THE EFFECT OF SUPERCHARGING ON PERFORMANCE AND EMISSION CHARACTERISTICS OF COMPRESION IGNITION ENGINE WITH DIESEL-ETHANOL-ESTER BLENDS

by

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Biofuels like ethanol, biodiesel, have attracted attention of people worldwide and proved to be the successful fuel alternates to petroleum products. In the present investigation, the effect of supercharging is studied on the performance of a direct injection Diesel engine using ethanol diesel blends with palm stearin methyl ester as additive. The performance of the engine is evaluated in terms of brake specific fuel consumption, thermal efficiency, exhaust gas temperature, unburned hydrocarbons, carbon monoxide, nitrogen oxide emissions, and smoke opacity. The investigation results showed that the output and torque performance of the engine with supercharging was improved in comparison with naturally aspirated engine. It is observed that the brake thermal efficiency of ethanol diesel blends was higher than that of diesel. With supercharging brake thermal efficiency is further improved. Brake specific fuel consumption of ethanol, ester, and diesel blends are lower compared with diesel at full load. Further reduction in brake specific fuel consumption is observed with supercharging. Nitrous oxide formation seems to decrease with ethanol, ester, and diesel blends. Hydrocarbons and carbon monoxide emissions are more with ethanol, ester, and diesel blends with supercharging slight reduction in those values are observed.

Key words: *biofuels, ethanol-diesel blends, palm stearin methyl ester, supercharging, engine emissions*

Introduction

Diesel engines have higher thermal efficiency than gasoline engines. However, they emit more hazardous pollutants such as NO_x and particulate matter (PM) than gasoline engines. It is difficult to reduce the NO_x emission and PM at the same time because of the properties of diffusion combustion. Ethanol-diesel blend fuel has been studied as a possible alternative fuel for petroleum [1-6]. Because ethanol contains oxygen (34.3% of oxygen content) in the fuel, it can effectively reduce the emission of PM in the diesel engine [7-9].

Sustainable development of country depends on exploitation of alternative sources of energy. Transportation and agricultural sectors are the major consumers of fossil fuels and

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biggest contributors to environmental pollution, which can be reduced by replacing mineral-based fuels of bio-origin. Various bio-fuel energy resources that are in use worldwide include biomass, biogas, primary alcohols, vegetable oils, biodiesel, *etc*. These alternative energy resources are largely good to environment but they need to be evaluated on case-to-case basis for their advantages, disadvantages and specific applications. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties closer to conventional fuels [10-12].

Ethanol for compression ignition engine has been the option for so many years. It was observed that the effects of adding ethanol to diesel fuel were increased ignition delays, and increased rates of premixed combustion, increased thermal efficiency and reduced exhaust smoke. The more premixed combustion of the blend fuel will increase the peak pressure in the cylinder, but the peak pressures does not increase as efficiently as maximum heat release ratio [13]. Solubility of ethanol in diesel is mainly affected by temperature, hydrocarbon composition of diesel and water content in the blend. With the increase of ethanol soluble temperature increases and reaches the maximum when ethanol content is about 50% by volume [14]. Usually the separation of ethanol-diesel fuel can be prevented by emulsifiers, which can suspend small droplets of ethanol with diesel fuel. Few researchers suggested adding of isobutanol to diesel ethanol blends to improve the solubility [15]. Biodiesel can also be added to improve the solubility of ethanol in diesel. Biodiesel is the fuel comprised of mono alkyl esters of long chain fatty acids derived from vegetable oils. Using the ester-ethanol-diesel blends in the Diesel engine, there is a significant reduction in smoke density [16].

Palm oil derived biodiesel could be used as an effective additive for diesel ethanol emulsions to improve the solubility of ethanol, and to some extent improve the fuel and emission characteristics of the ethanol diesel blends [17]. Palm stearin methyl ester (PSME) was added to ethanol diesel blends and observed that the mixture is stable for longer periods. The properties of the selected pure biodiesel, ethanol and diesel are shown in tab.1.

Table 1. Properties of fuels

Property	Diesel	Ethanol	PSME
Density [kgm^{-3}]	840	789	874
Kinematic viscosity [cSt]	2.44	1.52	4.76
Heating value [$kJkg^{-1}$]	42,500	29700	39,900
Cloud point, [°C]	3	–25	16
Pour point, [°C]	–6	–113	19
Flash point, [°C]	70	17	145

The fuel characteristics of different blends may affect the combustion and emission parameters to some extent depending upon the amount of ethanol or biodiesel added to the diesel. Few authors reported biodiesel has high bulk modulus which when added to diesel can affect the injection timing there by increasing the NO_x emissions [18]. However ethanol addition to the diesel may have little effect on fuelling, injection timing, injection duration and maximum injection pressure. The little amount of biodiesel which is added to ethanol diesel blends can significantly improve the combustion characteristics of the blend and may be said to have little effect on bulk modulus of overall blend.

