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Comparative study of combustion and emission studies on Variable Compression Ratio engine utilizing edible oil and non-edible oil biodiesel

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Abstract*— The present energy scenario depicts the fossil fuel crisis along with the detrimental effects on the environment caused by exhaust emissions like HC, CO, CO_2, and NO_X, and particulate emissions. Fossil fuels are considered to be the primary source of greenhouse gases (GHGs) which is the leading origin behind the universal environment deprivation. The present work represents the comparative study of combustion characteristics and exhaust emission in unmodified diesel engine utilizing low percentage of methyl esters of edible oil (waste cooking oil-WCME) and non-edible oil (linseed oil-LME) at compression ratio 17 and 18. The comparative studies of peak pressure inside the cylinder, heat release rate and exhaust emissions like HC, CO, CO_2, and NOx, have been made during conduction of the various experiments on a 4-stroke unmodified diesel engine. All results of alternative fuels are compared with standard diesel.

***Keywords*— Variable Compression Ratio; linseed methyl ester (LME), waste cooking oil methyl ester(WCME), alternative fuels**

I. Introduction

The numerous researchers shown their interest in the ecological pleasant diesel fuels which is mainly due growing universal concern caused by air pollution by internal combustion engines. However, the many of the investigators have produced results with decline in the exhaust emissions of conventional diesel engines. The forecasts of scarcity of fossil fuel lead to numerous investigations in many nations to substitute petroleum based diesel fuel with alternative fuels such as biodiesel, ethanol etc. Currently, neat biodiesel and its blends are used as an alternative of petroleum based diesel fuel by different companies because biodiesel accomplishes the ASTM D 6751-03 for USA and EN 14214 for European Union [1]. Although there are some fuel properties like cetane number, viscosity, almost non-aromatic emissions and free sulphur are observed when the biodiesel from different feed stocks are used [2,3]. The extent of fatty acids in biodiesel greatly affects the fuel properties of biodiesel which ultimately originates different engine characteristics such as combustion, performance, injection and exhaust emissions. Canakci et.al. [4] utilized from soybean oil and yellow grease with 9% free fatty acids and produced biodiesels on a direct injection (DI) engine (make: John Deere 4276 T). It was examined that the injection timing was quick in case of biodiesels however ignition delay was shorter when compared with diesel fuel. Hansen et. al. [5] also obtained the similar results when utilized canola oil methyl ester in a DI diesel engine. Peterson et.al. [6] reported that the viscosity of biodiesel can be reduced by universal adapted process of transesterification which is an effective method of manufacturing biodiesel as well as viscosity reduction. Ryan et.al.[7] found that the biodiesel produced from vegetable oils such as peanut, sunflower, cottonseed and soybean oils display features in contrary to those predictable in most other fossil fuels. The well-known fact about fossil fuel is its scarcity, rising cost and contamination to the ecological system, however to accomplish the deficiencies of fossil fuels, the selection of an substitute fuel to suit the conventional diesel engine without any modification is point of consideration with more economic and noticeable approach immediately. By this reason, there is requirement of a substitute liquid fuel that can be blend easily with diesel fuel whenever required. Thereby present study focused upon the utilization of low percentage of methyl esters of edible oil (waste cooking oil-WCME) to evaluate the comparative combustion characteristics and exhaust emission studies in unmodified diesel engine.

