Lemon Essential oil – A Partial Substitute for Petroleum Diesel Fuel in Compression Ignition Engine

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Abstract- The demand for petroleum based fuel has grown in an extensive way because of the increasing industrialization and the growth in transportation sector. This growth has a direct effect on the economy and remains a monopoly in the fuel trade. Bio-fuels are available in a larger volume across the world due to the advantage that they can be directly blended with the petroleum fuels and the results obtained are better when compared to the standard values of neat diesel fuel. Such kind of bio-fuels can be extracted from lemon fruit and its availability is abundance across globe. This work aims in introducing a new bio-fuel called as Lemon Essential Oil (LEO) which can be obtained through steam distillation process of lemon rinds. A 20% LEO is blended with diesel (LEO20+ Diesel80) and it is fed as fuel to the engine. The various properties of LEO are examined and they are compared to mineral diesel. The experimental investigation revealed that brake thermal efficiency of LEO20 is marginally higher than diesel at higher loads. Also significant reduction is observed for carbon monoxide, unburned hydrocarbon and smoke emissions. However, the oxides of nitrogen in LEO20 is comparatively higher than petroleum diesel at rated power output. Furthermore, the in-cylinder gas pressure of LEO20 is followed the similar trend with diesel fuel. In addition, higher heat release rate is also observed for LEO20 from the tested results. Hence, the present research work is showed that the 20% of Lemon Essential Oil could be partial substitute for conventional diesel engine in near future.

Keywords- Biofuel, lemon essential oil, substitute for diesel fuel, performance, diesel engine.

1. Introduction

Petroleum-based fuels are used extensively in the transportation sector around the world. As the enthusiasm for these fuels build, the expenditure of the fuel has transformed to be a misfortune for the nation's economy. To meet the growing demand the country has to import rough oil which creates various impacts on the nation's economy. The ceaseless increase in population and massive utilization of fossil fuels pushes its daily energy needs to a deadlock situation, which leads to shift for an alternative and sustainable source of fuels [1, 2]. The ever increasing usage of fossil fuels can lead to shortage in near future, and hence researchers are trying to find an alternative and sustainable source of energy. Biodiesel is found to be a cleaner renewable fuel and is a best substitute for petroleum diesel in CI engine without much modification. Other than biodiesels the alternate energy source based on alcohols and emulsion fuels are also employed for partial substitution or replacement in diesel engine operation [3].

In order to meet growing demand in energy source the biodiesels are prepared from readily available materials like fruits, vegetables, animal fats, etc. Biodiesels extracted from natural means are gaining overall consideration due to their availability in numerous parts of the world and are more efficient, nature friendly as well as more economical also. Since, some of the important properties of vegetable biodiesel extracts are found out to be nearer to diesel fuel, it is considered as good alternative source of energy for use in the internal combustion engines. Such type of fuels can reduce the cost and it is clearly known that biofuels have shown good results on comparison with diesel [4]. Numerous works are experimentally verified by researchers on biodiesel and bio fuels related work on diesel engine for the partial substitution as a perfect alternative fuel. Such partial substitution is followed in some countries and helps in reducing the cost of fuels without sacrificing the performance parameters of the diesel engine [5, 6]. Dhinesh et al. has studied the impact of partial substitution for diesel fuel on cymbopogon flexuosus biodiesel in CI engine. They concluded that 20% substitution with diesel shows a better thermal efficiency with lesser emissions of carbon monoxide, hydrocarbons and smoke in the exhaust [7]. Vallinayagam et al. [8] partially substituted the biodiesel extract from pine oil which is used in a diesel engine without any modification. Also they have tested varying the quantity of pine oil and a better performance is obtained for the operation 100% of pine oil. Emission values of pine oil seem to be better when compared to conventional diesel fuel.

For the probable partial alternate of diesel fuel the biodiesel obtained from calophyllum inophyllum seed and the blends (B10 and B50) are tested for various fuel property characteristics is carried by Venkanna and Venkataramana. The results ensure that the property of the calophyllum inophyllum blend is in the limit of ASTM standard and they concluded that the biodiesel blends are promising substitute for diesel engine [9]. Muthukumaran et al. [10] experimentally obtained the performance and emission characteristic of different calophyllum inophyllum blends in diesel engine. The studies reveal that B25 blend shows a comparable in thermal efficiency and emissions with diesel fuel. Helin et al. [11] experimentally tested diesel engine with various blends of 2-methylfuran (MF) for the partial substitution. The diesel-MF20 blend shows a better brake thermal efficiency but the oxides of nitrogen shows an increment across all the engine loads. De-gang et al [12] proposed diesel ethanol blend as a partial replacement of diesel fuel operation. The performance result shows that the brake thermal efficiency has marginally increased with an addition in more ethanol content in the fuel blend.

