The Effect of Orange Oil-diesel Fuel Blends on Direct Injection Diesel Engine Performance Exhaust Emissions and Combustion

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Abstract

This paper presents the comparative bench test results of a four stroke, single cylinder, direct injection, unmodified, and naturally aspirated diesel engine when operating on 70 %, 80 %, and 90 % of orange oil blends with diesel fuel. Brake thermal efficiency increased with increase in orange oil blends compared with the diesel fuel. The brake thermal efficiency at maximum load was 28.22 % for diesel, 29.21 % for 70 % orange oil blend, 29.83 % for 80 % orange oil blend and 31.4 % for 90 % orange oil blend. CO, HC and Smoke emissions were lower than the diesel fuel for the entire range of operation. NO_x emission increased with increase in orange oil blends compared with the diesel fuel operation. Ignition delay was higher with 90 % orange oil than that of diesel, 70 %, and 80 % orange oil blends. Peak pressure and rate of pressure rise were higher with all the orange oil blends compared to diesel fuel operation. Orange oil blends showed higher premixed combustion phase compared to standard diesel operation with longer combustion duration. The test results showed that orange oil could be used as a diesel substitute in a diesel engine.

Keywords: Diesel engine, orange oil diesel fuel blends with higher concentration, Performance, Emissions, combustion.

1. Introduction

Many fuels are being investigated [1–5] as potential substitutes for the conventional petroleum fuels. Vegetable oils may provide one such alternative to diesel fuel and their use in compression ignition engines has been examined in the past years by several researchers. Many researchers have indicated that the successful use of vegetable oil in diesel engines is a renewed interest. Vegetable oil cannot be safely used in an indirect-injection, naturally aspirated and air-cooled engine for long periods of time. This problem is related to the high viscosity of vegetable oil, which causes inadequate atomization and incomplete combustion. Another problem associated with the use of vegetable fuels as a diesel substitute is the reactivity of the unburned fuel, which is the cause of fouling of the injector nozzles and cylinder deposition. A major problem encountered with the more widespread use of the diesel engine is the emission of particulate matter and oxides of nitrogen. This has been the subject of public concern over adverse effects on human health, and particularly respiratory disorders in urban environment.

Cherng et al [6] have studied the use of four types of diesel fuel, bio-diesel with and without an additional peroxidation process, a commercial bio-diesel and ASTM No. 2D diesel. These were compared for their fuel properties, engine performance and emission characteristics. Kalligeros et al [7] investigated the fuel consumption and exhaust emissions from a single cylinder, diesel engine. The engine was fueled with pure marine diesel fuel and blends containing two types of bio-diesel, at proportions up to 50 %. The two types of bio-diesel appeared to have equal performance, and irrespective of the raw material used for their production, their addition to the marine diesel fuel decreased the particulate matter, unburned hydrocarbons, nitrogen oxide and carbon monoxide emissions.

Pramanik [8] analysed the blends of various proportions of jatropha curcas oil and diesel compared with diesel fuel. The effect of temperature on the viscosity of bio-diesel and jatropha oil was also studied. The performance of the engine using blends and jatropha oil was evaluated in a single cylinder compression-ignition C.I. engine. The specific fuel consumption and the exhaust gas temperature reduced due to a decrease in viscosity of the vegetable oil. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50 % volume of jatropha oil. From the properties and engine test results it has been established that 40–50 % of jatropha oil can be substituted for diesel without any engine modification and preheating of the blends.

Leenus et al [9] have used raw cotton seed oil and its ethyl esters as fuel for a C.I. engine. Cottonseed oil is not ideally suited as an engine fuel as such because of its high viscosity and low volatility. Transesterification has to be done to improve the properties of cottonseed oil to make it comparable with diesel. Properties of the ethyl ester of cottonseed oil were evaluated and compared with diesel. The esterified fuel was used to evaluate the performance, combustion and emission characteristics of a single cylinder, direct injection diesel engine. The data generated were compared with the base line diesel and raw cottonseed oil. The engine exhibited very good performance without any problems of combustion. It is suggested that, the ethyl ester of cotton seed oil can be used as an alternate fuel for diesel engines.

