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Comparative Analysis of Performance and Exhaust Emission of Variable Compression Ratio Engine Utilizing Blends of Waste Cooking Oil and Linseed Oil as an Alternative Fuel

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Abstract: *Biodiesel is an alternative fuel for petroleum-derived diesel and a high potential renewable energy source which can be used in existing diesel engine without modification. Numerous researchers are still examining the suitability of utilization of edible and non-edible oils in compression ignition engines. In the present work an experimental analysis was performed to compare the performance and exhaust emission effects of variable compression ratio engine utilizing waste cooking oil methyl ester (wcme) and linseed oil methyl ester (lme) blends. In the experiment content of waste cooking oil methyl ester (wcme) biodiesel was varied as 15% (wcme15), 20%(wcme20) and 25%(wcmedld25) with neat standard diesel whereas the second fuel, linseed methyl ester (lme) was also prepared with similar proportions as lme15, lme20 and lme25. All experiment tests were performed with engine speed 1500 rpm and variable compression ratio 17 and 18 at different load conditions. The effect of blends and compression ratio on different performance parameters viz. Brake thermal efficiency (bte), brake specific fuel consumption (bsfc), and exhaust gas temperature along with emissions co, co2, hc and* no_x*, was investigated and thus compared with different blends of both fuels. Results showed that lme exhibited the prominent engine performance and exhaust emissions compared to wcme.*

Keywords: *Linseed Methyl Ester, Waste Cooking Oil Methyl Ester, Variable Compression Ratio*

1. INTRODUCTION

The inadequate resources of fossil fuels, rise in crude petroleum prices, and serious ecological concerns have directed to the search of alternative fuels, [1,2] the international energy agency (iea) forecasts that world primary energy demand between now and 2030 will increase by 1.5% per year oil and other petroleum products are also expected to continue to account for the largest share of world energy consumption. It is predictable that the share of biofuels will increase in the coming years.[3,4]. India is highly dependent on import of crude oil. Net imports of crude oil have increased from 99.41mts during 2005-06 to 184.80 mts during last year. Whereas consumption of crude oil have increased from 130.11mmt to 219.21mmt[5]. The serious problem associated with the use of conventional petroleum fuel is the increase in pollutants emissions like co_2, hc, no_x, so_x and many other hazardous gasses. These gases are detrimental to the biodiversity along with adverse effect on human health [6]. Therefore in recent years, several other socioeconomic aspects have driven research to develop alternative fuels from renewable resources that are cheaper and environmentally acceptable [7] biodiesel can be one of the best alternatives. The use of vegetable oils as alternative renewable fuel competing with petroleum was proposed in the beginning of 1980s. It is made from the oils of various types of oilseed crops like sunflower, palm, cottonseed, rapeseed, soybean, linseed etc. The biodiesel fuel (vegetable oils processed with methanol or ethanol) is a renewable fuel, so it is non-toxic and does not increase the level of co_2 at all in the atmosphere at global level. The exhaust emission of the fuel absolutely does not have so_x, and considerably less amount of no_x are produced.[8-12]however, due to lack of vast study of performance, combustion and emission characteristics using waste cooking oil, it is gaining recently attraction of researchers for investigations [13,14]. Therefore present work has been investigated using waste vegetable oil and linseed oil methyl esters.

A number of studies of performance combustion and emission utlising a variety of biodiesel have been carried out and for a comprehensive review, some of the research findings are summarized below

Silvio et. Al. [2002] investigated engine performance and emissions using pure palm oil as an alternative fuel. Engine performance and emissions were influenced by basic differences between diesel fuel and palm oils such as mass based heating values, viscosity, density and molecular oxygen content. They also concluded that the specific fuel consumption of palm oil was found almost 10% higher than diesel at low loads [15].

Agarwal et. Al.(2006) studied the combined effect of biodiesel and exhaust gas recirculation (egr) in ci engines which resulted in reduction of nox, hc and co and smoke. However egr increases the hc and co emissions without compromising engine performance and emissions.[16].

Banapurmath et. Al. [2008] compared performance of di engine fuelled with neat diesel, methyl esters of honge oil, jatropha and sesame oils. Resultsshowed a slightly reduced thermal efficiency and poor performance with all the esters[17].