Engine performance can be improved with supercharging especially when used with biofuels. Supercharging improves the combustion process of Diesel engines. An increase in pressure and temperature of the engine intake reduces ignition delay, resulting in a quiet and smooth operation with a lower rate of the pressure rise. Thus, supercharging encourages the use of low grade fuels in Diesel engines [19].The rise in intake air temperature reduces the unit air charge and also reduces the thermal efficiency moderately, but the increase in the density due to the supercharging pressure compensates for the loss, and inter-cooling is not necessary except for highly supercharged engines [20]. A two stage reciprocating compressor has been used for supercharging. An inlet pressure of 50 kPa is maintained for supercharging condition.

Present work aims to show the significance of biofuels for utilization in internal combustion engines with chosen parameter supercharging with additive methyl ester for diesel ethanol blends. Even though similar type of work has been done in this area by different researchers, present work mainly supports the previous research to maintain the awareness of biofuels for future necessity of utilization.

Details of experimental set-up

A naturally aspirated single cylinder diesel engine with D. C. shunt dynamometer was selected for experimentation. The supercharging operation is carried out at inlet pressure of 0.05 MPa. Two stage reciprocating compressor has been used for supercharging purpose. A surge tank with a valve is provided to maintain uniform inlet air pressure. Digital temperature indicators were used to measure the inlet and exhaust temperatures. Gas analyzer of make Kane-May was used to measure concentrations of NO, unburnt HC, and CO. AVL smoke meter has been used to measure the smoke opacity of the exhaust gas. Schematic diagram of experimental set-up is shown in fig. 1. Engine specifications are given in tab. 2 and ranges of the instruments used are shown in tab. 3.

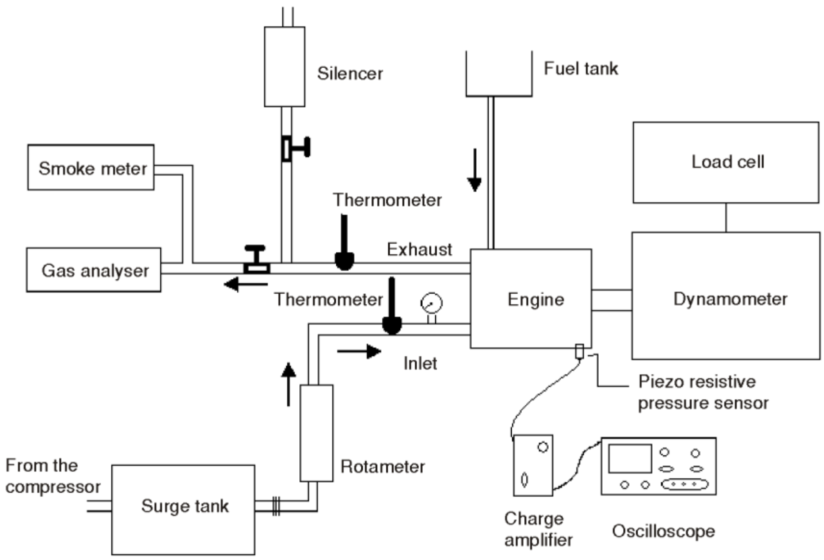

Figure 1. Schematic of engine test set-up

Table 2. Engine specifications

Engine manufacturer	Kirloskar oil engines limited, India
Engine type	Four stroke, direct injection
Number of cylinders	One
Type of cooling	Water cooling
Rated power	3.7 kW at 1500 rpm
Bore/stroke	80/110 mm
Compression ratio	16.5
Start of fuel injection	230 bTDC
Fuel injection pressure	18 MPa

Table 3. Sensitivities and range of test devices

Measurement	Instrument (make)	Range	Sensitivity
CO	Gas analyzer (Kane-May)	0-10%	0.01%
NO	Gas analyzer (Kane-May)	0-5000 ppm	1 ppm
HC	Gas analyzer (Kane-May)	0-3000 ppm	10 ppm
Smoke opacity	Smoke meter (AVL)	0-100%	0.01%
Temperature	Thermocouple (Omega)	0-800 °C	1 °C

Experimental procedure

Engine was run at constant speed 1500 rpm and the fuel injection pressure is kept at recommended value of 18 MPa with the fuel injection timing 23° bTDC. Advancing the fuel injection timing increase the chances of more NO_x formation and retarding fuel injection may increase the unburned hydrocarbons. Literature suggests that almost all of the NO forms within the 20° following the start of combustion. As injection timing is retarded the combustion process is retarded, NO formation occurs later, and concentrations are lower since peak temperatures are lower [20]. So the injection timing was kept at recommended value (23° bTDC) during the entire test procedure keeping the view of low NO_x emissions.