Within this context, this work mainly focuses on finding a suitable alternative for the current demand of petroleum fuels and partially substituted with mineral diesel fuel in a CI engine. The availability of lemon is very huge compared to any other fruit all over the globe and it is widely used in the food sector, cosmetics and medicine sector. The appearance of the oil is colourless like water and its viscosity is very low. Citrus lemon (CL) comes from Rutaceae family and commonly known as limaosicliano in Brazil. The physical and chemical properties shows the main constituents of citrus lemon which are limonene (LIM) and beta pinene (PIN) as the major two components [13]. However, the lemon rinds (peels) are not consumed or utilized in the food consumables and hence it can be utilized as a bio waste. The lemon essential oil from waste citrus peels which is a source of several bio active compounds is rich in D-limonene. [14]. Also, the main reason for choosing the particular oil is that it can be directly used without been taken for esterification or trans-esterification methods as a result it helps to decrease cost and less time consuming. Hence, the biofuel is extracted from lemon rinds through the steam distillation process and blended with diesel for experimental testing. The Steam distillation process is done in order to extract oil from the fruit peel as it is the most clean and extensive production process [15-18]. Ahmed et al. [19] carried out an extensive research work by blending 20%, 40%, 60% and 80% of lemon grass oil with neat diesel by volume and they reported that brake specific fuel consumption and emissions have reduced to a reasonable limit.

The goal of the current study arises from the various literatures ensures that there no research work has been carried out as a partial substitute using lemon essential oil in the operation of diesel engine. Hence, this work focus to evaluate the possible utilization of lemon essential oil as a diesel blends for ensuring the performance evaluation in diesel engine application. In this work the lemon essential oil of 20% is blended with 80% of diesel and the fuel named as LEO20 was used as fuel in the CI engine. The values obtained from the experimental analysis of performance, emission and combustion are compared with the values of neat diesel. The study shows that the lemon essential oil blend (LEO20) showed an equivalent performance with diesel and it is found to be a best partial substitute to the diesel fuel due to the rising issues related to the petroleum resources.

2. Lemon Essential Oil Preparation

Steam distillation technique is accomplished in this work for the extraction of lemon essential oil (LEO) from the rinds of lemon. This method is one of the pioneer techniques that are being utilized as a part of the extraction of fundamental oils. The schematic setup of the steam distillation process is shown in Fig.1 and this process involves the flow of steam into the chamber which consists of lemon rinds (peel).

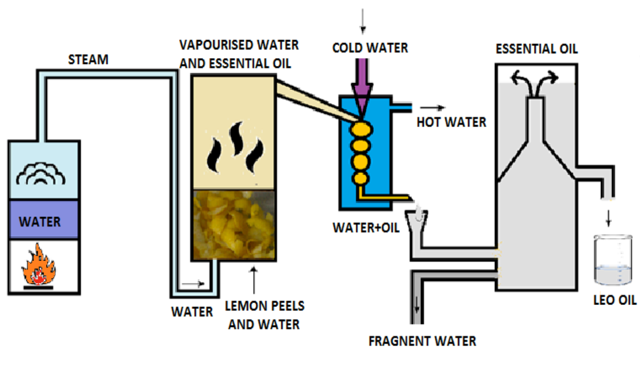

Fig. 1. Steam distillation process in the preparation of lemon essential oil

Lemon peels are taken in to a distillation chamber that has boiling water which produces an enormous amount of steam and this steam is evaporated to a condensing chamber. The water vapour and oil obtained from boiling chamber is brought to condensing chamber via spiral tube. This chamber is supplied with constant flow of cooled water. Cold water supply is kept constant as it condenses the vapour as it passes out of the chamber. The condensed material is made to exit the chamber and it gets collected in a separate chamber that is similar to that of a separating funnel. In the new chamber the separation process is carried out, where oil and water is collected at different points. The oil thus obtained is the lemon essential oil and quality of the distilled oil is depending on various factors such as duration of the process, temperature, pressure and refining equipment nature.

3. Characteristics of Extracted Lemon Essential Oil

The various properties of Lemon essential oil are found out as per standards. They are being tabulated in table 1. The values are being compared with neat diesel. It can be noted that the density of lemon essential oil is greater than that of neat diesel at 15°C. It can be seen that the viscosity of the LEO is very low when compared to that of diesel. This property gives it a watery effect when touched. The other main reason for the low viscosity is the absence of fatty acids. This property helps in a way that the transesterification process can be avoided here. The calorific value of diesel and LEO blend is almost similar to each other and other important properties of the oil are listed in the table.