Prem anand et. Al.(2010) performed experiment to evaluate the exhaust emission characteristics using turpentine oil fuel (tpof) blended with conventional diesel fuel (df) fueled in a diesel engine. Observation results explain the reduction of hc, co emissions is mainly due to the effect of complete combustion for increasing tpof in blends. It is also observed that due to low temperature combustion of tpof blend, maximum reduction of nox emission is obtained[18].

Violeta et. Al. [2014] utilized microalgae oil methyl esterstoanalyze performance characteristics of diesel fuel. Result showed that ateach engine load, the brake-specific fuel consumption was approximately 3–3.5% higher with rapeseed oil methyl esters (b30rme) and algae oil methyl esters (b30ame) than mineral diesel fuel, while running on (b30ame), the engine's thermal efficiency was 2.5–3% higher compared to mineral diesel fuel[19].

2. EXPERIMENTAL SETUP

In the present study waste cooking oil methyl ester was made accessible from a restaurant whereas linseed oil methyl ester was prepared from raw linseed oil. The transesterification process was performed by converting the triglycerides of vegetable oils to their monoester by reacting them with alcohols in the presence of a catalyst to reduce viscosity and improve cetane number of fuels. The fuel samples were prepared (%by volume) by addition of wcme and lme 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 blends were inspected thoroughly.

The main fuel properties of various blending stocks and standard diesel fuel are shown in table 1. Cetane number for different blend was estimated as follows:

$Cn_h = \sigma_i \, cn_i * x_i$

Where cn_h is the equivalent cetane number of the blended fuel, while cn_i is the cetane number of each constituent. [20, 21]

The engine used in experiment was a single cylinder, naturally aspirated, four stroke, and direct injection diesel engine. Experiment tests were performed with engine speed 1500 rpm and variable compression ratio 17 and 18 at different load conditions. The engine set up used in the tests is shown in fig.1. There are different methods to achieve different compression ratio, one of them is tilting cylinder block arrangement which was given in setup to vary the combustion space 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, NO_x and CO_2 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

FUEL PROPERTIES	WCME15	WCME20	WCME25	WCME100	LME15	LME20	LME25	LME100	DIESEL
DENSITY (KG/M3)	841.7	845	846.3	874.8	832.8	833.1	833.7	835.8	832.6
VISCOSITY (MM2/S)	3.118	3.2	3.476	4.256	3.156	3.214	3.271	4.256	2.946
CALORIFIC VALUE (MJ/KG)	44.54	45.4	45.834	41.67	45.781	45.521	44.981	38.17	47.231
CETANE NUMBER	47	47	47	46	48	48	48	47	48

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

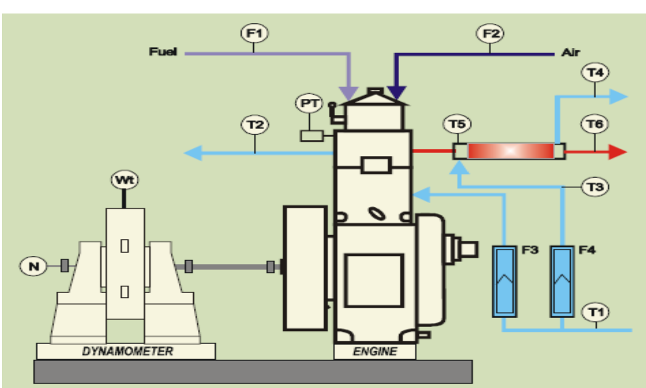

Fig. 1. Engine Set Up

3. RESULTS AND DISCUSSION

3.1 PERFORMANCE CHARACTERISTICS

The variation of brake thermal efficiency (bte) and brake specific fuel consumption (bsfc) and exhaust gas temperature(egt) with brake mean effective pressure (bmep) for the fuel samples wcme15, wcme20, wcme25 and lme15, lme20, lme25 with standard diesel at compression ratio 18 and 17 is shown in figures (2-10).

3.1.1 BRAKE THERMAL EFFICIENCY

It was observed that increase in brake power; caused increase in thermal efficiencies of all the fuels at part load condition figures(2,3) but on further increment, bte of all fuels at compression ratio (cr) 18 and cr17 were reported a lower than diesel fuel.

