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Combustion, emission and performance analysis of a direct injection diesel engine using high gadoleic fatty acid Jojoba methyl ester blends as fuel

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Abstract

The present investigation analyses the combustion, emission and performance analysis of a direct injection diesel engine using the blends of high gadoleic fatty acid jojoba methyl ester. The significance of this investigation is the complete replacement of standard diesel with bio-fuels. Different blends, namely, MEJ100, T20–MEJ80, T40–MEJ60 were prepared on volume basis and tested as fuels. From the property analysis it was found that the properties of these blends are similar to those of diesel. The presence of turpentine oil in the blends improves the viscosity and volatility of the fuel blends. The combustion, performance and emission characteristics of the blends at all loads have shown good results. From the emission analysis, it was found that CO, HC and smoke are lower for T20–MEJ80 blend when compared to diesel with slight increase in NOx emission. The brake thermal efficiency of T20–MEJ80 blend is slightly higher than that of diesel. Cylinder pressure, Heat release rate and Ignition delay are in similar trend with diesel fuel operation. On the whole, it is found that performance and emission characteristics of T20–MEJ80 blend are closer to those of diesel.

Keywords: Gadoleic fatty acid, methyl ester, diesel engine, emission

1. Introduction

Diesel engines provide important transportation power sources which are receiving additional attention due to their relative operating efficiency. Uncertainties concerning stable supplies of petroleum fuels and the need to clean up the environment have renewed interest in the use of alternative fuels for diesel engines. In this context, research has been focused on bio-fuels as alternative fuels for internal combustion engines. Vegetable oils can be directly used in diesel engines as they have a high cetane number and calorific value, which are very similar to those of diesel. However, the brake thermal efficiency of vegetable oils is inferior to that of diesel. This leads to problems of high smoke, HC and CO emissions. This is because of the high viscosity and low volatility of vegetable oils, which lead to difficulty in atomizing the fuel and mixing it with air. Further, gum formation and piston sticking under long term use due to the presence of oxygen in their molecules and the reactivity of the unsaturated HC chains, present problems in the use of vegetable oils. These problems were overcome by chemically altering the vegetable oil (transesterification) and blending it with diesel [1-4]. A marginal increase in NOx emission and a reduction in CO, HC and smoke, due to the presence of oxygen in neat bio-diesel and bio-diesel-diesel blends were recorded and reported [5&6]. The behavior of the bio-diesel prepared from modified feed stocks was studied and it was reported that the engine performance and combustion process of all the blends were similar to those of diesel fuel with marginally higher fuel consumption, a shorter ignition delay, and a lower premixed burning rate [7, 8].

The high cetane value of bio-diesel produced from palm oil could compensate for the decrease of the cetane number of the blends caused by the presence of ethanol. It was also reported that the emissions of

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the blends reduced significantly at high engine load, whereas NOx increased when compared to diesel fuel operation [9-11]. In this study, biomass derived Turpentine oil and methyl ester derived from Jojoba oil were blended separately at different proportions and performance, emission and combustion characteristics are evaluated using a naturally aspirated, direct injection diesel engine.

2. Property Analysis

The physico chemical properties of Turpentine oil, methyl ester of Jojoba oil are compared with diesel fuel and given in Table 1. Fatty acid composition of Jojoba oil is given in Table 2. The fatty acid composition of Jojoba methyl ester is entirely different from other vegetable oil (Table 2). Major constituent of Jojoba oil is Gadoleic acid. Important properties of Turpentine oil like lower heating value, viscosity, density, boiling point, and flash point are comparable with those of diesel [12].

To determine the cetane number (CN) of the methyl ester, WANG Li –bing et al. proposed an equation which is based on the fatty acid composition of methyl ester [13]. According to the above cited reference, Degree of Unsaturation (DU), CN, IV can be found out.

$$DU = (\text{monounsaturated } C_n{:}1, \%) + 2\,(\text{polyunsaturated } C_n{:}2, \%) + 3\,(\text{polyunsaturated } C_n{:}3, \%) + 4\,(\text{polyunsaturated } C_n{:}4, \%) \quad (1)$$

$$CN = -0.1209 * DU + 65.0958,\ R^2\,(adj) = 0.8923 \quad (2)$$

$$IV = 0.6683*DU+25.0364,\ R^2(adj) \quad (3)$$

Using the above equations, DU, CN and IV of Jojoba methyl ester were found out as follows.

