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A Comparative Analysis of Diesel Engine Fuelled with Diesel Fuel and Methyl Ester of Waste Cooking Oil

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Abstract

An experimental work has been investigated on a constant speed diesel engine using methyl ester waste cooking oil (MEWCO) and diesel. The biodiesel was prepared by transesterification process and mixed with original diesel with 10%, 20%, and 100% of MEWCO on volume basis. The impact of the blending ratio on performance, pollutant emissions as well as combustion parameters, were examined at variable load conditions. The results reported significant reduction in nitrogen oxides (NOx) and raising carbon emissions as well in all tested blend of MEWCO. 20% MEWCO is the recommended mixing percentage and above this ratio, noticeable reduction in the outcome of the performance has been observed.

Keywords: Waste cooked oil, transesterification, Diesel engine, Performance, Emissions.

Nomenclature

Symbol	Definition and unit
10% MEWCO	Blend ratio of 90 % diesel and 10 % MEWCO
20% MEWCO	Blend ratio of 80 % diesel and 20 % MEWCO
100% MEWCO	Blend ratio of 100 % MEWCO
BTE	Brake Thermal Efficiency (%)
BSEC	Brake specific energy consumption (MJ/kW.hr)
BSFC	Specific Consumption of Fuel (Brake) (g/kW.h)
EGT	Exhaust gas temperature (C)
CA^o	Crank shaft angle (deg.)
NOx	Oxides of nitrogen (%)
P	Cylinder pressure (pa)
HC	Hydrocarbon emission (%)
TDC	Top Dead Centre

INTRODUCTION

Renewable sources, especially vegetable oils stand for more attention all over the globe. The main driving criteria that divert the researchers' attention, is the limited fossil fuel sources, environmental pollution concerns, energy self sufficiency as well as the development of rural economy [1]. Edible and non edible vegetable oils can be employed as replacements for original petroleum fuel [2]. However, edible oils can't be spared for utilization of energy and the remaining choice is to induce the usage of non-edible or waste frying oils for energy uses.

The production of biodiesel from vegetable oils is different from country to country due to different soil and climate conditions, hence; each country is looking for definte types of vegetable oils to compensate diesel fuel [3].

The present day scenario says: there is a not that much attempt makable to utilize biodiesel from non-edible sources commercially to substitute petroleum fuel.

Several investigations have reported the results of the test engine with waste frying oil without transesterification process and the emission findings are different some researchers reporting reduces of a certain pollutants and other reporting increases [4]. As the new diesel engine has direct injection systems that is too sensible to quality of fuel, hence properties which are nearer to diesel fuel are required [5]. Therefore the recent research work is considering the transesterification of waste cooking oils before feeding the engine. The utilization of wasted cooked oils as biodiesel feedstocks reduce the price of production [6] as the feedstocks spend roughly 70-95% of the gross monetary value of production of biodiesel [7]. However, using wastage frying oil and oils based on inedible sources would be afford superior precedency above the sources of etable one as feedstock of biodiesel.

A massive number of investigations are made with vegetable oils as a substitution for the fuel of internal combustion engine by different researchers. A part of these experimental findings are summarized below:

Isigigur et al. [8] tested diesel fuel blended with 10% and 20% MEWCO and reported that even the energy content and cetane number are less than for ordinary diesel, most properties of blended fuels are nearer to those for pure diesel.

Mittelbach et al. [9] investigated the influence of used wastage oil methyl ester on exhaust pollutant emission of a diesel engine. The observations are reduction in carbon emissions and increasing nitrogen oxides on the other hand. Regarding performance parameters, it is recorded lower fuel economy for the biodiesel comparatively to diesel.

Reed et al. [10] converting wasting frying oil to its methyl ester and examined biodiesel and a 30% proportion of biodiesel with 70% diesel in a diesel bus by using a chassis dynamometer.