PSME was added as additive to improve the solubility of ethanol in diesel. The blends of ethanol diesel, biodiesel E10B, E20B, E30B was prepared and observed that the blends were stable for a long period of time. The calorific values of the selected blends have been found to be 40,750, 39,033, and 37,542 kJ/kg for E10B, E20B, and E30B, respectively.

Engine performance with variable injection pressures was carried out for initial set of readings. Fuel injection pressures 18, 21, and 24 MPa have been checked for naturally aspirated condition and supercharged condition. It was observed that a rise in injection pressure can significantly improve the work output. If the engine is of constant speed, with a rise in fuel injection pressure more or less same performance was observed in terms of bSFC and BTE is concerned. However, the emission formation tendency changed indicating a rise in peak temperatures leading to more NO_x formation, more unburned hydrocarbons due to increase in crevice losses at higher injection pressures. More the injection pressure more the energy needed to drive the injection system by reducing the leak flow and by dynamically adjusting the maximum pressure to the actual needs of the engine [21]. So the engine was operated at injection pressure of 18 MPa keeping the point of lower pollutant emissions.

Engine was first tested with the naturally aspirated condition and then with the supercharged condition. The supercharged conditions of the Diesel, E10B, E20B, and E30B are denoted as DS, E10BS, E20BS, and E30BS, respectively. Cooling water outlet temperature of 55 °C is maintained throughout the engine operation. Fuel consumption, exhaust emissions concentration and smoke are measured after the engine has attained the steady-state condition.

Engine performance

Brake specific fuel consumption and brake thermal efficiency

The variation of BSFC with load is shown in figs. 2 and 3. It is observed that E10B and E20B have shown similar fuel consumption values when compared with diesel but E30B observed to be little expensive at part load operation but economical at higher loads. With supercharging the fuel consumption values of E10B, E20B, and E30B are reduced in comparison to diesel fuel. The graphs of BTE *vs*. load are shown in figs. 4 and 5. Thermal efficiency values of E20B and E30B observed to be little high in comparison to diesel with no supercharging, whereas E10B showed values similar to diesel. With supercharging E10B and E20B showed improvement in thermal efficiency and E30B showed performance similar to diesel.

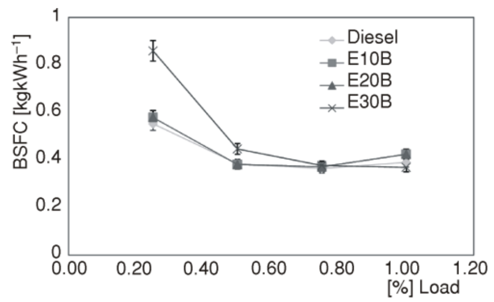

Figure 2. Variation of BSFC with load for ethanol diesel blends

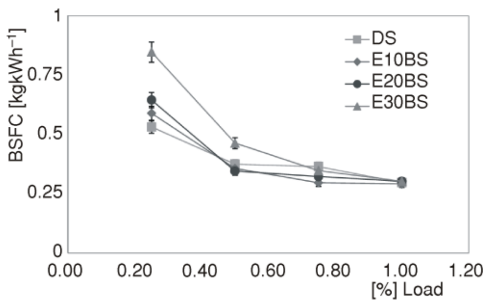

Figure 3. Variation of BSFC with load for ethanol diesel blends with supercharging