II. MATERIAL AND METHODS

In the present study waste cooking oil was made obtainable from a restaurant however linseed oil methyl ester was produced from raw linseed oil. The small scale transesterification process was performed in laboratory and biodiesel was produced utilizing methanol to oil ratio of 6:1 with catalyst potassium hydroxide (KOH) taking (1% of oil by weight). Thus by the triglycerides of vegetable oils was converted to their monoester by reacting them with alcohols to reduce viscosity and improve cetane number of fuels. The fuel samples were prepared (% by volume) by addition of WCME and LME proportions in standard diesel fuel. Proportions of three blends of WCME and LME were varied as 15% (WCME15, LME15), 20% (WCME20, LME20) and 25% (WCME25, LME25) by volume with neat standard diesel. Homogeneity and stability of all biodiesel blends were examined exhaustively. The main fuel properties of various blending stocks and standard diesel fuel are shown in table 1. A single cylinder, naturally aspirated, four stroke, and direct injection diesel engine was used in this experiment. Experimentation trials were performed with engine rated speed at 1500 rpm at variable compression ratio 17 and 18 at different load conditions. The engine set up used in the tests is shown in Fig.1. To attain different compression ratio, there are numerous methods; one of them is tilting cylinder block arrangement which was given in setup to vary the combustion space volume i.e. clearance volume for change in compression ratio. This is achieved without stopping the engine and altering the combustion chamber geometry. The arrangement consists of a tilting block with six Allen bolts, a compression ratio adjuster with lock nut, and compression ratio indicator. For a chosen compression ratio within the range given, the Allen bolts provided for clamping the tilting block are loosened slightly. The lock nut is loosened on the adjuster and the adjuster is rotating to set the compression ratio on the compression ratio indicator marking. Thus locking the adjuster by the lock nut and all the Allen bolts are to be tightened gently. The different performance parameters were measured from engine set up. AVL DI Gas analyzer was used to measure the HC, CO, NOX and CO2 emissions. The specification of the diesel engine is shown in Table 2. Whereas the specifications of AVL DI Gas analyzer and AVL Smoke meter is shown in Table 3.

Table 1: The fuel properties:

S. No.	Fuel	Kinematic Viscosity (cSt)	Calorific Value(MJ/kg)	Density (kg/m3)	Cetane Number	Flash Points(0C)
1	Diesel	2.94	47.23	832.6	48	76
2	WCME15	3.11	44.54	841.7	47	91
3	WCME20	3.19	45.37	844.5	47	93
4	WCME25	3.47	45.83	846.3	47	106
5	WCME100	4.25	41.67	874.8	46	196
6	LME15	3.15	45.78	832.8	48	93
7	LME20	3.21	45.52	833.1	48	100
8	LME25	3.27	44.98	833.7	48	108
9	LME100	4.25	38.17	835.8	47	200

Table 2: Engine Specification

Make	Kirloskar, India
Product	VCR Engine Setup
Rated Brake Power (kw)	3.50
Rated Speed(rpm)	1500
Number of Cylinder	One
Bore (mm)	87.5
Stroke (mm)	110.0
Connecting Rod length (mm)	234.0
Swept volume (cc)	661.45
Compression Ratio(variable)	12-18
Fuel injection starts before TDC	23^0
Cooling System	Water Cooled
Lubrication System	Forced Feed
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse

Table 3: Specifications of AVL DI Gas analyzer:

Emission	Range	Resolution
HC	0-20 ppm vol.	1 ppm
CO	0-10% vol.	0.01% vol
CO_2	0-20% vol	0.1% vol
NO_X	0-5 ppm vol	1 ppm