With the use of prepared biodiesel, not that much difference in performance has been noticed with the exception of dramatic decrease in soot emissions esters of the used oil.

D. Subramaniam et al. [11] made an experimental work to investigate the effect of different biodiesels namely (Neem, Punnai, Wasted frying Oil) on the exhaust emissions and combustion in a diesel engine at different conditions of load. Several proportions are prepared and the result point out up to 30% biodiesel didn't impact the characteristics of combustion as well as the pollutant emissions.

From all above facts, an effort has been done to observe the characteristics of combustion parameters of performance, and exhaust of pollutant emissions of MEWCO with the help of Kirloskar single cylinder (water-cooled) diesel engine. The aim of this experimental study is to analyze the suitability of MEWCO as an alternative fuel by breaking down the effects of fueling a diesel engine with varying proportions of diesel and MEWCO. The blends investigated were 100% diesel fuel, 10% biodiesel/90% diesel, and 20% biodiesel/80% diesel

The experimental work details

Different samples from various restaurants are collected and subjected to cleaning and filtering prior to transesterification process as remaining food particles and oil deposits have tremendous impact on combustion characteristics. The preparation of biodiesel under study was in the chemical engineering department, college of engineering, university of Al-Qadisiyah using transesterification process in addition to methyl alcohol that is catalyzed by NaOH. This method is influenced by several factors such as: reactive mode, the proportion of alcohol / oil, alcohol kind, catalyst quantity, reactive time and reactants pureness as well. The general equation of preparation is demonstrated in Fig. (1)

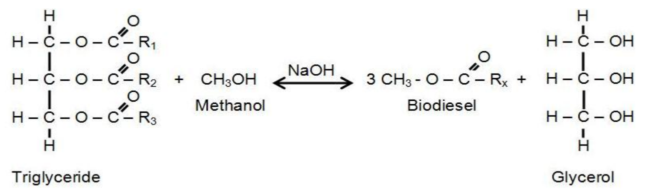

Figure 1: Biodiesel production by transesterification process [12].

The properties of biodiesel are shown in Table (1)

Table 1: Properties of diesel and MEWCO

Property	Diesel	B10% MEWCO	B20% MEWCO	MEWCO
Density at 15 °C (kg/m^3)	830	835	839	870
Viscosity at 40 °C (cst)	3.0	3.19	3.4	4.9
Calorific value (MJ/kg)	42.5	42.27	42.04	40.20
Flash point (°C)	76	81.4	87	130
Cetane number	48	48.3	48.6	51

The MEWCO is blended with pure diesel fuel on different ratios (10%, 20% and 100 %) by volume and being tested using the research engine available in the IC. Engines lab at the University of Babylon as shown in figure 2. The observed data are collected with variable load and the necessary calculations are completed successfully to measure the required data of the engine. The technical design of the test rig is shown in Table 2

Figure 2: Research engine test rig

Table 2: Specifications of the engine

Brand of Engine	Kirloskar Diesel Engine
Kind	1-Cylinder , 4-Stroke
Bore (mm)	80
Stroke (mm)	110
Ratio of compression	17.5
Brake power (kW)	3.7 kW
R.P.M	1500
Injection pressure (bar)	220
Software	Lab view

The operating ranges with accuracies for gas analyzer and smoke meter are given in Table 3. Data acquisition system (abbreviated with the acronym DAQ) system was also provided with the test rig to acquire crank angle and cylinder pressure data. The test rig was installed with AVL software for obtaining various curves and results during operation.

