

Performance and Emission Studies of a Variable Compression Ratio CI Engine using Bio Diesel Made from Waste Cooking Oil

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Abstract

Compression ignition (CI) engine is the un-debated choice for power applications, stationary or mobile. There is an urgent need of alternative high potential fuel for CI engines in order to fulfill energy needs without hampering the thermal performance and stringent emission standards. Here waste cooking oil is chosen as an alternative fuel, which is upgraded into biodiesel in the laboratory using mechanical stirring and ultrasonic cavitation technique of biodiesel production.

Four blends of cooking oil are made by increasing 20% its amount in conventional diesel fuel. Performance is analyzed for two compression ratios, 15 and 17.5, on the existing VCR diesel engine set up interfaced with "Engine Soft" software. The results show that as bio-diesel concentration in a blend increases, the thermal performance (i.e., brake thermal efficiency) and emissions (i.e., CO, HC and NOx, and smoke intensity) are observed to be marginally higher; on the other hand, as compression ratio increases, the thermal performance improves; CO and smoke opacity decreases.

1. Introduction

The scarcity of fast diminishing resources of fossil fuels, increasing prices of crude oil, and environmental concerns have been the various reasons for exploring the use of vegetable oils as alternative to diesel oil [1-4]. Vegetable oils offer almost the same output with slightly lower thermal efficiency when used in diesel engines [5]. Reduction of engine emissions is a major research aspect in engine development with the increasing concern over environmental protection and the stringent exhaust gas regulation [6]. The use of neat vegetable oils poses some problems such as coking and trumpet formation on the injectors, carbon deposits, oil ring sticking and thickening and gelling of lubricating oil, when subjected to prolonged usage in CI engines. These problems are attributed to high viscosity, low volatility and polyunsaturated character of vegetable oils [7]. Some of the common problems posed by using vegetable oils in diesel engines are as a result of contamination by the vegetable oils. Different methods such as preheating, blending and trans stratification are being used to reduce the viscosity and to produce bio-diesel, suitable for engine applications. In the present investigation, bio-diesel is prepared from waste cooking oil. The performance and emission characteristics were studied on a four-stroke, single cylinder, variable compression ratio direct-injection diesel engine to ensure its suitability as CI engine fuel.

2. Experimental System Development for Bio Diesel Production

2.1 Methodology

Huge quantities of waste cooking oils and animal fats are available throughout the world, especially in the developed countries. Management of such oils and fats pose a significant challenge because of disposal problems and possible contamination of the water and land resources. Even though some of this waste cooking oil is used for soap production, a major part of it is discharged into the environment. The use of waste cooking oil as a biodiesel source has a potential to reduce CO₂, particulate matter and other greenhouse gases as the carbon contained in biomass-derived fuel is largely biogenic and renewable.

Waste cooking oil, which is otherwise wasted, is one of the most economical choices to produce biodiesel. It is recognized that the production of waste cooking oil will be the function of the frying temperature and length of use as well as the material used for frying. In this experiment, waste cooking oil was collected from an hotelier industry.

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2.2 Magnetic Stirring Technique

In this process mixing of oil and alcohol is done by a magnetic stirrer. A magnetic capsule is dipped in the immiscible liquid (oil and alcohol are not miscible with each other), as the capsule starts rotating, a whirl is formed which disturbs the phase boundary between two immiscible liquid and resulted in emulsification of mixture. Magnetic stirrer used is as shown in figure 1.



Fig. 1: Mechanical Stirrer

2.3 Ultrasonic Cavitation Technique

Methanol is immiscible with the cooking oil. The mixture of oil, methanol and catalyst is poured in ultrasonic processor transducer (model TU-50). Test is performed for the ultrasonic frequency (28.5 KHz). During the reaction the temperature of mixture is kept between 45-60°C. When reaction is completed the beaker is kept for the separation. Fatty acid has higher specific weight therefore it will settle at bottom. Separation of methyl ester and glycerol will take 2 to 3 hr duration. After complete separation bio-diesel (methyl Ester) is visible in the upper layer and glycerol at the bottom as shown in figure 2. Bio-diesel is separated from beaker for purification process. The catalyst present in the methyl ester is impurity. Excess methanol present in biodiesel has been removed by vaporization process.

3. Experimental Setup

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Provision is also made for interfacing airflow, fuel

flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, two fuel tanks for dual fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water flow measurement. 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 and heat balance. The blends B20, B-40, B-60, B-80 and B100 were prepared in the laboratory by mixing appropriate volume of diesel with waste cooking oil.