Senthil Kumar et al [10] carried out research work on various methods of using vegetable oil (Jatropha oil) and methanol such as blending, transesterification and dual fuel operation. Lu¨ Xing-cai et al [11] have studied the influence of a cetane number improver on heat release rate and emissions of a high-speed diesel engine fueled with ethanol–diesel blend fuel. Huang et al [12] reported that an increase in the methanol mass fraction will result in an increase in the heat release rate in the premixed burning phase and shorten the combustion duration in the diffusive burning phase. Ignition delay increases, rapid-burn duration varies little, an and the total combustion duration decreases with increase in methanol mass fraction. The maximum rate of pressure rise and the maximum rate of heat release increase with an increase in the methanol mass fraction at all engine loads. The maximum cylinder pressure increases with an increase in the methanol mass fraction. The presence of oxygen reduces the peak pressure, but the reduction was found to be insensitive to the proportion of oxygen within the 6-11 % range of testing.

India is an agricultural based country and biomass like orange skin is available in large quantity. Hence the disposal of solid waste becomes a problem. Oranges are available in large quantities around the world. Orange skin is a biomass and oil extracted from orange skin is presently used in the manufacture of perfumes, chemicals etc.

Recently researchers have studied the use of orange oil as fuel for spark ignition engines. Since most of its properties are closer to gasoline, it can be a good alternative fuel for spark ignition engines. Ramesh et al [13] suggested that orange oil and eucalyptus oil were found to be potential candidates for spark ignition engines. The high octane value of these fuels can enhance the octane value of the blend when it is blended with low-octane gasoline. Hence, the knock limited compression ratio can be further increased when this fuel is blended with gasoline. Results indicated that a gasoline-orange oil blend with catalytic coating performs better when compared to the normal lean burn engine. The percentage improvement in brake thermal efficiency is about 20.5% with a eucalyptus oil blend and 6.0 % with an orange oil blend, respectively, at 2 kW and 3000 rpm as compared with normal gasoline fuel. HC and CO emissions are reduced with a catalytic coating.

Ghazi [14] reported that the fumigation technique offers the advantage of easy conversion of the diesel engine to work in dual fuel mode with volatile fuels and vegetable oils. A dual fuel engine with appropriate conversion has superior characteristics than those of straight fuel operation. Senthil Kumar et al [15] studied that orange oils can be fumigated up to 35 % and high cetane number fuel can be injected as pilot fuels for ignition. In their study, diesel, Jatropha oil and methyl ester of Jatropha oil were used as pilot fuels.

In the present work, experiments were conducted to study the performance, emissions and combustion characteristics of higher concentrations (70 %, 80 % and 90 %) of orange oil in diesel in a compression ignition engine.

2. Fuel Preparation

D - Limonene is the major component of the oil extracted from the citrus peel during the citrus juicing process. When the fruit is juiced, the oil is pressed out of the peel, separated from the juice and then distilled to recover certain flavour and fragrance compounds. After the juicing process, the peels are conveyed to a steam extractor. When the steam is condensed, a layer of oil floats on the surface of the condensed water. This removes the bulk of the oil from the peel. Food grade d-limonene is extracted through the juicing process and technical grade d- limonene is removed through the peel. Orange oil is extracted from the orange peel by cold pressing and yields 3 to 5 %.

In the market, three grades of orange oils are available:(i) Natural Orange oil with 40% propylene glycol, (ii) Two fold orange oil, (iii) Five fold orange oil. The first type of Orange oil was taken for the study as it has a low viscosity and also is less expensive. The properties of orange oil are compared with that of diesel fuel in Table 1. The ultimate analysis of orange oil and properties of d-limonene are shown in Table 2 and Table 3 respectively.

D-Limonene is the major component of the Orange oil, extracted from the citrus peels. The chemical name is 1 methyl-4-prop-1-en-2-yl-cyclohexene, and the chemical formula is $C_{10}H_{16}$ (d-limonene). This is used in the production of cosmetics, essences and confectionaries.