Table 1. Properties of the lemon essential oil and diesel fuel

Properties	Standard in ASTM	Diesel	LEO20
Density kg/m^3	D1298	822	843
Kinematic Viscosity @ 40°C	D445	3.6 x 10^{-6}	2.5 x 10^{-6}
Gross Calorific Value kJ/kg	D420	42700	42059
Cetane index	D976	52	44
Sulphur content in %	D5453	<0.005	<0.005

4. Experimental Setup

The experiments are performed on a Kirloskar TAF1 single cylinder diesel engine and the specifications are listed in Table 2. The torque measurements are recorded with the help of an eddy current dynamometer (air cooled) along with a load cell. The complete test setup is shown in Fig. 2. The load is varied from minimum to the maximum capacity of the engine by keeping speed constant at 1500 rpm. Experiments are conducted at a constant injection timing of 23°bTDC and 200 bar of injection pressure. Fuel consumption is measured using a stop watch and standard burette system. Digital K-type thermocouple (chrome alumel) is used to measure the engine exhaust gas temperature. An AVL-digas 444 five gas analyzer is used to analyse the exhaust gas constituents. Smoke level is measured using standard AVL 437C smoke meter. AVL combustion analyzer is employed for the various combustion parameters such as rate of pressure rise, cumulative heat release, etc. AVL pressure transducer is employed to measure in-cylinder pressure and the crank rotation measurement is accomplished with help of AVL 365C encoder. The combustion characteristics of diesel engine are analysed using AVL INDIMICRA software by acquiring the in-cylinder pressure data with respect to crank angle by a data acquisition system. Performance, combustion and emission parameters are obtained for lemon essential oil blend (LEO) as shown in Fig.3 and the results obtained are compared and analysed with conventional diesel for various operating loads.

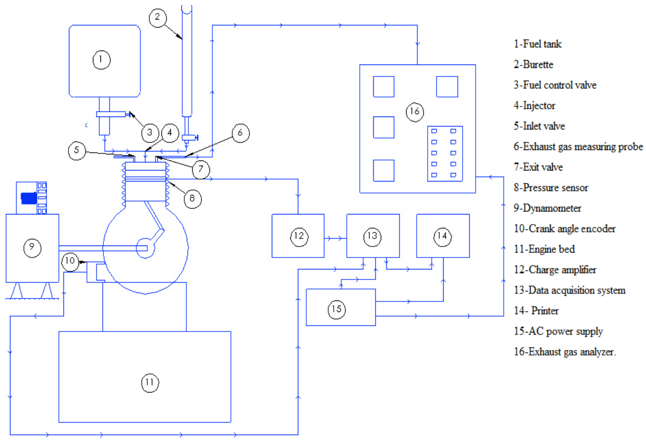

Fig. 2. Schematic arrangement of experimental test bed setup

Table 2. Specification of engine

Engine parameters	Specification
Ignition	Compression Ignition
Bore	87.5 mm
Stroke	110 mm
Compression Ratio	17.5:1
Speed	1500 rpm
Rated Power	4.4 kW
Number of engine and	Single cylinder and air
Injection timing	23° bTDC

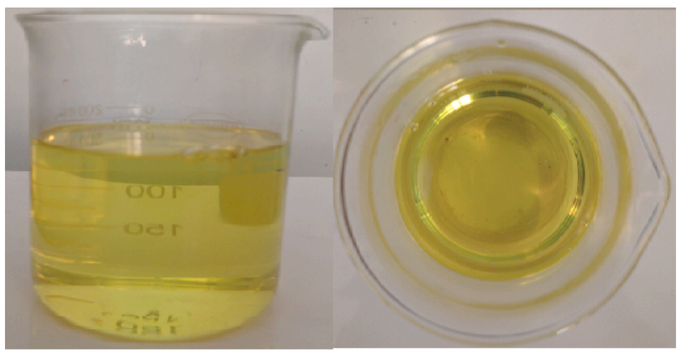

Fig. 3. Lemon essential oil blend (20% LEO + 80% diesel)

5. Results and Discussion

Diesel engine operated at different loading condition varied from zero load, 25% to 100% for both the diesel and LEO20 fuels. The performance, combustion and emission parameters of both the fuels are obtained and the results are compared.

5.1. Brake thermal efficiency

BTE is the evaluation of an engine's capacity to change the heat energy of fuel to mechanical energy. The trend for BTE of LEO20 biofuel and neat diesel is depicted in Fig 4. From the graph it's clear that LEO20 have better BTE than diesel particularly at higher loads and for the part load conditions the efficiency value is matched with the diesel fuel. BTE mainly depends on the factors like calorific value and brake specific fuel consumption. The calorific value of LEO20 is closely matched with diesel fuel which leads to provide the same BTE in part load conditions. As the viscosity of the biofuel is low it helps to increase fuel atomization, vaporization, and combustion which helps an increase in BTE.