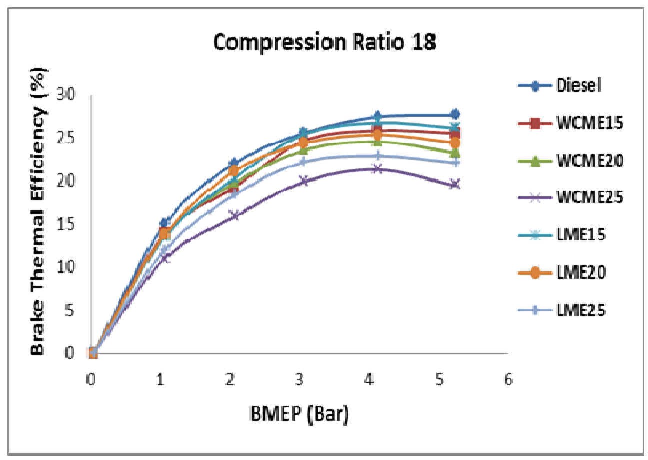

Fig. 2. Variation of brake thermal efficiency with brake mean effective pressure at cr 18

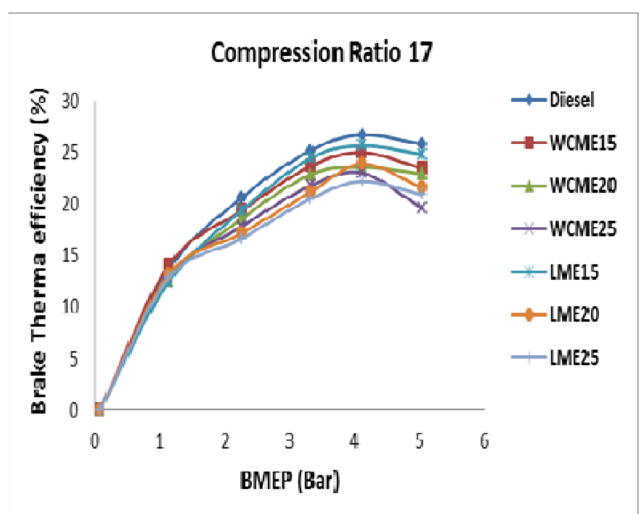

Fig. 3. Variation of brake thermal efficiency with brake mean effective pressure at cr 17

Further at cr 18 and cr 17 lme15 showed bte very close to diesel fuel. Though at cr 18 and cr 17, wcme25 showed minimum efficiency. This is due to the fact that biodiesel have higher viscosity and lower heating value than diesel fuels. Reduction in lower calorific value and high viscosity cause improper atomization of the blends as compared to diesel fuel. It was reported that the bte increases with increase in load due to the fluctuations in engine speed and power output. These results are correlated with the result obtained by nadir yilmaz. Et. Al.[22].

3.1.2 BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

It can be seen from figures (4,5) that at cr 18 and cr17, bsfc for all fuel samples is found to be higher than that of diesel fuel. While at cr 18 and cr17, bsfc for lme25 is close to diesel fuel. Wcme15 exhibited highest bsfc at cr 18 and cr 17.

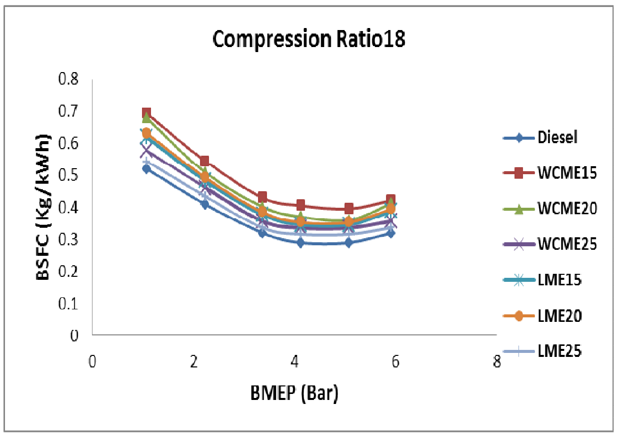

Fig. 4. Variation of bsfc with brake mean effective pressure at cr 18

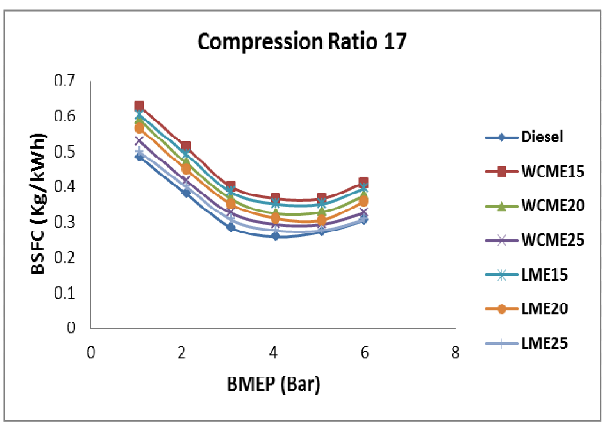

Fig. 5. Variation of BSFC with brake mean effective pressure at cr 17

The higher amounts of oxygen present in the considered blends may lead to lower bsfc . It was observed that at higher temperature viscosity decreases which leads to better atomization and combustion and results in lower brake specific fuel consumption. Results obtained are similar to those obtained by bhupendra et. Al.[23].

