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Experimental Investigation of Performance, Combustion and Emission Characteristics of A Variable Compression Ratio Engine Using Waste Cooking Oil Biodiesel Blends

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Abstract- The performance, combustion, and emission characteristics of a single-cylinder compression ignition (CI) engine fueled by biodiesels derived from waste cooking oil biodiesel (WOB) and diesel fuel (BF) were compared in this study. At constant engine speed (1500 rpm) and with five engine compression ratios (14.5-18.5) and 100% loads, performance and combustion studies were conducted. WOB blends exhibited slightly higher specific fuel consumption (SFC) and slightly lower oxides of nitrogen (NOx) emissions than BDF blends. Brake thermal efficiency (BTE) and ignition delay (ID) were lower when comparing WOB and BDF, whereas carbon dioxide (CO2) emissions were higher. At CR15.5 under maximal load, the cylinder pressure of WOB20 was marginally greater than that of BF

Keywords Waste energy recover from waste; Presentation, Ignition; Discharges

1. Introduction

Finding new sources of useable energy and making the globe a healthier, more environmentally friendly place to live will continue to pique the curiosity of researchers. Because of the rapid depletion of the planet's fuel supplies, people in every region of the globe are already well aware of the fact that they need to devise new strategies in order to fulfil their ever-increasing need for energy. In addition to this, there is a need to find a solution to the issue of dangerous pollution caused by fossil fuels. In the recent past, biodiesel that is produced from a variety of environmentally friendly sources has emerged as a viable contender for the function of fuel in compression ignition engines (CI engines). The monoalkyl esters of long-chain fatty acids that are the building blocks of biodiesel are referred to collectively as "alternative" esters. Alternative is derived from vegetable oils and is afterwards introduced into CI engines that have not undergone any kind of modification. The production of biodiesel is accomplished by a chemical process known as transesterification S. Kathirvel, V. Sharma, D. Balasubramanian et al [1] [2] [3].

The different amounts of methyl esters in alternatives made from different bases has a big effect on the physical and chemical properties of the alternatives and, by extension, the properties of the engine being used. S. Kumar, P. Chaurasiya et al. [4]-[5]. Most people think that WOB is one of the most important alternative resources when it comes to the pyrolysis process, which is used to make liquid biofuels. This happens because WOB is easy to get and doesn't cost much in these countries A. Ben et al [6]. C. Patel et al [7] compared Jatropha biofuel, Karanja oil biofuel, and waste cooking oil biofuel (WOB) with diesel fuel on a vertical single cylinder, four-stroke engine with varying loads. They discovered that the heat release rate of WOB was greater than that of diesel fuel, whereas Karanja and Jatropha biodiesels had marginally lower. Compared to diesel, biodiesel emissions of hydrocarbons and nitrogen oxides were lower, whereas carbon monoxide emissions were higher. J. Mattson et al. [8] examined the effects of biodiesel (WCO) blend was utilised in a DI transport engine. They discovered that ignition delay, CO emissions, and HC emissions were all slightly reduced compared to diesel. M. Akcay et al. [9] used a 1.461-liter, four-stroke, water-cooled, turbocharged engine and put different loads on it at a steady 1,750 rpm. Compared to natural diesel, hydrogen lowered HC and raised nitrogen fumes and cylinder pressures. H. Hazar, et al., [10] examined the characteristics of emulsion fuel and its effect on a diesel engine at various levels of fuel (20 to 50%). The results indicate that the addition of 20% biofuel to a blend marginally increases the temperature of exhaust gas, whereas CO and HC emissions decrease with increasing WOB content.

Y.Teoh et el., [11] examined the characteristics of WOB fuel and its effect on a diesel engine at various loads (1.3-5.3 bar). The results indicate that the addition of WOB biofuel to a blend marginally increases CO and HC emissions, whereas BTE decrease with increasing WOB X. Xia, G Abbas et al [12] [13] characteristics of Karanja and Linseed oil biodiesel as diesel engine fuel at varying brake power (0.5-3.5 kW). Adding Karanja and Linseed oil biofuel blends marginally increases BSFC, exhaust gas temperature, and mechanical efficiency, while BTE and particulate emissions decrease with increasing Karanja and Linseed oil biofuel content in the blends.

