Effect of D–DEE–E Blend and Various Operating Parameters on CI Engine Performance: An Experimental Study

Chandan Kumar, K. B. Rana, Mohd. Suhaib Ansari, and Raju Malani

1 Introduction

All over the world, air pollution has become a big threat for the future of the next generation and as such researchers are working relentlessly to find an alternative clean fuel in other green fuel recourses for running CI (compression ignition) engines. India was placed 141 out of 180 nations in the 2016 environmental performance index (EPI). In 2018, India got 9th rank on most polluted (included both air and water pollution) countries in the world [1]. In India, 70% of air pollution comes from automobiles. The automobiles on the road have crossed over 3.7 million, and every year, they are increasing with an average rate of 8% [2]. These vehicles release toxic gases such as carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbon (HC), and others, which create an unhealthy environment. The California Air Quality Board concluded that the small particle from the emission of the diesel engine caused the highest lung cancer. The Asthma and Allergy Foundation of America reported that the main cause of asthma is smoke. But society is very much dependent on these vehicles and cannot eliminate the entire vehicle from society. To overcome the harmful gases from the vehicle, the government of India released the vehicle of BS–IV emission standard in the country on 1 April 2017. Now, the government wants to introduce a BS–VI vehicle by April 1, 2020, escaping the BS–V so that less pollution is generated by the vehicle [3].

Worldwide, the use of diesel engines is increasing compared to SI engines due to their advantageous features. According to the CSO's report, India's economic growth in the year 2018–19 was 7.2%, which was more than 0.5% from the year 2017–18

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[3]. Economic growth increases fuel and gas energy consumption. Improvements to the engine's performance and emissions characteristics can have a significant impact on the economy and human health. Diesel engines are very popular for their high efficiency and lower fuel consumption. But they produce high particulate matter (PM), NOx, CO, smoke, and HC with conventional diesel fuel. Changing numerous engine settings such as injection pressure (IP), compression ratio (CR), and injection timing (IT) can improve engine performance and exhaust emission characteristics [4, 5]. Changing the engine design is difficult and expensive, so it should be appropriate to change some operating parameters. The diesel engine emits more NOx compared to spark ignition (gasoline engine) [6]. The NOx is responsible for acidic rain and photochemical smog. The percentage of NOx produced by a CI engine grows as the pressure and temperature in the combustion chamber rise [7].

The simplest way to remove this problem is fuel additives. The fuel additive is the chemical compounds added with major fuel (pure diesel) in the engine to improve the quality and performance of the vehicle. Oxygenated additives have the potential to improve the combustion process inside the combustion chamber [8]. Oxygenated fuels are a sustainable source of energy, and their oxygen atoms improve the combustion process. Both alcohol and ether have higher densities than diesel, resulting in a more homogenous mixture, as well as a higher oxygen concentration (in their molecular structure) and lower viscosity, making them acceptable for CI engines [9].

The current goal of the research is to better understand the performance characteristics and exhaust emissions of a direct injection diesel engine with a variable compression ratio (VCR) at various CR and IP for a blend of diesel, ethanol, and diethyl ether. The work is carried out at 80% diesel, 10% ethanol, and 10% diethyl ether blend (as suggested by the literature). For this purpose, experiment was performed on direct injection VCR diesel engine without changes of engine design. The findings are also compared to the performance parameters of ternary fuel (diesel–diethyl ether–ethanol) blend with the pure diesel.

By reviewing the various research publications, it was found that there is a need to investigate diesel, diethyl ether, and ethanol blend (D80–DEE10–E10) results at different CR and IP [10].

Diethyl ether is having a high oxygen content, lower auto-ignition temperature, better cetane number (CN), and elevated volatility. It is a very effective fuel in a sub-zero temperature zone for starting the engine in a cold climate. One of the exceptional properties of the DEE is that it burns smoothly in the rich fuel region inside the combustion chamber.

- A high volume of diethyl ether with diesel promotes knocking in the engine [11]
- Smoke, NOx, and PM can reduce by adding DEE with diesel in the CI engine [12]
- BTE enhanced by 7.2% and BSFC reduced by 6.7% when diesel engines were fed with DEE with diesel [13]
- HC and CO can be minimized by DEE and diesel blend.

Ethanol is a good fuel additive among all alcohols for CI engines. It can be obtained from various sources, like sugarcane, sugar beets, corn, and waste biomass materials. Because of its good physicochemical features, such as low flash point, low boiling point, and high oxygen content, ethanol is a good alternative biofuels for CI engines. It is also a safe additive because of its low flashpoint. Ethanol gives us better and complete combustion compare to diesel.

