circuits to inject the correct quantity of fuel blends during the intake stroke. Tests were conducted with an electronically controlled bioethanol injection system and the results were compared with base line diesel fuel.

2. Experimental setup and procedure

A single cylinder, four stroke, air cooled, DI diesel engine developing 4.4 kW at 1500 rev/min, was modified for port injected HCCI operation. The technical data of the engine specifications are given in Table 1. The schematic of the experimental set-up is shown in Fig. 1. An orifice meter was used to measure air consumption of the engine with the help of U tube manometer. The time taken for a fixed quantity of fuel consumed by the diesel engine is indicated on the panel, measured with the help of stopwatch. Chromel alumel thermocouple in conjunction with digital temperature indicator was used for measuring the exhaust gas temperature. The surge tank fixed on the inlet side of the engine maintains a constant airflow through orifice meter. A water-cooled piezoelectric pressure transducer is used for cylinder pressure measurement. By coupling the surface mounted pressure transducer to a charge amplifier, a voltage signal supplied to the cylinder pressure was obtained. From the charge amplifier, the output signal transferred to DL750 Scope reader and then it was transferred to the computer to analyse the data to obtain the pressure-crank angle and heat release rate diagrams. For the measurement of cylinder pressure with respect to the position of the crank, a magnetic pickup was used. The pickup generates a signal to locate the TDC point. A mild steel projection was fixed on the flywheel and whenever this comes closer to the pickup, it produced voltage reading that located at TDC.

Table 1: Engine specifications

Parameters	Specifications
Rated power	4.4 kW at 1500 rpm
Bore	87.5 mm
Stroke	110 mm
Injection timing	23 deg bTDC
Injection pressure	200 bar
Compression ratio	17.5:1
Method of cooling	Air cooled



1. Intake value, 2. Diesel DI injector, 3. Exhaust valve, 4. Premixed fuel injector, 5. Exhaust gas analyser, 6. Charge amplifier, 7. Data acquisition, 8. Crank angle encoder, 9. Dynamometer, 10. Diesel fuel tank, 11. Fuel injection pump, 12. Flywheel, 13. Flow meter for Diesel HCCI mode, 14. Bioethanol fuel control valve, 15. Pressure sensor, 16. Bioethanol-DEE blend fuel tank, 17. Engine, 18. Electronic control circuit (ECU)

Fig. 1: Experimental setup

Exhaust emissions such as HC, CO, NOx from the engine are measured with the help of QROTECH, QEO-402 gas analyzer. The specification is given in Table 2. This analyzer is configured to perform a measurement by applying Non Dispersive Infra Red (NDIR) method for analyzing CO and HC and electrochemical method for analyzing NOx. In the NDIR analysing method, a flashing lamp which flashes the infrared rays is attached at one end of the sample cell and at the other end a detecting sensor is attached so that it can detect the component of a gas and then calculate the gas density. The electrochemical method measures the gas density by using the quantity of oxidation and reducing reaction of the gas. HC and NOx are measured in ppm and CO in % by volume. Smoke intensity is measured with help of Bosch smoke meter whose specifications are given in Table 2. Bosch smoke meter usually consists piston type sampling pump as a smoke level measuring unit. A filter paper of diameter 50mm was used to collect smoke samples from engine, through smoke sampling pump for measuring Bosch Smoke Number (BSN).

Table 2: Bosch smoke meter specifications

Parameters	Specifications
Measuring item	CO, HC, CO_2, O_2, λ, AFR, NOx
Measuring method	CO, HC, CO_2-NDIR method
Repeatability	Less than ± 2 %
Response time	Within 10 seconds
Measuring range & resolution	CO- 0.00 to 9.95 % & 0.01 % HC- 0 to 9999 ppm & 1 % CO_2 - 0.0 to 20.0 % & 0.1 % AFR-0.0 to 99 & 0.1 λ - 0 to 2 & 0.001 O_2 - 0.0 to 25 % &0.01 %
Sample collecting quantity	4 - 6 L / min
Warming up time	About 2 - 8 minutes
Power consumption	About 50 W
Smoke	BSN 0-10