Table1 Comparison of properties of orange oil with diesel fuel

Properties	Diesel	Orange oil
Calorific Value, kJ/kg	43,000	34650
Density@30°C kg/l	0.8284	0.8169
Viscosity@40°C, cSt	2.7	3.52
Flash Point, °C by PMCC Method	52	74
Fire Point, °C by PMCC Method	65	82
Cetane Number	49	47

Table 2 Ultimate Analysis of Orange oil

	Percentage of components
Moisture	Nil
Mineral matter	Nil
Carbon	84.28
Hydrogen	12.47
Nitrogen	0.19
Sulphur	0.007
Oxygen	3.05

Table 3 Properties of D-Limonene

Components	D- Limonene
Molecular mass g / mol	136.24
Melting point, °C	-95.2
Boiling point °C	176
Density g / cm^3	0.8411
Refractive index	1.4730
Flash Point °C	50

3. Experiment setup

A series of tests was carried out on a single cylinder, air cooled, direct injection stationary diesel engine that has a bore of 87.5 mm, stroke of 110 mm and displacement of 661cc. The schematic diagram of the experimental setup is shown in Fig. 1. The engine (1) had a rated output of 4.4 kW at 1500 rpm with compression ratio 17.5:1 and injection taking place at a pressure of 215 bar and at 23° before top dead centre, as set by the manufacturer. The engine was coupled to an electrical dynamometer (2) to provide a brake load with an electric panel (3). A fuel switching circuit (7) was used to change over from one fuel to another while the engine was running. The fuel consumption was measured with the aid of a burette (5, 6) and a stopwatch arrangement. The exhaust gas temperature was measured using a thermocouple (10).

Measurement of combustion chamber pressure was made by installing a KISTLER, water cooled piezo – electric pressure transducer (13) that has a sensitivity of 14.80 pC / bar, into the cylinder head which was connected to the charge amplifier (14) and a TDC encoder (12) was fixed on the flywheel of the engine. These analogue signals were converted to digital signals and fed to a Cathode Ray Oscilloscope (CRO) (15). A printer (16) was used to get the signal output of the Cathode Ray Oscilloscope (CRO). For emission measurements, a Five Gas Analyzer (11) – Make KANE International Ltd., QRO- 401 Exhaust gas analyzer (CO, HC, CO_2 – NDIR Method, O_2, NO_x - Electro Chemical Method) was used to measure the level of HC, CO_2, CO, O_2 and NO_x. The accuracy of this instrument is $\pm$ 5 ppm and the resolution is $\pm$ 1 ppm.

Experiments were carried out initially using diesel fuel to generate the base line data. The orange oil blends were stored in a separate fuel tank as shown in Fig. 1. The engine was started with diesel and then switched over to 70 %, 80 % and 90 % orange oil diesel fuel blends for the investigation. After experimentation with orange oil diesel fuel blends, the fuel was changed to diesel to enable trouble free operation later on. 1. Test Engine, 2. Dynamometer, 3. Panel Board, 4. Orifice Flow meter, 5. Diesel Burette, 6. Orange oil burette, 7. Fuel shifting valve, 8. Diesel Tank, 9. Orange oil tank, 10. Exhaust gas thermocouple, 11. Five gas analyzer, 12. Crank angle encoder, 13. Piezo electric transducer, 14. Pressure amplifier, 15. CRO, 16. Printer.

During the experiments the following data were recorded: Cylinder pressure variation with crank angle. With the help of cylinder pressure, heat release rate was calculated for analysis of the combustion parameter. Using fuel consumption, other performance parameters like brake thermal efficiency and brake specific energy consumption were calculated. The exhaust gas temperature, HC, CO_2, CO, O_2 and NO_x were also measured for analyzing the emissions parameters of the test fuels and comparing with diesel fuel.