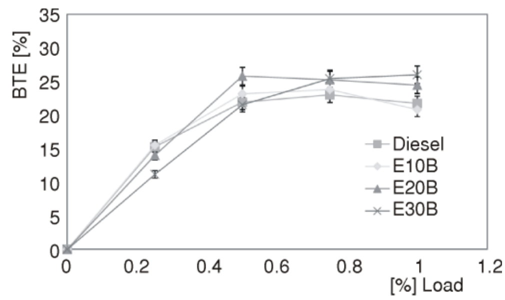

Figure 4. BTE *vs.* load for ethanol diesel blends

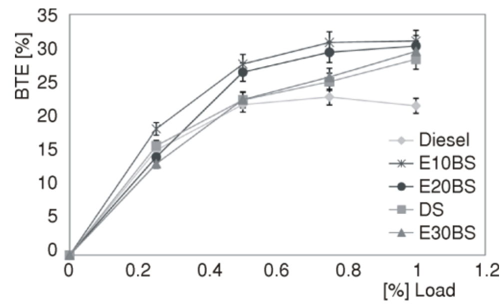

Figure 5. BTE *vs.* load for ethanol diesel blends with supercharging

The values of BSFC and BTE with different blends at full load are shown in tabs. 4 and 5. The BSFC values observed to be reduced with ethanol concentration in diesel, which can be clearly noticed for E30B with 5.38% reduction in fuel consumption with no supercharging and 22.03% with supercharging. Similarly an improvement in fuel conversion efficiency was observed for E30B with a rise of 19.65% with no supercharging and 36.46% with supercharging in comparison to diesel. The higher BTE of ethanol diesel blends mainly because of improved quality of spray characteristics of blends fuels since the boiling point of ethanol is lower than that of diesel, a decrease in heat losses to due low flame temperature of ethanol than the diesel and ethanol diesel blend has high reaction activity in fuel rich zone due to oxygenate of ethanol that improves the combustion performance [22].

Table 4. Comparison of BSFC for different cases with diesel fuel at full load

Fuel	BSFC	Percentage reduction
Diesel	0.3898	0
E10B	0.4243	–8.85
E20B	0.377	3.28
E30B	0.3688	5.38
DS	0.2975	23.67
E10BS	0.292	25.08
E20BS	0.3028	22.31
E30BS	0.3039	22.03

Table 5. Comparison of BTE for different cases with diesel fuel at full load

Fuel	BTE	Percentage improvement
Diesel	21.72	0
E10B	20.82	–4.14
E20B	24.44	12.52
E30B	25.99	19.65
DS	28.47	31.07
E10BS	31.15	43.41
E20BS	30.42	40
E30BS	29.64	36.46

Nitrous oxide emissions

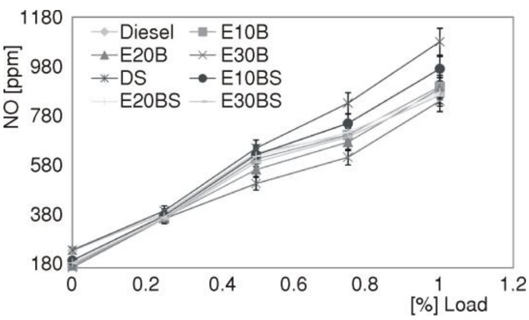

Figure 6. Nitric oxide emissions *vs.* load for ethanol diesel blends

NO_x formation is effected by the temperature and fuel air residence time. At higher temperatures the nitrogen dissociates into nitrous oxide which is a harmful pollutant. The variation of NO with load is shown in fig. 6. It can be noticed that with the increase of engine load NO formation increased because of the rise in peak temperatures of combustion. As the ethanol content in the diesel increased there is a reduction in nitrous oxide emissions due to temperature drop due to high heat of evaporation of ethanol. Trace amounts of water present in the blends may suppress the formation of thermal NO [23]. Ethanol diesel blends (E10B, E20B, and E30B) showed fewer values of NO in comparison to diesel. With supercharging there is a slight increase in formation of NO due to a rise in temperature of combustion.

Carbon monoxide emissions

Carbon monoxide in the exhaust is the indication of an extent of incompleteness of combustion. Varation of CO emissions with load is shown in fig. 7. CO formation shows a decreasing trend with zero, one fourth and half loads and then increasing trend observed at higher loads. CO emissions are slightly increased with E10B, E20B, and E30B when compared with diesel. High CO concentrations with ethanol blends can be explained by an increased premixed combustion due to increased ignition delay period by the high latent heat of vaporisation of ethanol [24]. With supercharging the amounts of CO emission seems to be little reduced due to reduced ignition delay period, a rise in temperature of combustion.

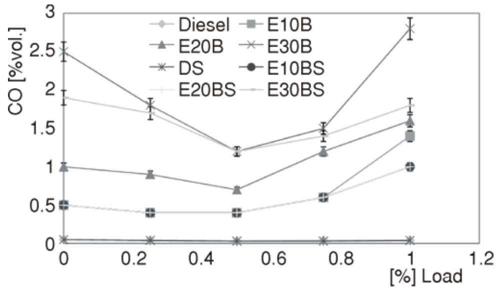

Figure 7. CO emissions *vs.* load for ethanol diesel blends

Unburned hydrocarbons

Unburned hydrocarbon emissions are remarkable for ethanol diesel blends at no load and part load because of high heat of vaporization of ethanol, low viscosity, density and cetane number. High heat of vaporization produces slow vaporization and mixing of fuel and air leading to increase unburned HC. Non homogeneity of the mixtures due to low viscosity and density at some regions of combustion chamber may also contribute to leaner mixtures results in more unburned HC [24]. With supercharging the unburned HC emissions decreased because of the reduction in the delay period of combustion and improved homogeneity of the mixtures. The variation of unburned HC emissions with load is shown in fig. 8.