It is found that monounsaturated fatty acids like Oleic acid, Gadoleic acid and Erucic acid are present in the Jojoba methyl ester.

$$DU = (1+12+65+8+1.5) + 2(0) + 3(0) = 87.5$$

$$CN\ (MEJ) = -0.1209 *87.5 + 65.0958 = 54.5$$

$$IV = 0.6683*87.5+25.0364 = 83.5$$

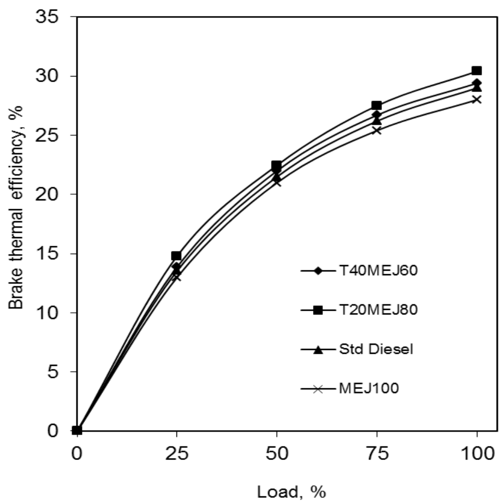

Fig. 1. Variation of brake thermal efficiency with load for standard diesel, turpentine oil-methyl esters blends

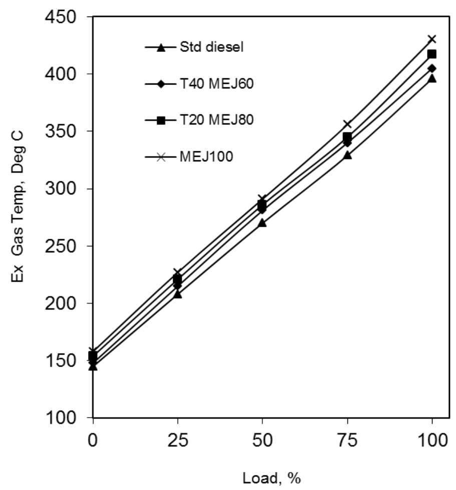

Fig. 2. Variation of exhaust gas temperature with load for standard diesel, turpentine oil-methyl esters blends

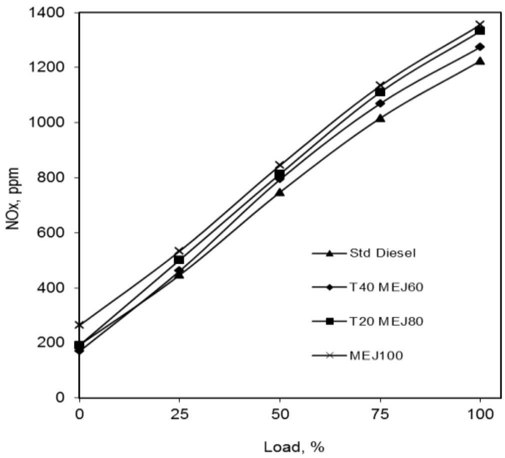

Fig. 3. Variation of oxides of nitrogen emission with load for standard diesel, turpentine oil-methyl esters blends

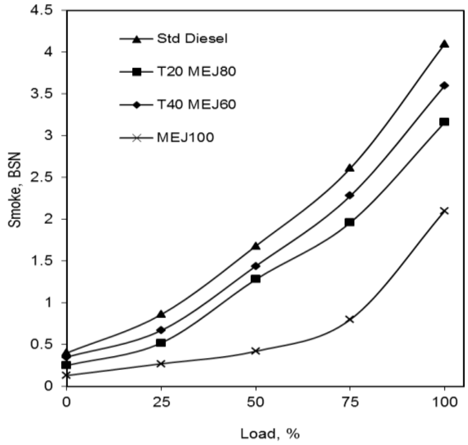

Fig. 4. Variation of smoke emission with load for standard diesel, turpentine oil-methyl esters blends