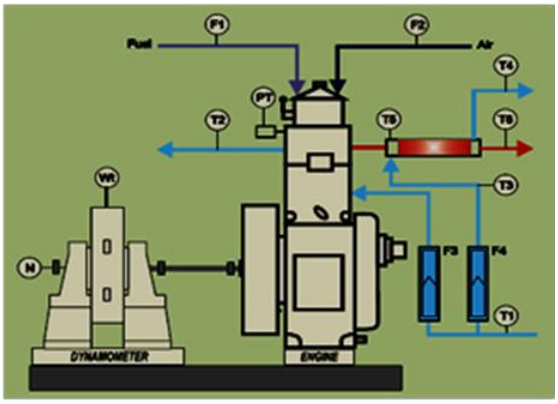

Fig. 1: Engine Set Up

III. RESULTS AND DISCUSSION

Combustion Characteristics

Cylinder Gas Pressure

The variations in the pressure inside the cylinder with crank angle for different blends of WCME and LME with standard diesel at compression ratio 17 and 18 are presented in Fig (2,3). The peak pressure inside the cylinder of a CI engine depends upon the portion of fuel burnt during the premixed burning phase. It was reported that at highest load and at compression ratio 17, the peak pressure inside the cylinder for the test fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 was achieved as 53.21bar, 51.89 bar, 53 bar, 50.57 bar, 52.03 bar and 49.56 bar respectively with respect to highest pressure of 56.37 bar for standard diesel fuel. However at compression ratio 18; The test fuels WCME15, LME15, WCME20, LME20 WCME25 and LME25 displayed the peak pressure values as 61.44 bar, 58.33 bar, 58.44 bar, 57 bar, 58.48 bar and 56.87 bar respectively with respect to diesel with peak pressure of 64.95 bar. The low viscosity of WCME and LME blends may cause the peak pressure inside the cylinder lower than other fuel. One of the other possible reasons may be due to the high heat release rate during premixed stage of combustion process or caused by variation in the exhaust temperature. While at compression ratio 18; all blends of alternative fuel exhibited the high values of peak pressure inside the cylinder due to increased temperature and pressure inside the cylinder. Results are confirmed by earlier investigations. [10-12].

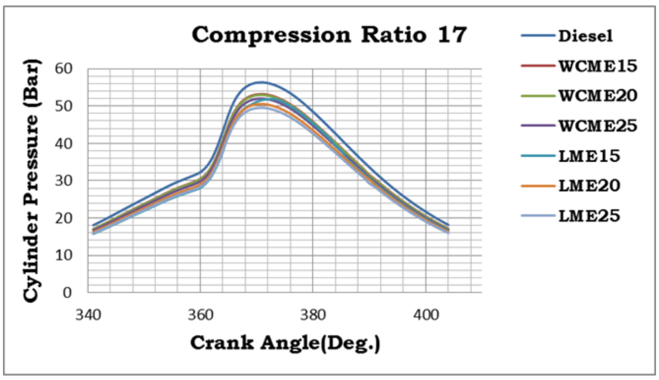

Fig. [2]

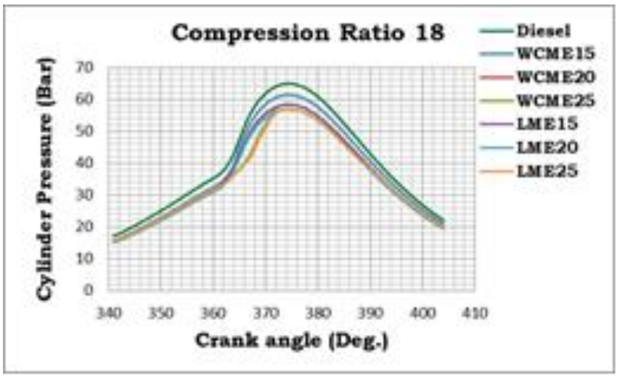

Fig. [3]

Net Heat Release Rate

The characteristics curves for heat release rate for different biodiesel blends for maximum load condition of engine at compression ratio 17 and 18 are presented in Figures(4,5). The test fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 showed the peak rate of heat release as 49.40 kJ/Deg., 46.12 kJ/Deg., 49.09 kJ/Deg., 45.61 kJ/Deg., 47.68 kJ/Deg. and 43.80 kJ/Deg. respectively. However Experimemt results showed that standard diesel fuel with peak heat release rate of 54.18 kJ/Deg. is highest among all alternative fuels. Although at compression ratio 18; that peak heat release rate (HRR) for fuel samples WCME15, LME15, WCME20, LME20, WCME25 and LME25 is found to be 51.97 kJ/Deg., 50.90 kJ/Deg., 51.86 kJ/Deg., 50.31 kJ/Deg., 50.96 kJ/Deg. and 49.15 kJ/Deg., when compared to that of diesel with 56.96 kJ/Deg. The pressure and temperature distribution inside the cylinder is extremely dependent on rate of and heat-release of the fuel. Henceforth it significantly affects the output power, consumption of fuel and the engine exhaust emissions. As far as CR 18 is concern; the peak heat release for different blends were found to be increased due to presence of enriched oxygen and increase in pressure and temperature inside the cylinder, thus combustion of biodiesel will be proper and hence the net heat release rate will be high. The consistency in results may be agreed by earlier research results. [13,14]