Fig. 2: Biodiesel from WCO

A set of reading was obtained first by running the engine with diesel at CR of 17.5 and varying the load from idle to rated load of 3.5 KW in steps of 1 up to 3 KW and then to 3.5 KW. The engine performance characteristics were recorded by using the software Engine Soft and instrumentation provided by the National Instruments. The emissions were recorded for each load by using Gas Analyzer (Model: AVL DI Gas 444) and the opacity was recorded by Smoke meter (Model: AVL 437).

The engine was started at compression ratio of 17.5 and then the compression ratio was changed by using the tilting head arrangement. The compression ratio was indicated by the rings made on the lever of the arrangement. The VCR engine test rig is shown in figure 3.

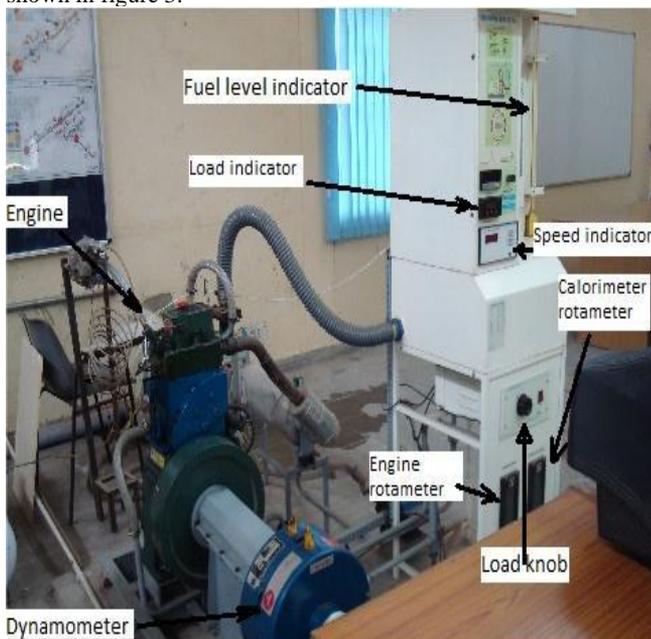


Fig. 3: VCR Engine Test Rig

4. Results and Discussion

4.1 Engine Performance

4.1.1 Brake Power

The effect of variation of brake power output at two different compression ratios has been studied for thermal performance (in

terms of brake thermal efficiency, specific fuel consumption, mechanical efficiency volumetric efficiency) and emissions (in terms of carbon-monoxide, nitrogen oxides, hydrocarbons emissions and smoke opacity).

4.1.2 Brake Specific Fuel Consumption

Brake specific fuel consumption (bsfc) as a function of load obtained during engine operation on bio-diesel blends and diesel fuel at compression ratio of 17.5:1 is shown in Figure 4. For all fuels tested, bsfc decreased with increase in load at both compression ratios. At the compression ratio 15: 1, the bsfc of 0.29 kg/kWh was obtained for the Diesel fuel and at compression ratio 17.5:1 the bsfc of 0.27kg/kW/h. The data showed that at higher compression ratio there is slightly decrease in brake specific fuel consumption., the fuel blends B20 maintain about the same bsfc as that of diesel fuel, The brake specific fuel consumption at compression ratio 17.5:1 at B40 and brake specific fuel consumption at compression ratio 15:1 at B20 are same i.e 0.31kg/Kw/h. The reason for the above trend is more likely due to lower calorific values of bio-diesel blends compared to those of neat diesel [8]. So in order to produce equivalent power to that of diesel more bio-diesel blended fuel is required. The reason for increase in bsfc for all loads is the lower calorific value of bio-diesel blends than pure diesel.

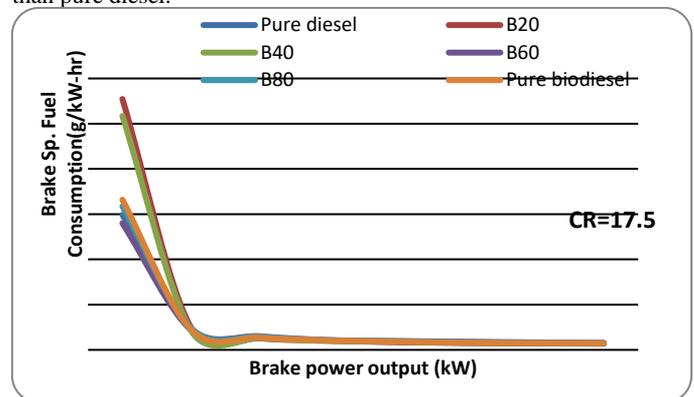


Figure 4: bsf vs. BP at CR 17.5:1

4.1.3 Brake Thermal Efficiency

The brake thermal efficiency increases with an increase in load at different compression ratios and at various biodiesel blends. This can be attributed to reduction in heat loss and increase in power with increase in load. The maximum brake thermal efficiencies obtained is about 31.18% for B40 at 17.5:1 and at 15:1 the brake thermal efficiencies is about 29.77% as shown in figure 5.