Table 3: The operating ranges and accuracies

Emission	Range	Accuracy
CO	0-10 % vol	± 0.2 %
CO2	0-20 % vol	± 1 %
HC	0-20000 ppm	±10 ppm
O2	0-22 % vol	± 0.2 %
NOx	0-5000 ppm	±10 ppm

The experiments were conducted with a constant ratio of compression (17.5) through the experimental work. Initially, it is fueled with diesel fuel to generate the baseline data, and then MEWCO was tested as B10%, B20 % and as a pure biofuel B100% on a volume basis. These blends were subjected to performance and emission tests on the engine. All tested fuels were conducted at four loads of engine (0, 0.925, 1.85, 2.75 and 3.7 kW) respectively at a constant engine speed of 1500 RPM. During the experiments the values of torque, exhaust temperature and pollutants such as, CO, HC, NOx and CO_2 were measured through the gas analyzer attached to the engine. The tests were 3 times repeated, hence the value depended in this work was the mean of the 3 results.

RESULTS AND DISCUSSION

Engine performance: This part of discussion deals with BTE, BSFC and BSEC variation with various loads for diesel fuel and MEWCO blends. Fig.3 shows load v/s BTE for various blends. As percentage of MEWCO increases, BTE decreases because of the reduction in the lower heating content for the blended fuel. 20% MEWCO almost closer to pure diesel fuel and behaves much better than other blends of MEWCO. This is because of cetane number improvement through transesterification process and the change in the chemical structure of the oil which is desirable for diesel engine.

Fig.4 displays the effect of load variation on the BSFC for MEWCO blends in diesel fuel. It can be observed that BSFC decreased as the brake power of engine increases because of the rate of increasing brake power is greater than consumption of fuel. The BSFC increased with the increasing MEWCO percentage due to the higher viscosity and density and lower heating value of biodiesel compared to diesel fuel.

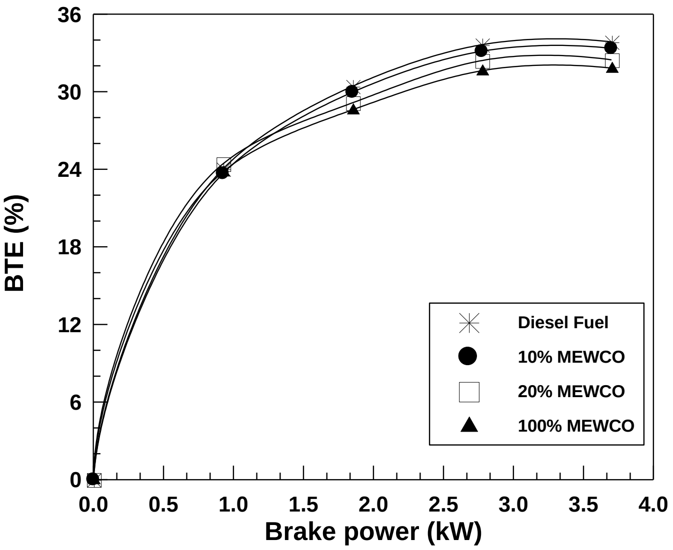

Figure 3: Load v/s BTE

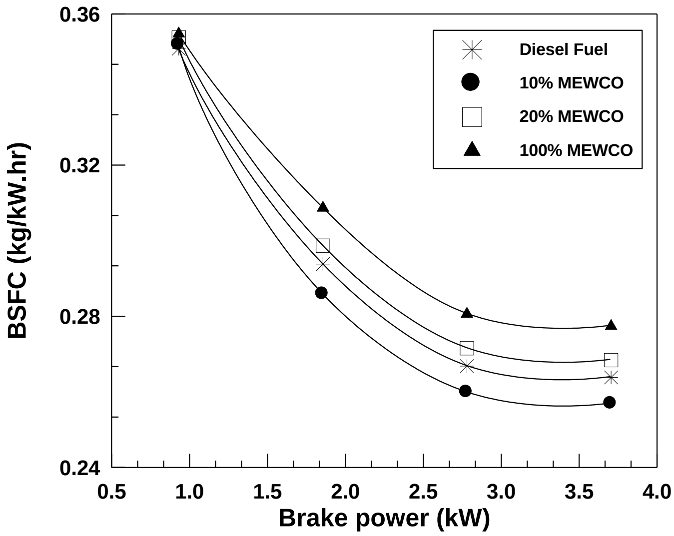

Figure 4: Load v/s BSFC

Fig.5 examines the variant of BSFC and the brake thermal efficiency (BTE) with MEWCO biodiesel blends. It is found all blending of MEWCO had lower BTE for the whole load by 6% Decreasing trend of BTE due to the difference in heating values of the blended fuels.