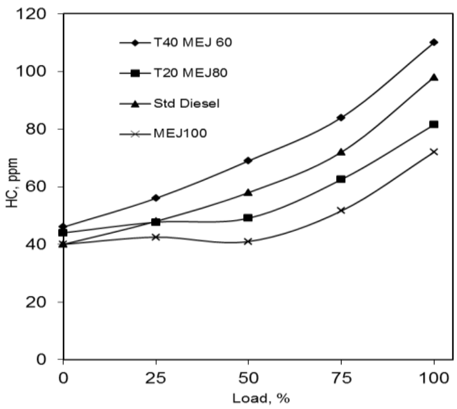

Fig. 5. Variation of Hydrocarbon emission with load for standard diesel, turpentine oil-methyl esters blends

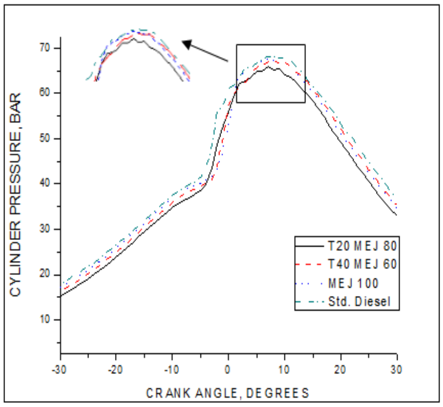

Fig. 6. Variation of exhaust gas temperature with load for standard diesel, turpentine oil-methyl esters blends

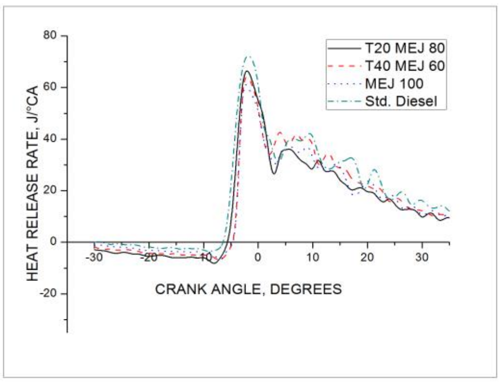

Fig. 7. Variation of Heat release rate at 75% load with crank angle standard diesel, turpentine oil-methyl esters blends

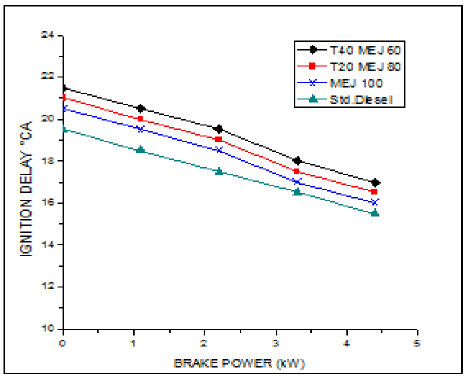

Fig. 8. Variation of ignition delay with Brake power for standard diesel, turpentine oil-methyl esters blends

3. Results and Discussion

The performance, emission and combustion characteristics of a DI diesel engine using methyl ester and Turpentine blends were carried out using four stroke single cylinder diesel engine. The specification of the engine is given in Table 3. The following section describes performance emission and combustion analysis.

3.1 Brake thermal efficiency

The variation of brake thermal efficiency for different Turpentine oil– MEJ blends and for standard diesel at various load conditions is shown in Figure 1. The presence of Turpentine oil in the blend increases the ignition delay, leading to a large percentage of fuel burning in the premixed mode. This leads to an increase in the brake thermal efficiency. The brake thermal efficiency of the T20MEJ80 blend was better than that of the other blends and standard diesel. Further, the reduction in viscosity leads to improved atomisation, fuel vapourisation and combustion. This may be the other reason for the improvement in brake thermal efficiency. Higher proportion of turpentine in the blend may result in lower heating value, thus lower efficiency but slightly higher than remaining blends.