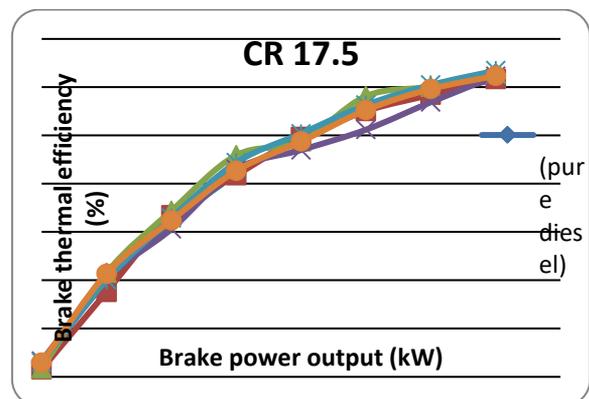


Figure 5 Break thermal efficiency at CR 17.5:1

This shows that at lower compression ratio there is decrease of 1.41% for the B40 biodiesel blends. The mixing of bio-diesel in diesel oil yields good thermal efficiency curves. Initially the thermal efficiency of the engine is improved by increasing concentration of the bio-diesel in the blend. The possible reason for this is the additional lubricity provided by bio-diesel. The molecules of bio-diesel (i.e. methyl ester of the oil) contain some amount of oxygen,

which takes part in the combustion process. It is noticed that after a certain limit with respect to diesel ester blend, the thermal efficiency trend is reversed and it starts decreasing as a function of the concentration of blend.

4.2 Emission Parameters

4.2.1 Carbon Monoxide

Figure 6 shows the plots of carbon monoxide (CO) emissions of blends and diesel fuel at different load conditions and compression ratio of 17.5:1.

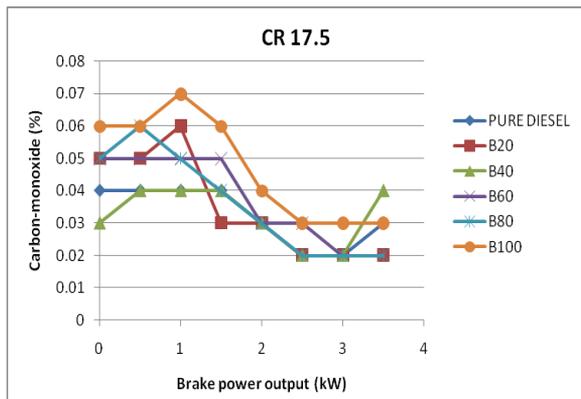


Figure 6 CO emissions at CR 17.5:1

This is typical with all internal combustion engines since air/fuel (A/F) ratio decreases with increased load. Also the data showed increase in CO emissions as the load was increased up to 50% when running on bio-diesel blends.

4.2.2 Un- burnt Hydrocarbon

The emission of un-burnt hydrocarbons (HC) for all fuels and compression ratios is small, 25-122 ppm, increasing slightly with load and proportion of fuel injected. It is quite difficult to determine any reliable dependencies; the waste cooking oil operation showed very low HC emissions throughout the load range. The plot indicates that HC emissions peaked at a particular A/F ratio and then dropped with further increase in load. The plot showed increase in HC emissions as the quantity of diesel fuel in the blend increases. A very significant difference was noted at low and high load conditions at the compression ratio 17.5:1 as shown in figure 7.

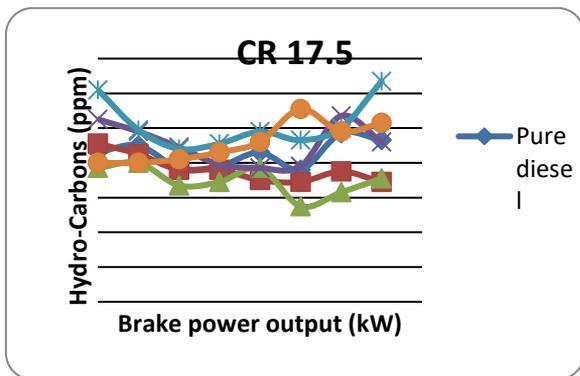


Fig. 7. HC emissions at CR 17.5:1

The increase in diesel/WCO blend showed highest HC concentration in the exhaust when compared with the results of increase in WCO/diesel blend. However at light load, the biodiesel blends did not show any marked difference in HC emissions irrespective of compression ratios. For minimum load the reduction was practically unaffected by the addition of bio-diesel in the diesel fuel at all Compression ratios. The most beneficial reduction appeared at intermediate loads. Hydro carbon emissions as a function of engine load at various compression ratios.