The BSFC is increasable according to the increment in the blending ratio of MEWCO. To obtain same power output and torque for each fuel examined, the BSFC was higher for MEWCO and its blends. BSFC for 20% MEWCO reported 4.28% rise, while it is higher by 7.78% for 100% MEWCO. The difference in density and heating values are responsible for BSFC increment. The results are similar to those of (Mustafa C. et al. [13] and Monyem A. [14]).

Another important message from this figure saying that: the decrease in BTE meets the increase in BSFC and intersects at 20% MEWCO and clearly feasible beyond this ratio a reduction in the performance parameters is noticed, hence 20% MEWCO is the favoritable ratio of blending.

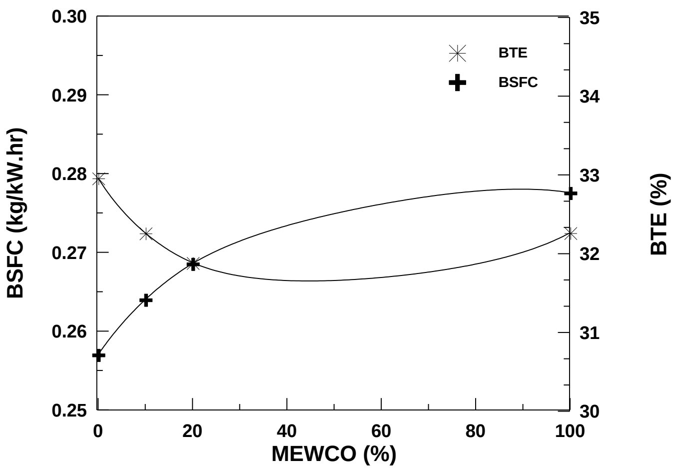

Figure 5: MEWCO % v/s BSFC and BTE

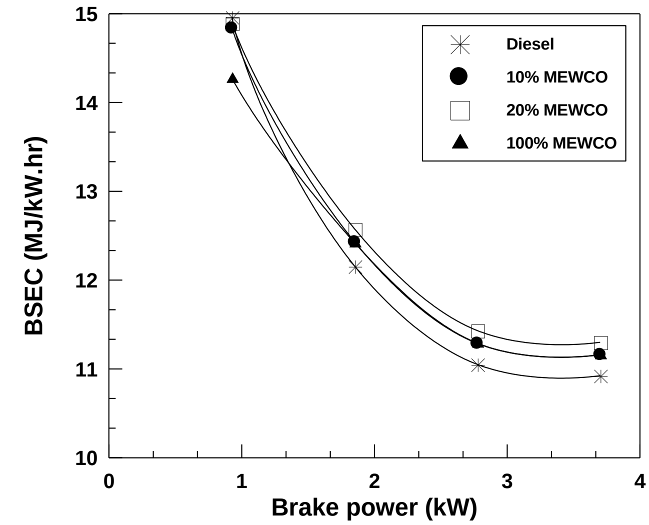

Figure 6: Load v/s BSEC

Fig.6 presents the relation between BSEC and brake power for diesel and MEWCO blends. As the load increases, the BSEC decreased due to the improvement in the brake power rather than fuel consumption. For diesel fuel 24.78% decrease in BSEC was noticed when the engine load increased from 0.925 kW to 3.7 kW. The BSEC depends on the BSFC and lower heating value. It can be seen that 100% MEWCO has least BSEC as compared to diesel fuel and other blend MEWCO due to lower heating value of MEWCO as compared to other fuels tested. When the engine runs on 100% MEWCO biodiesel, there is 2.15% increment in the BSEC.