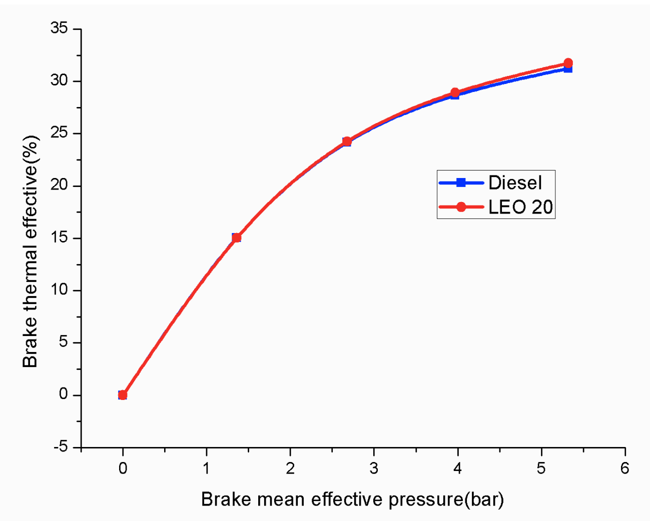

Fig. 4. Variation in BTE with BMEP

5.2. Performance of the engine economy

Engine economy is one of the important characteristic in the performance evaluation and it is analysed using the parameters like BSFC and BSEC. Fuel mass utilized for the generation of unit power is called as BSFC and BSEC is the energy accomplished for unit power generation output which is an indication of efficiency. Comparative assessment of BSFC and BSEC is depicted in Fig.5 and 6 respectively which are the indication of engine economy for evaluating the performance of LEO20 blend.

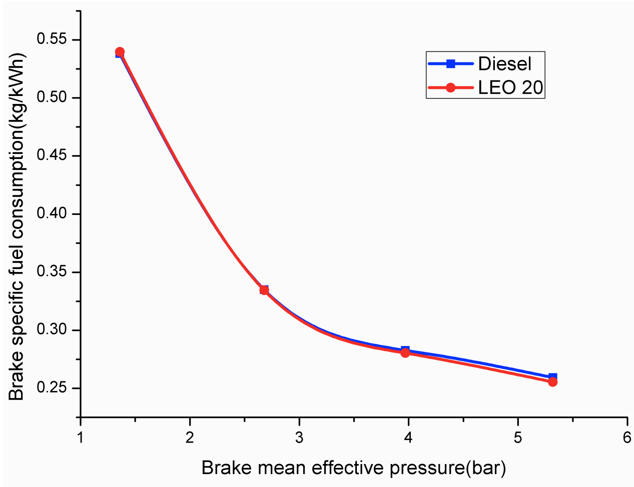

Fig. 5. Variation in BSFC with BMEP

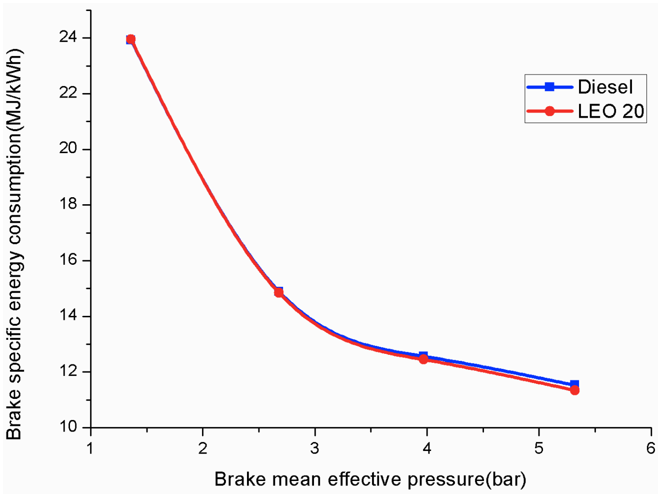

Fig. 6. Variation in BSEC with BMEP

Both the engine economy parameters BSFC and BSEC for LEO20 are very close to diesel under different operating conditions and for the full load the values are increased and compared with diesel. From the analysis it clear that the overall fuel consumption of lemon essential oil blend is comparatively lesser than diesel fuel. This condition is prevailing due to the better mixing and evaporation of LEO20 with the air molecules when compared with diesel. Also the lower viscosity of LEO20 boosts up atomization process and helps in faster and complete combustion.