4.2.3 Oxides of Nitrogen

The emission of nitric oxide (NO) increases gradually with load, (figure 8) reaching the maximum values of 1578 ppm for blend80 at compression ratio 17.5:1 and its value decreases to 1478 ppm for blend 100 at the same compression ratio. When operating at the compression ratio of 15:1, the minimum NO emissions at adequate loads were maintained by the B20 blend. Biofuels with higher oxygen contents, 1.45% to 4.075%, and neat bio-diesel produce higher or a bit lower NO emissions, depending on the load.

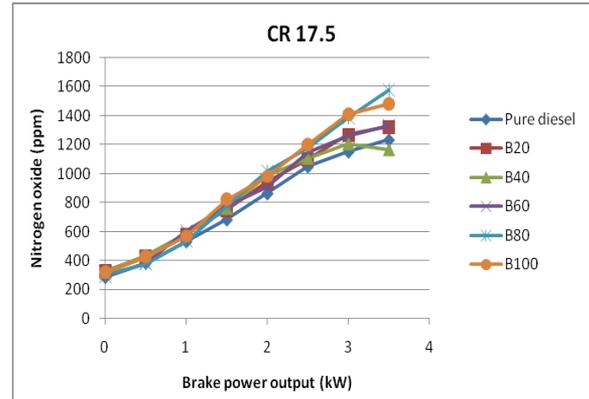


Figure 8. NO emissions at CR 17.5:1

The reason for the decrease in NO was that the cetane number of the bio-diesels was higher than that for diesel fuel and this is associated with lower NO emissions [9]. Increasing cetane number reduces the size of the premixed combustion by reducing the ignition delay. This results in lower NO formation rates since the combustion pressure rises more slowly, giving more time for cooling through heat transfer and dilution and leading to localized gas temperatures [9]. Furthermore the emission of nitrogen oxide from engine exhaust are highly dependent on oxygen concentration and thus the combustion temperature.

4.2.4 Smoke Opacity

The smoke (soot) opacity with brake mean effective pressure of exhaust gas for neat diesel fuel and bio-diesel blends is shown in figure 9.

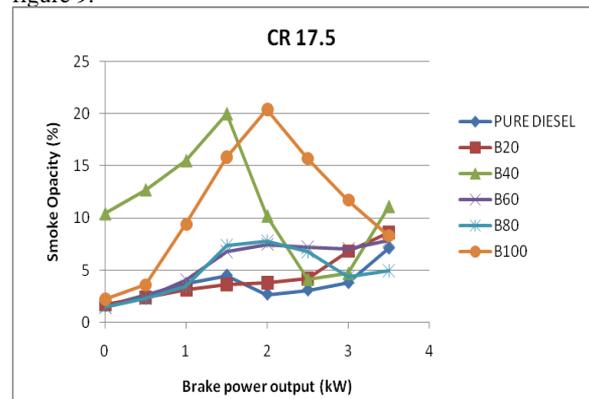


Figure 9 Smoke Opacity at CR 17.5:1

One can observe that soot emitted by all bio-diesel blends is lower than neat diesel at low loads and lower compression ratio. This is attributed to the combustion being mixed controlled for these blends, as is also the case for neat diesel, which is however assisted by the presence of the fuel bound oxygen [10]. However, there is no definite trend observed in smoke density with increase in blend percentage of bio-diesel. At all compression ratios, B100 was found to emit maximum smoke at full load. The minimum and maximum smoke opacities produced for B60 and B100. The smoke emissions generally increase or decrease in relation to the sulphur concentration. Sulphur in the fuel, results in sulphates that are absorbed on soot particles and increase the smoke emitted from diesel engines. In addition, the increase of oxygen content in the

fuel contributes to a complete fuel oxidation even in locally rich zones, leading to a significant decrease of smoke [9-10].

5. Conclusions

Four blends of cooking oil are made by increasing 20% its amount in conventional diesel fuel. Performance is analyzed for two compression ratios, 15 and 17.5, on the existing VCR diesel engine set up interfaced with "Engine Soft" software. The results show that as bio-diesel concentration in a blend increases, the thermal performance (i.e., brake thermal efficiency) and emissions (i.e., CO, HC and NO_x, and smoke intensity) are observed to be marginally higher; on the other hand, as compression ratio increases, the thermal performance improves; CO and smoke opacity decreases.

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