Fig.7 presents the relation between brake power and (A/F) ratio. As the load increased, there is a decrease in (A/F) ratio and this is correct with all IC engines as (A/F) ratio decreases as the load increased [15]. The (A/F) ratio decreases as the blending ratio of MEWCO increases. The reasonable decrease in the (A/F) ratio was recorded for 20% MEWCO as compared to other blends of MEWCO.

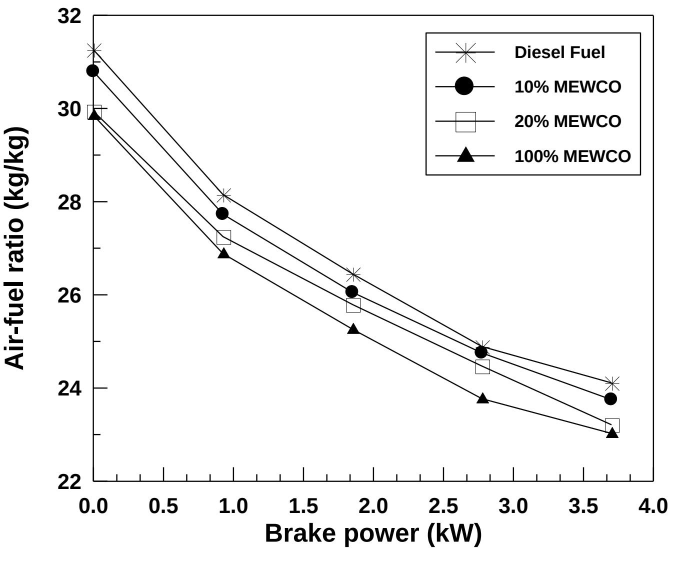

Figure 7: Load v/s Air-fuel ratio

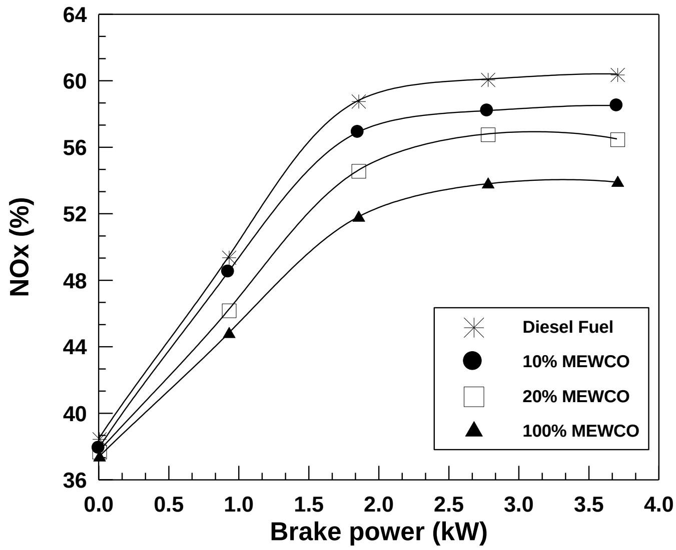

Figure 8: Load v/s NOx

Engine Emissions: The gas analyzer attached to the research engine enables measuring NOx, carbon monoxide (CO), carbon dioxide (CO_2), and Oxygen (O_2). NOx emissions v/s load in terms of brake power is depicted in Fig.8. NOx emissions increased as the engine load increased, due to the increase in combustion temperature. It is the most important emission characteristic of biodiesel and its blends. The reduction of it is always the target for engine researchers and manufacturers. Three conditions which enhance the formation of NOx are: highly temperature of combustion, greater quantity of oxygen and quickly rate of reaction [16]. The oxides of nitrogen start reducing as the MEWCO blend increases. The emission of NOx with 100% MEWCO is decreased because of the decrease in the rate and temperature of combustion which leads to reduced NOx emissions. These results are confirmed by the report of Agarwal [17], and Patterson et al. [18]. For 100% MEWCO at full load NOx is reduced by 10.76 % comparatively to oridinary diesel.