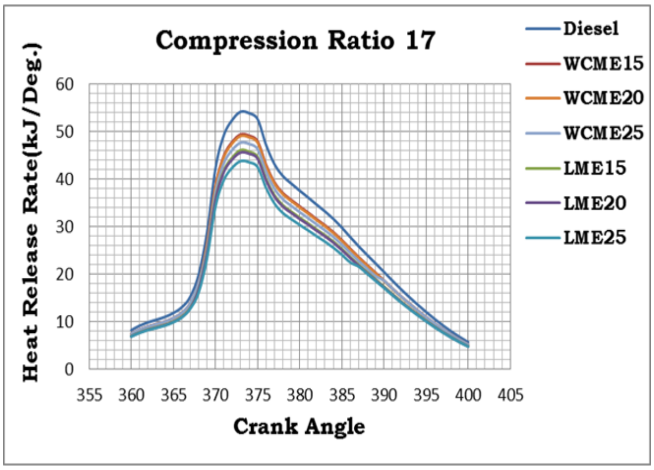

Fig. [4]

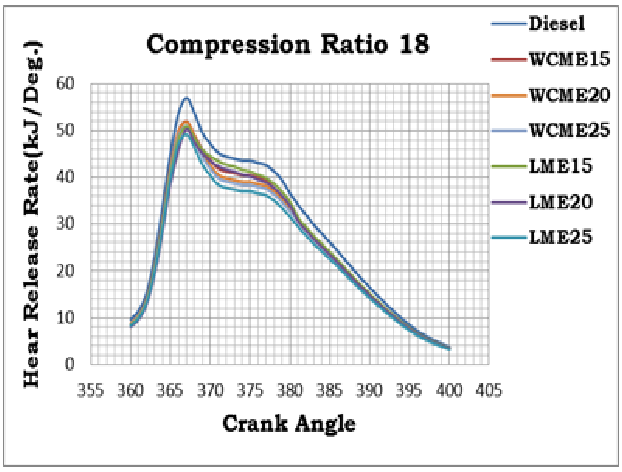

Fig. [5]

Exhaust Emission Characteristics

Exhaust emission viz. HC, CO, CO_2 and NO_x were measured by AVL DI Gas analyzer. Characteristics of emissions are explained below:

HC Emission

The exhaust emission characteristics of unburnt hydrocarbons for various blends of different fuel samples at compression ratio 17 and 18 for no load to full load condition, are depicted in Figures (6, 7). It was observed that fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 showed the emission of unburnt hydrocarbons was reported reduced by 4.3%, 3% 7%, 10% 14.2% and 10% respectively when compared to diesel fuel with maximum emission of hydrocarbon of 70ppm. While at compression ratio 18; the various test fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 presented the reduction in unburnt hydrocarbons emissions as 4%, 3%, 10.9%, 6.8%, 15% and 12.3% respectively with respect to standard diesel with HC emissions as 72.5 ppm at maximum load of the engine. Exhaust emissions of hydrocarbons are deliberated as a concern of imperfect combustion of a fuel containing hydrocarbon. Furthermore, it was proposed that the large difference in exhaust emissions of hydrocarbon between low loads to high loads might be primarily due to the low volatility of various blends biodiesel with respect to the standard diesel fuel. This may be attributed to condensation of hydrocarbons in tailpipe resulted from low exhaust temperature due to unburned biodiesel at low engine loads. Results are in correlation with outcomes attained by researchers [15, 16].