5.3. In-cylinder pressure characteristic of diesel and biofuel blend

The combustion study on CI engine is a critical and most important task as this process depends upon various factors like properties of fuel, fuel injection system, combustion chamber design criteria and engine working conditions. Variation of pressure inside the combustion chamber for both the fuels is depicted in Fig.7 (a) and (b) respectively for 25% and 100% engine load conditions. Fuel quantity entertained and burned in the premixed combustion region (uncontrolled combustion phase) is the responsible for the variation of the in-cylinder combustion pressure. Mixing phenomena of the fuel with air and burning ability is understood from the variation of the gas pressure inside the cylinder. In the present work the average data of 100 consecutive cycles are obtained from the experimentation and the data's are correlated in order to minimize the cyclic variations in the combustion process.

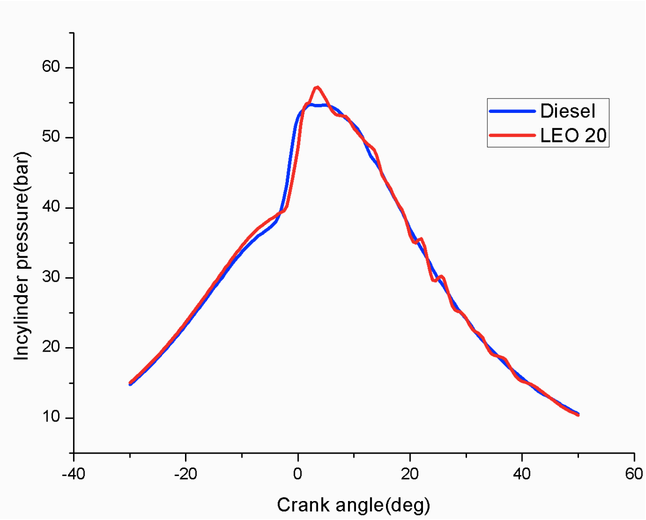

Fig. 7 (a). In cylinder pressure variation with crank angle for 25% load

As the viscosity of the LEO20 comparatively lower than the diesel fuel leads to provide a better atomization due to the ease in the fuel molecule breakage, which causes the combustion to be complete as compare to diesel fuel. However, slight variations and random variations are observed from the curve at the peaks of in-cylinder

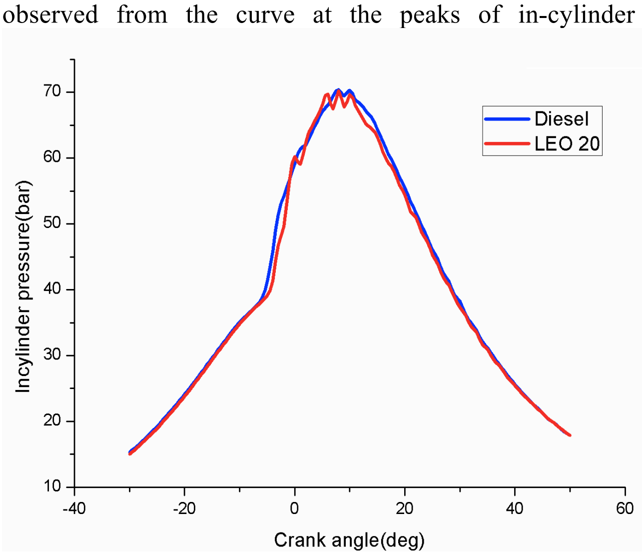

Fig. 7 (b). In cylinder pressure variation with crank angle for 100% load

pressure curve for 25% and 100% loading conditions respectively. The longer ignition delay may be the reason for peaks occurred for in cylinder curve. Hence, the combustion takes place slowly due to the delay period and causes to accumulate the fuel which leads to an increase in pressure rapidly in the peak of the combustion. However, the indicated mean effective pressure (IMEP) represented in the Fig.8 shows the higher value for the diesel fuel across the entire load as compare to LEO20 blend. Since, IMEP is the indication of average pressure acting inside the cylinder during the particular consecutive cycles and this shows that it always higher for diesel fuel.