- Ethanol can reduce the PM and NOx of the exhaust emission [14]
- Dissolving ethanol in diesel can reduce the emissions of the vehicle
- The amount of ethanol increased the HC and CO from the engine's emission [15]
- BTE and BSFC both increase with the amount of ethanol [16]
- 10% vol. ethanol addition with diesel did not require any modification and stabilizer in the engine [17].

Several research on the effects of DEE and ethanol on a direct injection diesel engine was conducted. Iranmanesh et al. [18] investigated the possibility of DEE as an additive for improving CI engine combustion characteristics and lowering exhaust emissions. The experiments revealed that BSFC and BTE have improved slightly. The impact of DEE on the exhaust emissions and performance of a four-stroke CI engine was investigated by Mohanan et al. [19]. The most effective emission and performance metrics were found to be a blend of 5% DEE with diesel. Patil et al. [20] experimented on a four-stroke, single-cylinder, direct injection, compression ignition engine, with the results revealing low efficiency and high BSFC at full load conditions. Using a compression ignition engine, Huang et al. [21] investigated the potential of ethanol. At various ethanol blending ratios, fuel consumption increased by 5–31%. HC and CO levels drop during peak loads, while NOx levels drop during low loads. Li et al. [22] looked into the exhaust emissions and performance characteristics of a diesel–ethanol blend fueled in CI engine. The BTE and BSFC increased with the addition of ethanol to the blend. According to their findings with the ethanol–diesel blend, the smoke was reduced by 10% to 15%. In the ethanol–diesel blend, NOx and CO were reduced by 10% and 15%, respectively. Paul et al. [23] concluded that ethanol is not miscible beyond the 10% in diesel, but up to 10% there is no problem of miscibility with ethanol in diesel. Rakopoulos et al. [24] studied the exhaust emission and performance parameters of diesel engines using a diesel–DEE blend. The high proportion of DEE in the blending greatly lowered smoke and NOx emissions. With a larger percentage of DEE in the blend, the number of unburned HC particles rose. The effect of combining ethanol and DEE on the exhaust emission and performance parameters of a CI engine was studied by Paul et al. [10]. The optimum fuel blend was found to be 80% diesel, 10% DEE, and 10% ethanol out of all the blends tested. Because of their better qualities and combustion characteristics, D80–DEE10–E10 blends were utilized at fixed concentrations in this investigation. The engine performance and emission characteristics of the D80–DEE10–E10 blend were examined on a non-road, stationary variable compression ratio, compression ignition engine at different engine operating parameters such as injection pressure and compression ratios, which had not been documented in any research study in the accessible literature.

Table 1 Comparison of various properties [9]

Properties	Diesel	DEE	Ethanol
Molecular formula	$C_{12}H_{23}$	$C_4H_{10}O$	C_2H_5OH
Calorific value (kJ/kg)	44,000	33,900	26,950
Density (kg/m^3)	829	713	792
Viscosity (cST)	2.45	1.20	1.04
Cetane number	52	125	07
Late heat (kJ/kg)	250	350	840
Oxygen content (%)	0	22	34
Self-ign. temp. (°C)	250	380	420

2 Experimental Setup and Methodology

2.1 Preparation of Fuel Blend

The experiments started with the creation of a blend. On a volume basis, a single mixture of diesel, diethyl ether, and ethanol was made (D80, DEE10, and D10). The blend was prepared on a magnetic stirrer with a heating plate. Table 1 summarizes the various physical and combustion characteristics value of pure diesel, DEE, and ethanol.

First, pure diesel (80%) was taken according to the mixing ratio in a glass jar. After that, the DEE (10%) and ethanol (10%) were mixed according to the blend ratio. DEE and ethanol were blended with pure diesel drop by drop. Blend stabilization was checked before experimenting. The blend was kept for 72 h.

2.2 Engine Set up

This experiment was conducted with a 4-s single-cylinder, variable compression ratio compression ignition engine that was water-cooled. With the use of a lever arrangement located on the head (engine top) of the engine, the compression ratio of the engine can be altered by altering the cylinder head position. The injection nozzle is fitted with a calibrated protector, which allows the nozzle pressure to be adjusted. The engine arrangement is depicted in Fig. 1.