Fig. 9 shows CO emissions at different conditions of load for neat diesel and various blends of MEWCO. The increased emissions of CO for 100% MEWCO compared with base operation line of diesel because of the bulky structure of molecular and higher viscosity which reduce fuel atomization and increasing carbon emission. Same observations are reported by Devan et al. [19]. Nevertheless, CO emissions for 10% MEWCO and 20% MEWCO are less comparable with 100% MEWCO

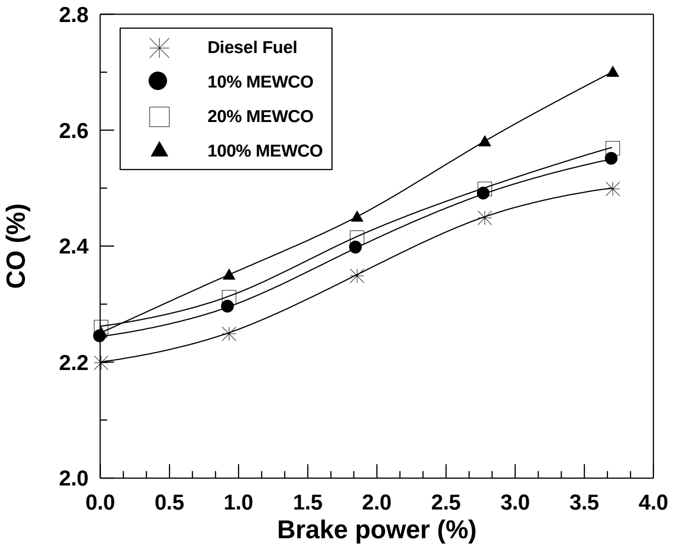

Figure 9: Load v/s CO

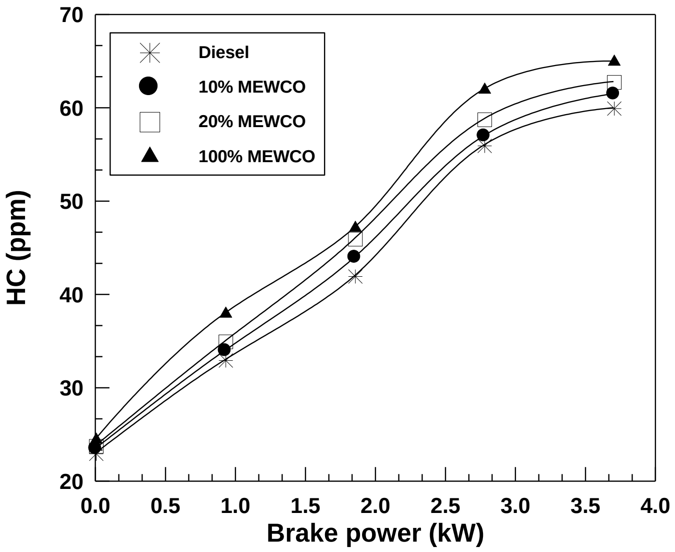

Figure 10: Load v/s HC

One of the essential parametric that indicates the engine behavior is the HC emission as it is a dangerous trouble at low load for compression ignition engine. The result of HC emission is displaced in Fig. 10 at different loads in terms of brake power. At partial loads, little fuel quantity impinges on surfaces because the fuel is distributed awfully, hence massive quantity of excess air is escaping through the exhaust system [20]. This explanation is supported by results acquired in this study. While HC emission is measured 23 ppm for diesel fuel at 0 kW; it is 60 ppm at 3.7 kW. As shown in Fig.12, HC emission increased as the percentage of biodiesel substitution increased.