3.1.3 EXHAUST GAS TEMPERATURE(EGT)

Experiment results showed figures (6,7) that the increase in brake power causes increase in exhaust gas temperature for all fuels. At cr18, lme15 showed the highest value of exhaust gas temperature of 406^{0}c but slightly lower than that of diesel with temperature of 425^{0}c. Though lowest temperature of 352^{0}c was obtained for lme 25.

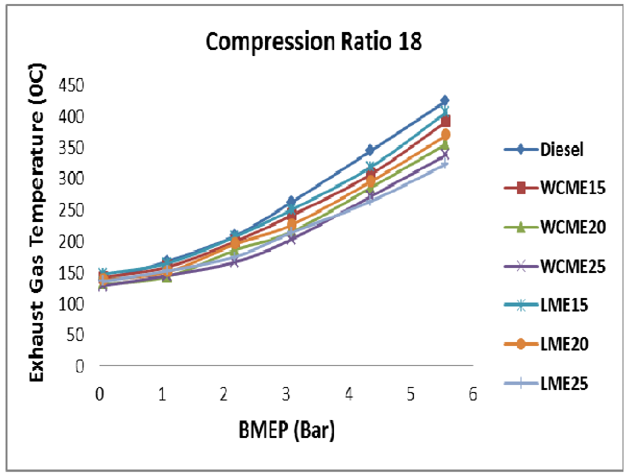

Fig. 6. Variation of egt with brake mean effective pressure at cr 18

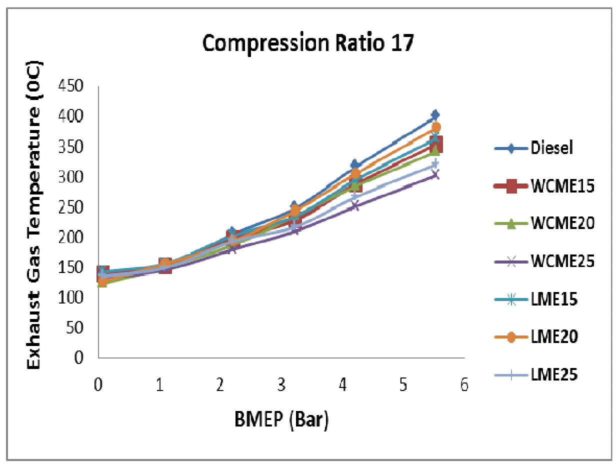

Fig. 7. Variation of egt with brake mean effective pressure at cr 17

While lme20 at cr17 showed highest exhaust gas temperature. It was reported that biodiesel has poor combustion characteristics due to high viscosity which causes higher exhaust gas temperature. The higher exhaust temperature with blends is indication of lower thermal efficiencies of the engine and at lower thermal efficiency, less of the energy input in the fuel is converted to work, thereby increasing exhaust temperature. Results are comparable to those obtained by pramanik k. Et. Al. [24].

4. EMISSION CHARACTERISTICS

Figures (8-13) show the variation of different exhaust emission characteristics viz. HC, CO, CO_2 and NO_X with brake mean effective pressure at compression ratio 18 and 17. All emissions were measured by AVL di gas analyzer. Characteristics of emissions are explained below:

4.1 EMISSION OF UN-BURNT HYDROCARBONS (HC)

It was observed that as load on engine increased, HC emissions are increasing for all fuels and at all compression ratios figures (8-13) . At cr18, wcme15 shows the lowest HC emission that the other fuels. However lme15 exhibited the lowest HC emissions at cr17. The HC emissions were reported 27% for wcme15 and 24% lower for lme15 at cr18 and cr17 respectively at maximum load condition.