3. Injection of bioethanol blends

A premixed port fuel injector was mounted in the intake system to prepare the homogeneous bioethanol blend-air mixture[7]. The engine was started with diesel and after starting, the ECU is connected to battery to give voltage to port fuel injector to inject the bioethanol blend fuels. The quantity injected by the port fuel injector is collected in burette. The tests were carried out up to 5 minutes. The measured quantity indicates the consumption of bioethanol blend. The Bioethanol blend was supplied into the engine intake port through port fuel injector as shown in Fig. 2. The diesel flow rate was reduced by increasing bioethanol blend flow by the adjusting injection controller in ECU, until the engine reaches the rated speed of 1500 rpm[2]. After the steady state conditions were reached, fuel consumption, exhaust gas temperature, cylinder pressure trace, particulate strapped, NOx, CO, unburnt HC and smoke were recorded by running the engine at a constant speed at different loads. After the measurements, bioethanol blend supply was decreased by disconnecting the ECU from the battery and consumption of diesel flow was increased, so that the rated speed of 1500 rpm is reached. The engine was allowed to run for at least 5 minutes at no load condition. The measured engine parameters are properly timed and controlled by ECU.

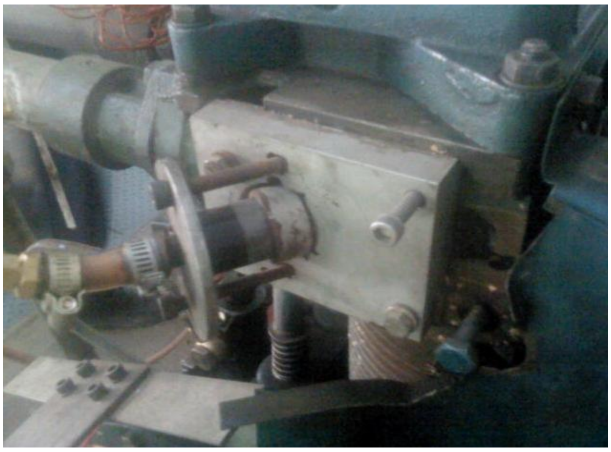


Fig. 2: Photograph showing port fuel injector

4. Results and discussions

The results obtained from the experimental investigations of bioethanol-DEE combustion are discussed in this chapter. The experimental investigation includes the study of performance, combustion and emission characteristics of ethanol-DEE. The results were compared with baseline diesel. The variation of brake thermal efficiency with brake power for various flow rates of bioethanol-DEE is shown in Fig. 3. It can be seen that at 75% of full load, the brake thermal efficiency was found to be 28% for diesel, 30% for 0.4 kg/h, 32% for 0.6 kg/h and 35.6% for 0.8 kg/h flow rates of bioethanol-DEE operation. The increase in brake thermal efficiency was due to better vaporisation, homogeneous mixture of the port injected bioethanol-DEE blended fuel, which ignites automatically by the early combustion of DEE[3].