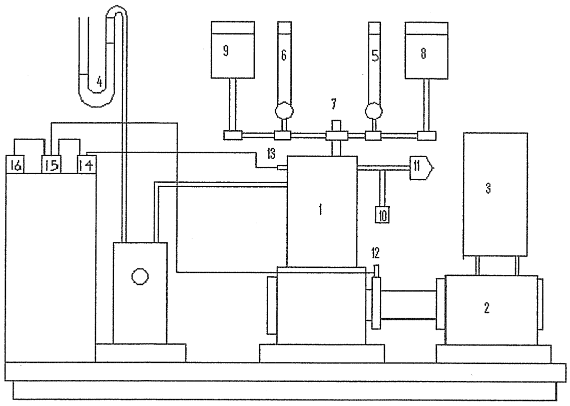

Fig. 1 Experimental Setup

4. Results and Discussion

4.1 Combustion analysis

4.1.1 Pressure Variation

Fig 2 shows the in cylinder pressure for the engine running on orange oil with diesel fuel blends at full load. It can be observed that orange oil blends exhibit a higher cylinder peak pressure compared to that of diesel fuel. The peak pressure is about 77 bar, 78 bar, 78.7 bar and 70.5 bar for 70 %, 80 %, 90 % orange oil blends and diesel fuel, respectively. The peak pressure of orange oil blends occur at 4.5° CA (Crank Angle) after the peak pressure of diesel at full load. This may be attributed to higher flame propagation that leads to complete combustion of orange oil and hence higher peak pressure is obtained [10]. Ignition delay is higher for orange oil blends compared to that of diesel fuel operation. The relatively poor volatility characteristics of the fuel possibly makes the physical delay of the orange oil longer than the chemical delay and hence causes an overall increase in ignition delay for orange oil compared to diesel fuel.

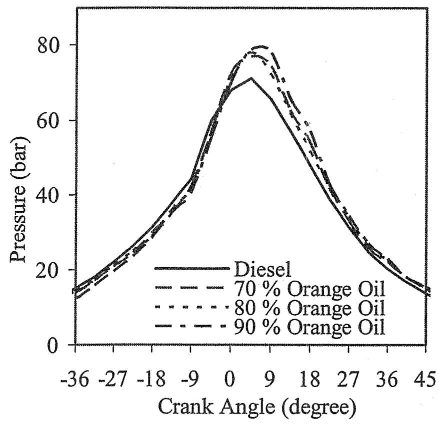

Fig. 2 Variation of Pressure with Crank Angle

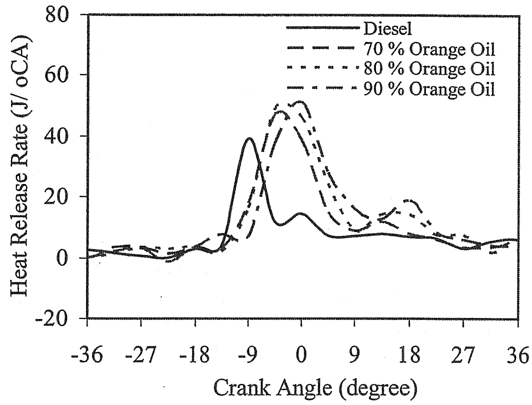

Fig. 3 Variation of Heat Release Rate with Crank angle

4.1.2 Heat Release Rate

The heat release rate for higher concentrations of orange oil blends and diesel fuel at full load is shown in Fig. 3. It may be observed that the premixed combustion is higher for orange oil blends than the diesel fuel. An increase in orange oil mass fraction in the diesel fuel would decrease the cetane number of the blends. This may lead to an increase in the ignition delay and also the amount of the fuel prepared within the period of the ignition delay [16]. This is the reason for the higher peak pressure and higher heat release rate in the premixed combustion phase. The ignition delay, the premixed combustion duration and fraction of premixed combustion increase with an increase in orange oil blends. The total heat release rate during premixed combustion period is 130 Joules, 146 Joules and 151 Joules, and premixed combustion duration is 22.5 °CA, 22.5 °CA and 27 °CA with 70 %, 80 % and 90 % orange oil blends, respectively. For diesel, the combustion duration is 13.5 °CA with a lesser heat release rate of 59 Joules. It was observed that the formation of a reasonable fuel-oxygen mixture is promoted when using the oxygenated blends. The enrichment of oxygen and the increase in the fraction of combustible mixture prepared during the period of ignition are promoted, as orange oil will evaporates rapidly in a high temperature environment [17].