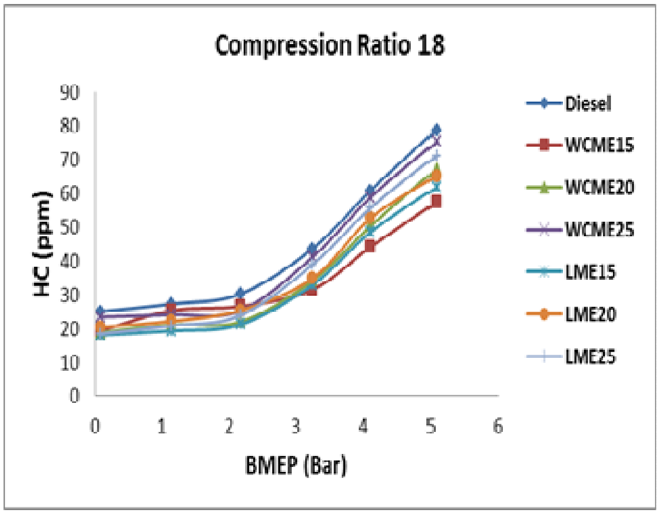

Fig.8: Variation of HC with brake mean effective pressure at cr 18

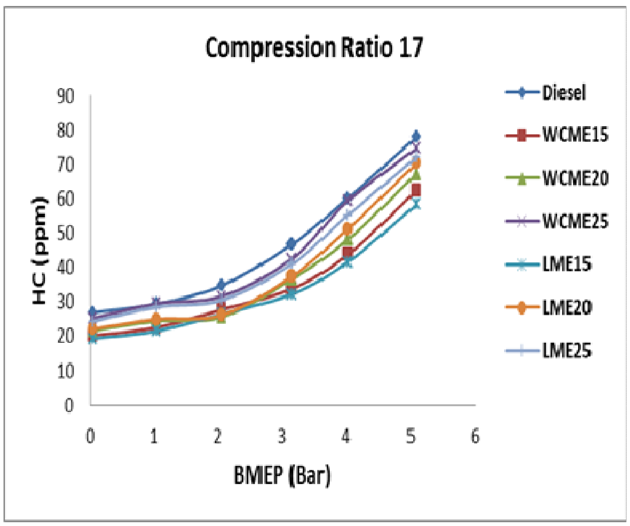

Fig.9: Variation of HC with brake mean effective pressure at cr 17

As we increase the compression ratio combustion enhanced but as the viscosity of the fuel is high hence it affect the combustion phenomenon and leads to incomplete combustion hence the hc emission increases. Also it has been seen that at the part load the variation in the hc emission is insignificant but on increasing the load beyond 60% the combustion affects and hence leads to incomplete combustion. Hc emission is the result of incomplete fuel combustion and it may increase because of excessively rich fuel air mixtures with insufficient oxygen content in the fuel. Consistency of results is verified with results obtained by s. Jindal et. Al.[25].

4.2 EMISSION OF CARBON MONOXIDE (CO)

Emissions of co are explained in figures (10,11). Wcme15 has highest co emission followed by lme15 at both compression ratio. Whereas wcme25 and lme22 have shown significant reduction of co emissions at cr 18 and cr17 respectively when compared to diesel fuel.