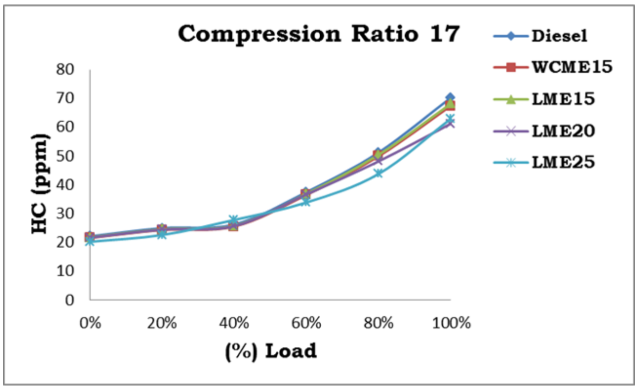

Fig. [6]

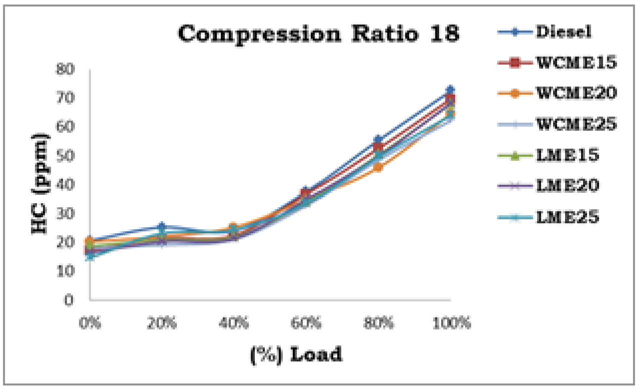

Fig. [7]

CO Emissions

The influence of blends of different fuel samples on exhaust emission of carbon monoxide (CO) at compression ratio 17 and 18 for various load conditions of engine are illustrated in in figures (8,9). At compression ratio 17; the fuels LME15, WCME15, LME20, WCME20, LME25 and WCME25 exhibited reduction in CO emissions as 13.2%, 16.9%, 9.6%, 20.7%, 18.8% and 22.6% respectively as compared to standard diesel with highest CO emissions at full load. Though at compression ratio 18, test fuels DLD15, IPD15, LME15, and WCME15 LME20 and WCME20 LME25 and WCME25 displayed the CO emissions reduction as 10.3%, 12.1%, 12.1%, 15.5%, 13.8% and 15.5% respectively as compared to standard diesel. The all fuels created CO emissions in small extent at part loads whereas level of CO emissions and are giving more emissions at greater engine load conditions. This may be due to reduction in the air–fuel ratio when load on engine is increased whereas of decrease in temperature inside cylinder and delay in process of combustion also effect the CO emissions. Results are in correlation with investigators [17].

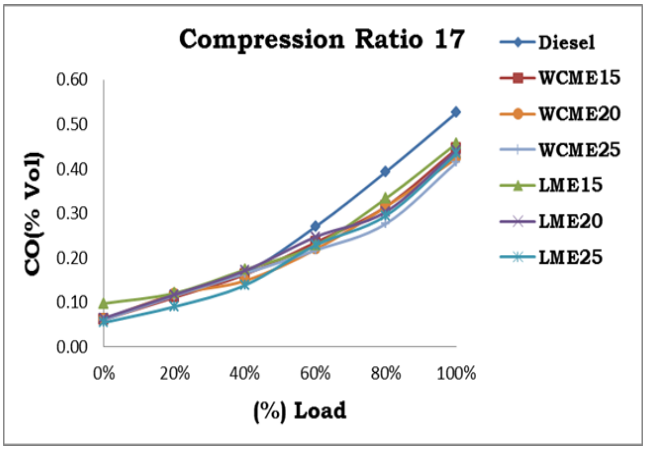

Fig. [8]