Various sensors were fitted to the engine in order to calculate the temperature of various parts of the engine. An eddy current dynamometer, control panel, personal computer, gas analyzer, and smoke meter are also attached to the engine. Table 2 lists the specifications for each piece of equipment.

(a)

(b)

Fig. 1 **a** Engine configuration in pictorial form and **b** pictorial view of a control panel

2.3 Test Conditions and Procedure

At a constant speed of 1500 rpm, the experiments were carried out. The load had been varied as 0%, 25, 50, 75%, and 100%. The load calculation had done by the eddy current dynamometer. The experiment was started with ignition switches for

Table 2 Equipment specifications

Equipment	Specification
Engine	TVI Kriloskar, 3750 W, 1500 rpm
Dynamometer	Power 3750 W, eddy current, 1500 rpm, air-cooled
Exhaust gas analyzer	AVL Modal—444 N
Smoke meter	AVL Modal—437C

this battery was connected with their terminals. All the water connections should be open for the cooling of the engine. Check the leak in the gas analyzer also. Adjust the dimmer status on the control panel to gradually vary the load on the engine. The strain gauge load cell measures the engine's applied load. Performance and emission data for various load conditions of the engine were monitored and recorded after 20–25 min.

3 Results and Discussion

3.1 D–DEE–E Blend Performance and Emissions Characteristics

The BTE of the engine for the ternary blend (D80–DEE10–E10) concerning engine load is depicted in Fig. 2. The maximum efficiency of 45% was obtained at full load with 19.5 CR. By changing the IP of the engine, maximum efficiency of 43.4% was obtained at the 210 bar at full load condition as shown in Fig. 3 [25]. If the BTE of the ternary blend is compared with the pure diesel, then the ternary fuels have higher efficiencies at almost all higher compressor ratios and injection pressure.

Break specific fuel consumption has been shown in Fig. 4 concerning load at different CR. The figure indicates that BSFC decreases in almost all cases. The

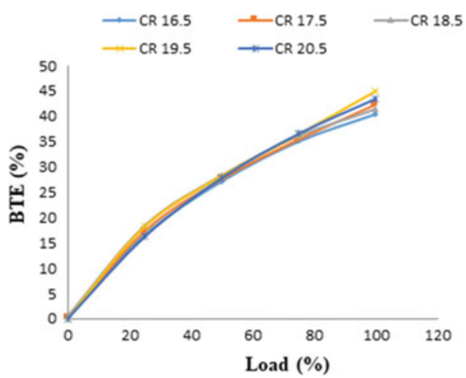


Fig. 2 BTE versus load at different CR

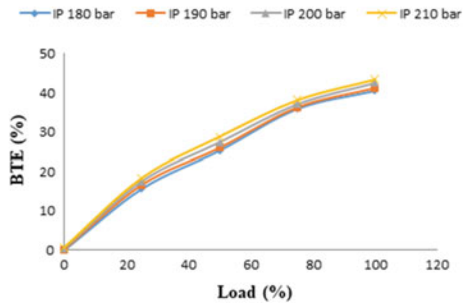


Fig. 3 BTE versus load at different IP

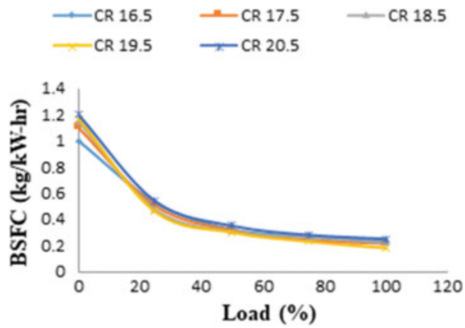


Fig. 4 BSFC versus load at different CR

lowest BSFC 0.18 kg/kW–h at 19.5 CR was obtained under full load conditions. Generally, BSFC decreases with the rise in the CR because of smooth combustion in the combustion chamber [26].

Figure 5 illustrates the effect of IP on BSFC. BSFC improved with higher applied load and injection pressure. At the IP of 210 bar, the ternary blend provides the minimum BSFC that of 0.2 kg/kW-hr.

Figure 6 shows the NOx characteristics concerning the applied load at different CR. The quantity of NOx increased when the load was applied and CR was higher on the engine. The value of NOx decreased when the injection pressure of the fuel is higher as discussed in Fig. 7.