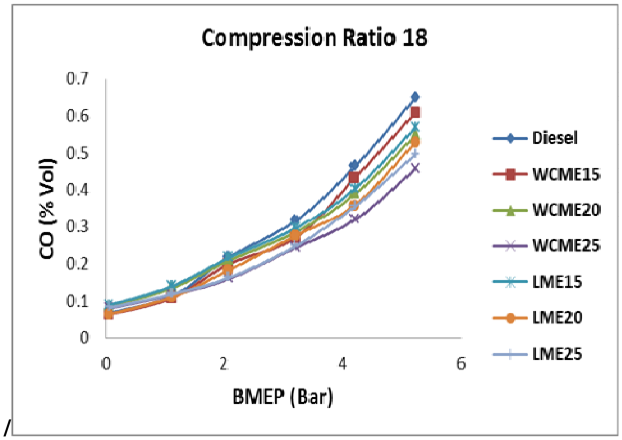

Fig. 10. Variation of CO with brake mean effective pressure at cr 18

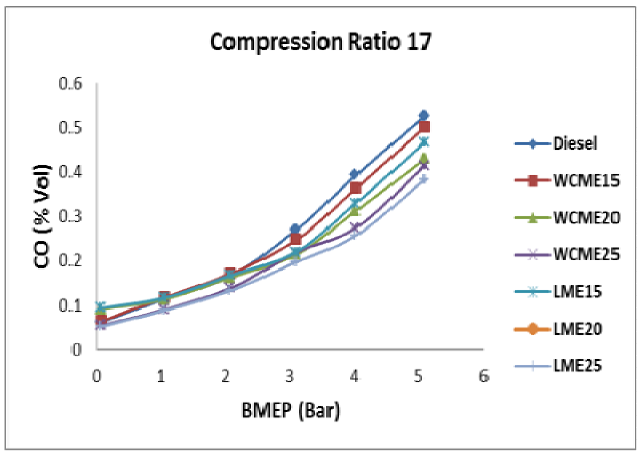

Fig. 11. Variation of CO with brake mean effective pressure at cr 17

With increasing biodiesel percentage, co emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and proper oxidation. The increase in load causes increase in co emissions due to decrease in the air–fuel ratio with increase in load such as all typical internal combustion engines. Results are in agreement with results obtained by kumar ms et. Al.[26].

4.3 EMISSION OF CARBON DIOXIDE (CO_2)

The variation of co_2 with bmep at cr 18 and cr17 for all fuel samples are shown in figures (12,13).results showed substantial reduction in co_2 emission for fuel samples lme15 and wcme15, at cr 18 and cr17 respectively. At cr 18, wcme15 showed 23% reduction in co_2 emission though lme15 indicated 20% reduction respectively at cr17. These results are well confirmed by the results reported by nwafor omi. Et. Al. [27]

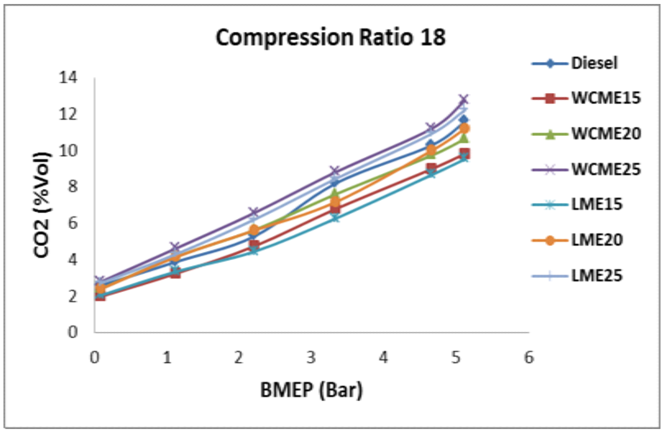

Fig. 12. Variation of CO_2 with brake mean effective pressure at cr 18

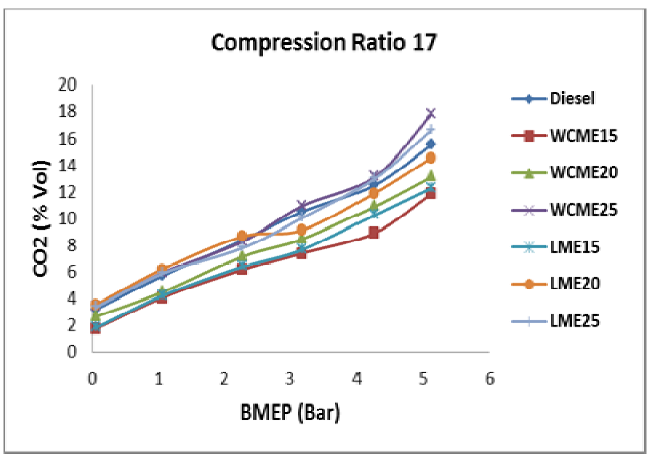

Fig. 13. Variation of CO_2 with brake mean effective pressure at cr 17

4.4 EMISSION OF NO_X

Figures (14,15) show the plots of no_x emissions of the diesel fuel and various fuel samples at cr18 and cr17.it was observed that all fuel samples exhibited higher no_x emissions than that of diesel fuel. However increase in no_x emission was reported maximum for lme25 at cr18 and cr17 at maximum load condition when compared with diesel fuel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which facilitated no_x formation.