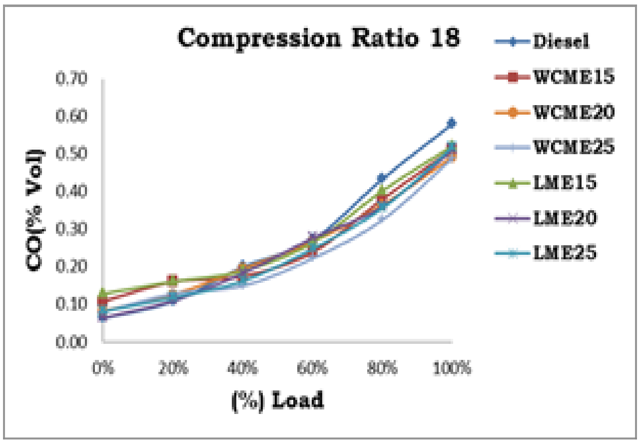

Fig. [9]

CO_2 Emissions

The variation of CO_2 emissions of blends of diverse fuel samples at compression ratio 17 and 18 for different load conditions are presented in figures (10,11). Results indicated that the alternative fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 displayed the increase in CO_2 emissions at compression ratio 17 as 6.1%, 9.3%, 9.7%, 8.7%, 15.5% and 10.6% respectively with respect to conventional diesel at maximum load condition. Whereas at compression ratio 18, test fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 exhibited 7.6%, 3.8%, 8.3%, 4.6%,13.7% and 11.5% more emissions of CO_2 respectively with respect to standard diesel fuel. Emissions of CO_2 were increased on increasing proportions of WCME and LME biodiesel in the blends which may be mainly due more oxygen content in these fuels which caused better combustion with respect to diesel fuel. Results are in accordance as reported other researchers [18,19].

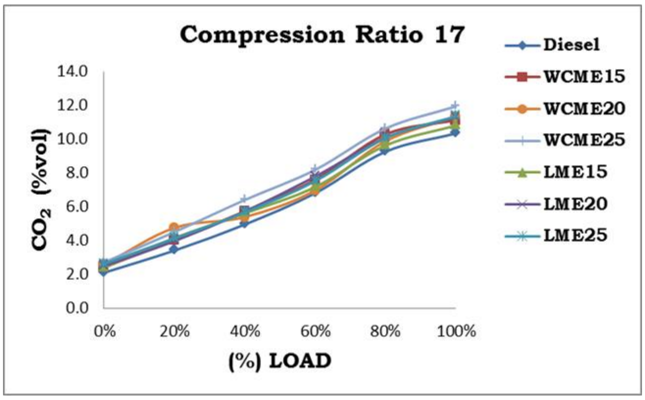

Fig. [10]

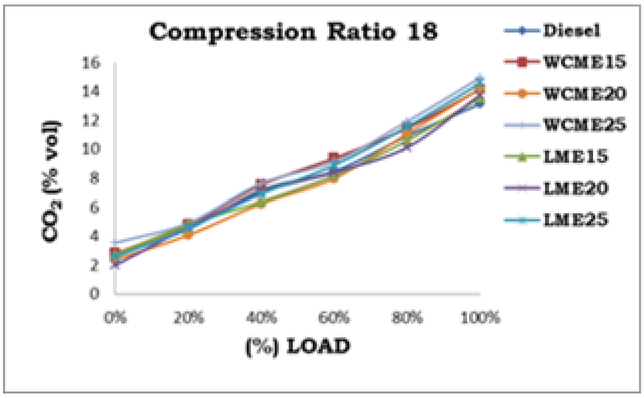

Fig. [11]

NO_X Emissions

The exhaust emission characteristics of NO_X for blends of different fuel samples at compression ratio 17 and 18 for different load condition, are represented in Figures. [12,13]. It has been observed that test fuels WCME15, LME15, WCME20, LME20, WCME25 and LME25 showed the increase in emissions of NO_X by 5%, 2.5% 7.6% 5.4%, 13% and 12.5% respectively and at highest load and compression ratio 17 when compared to diesel fuel. Though at compression ratio 18, test fuels WCME15, LME15, WCME20, LME20 WCME25 and LME25 displayed the increase in emissions of NO_X as 5.6%, 3.3%, 9.6%, 7.6% 12.9% and 10.1% respectively with respect to standard diesel. It has been observed that on increasing the load on engine, the formation of NO_X may be attributed to fact that increases in overall fuel air ratio origins the increment in combustion chamber temperature. It was analyzed that the extent of exhaust emissions of NO_X was noticed directly dependent on exhaust gas temperature whereas inversely correlated to emissions of carbon monoxide. Outcomes are in confirmation with the results attained by researchers [20-21].