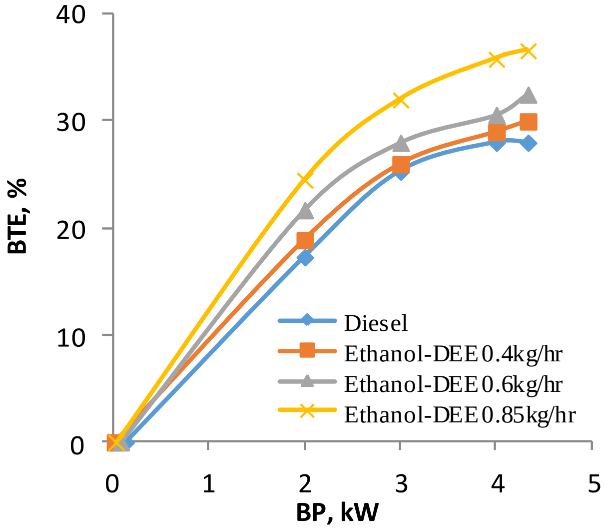


Fig. 3: Brake thermal efficiency vs. Brake power

The variation of unburned HC emissions with brake power is shown in Fig. 4. The unburned HC emissions vary from 20 ppm at low load to 48 ppm at full load for baseline diesel operation[5]. For bioethanol-DEE operation at full load the HC emissions varies from 66 ppm at 0.4 kg/h, 70 ppm at 0.6 kg/h and 73 ppm at 0.8 kg/h flow rates. The increase in HC emissions at full load is due to the premixed charge occupying the crevice volumes where flame will not able to propagate[5]. The other factor is due to the lower temperature inside the combustion chamber[1]. The gas layer near the cylinder wall region may contain a larger concentration of HC, which is left unburnt due to wall quenching effect of ethanol which results in higher HC emissions[8]. Fig. 5 shows that the variation of CO emissions with load exhibits similar trend as that of HC emissions. The CO emissions from bioethanol-DEE fuelled engine were higher at full load, when compared to the baseline diesel operation[3]. The concentration of CO emissions varies from 0.032 % at 0.4 kg/h, 0.04 % at 0.6 kg/h and 0.045 % at 0.8 kg/h of bioethanol-DEE operation at full load compared to 0.02 % for baseline diesel operation. The increase in CO emissions at full load in bioethanol-DEE operation is due to the premixed mixture in the cylinder is very lean and hence the flame will not able to propagate[8].

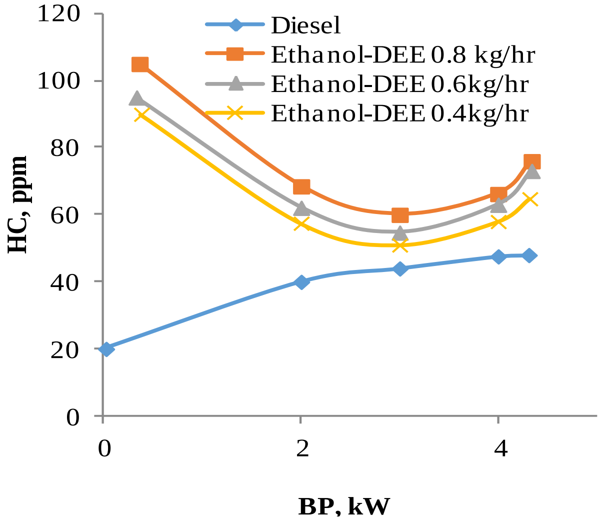


Fig. 4: HC Emission vs. Brake power

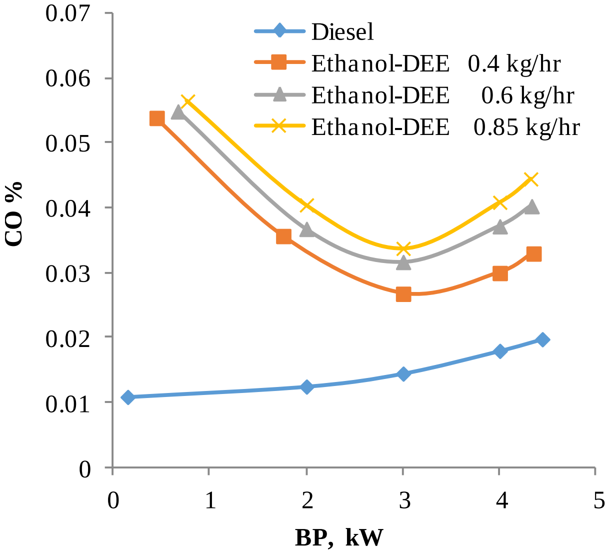


Fig. 5: CO Emission vs. Brake power

It can be observed from Fig. 6 that NOx emission is 2050 ppm at full load with neat diesel fuel operation. Bioethanol-DEE operation results in lower level of NOx emissions compared to diesel, ranging from 1900 ppm at

0.4 kg/h, 1800 ppm at 0.6 kg/h and 1610 ppm at 0.8 kg/h flow rates at full load. The reduction in NOx emission when operated on bioethanol is about 24% to 30% at different loads, compared to diesel operation. The increased vaporisation of ethanol results in lower combustion temperature which is associated to the reduction of NOx emission[3] [6] [8]. The largest attraction of the HCCI combustion is its potential to significant reduction in NOx emissions[8]. Generally, smoke is nothing but solid soot particles suspended in gaseous exhaust gases. The variation of smoke level with brake power is shown in Fig. 7. The smoke intensity is found to be lower at all loads for bioethanol-DEE operation compared to diesel. For diesel operation, it varies from 1.2 BSN at no load to 3.8 BSU at full load whereas for bioethanol-DEE, it varies from 0.8 BSU at no load to 2.4 BSN at full load for the flow rate of 0.8 kg/h. This is due to low carbon/hydrogen ratio which makes the engine clean and free from the formation of soot[1].