HC emission comes from the incorrect air and fuel mixing and doesn't affect by the overall air-fuel equivalence ratio [21]. The higher viscosity level and heaviest structure for MEWCO blends are responsible for the increased values of HC emissions comparatively to diesel fuel

Fig. 11 displays the effect of MEWCO proportion at different conditions of loads. Generally the EGT detected an increase as a result of increasing load as the input energy increases. Diesel fuel has a higher EGT than all MEWCO. The range of pure diesel is (107-295) ºC while it is (95-266.6) ºC for MEWCO blends. The highly temperature of exhaust indicates little work done through expansion stroke [22].

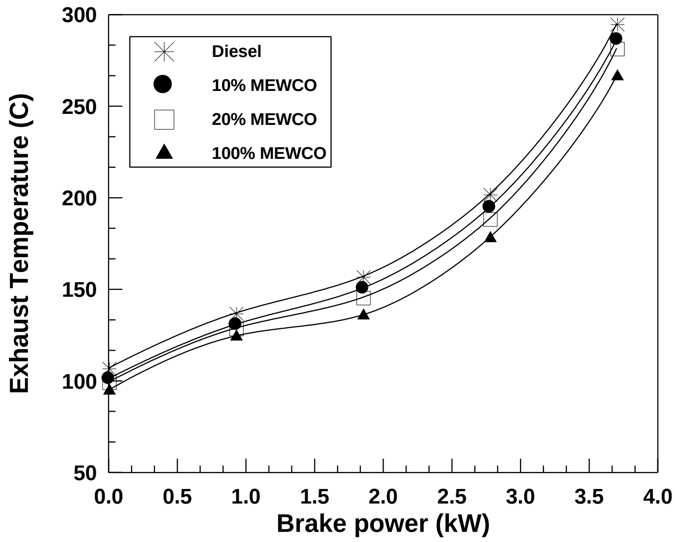

Figure 11: Load v/s Exhaust gas temperature

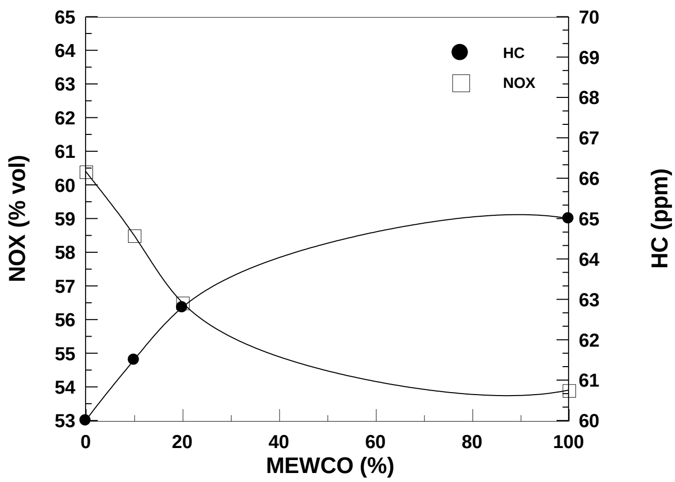

Figure 12: Load v/s NOx and HC

Fig.12 explains the relationship between NOx and HC emissions with variable percentages of MEWCO. HC emission for all MEWCO proportions were higher than pure petroleum. Average NOx data for 10% MEWCO, 20%, MEWCO and, 100% MEWCO were fewer comparable with diesel fuel by 3.14 %, 6.45 %, and 10.76 % respectively.

Once again another confirmation comes from figure 12 which reports 20% MEWCO as the advisable blending ratio due to intersection of NOx and HC curves. Even other percentages greater than 20% MEWCO records much reduction in NOx emissions, on the same way the HC emission is increasing sharply.