3.2 Exhaust gas temperature

The variation of exhaust gas temperature for different Turpentine oil– MEJ blends and for standard diesel at various load conditions is shown in Fig. 2. At lower loads only marginal increase in exhaust gas temperature is observed which may be due to cooling effect caused by higher latent heat of vapourisation of turpentine present in the blend [14].The cetane number of the blend is reduced with an increase of the Turpentine oil content in the blend because of the low cetane number of Turpentine oil. A lower cetane number means an increase in the ignition delay and more accumulated fuel/air mixture, which causes a rapid heat release in the beginning of the combustion, resulting in high exhaust gas temperature.

3.3 Oxides of nitrogen emission (NOx)

The variation of NO_x emission for different Turpentine oil– MEJ blend and for standard diesel at various load conditions is shown in Fig. 3. It can be observed from the figure that NO_x emission increases with the increase in the Turpentine oil proportion in the blends. The increase in NO_x emission may be due to the presence of oxygen in both the fuels, which leads to complete combustion. Normally, complete combustion will create higher combustion temperature, which will cause high NO_x formation. Another reason for the increase of NO_x emissions is the decrease of the cetane number with a higher Turpentine oil proportion. A lower cetane number means an increase in the ignition delay and more accumulated fuel/air mixture, which causes a rapid heat release in the beginning of the combustion, resulting in high temperature and high NO_x formation as reported by Kwanchareon et al (2007).

3.4 Smoke emission

The variation of smoke emission for different Turpentine oil– MEJ blend and for standard diesel at various load conditions is shown in Fig. 4. The significant reduction in smoke emission may be due to the complete combustion caused by the oxygenated blends. This may also be due to an improvement in diffusive combustion s seen from heat release rate graph.

3.5 Hydrocarbon emission

The variation of HC emission for different Turpentine oil– MEJ blend and for standard diesel at various load conditions is shown in Fig. 5. It is seen from figure that at low load and medium loads, HC emissions of the blends were not much different from that of standard diesel. However, at full load, HC emissions of the blends decreased significantly when compared with that of standard diesel. This can be due to improved evaporation of blends caused by higher cylinder temperature.

3.6. Cylinder pressure

The variation of cylinder pressure with crank angle for full load is shown in Fig.6. The peak pressure of blends at full load is closer to that of diesel fuel. This may be due to higher temperature developed in the combustion temperature resulting in improved evaporation and combustion. The peak cylinder pressure for blends is lower than that of diesel fuel which may be due to lower calorific value and unsaturation fatty acid present in the methyl ester. This may also be attributed to lower viscosity nad higher calorific value leading to shorter ignition delay and higher peak pressure.

3.7. Heat release rate

The variation of heat release rate with crank angle is shown in Fig. 7. As seen from the figure, in all the blends and diesel there is a negative heat release rate at the beginning, due to heat absorption by the fuel air mixture during the delay period. At full load, more heat is accumulated in combustion chamber helping to reduce delay period and hence the start of heat release is similar to diesel. However, maximum heat release rate was slightly lower for blends. This may be due to the presence of unsaturated fatty acid and lower calorific value.

3.8. Ignition delay

Ignition delay is defined as the period between start of injection and start of combustion and given in degrees of crank angle. The fuel does not ignite immediately upon injection into the combustion chamber. There is a definite period of inactivity between the first droplet of fuel hits the hot air in the combustion chamber and the time it starts through the actual burning process. This period is known as the ignition delay period. The variation of ignition delay with crank angle is shown in Fig.8. Cooling effect caused by Turpentine due to its higher latent heat of vapourisation resulted in longer ignition delay. This may also be attributed to lower Cetane number of the blended fuels. However, at full load start of pressure rise is similar to diesel as seen from the cylinder pressure diagram. At higher loads the cylinder temperature reaches maximum value which brings the delay period similar to that of diesel.

4. Conclusion

From the emission analysis, it is found that HC and smoke are lower for MEJ100 when compared to standard diesel. Among all the blends, NO_x emission is lower for T40–MEJ60 blend but slightly higher than that of standard diesel. The brake thermal efficiency of T20MEJ80 blend is slightly higher than that of standard diesel and other blends. Cetane number of T20–MEJ80 blend is higher than that of standard diesel and other blends. Combustion parameters like cylinder pressure, heat release rate and ignition delay are closer to those of diesel fuel. On the whole, it is found that performance and emission characteristics of T20–MEJ80 blend are closer to those of standard diesel.

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