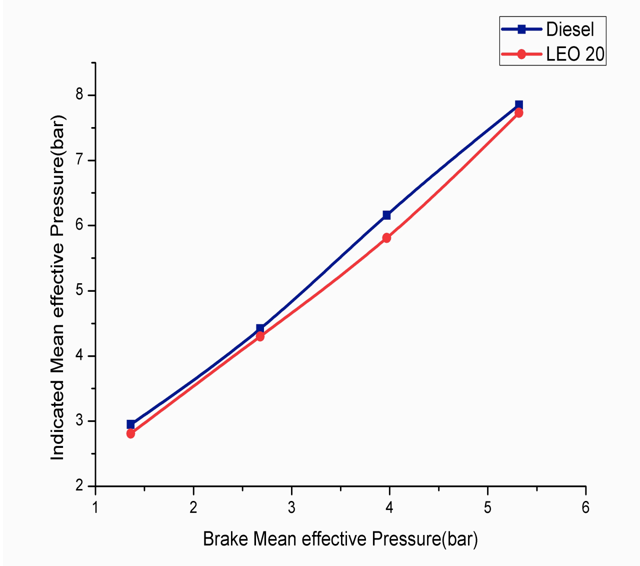

Fig. 8. Variation of mean effective pressure for various engine loads

5.4. Heat release rate characteristic of diesel and biofuel blend

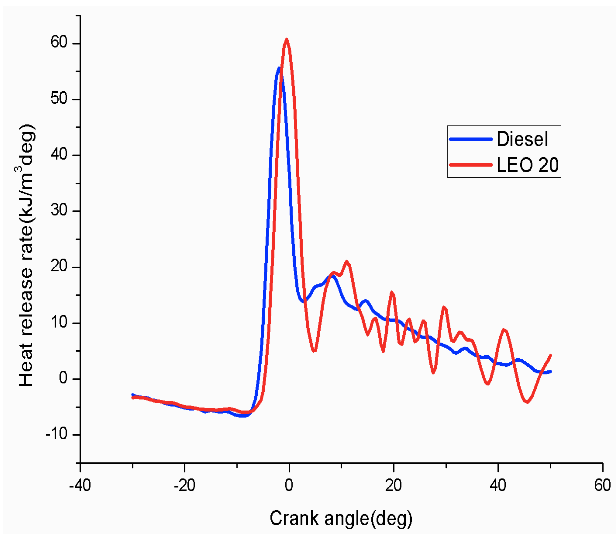

Fig. 9 (a). Variation in HRR with crank angle for 25% load

The combustion process of any alternative fuels can be analysed and investigated by calculating the HRR and ignition delay in the combustion chamber. The HRR for both fuels is shown in Fig. 9 (a) and (b) at 25% and 100%

engine load conditions. The properties of fuel plays an important role in determining the combustion characteristic of the fuel and lemon essential oil because LEO is less viscous it can easily evaporate and get mixed with the air. Because of higher ignition delay period the accumulated mixture and also the trapped air fuel mixture

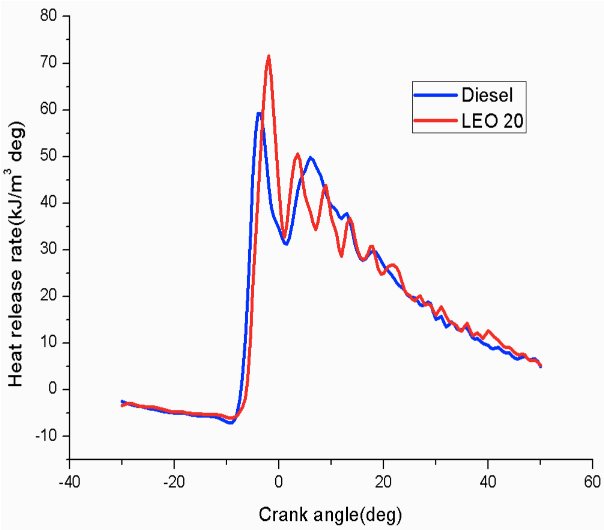

Fig. 9 (b). Variation in HRR with crank angle for 100% load

present inside the combustion chamber will start to burn after the delay which leads to the higher magnitude of initial rapid HRR. Since the combustion takes place all of a sudden, the complete amount of fuel is burnt resulting in higher premixed HRR which causes the heat release rate of LEO20 fuel to be greater than diesel fuel for both the loads. Also, the lower cetane number additionally adds the reason for premixed combustion and resulting in faster heat release for lemon essential oil.