Combustion Analysis: Figure 13 depicts the variation of full load cylinder pressure for diesel, and MEWCO blends. It is found here that maximal pressure (71.54 bar) for diesel, followed by 10% MEWCO, then 20% MEWCO and 100% MEWCO. However, the curve of in-cylinder pressure for 10% and 20% of MEWCO is closer to diesel curve. In contrary, the observed value for 100% biodiesel is noted to be lower than 10% and 20 % blends and diesel as well. One possible explanation for this behavior pressure for 100% MEWCO is reduced heating content and highly levels of viscosity and density comparatively to original diesel.

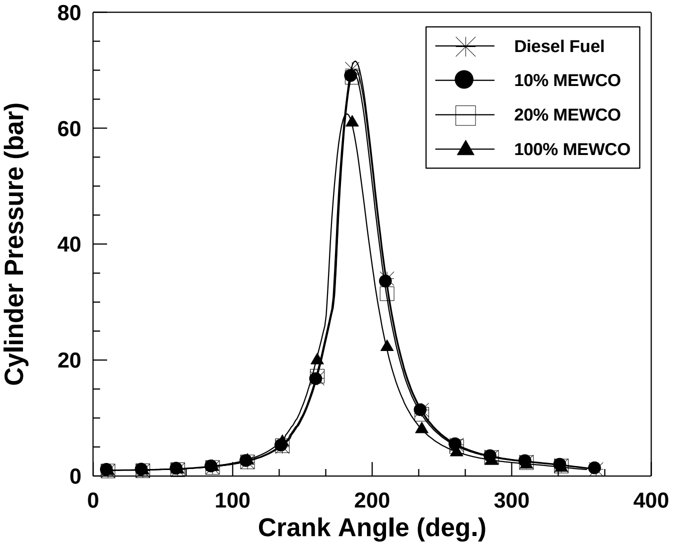

Figure 13: Load v/s Pressure

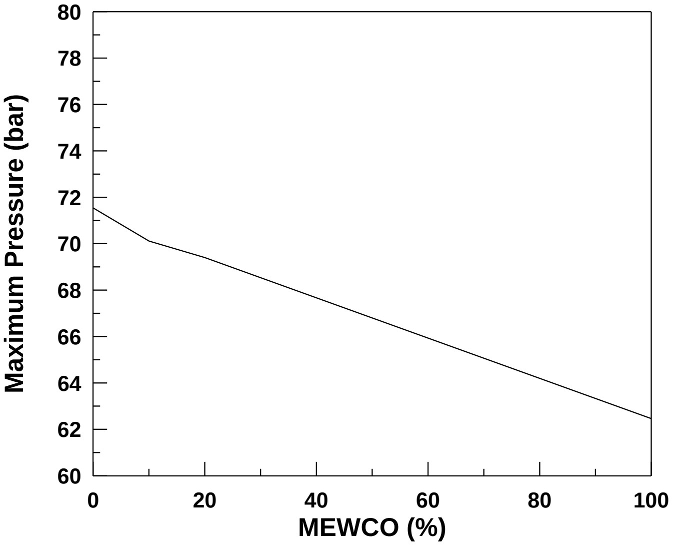

Figure 14: MEWCO % v/s Maximum pressure

Figure 14 presents the result of peak pressure v/s MEWCO proportion at full load. Peak pressure for all fuels tested slightly decrease as the blending ratio of MEWCO increased.

CONCLUSIONS

1. Used cooked oils, which are no way wasteful, are one of the mostly efficient selections for production of biodiesel.
2. Raising substitution of MEWCO came with a reduction in the BTE to a small extent and increased the fuel consumption.
3. MEWCO biodiesel has lower NOx emissions comparable with neat diesel.
4. Maximal pressure is observed to be nearer to top dead center whenever the ratio of MEWCO is increased.
5. MEWCO biodiesel has earliest combustion beginning comparative with original fuel.
6. 20% MEWCO is the advisable mixing ratio that keeps the outcome of performance, reduces the emissions of NOx as well as a slight increment in the carbon emissions comparable with other examined blends.

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