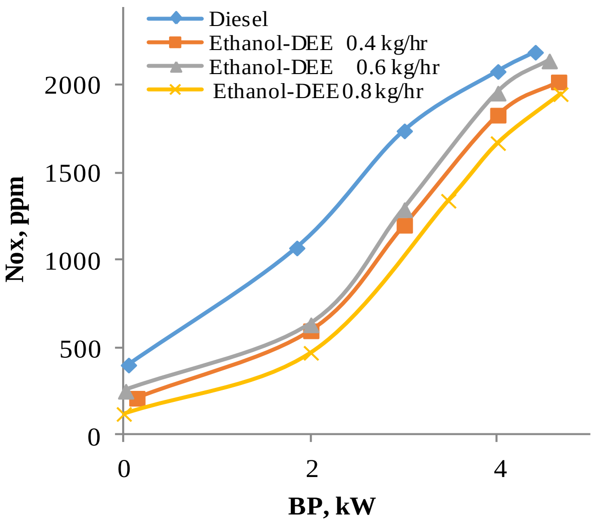


Fig. 6: NOx Emission vs. Brake power

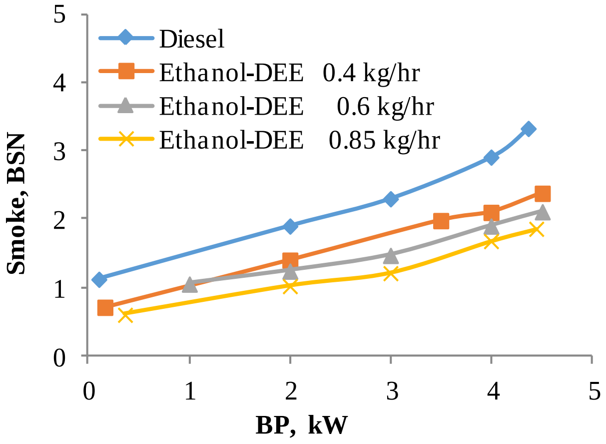


Fig. 7: Bosch Smoke Number vs. Brake power

The variation of exhaust gas temperature with load is shown in Fig. 8. The exhaust gas temperature varies from 450°C at 0.4 kg/h, 470°C at 0.6 kg/h and 480°C at 0.8 kg/h of bioethanol-DEE flow rate compared to 500°C for diesel at full load. It can be observed that the difference between diesel and bioethanol-DEE operation at low loads is less than 10% due to lower charge temperature. The reduction in exhaust gas temperature is due to the reason that ethanol has a higher latent heat of vaporisation which reduces the temperature[6]. The variation of heat release rate with load for bioethanol-DEE operation is shown in Fig. 9. For the case of diesel operation, premixed, diffusion and late combustion phases were observed[2]. In the case of bioethanol-DEE operation, two peaks can be seen. The appearance of larger peak corresponds to the main combustion. The smaller peak that appears like a bump corresponds to a pre-flame reaction before the start of main combustion. The maximum heat release rate of 82 J/°CA at 0.8 kg/h for bioethanol-DEE flow rate was obtained during high temperature region whereas for diesel operation it was 75 J/°CA. The increase in heat release rate was due to the longer ignition delay of bioethanol-DEE[2] [6] [8].

