Performance and Emission Characteristics of CI Engine Operated with Waste Cooking oil Methyl-Ester and Diesel Blends

Jeewan VachanTirkey, Amar Kumar Singh, S. K. Shukla

Abstract— ***Biodiesel from bio-oils are considered as the promising renewable alternative fuel for CI engine. However the damped waste cooking oil poured in the earth is one of the contributors of water and environmental pollution. In this study, biodiesel from waste cooking oil (WCO) is produced by transesterification reaction and blended with diesel fuel (B10, B20, B30, B40, B50). These blends were tested in single cylinder, 4-stroke, water cooled CI engine at different loads with 1500rpm constant engine speed to evaluate the performance and emission characteristics. Performance study contains brake thermal efficiency, specific fuel consumption while emission study consider NO_x, CO, CO_2 emission. During experimentation it was found that an increase of load leads to increase of brake thermal efficiency and decrease in specific fuel consumption. It was also observed that the results using biodiesel have similar characteristics to that of diesel. The NO_x emission increases as load increases, while CO emission decreases for B10, B20 as blending increases.CO follows the trend similar to that of diesel. Also CO_2 emission increases at partial and medium loading condition.***

Keyword— ***Waste cooking oil, waste cooking oil methyl ester, transesterification, emission***

I. INTRODUCTION

From almost three decades alternative and renewable fuels has gained importance. The depletion of world petroleum reserves and increased environmental concerns has stimulated recent interest in alternative sources for petroleum based fuels [1]. Biodiesel, [2] derived from vegetable oil or animal fats by transesterification with alcohol like methanol and ethanol is recommended for substitution petroleum based diesel fuel because it is a renewable, biodegradable, and eco-friendly fuel. However the high costs of biodiesel are a major barrier to its commercialization. The use of low-cost feedstock such as waste cooking oil (WCO) makes biodiesel competitive in price with petroleum Diesel fuel. This opens an opportunity for the use of waste cooking oil (WCO) as production feedstock [3]. And also the storage and disposal of used cooking oils from restaurants and domestic use are both troublesome and costly. Most of the used cooking oil is poured into the sewer system as we dump it into the drains.

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This work of ours contributes to the water pollution and environmental pollution, which is very harmful for human being [4]. It has been shown that the waste oils can be used in conventional diesel engines and can be transformed to an environmentally friendly fuel with lower emissions for HC and PM compared to diesel fuel [5-6]. Lapureta et al. [7] studied two different waste cooking oil (WCO) biodiesel diesel blends with a reference diesel fuel in a DI diesel commercial engine. The results showed that the brake thermal efficiency was not significantly affected, but the fuel consumption of biodiesel was increased. A sharp decrease was observed in smoke emissions as the biodiesel concentration was increased. Ozer Can [3] studied a mixture of biodiesel fuels produced from two different kinds of waste cooking oils was blended in 5% and 10% with diesel fuel tested in a single-cylinder, direct injection, four-stroke, natural aspirated diesel engine under four different engine loads (BMEP 0.48–0.36–0.24–0.12 MPa) and 2200 rpm engine speed and found that the ignition delay with the biodiesel addition was decreased for the all engine loads with the earlier combustion timings due to higher cetane number of biodiesel fuel [8-9]. And also found that increment on break specific fuel consumption (up to 4%) and reduction on break thermal efficiency (up to 2.8%).

Various testing also performed by varying load and compression ratio, Jagannath et al. [10] performed testing on a single-cylinder, four-stroke, direct injection diesel engine operated on WCO blended with mineral diesel oil by taking compression ratio 14.5, 16.5, 17.5 and varying loads (0.5kW to 4kW) at 1500 rpm and observed engine performance in terms of higher brake thermal efficiency and lower emissions with different blends of biodiesel.By WCO as biodiesel there is significant reduction in harmful exhaust emission. Abu-Jrai et al. [11] by using WCO 50/50 by volume with diesel oil at different engine condition observes considerable reduction in the smoke opacity and unburnt hydrocarbons associated with an increase in the CO_2 and NOx emissions due to unintentional advance of fuel injection timing, caused by the higher bulk modulus of WCO fuel and also results indicated an increase in brake specific fuel consumption with simultaneous reduction in the engine thermal efficiency compared to conventional diesel.