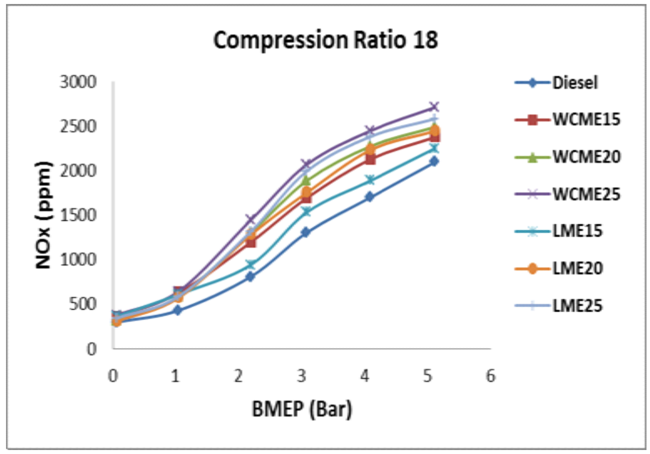

Fig. 14. Variation of NO_X with brake mean effective pressure at cr 18

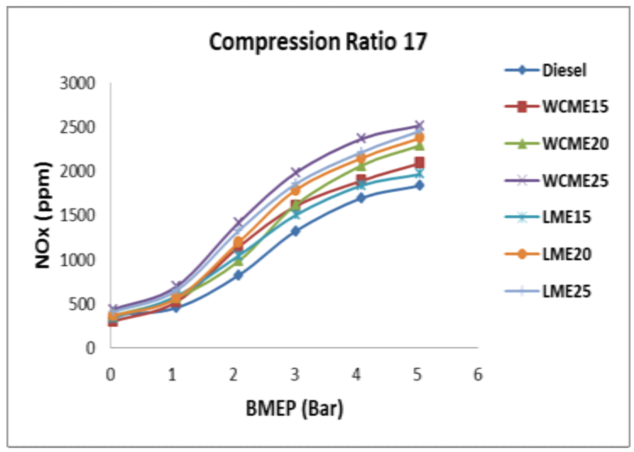

Fig. 15. Variation of NO_X with brake mean effective pressure at cr 17

In general, the NO_X concentration varies linearly with the load of the engine. NO_X emissions are a direct function of engine loads. With increasing load, the temperature of the combustion chamber increases and NO_X formation is enhanced because nox formation is strongly dependent on the temperature. Results are in confirmation with the results obtained by ban-weiss ga. Et. Al [28].

5. CONCLUSIONS

The objective of the present study is to investigate the performance 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. It was observed that increase in brake power; caused increase in thermal efficiencies of all the fuels at part load condition but on further increment, bte of all fuels at compression ratio (cr) 18 and cr17 were reported a lower than diesel fuel. At cr 18 and cr 17 lme15 showed bte very close to diesel fuel.

II. At cr 18 and cr17, bsfc for all fuel samples is found to be higher than that of diesel fuel. While at cr 18 and cr17, bsfc for lme25 is close to diesel fuel. Blend wcme15 exhibited highest bsfc at cr 18 and cr 17.

III. The increase in brake power causes increase in exhaust gas temperature for all fuels. At cr18, lme15 showed the highest value of exhaust gas temperature of 406^0c but slightly lower than that of diesel with temperature of 425^0c. Though lowest temperature of 352^0c was obtained for lme 25 and lme20 at cr17 showed highest exhaust gas temperature.

IV. It was examined that as load on engine increased, hc emissions are increasing for all fuels and at all compression ratios. At cr18, wcme15 shows the lowest hc emission that the other fuels. However lme15 exhibited the lowest hc emissions at cr17. The hc emissions were reported 27% for wcme15 and 24% lower for lme15 at cr18 and cr17 respectively at maximum load condition

V. Results showed that wcme15 has highest co emission followed by lme15 at both compression ratio. Whereas wcme25 and lme22 have shown significant reduction of co emissions at cr 18 and cr17 respectively when compared to diesel fuel. Because with increase in biodiesel percentage, co emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and proper oxidation. Results showed substantial reduction in co_2 emission for fuel samples lme15 and wcme15, at cr 18 and cr17 respectively. At cr 18, wcme15 showed 23% reduction in co_2 emission though lme15 indicated 20% reduction respectively at cr17

VI. It was observed that all fuel samples exhibited higher no_x emissions than that of diesel fuel. However increase in no_x emission was reported maximum for lme25 at cr18 and cr17 at maximum load condition when compared with diesel fuel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which facilitated no_x formation.

In general, the performance and exhaust emission results of blends of linseed methyl ester are very much comparable to diesel fuel and could improve engine performance and reduce the exhaust emissions, as well. Henceforth it can be concluded that blends of linseed methyl ester with diesel fuel can be used in the engine without any modification.

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