4.1.3 Peak Cylinder Pressure

Fig. 4 shows the peak cylinder pressure of orange oil blends and diesel fuel. The result shows that the peak pressure of the orange oil blends is higher than that of diesel fuel. Higher ignition delay of orange oil blends would increase the amount of fuel burned within the premixed burning phase, while at high loads more fuel would be burned in the premixed burning phase. The peak pressure is the same for both fuels at low loads. The peak pressures are 77, 78, 78.7 bar and 71 bar for orange oil blends of 70 %, 80 % 90 % and diesel fuel, respectively.

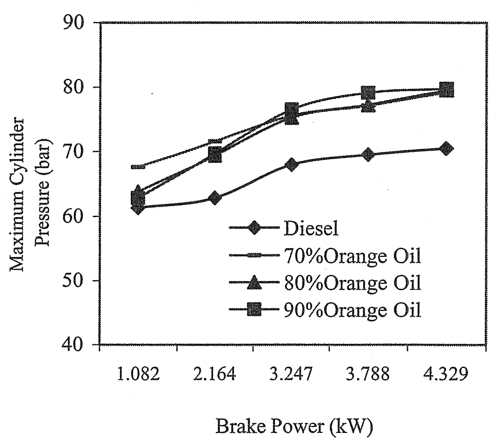

Fig. 4 Variation of Peak Cylinder Pressure

4.1.4 Maximum Rate of Pressure Rise

Fig. 5 shows that the rate of pressure rise (ROPR) is lower for orange oil blends than the diesel fuel due to longer ignition delay and longer combustion duration of orange oil blends. It is shown in Fig. 3 that the fraction of premixed burning rate is more for orange oil blends than the diesel fuel, with slow burning and more combustion duration. This leads to a decrease in the rate of pressure rise for orange oil blends. The maximum rate of pressure rise is 3.4 bar / °CA, 3.4 bar / °CA, 3.3 bar / °CA and 3.8 bar / °CA for 70 %, 80 %, 90 % of orange oil blends and diesel fuel operation, respectively, at full load. In a compression ignition engine, the rate of pressure rise depends on the combustion rate in the initial stages, which in turn is influenced by the amount of fuel taking part in the uncontrolled combustion. The uncontrolled or premixed combustion phase is governed by the delay period. It is also affected by the mixture preparation during the delay period.

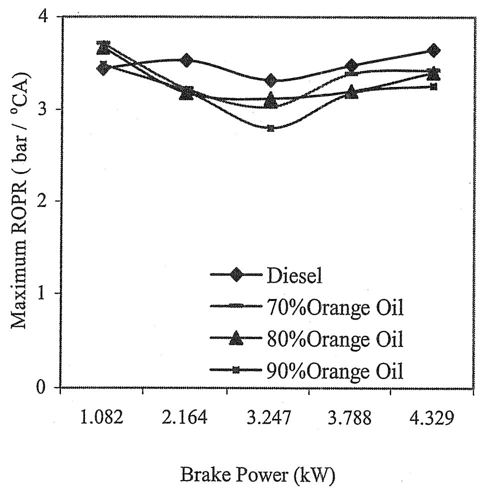

Fig. 5 Variation of Maximum Rate of Pressure Rise

4.1.5 Maximum Heat Release Rate

Fig. 6 illustrates the maximum rate of heat release and its corresponding crank angle for 70%, 80 %, 90 % of orange oil blends compared with the baseline fuel. Observation of the figure indicates that the maximum heat release rate for 70 % orange oil is 47 J/ °CA, for 80 % it is 49 J/ °CA, for 90 % it is 51 J/ °CA and for diesel it is 40 J/ °CA. The results show that the maximum rate of heat release decreases with an increase in orange oil blends at all operating conditions. This is due to slow burning with higher premixed combustion duration and higher ignition delay of orange oil blends.