Researchers also consider the effect of input parameter like injection pressure, Joonsik et al. [12] study the effects of the injection pressure and injection timing on the combustion and emission characteristics in a single-cylinder common-rail direct injection diesel engine fueled with waste cooking oil biodiesel and commercial diesel fuel and engine tests were conducted at two injection pressures (80 and 160 MPa) and different injection timings from 25 to 0 crank angle degree. The results showed that the indicated specific fuel

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consumption with respect to the injection timings of the biodiesel was higher than that of the diesel fuel under all experimental conditions. The peak cylinder pressure and the peak heat release rate of the biodiesel were slightly lower, while the ignition delay was slightly longer under all operating conditions and in term of emission there is reduction of smoke, carbon monoxide (CO), hydrocarbon (HC) emissions especially with high fuel injection pressure and NO_x emission relatively higher than those of diesel. Different authors also performed experiments at different speed and varying load, H. An. et al. [13] conducted experiments on a Euro IV diesel engine to evaluate the performance, combustion and emission characteristics of pure biodiesel and its blend fuels. The experiments performed at four different engine speeds (800 rpm, 1200 rpm, 2400 rpm and 3600 rpm) under three different loads (25%, 50% and 100% load). Results showed that the use of biodiesel/blend fuels resulted in a higher brake specific fuel consumption, especially at low engine speed and partial load conditions and for combustion characteristics, a slightly shorter ignition delay and lower peak heat release rate were found for biodiesel compared to pure diesel. Puhan et al. evaluated the performance of mahua biodiesel in a 3.7 kW Kirloskar make, single cylinder, four stroke, direct injection, constant speed diesel engine. The specific fuel consumption and thermal efficiency were 20% higher and 13% lower respectively than that of diesel [14]. Reefat et al. tested a 40% blend of biodiesel from WCO with mineral diesel, they observed BTE of 28%, BSFC of 0.31 kg/kWh and EGT of 500 °C. BTE was lower by 8% while BSFC and EGT were higher by 9% and 7% respectively compared to petroleumdiesel [15].

II. MATERIAL AND METHODOLOGY

A. *Biodiesel from Waste Cooking Oil*

Waste cooking oil used to produce biodiesel has been obtained from hostel mess, cafeteria which is used to fry vegetables, meat etc. Solid impurities such as food residue present in waste cooking oil (WCO) was removed by cloth filtration twice.

In present work, biodiesel is produced by using transesterification process. In this process Triglyceride reacts with three moles of alcohol to produce alkyl ester and glycerol as by product. The transesterification reaction is reversible and excess alcohol shifts the equilibrium to the product side [16]. Initially one liter of waste cooking oil is heated up to 60 °C on magnetic stirrer cum heater in order to avoid soap formation due to water present in that. To this heated waste cooking oil, mixture of methanol and NaOH is added. NaOH works as a catalyst which increases the rate of reaction and yielding of biodiesel. .Methanol and waste cooking oil are in 6:1 molar ratio and NaOH is 1.2% by weight of waste cooking oil. The reaction takes place for 90 minutes with continuous stirring. Product of the reaction placed into the separating funnel in order to separate glycerol from waste cooking oil methyl ester. After separation, waste cooking oil methyl ester washed with hot water several times until the washing was neutral. The ester was filtered in order to blend with diesel. Different blends of biodiesel (WCME10, WCME20, WCME30, WCME40 and WCME50) are prepared for conducting experiments on CI engine to investigate its performance and emission characteristics. Fuel properties are shown in table 1.

Table 1. Fuel properties

Fuel	*Calorific value (kJ/kg)*	*Density (kg/m^3)*
WCOME10	41380	835
WCOME20	40760	840
WCOME30	40140	845
WCOME40	39520	850
WCOME50	38900	855
Diesel	42000	830

B. Experimental Setup

The setup consists of single cylinder, four stroke, Multi-fuel, research engine connected to eddy current type dynamometer for loading. The major specifications of the engine used for the investigations are presented in table 2.The compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. In Diesel mode fuel injection point and pressure can be manipulated for research tests. Air temp, coolant temp, Throttle position and trigger sensor are connected to Open ECU which control ignition coil, fuel injector, fuel pump and idle air. Set up is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The set-up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and hardware interface. Rotameters are used for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package “Enginesoft” is provided for on line engine performance evaluation.

All the experiments with different fuels were conducted for a constant engine speed of 1500 rpm and constant compression ratio 18 and varying load on engine. Water flow through engine adjusted to 230 lph and 90 lph through calorimeter. Load varied from 0kg to 10.0kg. All the performance and emission characteristics were determined by averaging 10 consecutive cycles. For exhaust gas emission analysis AVL DiTEST CDS 440 gas analyzer was used.