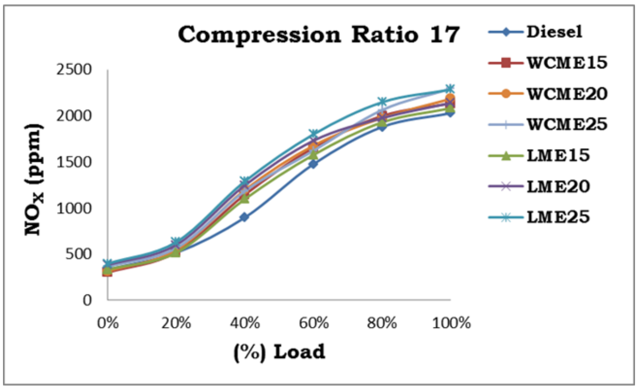

Fig. [12]

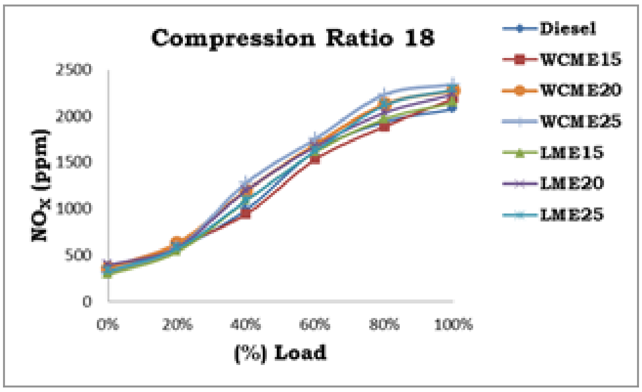

Fig. [13]

IV. CONCLUSIONS

The objective of the present study is to investigate the combustion and emissions of a diesel engine operating on Waste cooking oil methyl ester and Linseed oil methyl ester blends and to compare these results with those operating on neat diesel. Based on the experiment results, the following conclusions may be drawn from the present analysis.

i. Test fuels WCME15 exhibited the maximum peak pressure as 53.21bar with respect to highest pressure of 56.37 bar for standard diesel fuel at compression ratio 17. However at compression ratio 18; The test fuels WCME15 displayed the peak pressure values as 61.44 bar with respect to diesel with peak pressure of 64.95 bar.
ii. The test fuels WCME15 showed the peak rate of heat release as 49.40 kJ/Deg. respectively. Although at compression ratio 18; that peak heat release rate (HRR) for fuel samples WCME15 is found to be 51.97 kJ/Deg., when compared to that of diesel with 56.96 kJ/Deg.
iii. It was observed that fuel WCME25 showed the emission of unburnt hydrocarbons was reported reduced by 14.2% when compared to diesel fuel. While at compression ratio 18; the various test fuel WCME25 presented the reduction as 15% .

iv. The fuel WCME25 exhibited reduction in CO emissions as 22.6% at compression ratio 17, though at compression ratio 18, test fuels LME25 displayed the CO emissions reduction as 15.5% respectively as compared to standard diesel. Results indicated that the alternative fuel WCME25 displayed the increase in CO_2 emissions at compression ratio 17 as 15.5%. Whereas at compression ratio 18, WCME25 exhibited 13.7% more emissions of CO_2 respectively with respect to standard diesel fuel.

v. It has been perceived that test fuel WCME25 showed the increase in emissions of NO_X 13% respectively and at highest load and compression ratio 17. However at compression ratio 18, WCME25 displayed the increase in emissions of NO_X as 12.9% with respect to standard diesel.

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