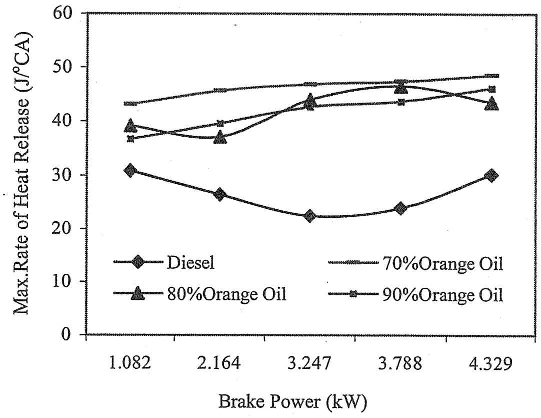

Fig. 6 Variation of Maximum Rate of Heat Release

4.2 Performance Analysis

4.2.1 Brake Thermal Efficiency

The thermal efficiency of orange oil blends is compared with base line data in Fig. 7. The brake thermal efficiency for diesel fuel at full load is 28.22 %. For 70 %, 80 % and 90 % orange oil, the thermal efficiency is 29.21 % and 29.84 % and 31.41 %, respectively. It can be observed that 90 % orange oil shows a better thermal efficiency of 31.4 %, which is 3.18 % higher than the diesel fuel at full load. It can also be seen from the figure that the improvement in brake thermal efficiency is more significant at higher brake outputs than at part loads with orange oil. It is known that at higher engine brake outputs, the combustion chamber surface is relatively hot and this might assist in better vaporization of the fuel and hence an improvement in the brake thermal efficiency [18]. In addition to that, the flame propagation and ignition limits play a key role in the changes in the performance of the fuel blend [15].

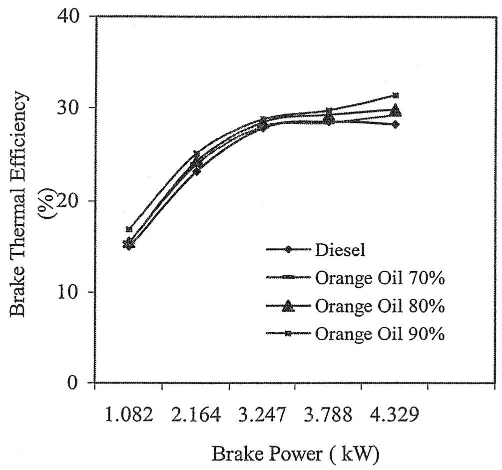

Fig. 7 Variation of Brake Thermal Efficiency

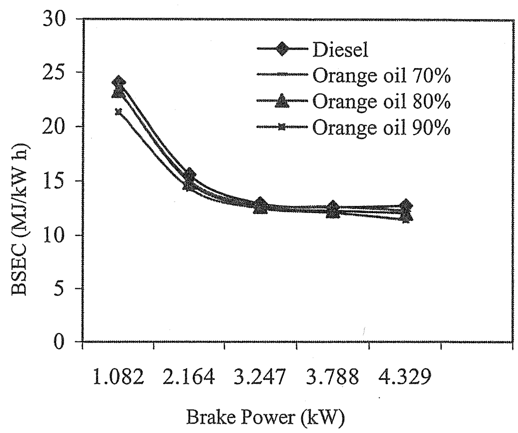

Fig. 8 Variation of BSEC

4.2.2 Brake Specific Energy Consumption (BSEC)

Fig. 8 shows the variation of brake specific energy consumption (BSEC) with brake power. It is seen that the BSEC is lower for orange oil blends because of better atomization of the fuel as compared to that of diesel fuel, which has been compensated for the required amount of energy for the same output. The trend shows that there is no significant difference, except marginal changes, in orange oil blends when compared with diesel. At minimum load the BSEC is 24.05 MJ / kWh for diesel and for 70 % orange oil blend it is 23.28 MJ / kWh, for 80 % orange oil blend, it is 23.22 MJ/kWh; For 90 % orange oil blend, it is 21.31 MJ/ kWh. At full load the BSEC is 12.75 MJ / kWh for diesel and for 70 % orange oil blend, it is 12.32 MJ / kWh, for 80 % orange oil blend it is 12.06 MJ/kWh and for 90 % orange oil blend it is 11.46 MJ/ kWh. It is seen that the BSEC decreases with increase in orange oil blends.