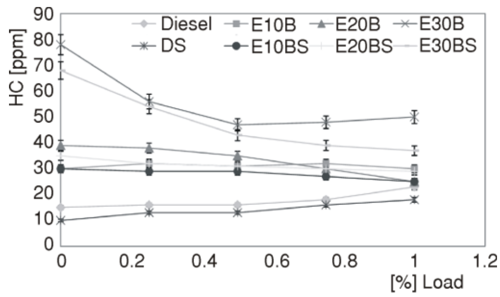

Figure 8. Variation of HC emissions *vs.* load for ethanol diesel blends

Exhaust temperature

Reduction in exhaust gas temperature was observed with supercharging, rise in temperatures were observed with ethanol blends due to increase in duration of the combustion process. E20B has got high temperature in comparison to E10B and with diesel. Nevertheless, with E30B reduction in exhaust temperature observed due to the reduction in an amount of heat released in the combustion process. It seems that addition

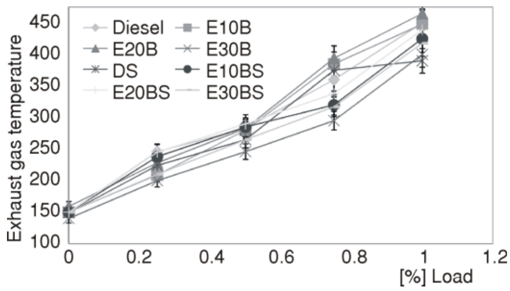

Figure 9. Variation of exhaust gas temperature with load for ethanol diesel blends

of ethanol more than 20% is not advisable. The graph of exhaust temperature *vs.* load is shown in fig. 9.

Smoke opacity

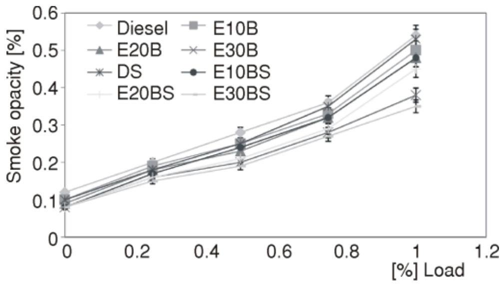

Figure 10. Variation of smoke opacity with load for ethanol diesel blends

With the increase in content of the ethanol in Diesel the smoke values were reduced. E10B, E20B, and E30B shows lower smoke opacity values compared with diesel. Low smoke opacity is the indication of lower PM emissions which is a desirable effect needed for Diesel engine. Supercharging improves the combustion quality so there is a reduction in smoke opacity. The smoke opacity values of different blends with load is shown as bar chart in fig. 10.

Conclusions

Palm stearin methyl ester addition to ethanol diesel blends helped in improving the solubility of ethanol in diesel. The engine performance test with ethanol-ester-diesel under natural aspiration and supercharging gives the following conclusions.

- With no supercharging E20B and E30B showed a reduction in values of brake specific fuel consumption in comparison to diesel at higher loads, and the same with E10B at lower loads. Brake specific fuel consumption values are further decreased with supercharging for all the blends.
- Brake thermal efficiency is high with E20B and E30B when compared with diesel and with super charging E10B showed much improvement, E20B and E30B showed a noticeable improvement.
- NO values are lowered with ethanol, ester and diesel blends when compared with pure diesel operation and with supercharging NO formation is little increased. Unburned HC and CO emissions seem to increase as the ethanol percent increases in the blend, but with supercharging these emissions are little lowered. Smoke opacity is significantly reduced with ethanol-ester-diesel blends and further reduction is observed with supercharging.
- With ethanol, ester addition, there is a significant improvement the combustion and emission formation characteristics of diesel fuel, and E10B showed good results with BTE, BSFC, and less emission formation.

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Nomenclature

BSFC – brake specific fuel consumption, [$kgkWh^{-1}$]
BTE – brake thermal efficiency, [%]
bTDC – before top dead centre
DS – diesel with supercharging
E10B – blend of 10% ethanol, 5% ester, 85% diesel by volume
E20B – blend of 20% ethanol, 10% ester, 70% diesel by volume
E30B – blend of 30% ethanol, 10% ester, 60% diesel by volume
E10BS – E10B with supercharging
E20BS – E20B with supercharging
E30BS – E30B with supercharging

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