Table 2. Engine specifications

Type of Engine	**4 stroke, water cooled**
Model	TV1
Make	Kirloskar oil engine
Number of cylinders	1
Bore/stroke	87.5/110mm
Rated power	3.5 kW
Rated speed	1500
Injection timing	23°BTDC

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Capacity	661cc
IVO/IVC	4.5° BTDC/35.5°ATDC
EVO/EVC	35.5° BTDC/4.5° ATDC

III. RESULTS AND DISCUSSIONS

A. Brake Thermal Efficiency

Brake thermal efficiency is a measure of overall efficiency of the engine, it is given by the ratio of brake power to the fuel energy. Fig. 1 shows the variations of brake thermal efficiency on addition of biodiesel to diesel with respect to load at compression ratio 18 and constant engine speed of 1500rpm. It follows the usual trend as load increases BTE increases for all biodiesel blends because brake power is increasing relatively more as compared with fuel energy. It was found that brake thermal efficiency of diesel is 26% slightly more as compared to biodiesel blends averaging around 24 to 25%. As blending increases BTE goes down slightly as expected due to high viscosity of biodiesel results in poor atomization and combustion. It is also seen that at partial load, difference in brake thermal efficiency of diesel and it's blends with biodiesel is less compared to medium and full load.

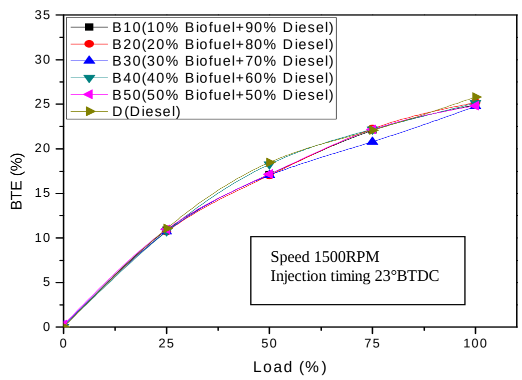

Fig 1.Variation of Brake Thermal Efficiency with respect to load

B. Brake Specific Fuel Consumption

Variation of specific fuel consumption of diesel and it's blend with biodiesel at compression ratio 18 and constant engine speed of 1500rpm with respect to load are shown in figure 2. BSFC of biodiesel blends with diesel averaging 0.33kg/kWh to 0.35 kg/kWh was found to be more as compared to diesel 0.29kg/kWh. As the percentage of blending increases SFC also increases it is generally due to low calorific value of biodiesel and high viscosity.

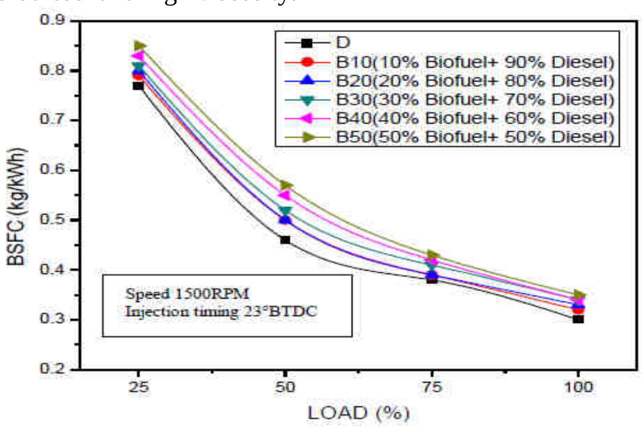

Fig 2. Variation of brake specific fuel consumption with respect to load

C. Exhaust Gas Emission

The variation of exhaust gas emissions of NO_x, CO_2, CO with respect to different loads at compression ratio 18 and constant engine speed of 1500rpm are shown in fig. 3, 4, 5 respectively. It was found that NO_x emission increases up to 75% of load. NO_x emission is depend upon combustion temperature, oxygen concentration and reaction time [17]. NO_x emission is increases due the presence of oxygen with biodiesel. As the blending increase NO_x emission increases and also it was found maximum in case of 50% blending. The combustion rates in the fuel rich zones were improved by longer flame lift-off length, and fuel-bound oxygen of biodiesel at the initial stage of the diffusion combustion phase and resulted in thermal NO_x formation with higher local in-cylinder temperatures [18],[19]. In addition, NOx formation rates in the post flame gas region was increased because of the longer residence time with the increase of the overall combustion duration. And there are also some factor which effect the NO_x emission such as engine design, characteristics of biodiesel fuel, fuel injection pressure.