4.3 Emission Analysis

4.3.1 Carbon Monoxide

The variation of CO emission with brake power is shown in Fig. 9. Generally, diesel engines produce lower CO due to a higher supply of oxygen. The CO emissions of the orange oil blends were marginally lower than that of diesel fuel at minimum load conditions, while they were slightly lower than the diesel fuel at part load and full load. At lesser loads, the orange oil blends have only a marginal effect on the CO emissions due to dominant premixed lean combustion with excess oxygen. The lower levels of CO at part load and full load are a result of longer ignition delay, due to late combustion in the premixed periods of the orange oil – air mixture. This leads to a lower combustion temperature at full load [11]. The CO varies from 3.1 g/kWh at lower load to 0.6 g/kWh at full load for diesel fuel. The CO at lower load for 70 %, 80 % and 90 % of orange oil blends is 2.6 g/kWh, 2.4 g/kWh, and 2.3 g/kWh which is lower than that of diesel fuel. Similarly, the CO at full load for 70 %, 80 % and 90 % orange oil blends is 0.35 g/kWh, 0.3 g/kWh, and 0.25 g/kWh, which is also lower than that of diesel fuel.

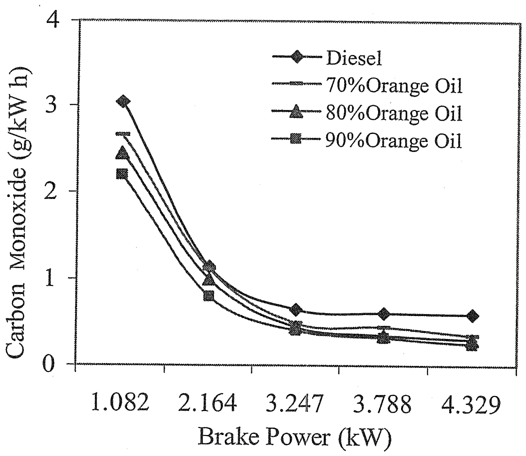

Fig. 9 Variation of Carbon Monoxide

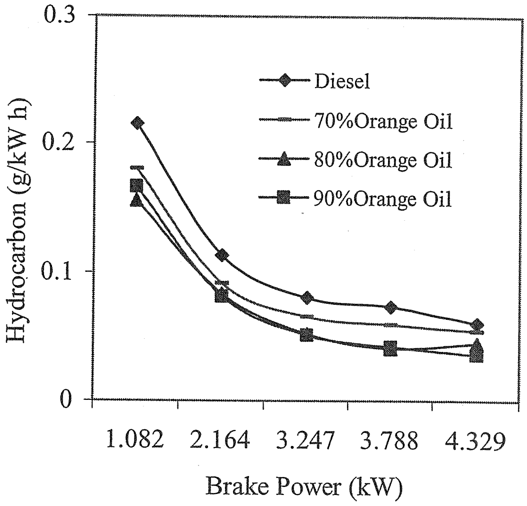

Fig. 10 Variation of Hydrocarbons

4.2.2 Hydrocarbons

The variation of HC emission with brake power for orange oil blends and diesel is depicted in Fig. 10. The HC emission decreased with an increase in percentage of orange oil blends. Among the orange oil blends, the 90 % orange oil blend shows the lowest HC emission at full load operation, compared to other orange oil blends. The HC emissions of orange oil blends are lower than that of diesel fuel. This is due to complete combustion, which reflects in higher brake thermal efficiency of orange oil blends than the diesel. The HC emissions for 70 %, 80 % and 90 % of orange oil blends are 0.18 g /kWh, 0.15 g /kWh, 0.16g /kWh at part load and 0.054 g / kWh, 0.045 g/kWh, 0.036 g/kWh at full load operation respectively. For diesel, it varies from 0.21 g / kWh to 0.07 g / kWh. As the ignition delay period lengthens, for example, due to a reduction in the fuel cetane number, a proportion of mixture may become leaner than the lean combustion limit. Often this may occur at the perimeter or periphery of the fuel spray, where vaporized fuel may be stripped off and carried away by the swirling air. This may be the reason for the reduction in HC emission for orange oil compared with diesel [19].