5.5. Ignition delay period in the combustion process

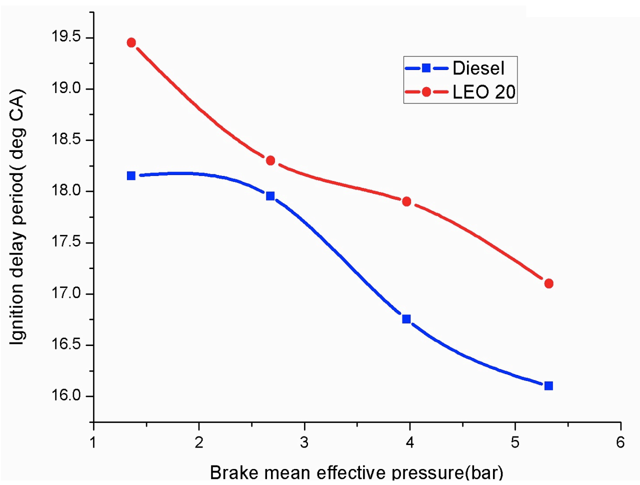

Fig. 10. Variation in ignition delay period for various engine loads

The ignition delay can be defined as the difference in degree between the start of fuel injection and start of fuel combustion. As the lemon essential oil has lower cetane number compared to diesel it creates ignition delay for longer duration as shown in Fig.10. As the cetane number and viscosity of the LEO is lesser than diesel which is one of the most influencing factors for ignition delay period. Hence, it can be interpreted that there is a higher ignition delay for lemon essential oil fuels because of the low cetane index [20, 21].

5.6. Brake specific oxides of nitrogen emissions

Brake specific NOx across various engine loads is shown in Fig.11 for diesel and biofuel. It is evident from the graph that NOx emissions for LEO20 at all operating conditions are higher than conventional diesel. This is due to higher temperature brought on by prolonged premixed burning and also due to the increased delay period, there is build-up of air-fuel mixture inside the

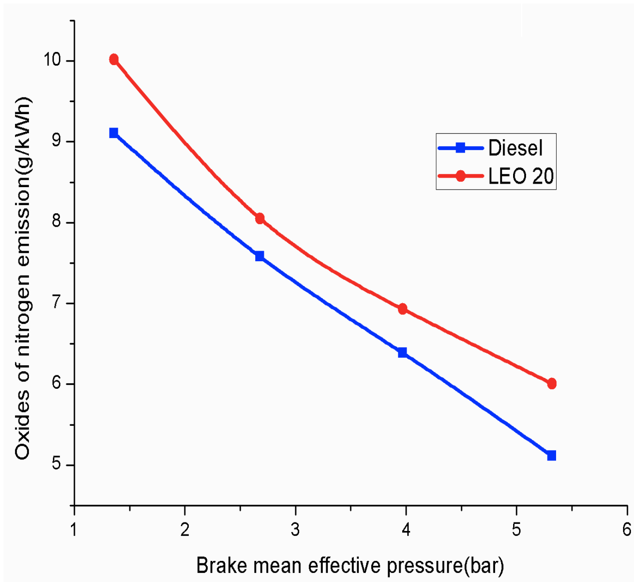

Fig. 11. Variation in oxides of nitrogen with various engine loads

combustion chamber for lemon essential oil. Hence, the accumulation of mixture and increase in peak combustion temperature is due to low cetane number of fuel, causing liberation of more heat. Hence, the higher temperature causes to produce more NOx as compare to the diesel fuel.

5.7. Soot content in the emission

Soot particle in the exhaust is the apparent sign for incomplete combustion process and the soot content consists of solid carbon, fraction of hydrocarbons from fuel as well as the lubricating oil particle. Comparisons between the soot formation between diesel and LEO fuels is shown in Fig.12 for various brake mean effective pressure. From the figure it is clear that LEO20 has lower soot formation as compare to the diesel fuel and at higher load condition it is noted that soot formation is reduced by 34%.