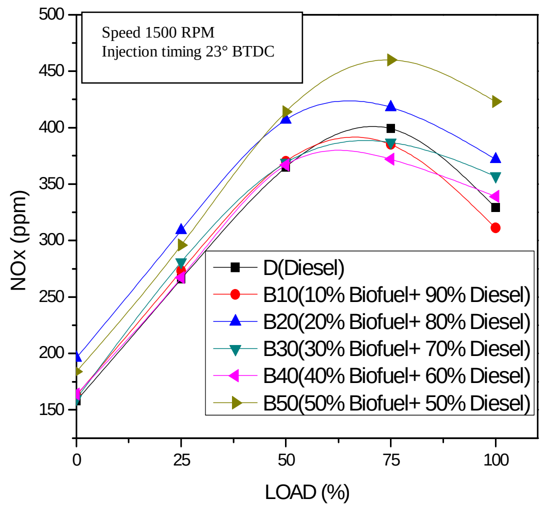

Fig 3. Variation of $NO_x$with respect to load

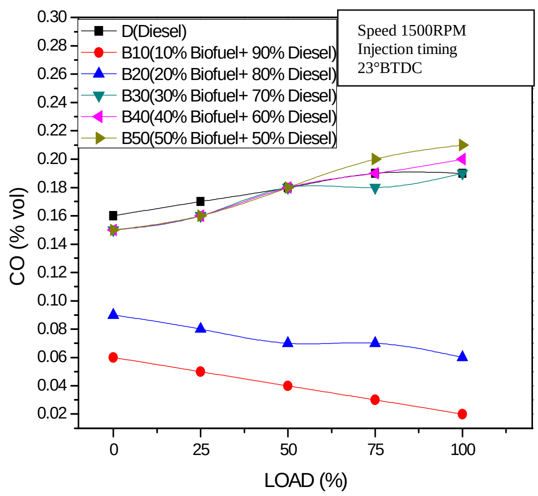

Fig.4 Variation of CO with respect to load

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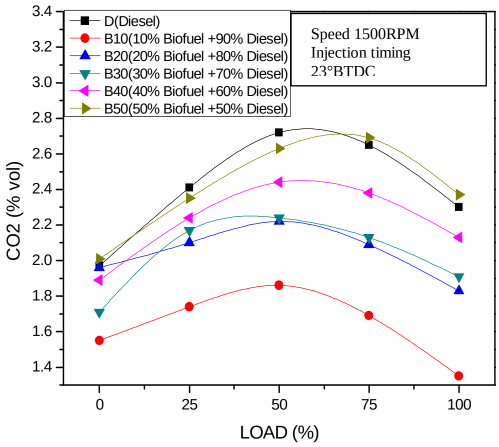

Fig.5 Variation of CO_2 with respect to load

The CO formations in engine, it is formed as a resultant of incomplete combustion due to mainly lack of oxidants, lower oxidation temperature and residence time [20]. As we found that for B10 & B20, CO decreases due to more presence of oxygen with biodiesel but as blending increases the trend is changed. It is expected that as biodiesel increases oxygen content also increases but also due to high viscosity and injection pressure, poor atomization occur which results in improper combustion of fuel lead to increase CO content.

In fig. 5, CO_2 is given in % volume of exhaust gas so as load increases it first increases then decreases it may be due to that as air box of engine is automatically operated at higher load it supplies more air as we found in exhaust gas emission amount of O_2 also follows the same trend like that for B10 oxygen content is (18.69, 18.20, 17.94,18.32, 18.84) so %vol. of CO_2 decreases at higher load.

IV. CONCLUSION

In the present study performance and emission characteristics of single cylinder four stroke diesel engine fueled with waste cooking oil diesel blends (10%, 20%, 30%, 40%, 50%) were investigated. This experiment was conducted on different load with constant engine speed of 1500rpm. The conclusion are described as follows

The prospect of waste cooking oil based biodiesel production looks very promising in a country like India, as it is economical feedstock to produce. Waste cooking oil methanol ester from the transesterification of WCO satisfies the important fuel properties as ASTM standards.

As it found that increase in load BTE is also increases for all biodiesel blends but BTE of biodiesel blends decreases as the blending percentage increase. BTE of B50 is 24.82% which is 3.90% less than the BTE of diesel.BSFC of biodiesel is found to be more for biodiesel as compared to diesel. At partial load BSFC of B50 is 9.40% more than that of diesel and at full load it is 16.67%.

NO_x emission increases with respect to increase in load. NO_x emission found to be higher as blending and load is increases. At partial load NO_x emission of B50 is 14.10% more than diesel and at full load it is 22.22%.

CO emission for B10, B20 decreases with increase in load. The minimum value occurs at full load it is 0.01% volume of exhaust gas. But as blending percentage increases trend changes although biodiesel increases oxygen content but due to high viscosity and injection pressure, poor atomization occur which results in improper combustion of fuel lead to increase CO content. B50 possess the maximum emission of 0.21% volume of exhaust gas.

Abbreviations and Acronyms

B10	10% WCOME + 90% diesel
B20	20% WCOME + 80% diesel
B30	30% WCOME + 70% diesel
B40	40% WCOME + 60% diesel
B50	50% WCOME+ 50% diesel
BTE	Brake thermal efficiency
CI	Compressed ignition
CR	Compression ratio
NaOH	Sodium Hydroxide
CO	Carbon monoxide
CO_2	Carbon dioxide
ECU	Electronic control unit
HC	Hydro Carbon
LPH	Litre per hour
NO_x	Oxides of nitrogen

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