4.2.3 Smoke

Fig. 11 shows the variation of smoke with brake power for the orange oil blends and diesel fuel. It may be observed from the figure that smoke decreases with an increase in the orange oil blend. The 90 % orange oil blend gives lesser smoke compared to other orange oil blends at part load and this may be due to better and complete combustion of the orange oil. Oxygen content in the fuel may also be the reason for lower smoke levels for all the orange oil blends, compared to that of diesel fuel operation. At full load, smoke for diesel is 0.89 BSU, for 70 % orange oil, it is 0. 0.85 BSU, for 80 % orange oil it is 0.83 BSU, and for 90 % orange oil, it is 0.82 BSU.

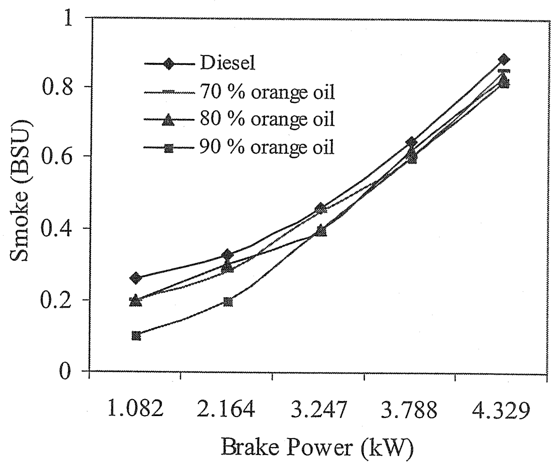

Fig. 11 Variation of Smoke

4.2.4 Nitric Oxide

The emission of NO_x is significantly influenced by the in-cylinder gas temperature and availability of oxygen during combustion. There is an increase in NO_x emissions due to the enhancement of the oxygen level of orange oil as seen in Fig. 12. Another probable reason for the increase in NO_x may be due to the higher intensity of heat release in the premixed combustion phase for orange oil. Differences in the fraction of injected fuel burnt during the premixed combustion phase have also been proposed as a reason for the increased NO_x with bio-diesel. A relationship between exhaust gas temperature and NO_x emissions, increases the NO_x with increasing exhaust gas temperature [15]. At full load the NO_x for 70 % orange oil is about 15.72 g / kW h, for 80 % orange oil it is 15.8 g / kW h, for 90 % orange oil it is16.3 g/kW h and for diesel it is 12.76 g / kW h.

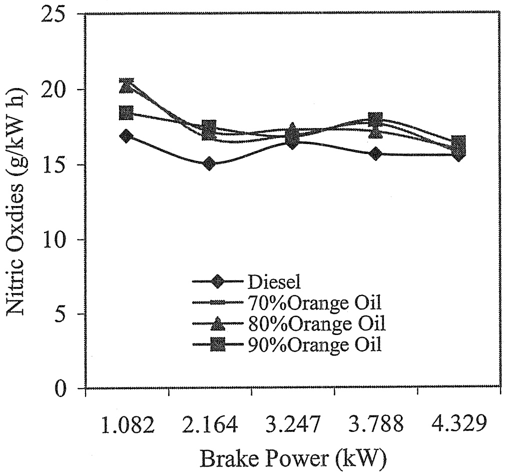

Fig. 12 Variation of Nitric Oxide

5. Conclusions

A single cylinder compression ignition engine was operated successfully using orange oil as an alternative fuel and the performance and emissions were compared with diesel fuel. The following conclusions are drawn based on the experimental results:

- Longer ignition delay and higher combustion duration are noticed for orange oil blends, compared to diesel. The heat release rate was higher for orange oil blends than for diesel.
- In-cylinder pressure was 99 bar for 90 % orange oil blend compared to diesel which was 71 bar at maximum power output.
- The brake thermal efficiency at full load increased to 31.4 % for 90 % orange oil from 28.2 % for diesel.
- HC and CO emissions are lower for orange oil than for diesel.
- Smoke level was lower for orange oil blends than for diesel fuel.
- NO_x was higher for orange oil than for diesel.

Acknowledgement

The authors thank the management of St. Peter's Engineering College, Avadi, Chennai and College of Engineering, Guindy, Anna University, Chennai for carrying out the experiments.

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