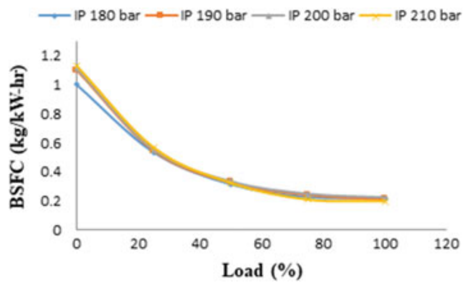


Fig. 5 BSFC versus load at different IP

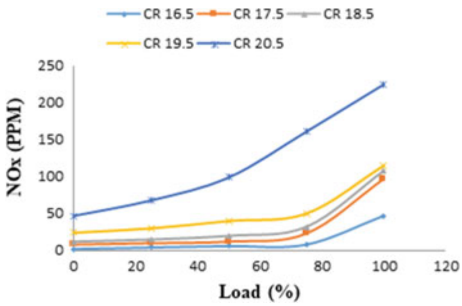


Fig. 6 NOx versus load at different CR

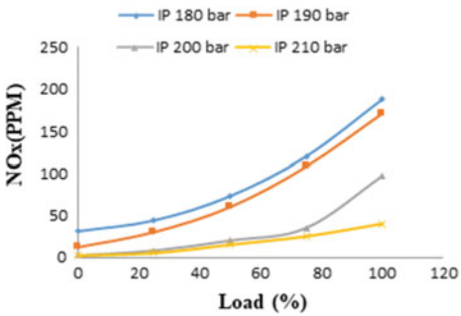


Fig. 7 NOx versus load at different IP

From the above, conclusion is that by reducing the CR and increasing IP in the engine the quantities of NOx reduce significantly at low load conditions [27].

Figure 8 depicts the variance of smoke (HSU) in different CRs with respect to the different applied load. Smoke in HSU decreased when the applied CR is higher. The lowest smoke was obtained at 19.5 CR.

Smoke in HSU (Hartridge Smoke Units) concerning load at different injection pressure has been shown in Fig. 9. Smoke reduces with higher injection pressure. The lowest smoke was obtained at the 210 bar.

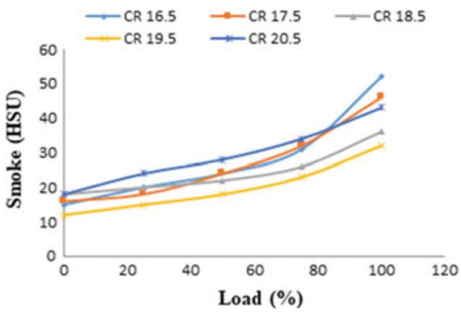
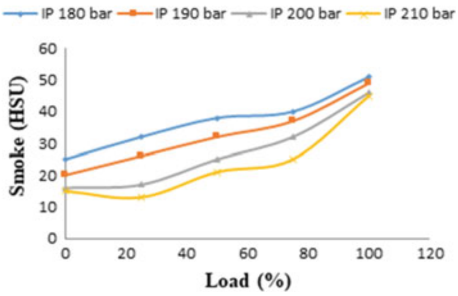


Fig. 8 Smoke versus load at different CR

Fig. 9 Smoke versus load at different IP



4 Conclusions

The exhaust emission and performance parameters of the variable compression ratio compression ignition engine with a ternary fuel blend (D80–DEE10–E10) were studied at various CR and IP. The following conclusions can be drawn based on the obtained results and analysis:

The BTE of the blended fuel (D80–DEE10–E10) has been obtained higher than pure diesel. The enhancement in BTE was obtained 4.4% with the blend at 19.5 CR and 200 bar IP as compared to pure diesel (with standard engine parameters) at peak load. Similarly, at 210 bar IP and 17.5 CR, the efficiency of the blend was obtained 2.5% elevated than the pure diesel fuel at peak load.

With an increase in CR, IP, and load, the blended fuel's BSFC was shown to be lower than pure diesel fuel. At a compression ratio of 19.5 and a normal injection pressure of the engine with blended diesel, the lowest BSFC of 0.18 kg/kW-h was obtained.

Oxides of nitrogen for pure diesel were obtained higher than the blended fuel. NOx increases with the higher CR but decreases with higher IP. The lowest NOx of 40 PPM was obtained with 210 bar and 17.5 CR (at peak load condition), which was low (212 PPM) as a comparison to the diesel for the same condition.

Smoke amount of diesel-blended fuel was lower in comparison to the pure diesel with higher IP and CR. The lowest smoke was obtained at 19.5 CR and normal IP with the blended fuel. From the result, it was observed that the engine at 19.5 CR and 210 IP gives the best results for BTE, BSFC, NOx, and smoke.

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