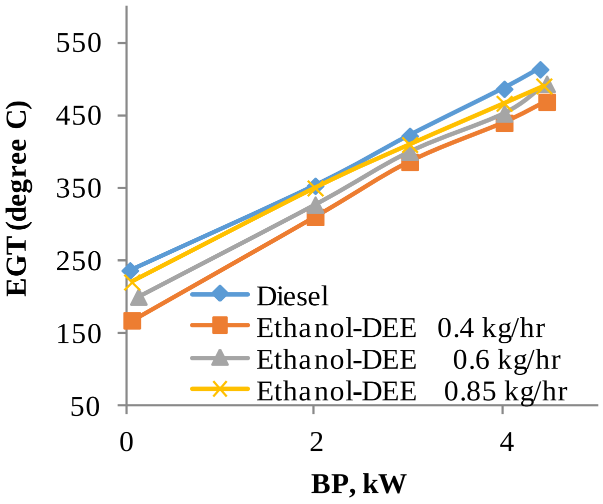


Fig. 8: Exhaust gas temperature vs. Brake power

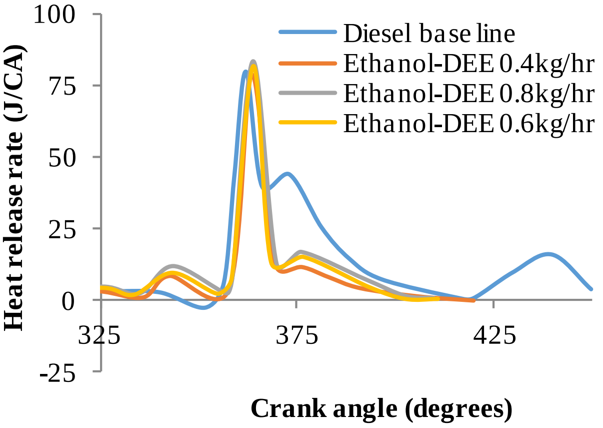


Fig. 9: Heat release rate vs. Crank angle

The variation of cylinder pressure with crank angle is shown in Fig. 10. At full load the peak pressure is about 72 bar in baseline diesel operation and with bioethanol-DEE operation it varies from 75 bar at 0.4 kg/h, 77 bar at 0.6 kg/h and 80 bar at 0.8 kg/h of bioethanol-DEE flow rate. The maximum percentage increase in peak pressure is 8% at 0.8 kg/h flow rate. The ignition delay for bioethanol-DEE operation is advanced by 6° for 0.4 kg/h, 7° for 0.6 kg/h and 8° for 0.8 kg/h of bioethanol-DEE flow rates. The increase in peak pressure in bioethanol-DEE operation is due the longer ignition delay compared to diesel operation[1] [3] [5].

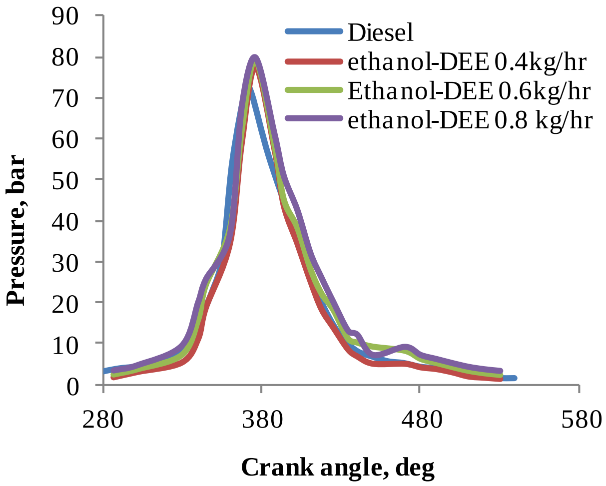


Fig. 10: Cylinder pressure vs. Crank angle

5. Conclusions

The experimental investigations carried out indicate that it is possible to operate HCCI engine smoothly over the entire range of load with bioethanol-DEE blended fuel with certain modifications depending upon the technique. Brake thermal efficiency of bioethanol-DEE fuelled engine is higher than that diesel due to better combustion of bioethanol in the hotter environment created by the early ignition of DEE. Ignition delay of bioethanol-DEE fuelled engine is longer than the diesel which may be due to higher latent of vaporisation of ethanol. CO and HC emissions are more in bioethanol-DEE fuel blend use than diesel operation. NOx emissions are less for bioethanol-DEE than diesel as a result of higher vaporisation and reduction in cylinder temperature. Smoke is lesser for ethanol-DEE compared to diesel due to soot free combustion.

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