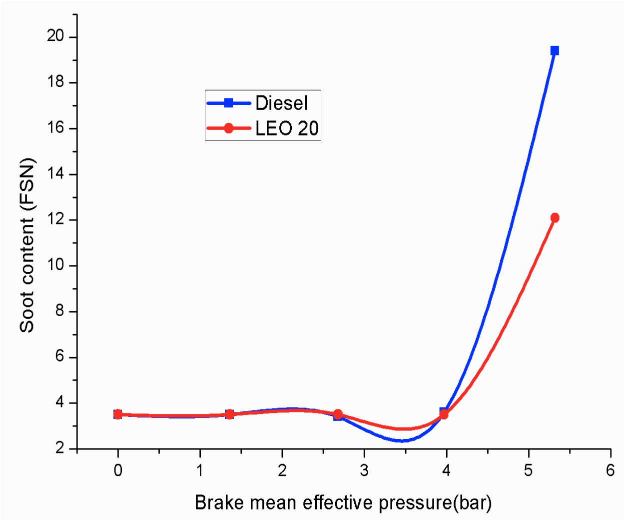

Fig. 12. Variation of soot content with various engine loads

5.8. Brake specific carbon monoxide

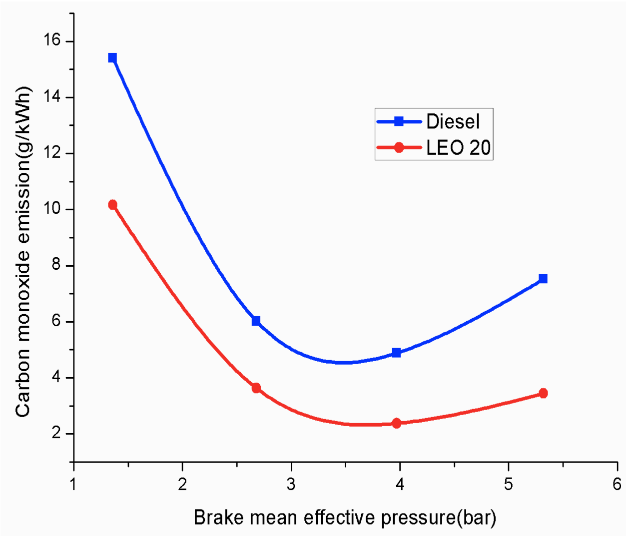

Fig. 13. Variation in carbon monoxide with various engine loads

CO emissions are formed due to inadequate quantity of oxygen content within the combustion chamber. Formation of CO is also due to the variation of air-fuel mixture from the chemically correct ratio into the cylinder causes to form the carbon monoxide. From Fig.13 it is clear that CO emissions of LEO20 blend is always lesser than that of diesel fuel for entire loading conditions, which ensures good combustion is accomplished at all loads of lemon essential oil. It is noted that there is a 31.3% decrease in CO emission at high loading condition whereas 39% decrease is noted for initial loading.

5.9. Brake specific unburnt hydrocarbons

The main reason for unburned hydrocarbons (UBHC) formation is because of incomplete combustion within the combustion chamber. The incomplete combustion is persisting because of improper mixing or by means of chemically incorrect air-fuel mixture. From the Fig.14 it is evident that UBHC emission of LEO20 is always lesser than diesel fuel across entire engine operating load which shows better combustion properties is existed in lemon essential oil. Hence it is found that 10% decrease in HC is noted for LEO at high load conditions.

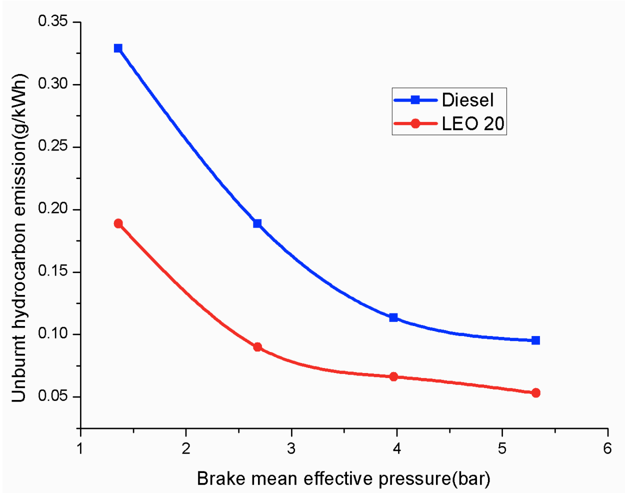

Fig. 14. Variation in unburned hydro carbons with various engine loads

6. Conclusions

The present experimental work investigates the possible substitution of diesel fuel in CI engine operation with lemon essential oil. Steam distillation process is employed for the extraction of lemon essential oil from the lemon rinds (peel). Performance, combustion and emission analysis of LEO20 blend is compared with diesel fuel and results are compared. LEO20 blend shows a slight increment in BTE and lesser BSFC than that of diesel at all loads. LEO blend has lower viscosity and cetane number causes ignition delay of the fuel to be higher. Due to the higher delay period, a rapid rise in the in-cylinder pressure at the uncontrolled phase of the combustion is observed. Higher heat release rate is observed during premixed combustion phase for LEO 20 biofuel blend at both 25% and 100% loading conditions, due to more accumulation of fuel during ignition delay period. Also the emissions values of the biofuel blend is lesser than diesel fuel expect the NOx. However, the lemon essential oil can be utilized for powering the CI engine directly without undergoing any trans-esterification processes. Hence, the overall performance and emission characteristic of the lemon essential oil is better than the diesel fuel which clearly indicates that lemon essential oil can be partially substituted for the diesel fuel.

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Nomenclature

ASTM – American Society for Testing and Materials
BMEP – Brake mean effective pressure
BSEC – Brake specific energy consumption
BSFC – Brake specific fuel consumption
bTDC – before top dead centre
BTE – Brake thermal efficiency
CI – Compression ignition
CL – Citrus lemon
CO – Carbon monoxide
HRR – Heat release rate
IMEP – Indicated mean effective pressure
LEO – Lemon essential oil
MF – Methyl furan
NOx – Oxides of nitrogen
UBHC – Unburned hydrocarbons