There are few studies in the scientific literature that cover engine performance, combustion, emissions, and biofuel production from waste oils. In this context, comparative engine performance, combustion, emission characterisation, and analysis of the discharge from a single-cylinder diesel engine fuelled by WOB and BDF at constant engine speed of 1,500 rpm and varying engine CR14.5-18.5 were investigated experimentally.

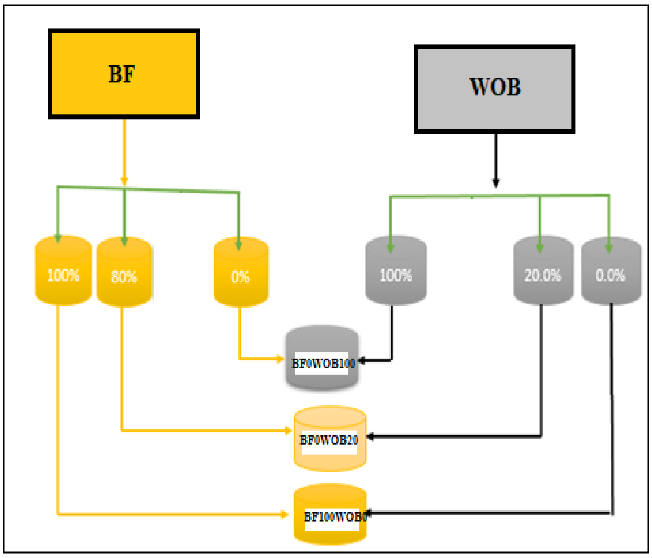

Fig.1. Blending procedure

2. Waste Oil Energy and Experiment Setup

2.1. Waste Oil Energy

Adding biodiesel to diesel fuel at volumes of 0%, 20%, and 100% yields the same results as adding biodiesel to diesel fuel at volumes of 100%, 80%, and 0%. During the phases of the experiment in which the test engine used a blend of base fuel (diesel) and WOB fuels, WOB was added to BF, and the resulting fuels were designated as BF100WOB0, BF80WOB20, and BF0COB100. It was injected into the engine cylinder using a device for fuel injection. The characteristics of the WOB correspond to the EN 590 parameters, as determined by examining Table 1. The BF, WOB, and blend fuel used in the study were subjected to a series of physical-chemical experiments to ascertain their properties. The results of these tests are depicted in Figure 1 and fuel sample in Fig.2.

2.2. Experimental Test Rig

The test setup is shown in Figure 2 which is a drawing. The engine technical specifications are shown in Table 2. The engine was subjected to load using a dynamometer. Fuel use was monitored using a fuel metre. By installing an air box on the motor, we were also able to evaluate the airflow rate. The temperature of the exhaust gas was tracked using a digital temperature display and a thermocouple. To measure and record cylinder pressure, a pressure transducer was attached to the engine cylinder head, and a charge amplifier was employed. NOx, HC, and CO levels were measured using an exhaust gas analyzer (Testo-350)

Table 1: Fuel Properties

Characteristics of fuel	**BF100 WOB0**	**BF80 WO B20**	**BF0WOB 100**
Viscosity (mm^2/s) at 40 °C	3.8	3.59	3.64
Density (kg/m^3) at 15 °C	838	849.5	874.7
Calorific value (MJ/kg)	45.5	44.6	40.4
Flash point (°C)	61.2	52.6	36.5
cetane number	45-52	52.9	49.5

Fig.2. Fuel Samples

All of the evaluations were performed using a data collection system interface at the maximum engine speed of 1500 rpm.

Fig. 3. Test Setup

3. Results and Discussion

3.1. Engine Performance

3.1.1. Specific Fuel Consumption (SFC)

Figure 4 depicts the difference in SFC between the BF100WOB0, BF80WOB20, and BF0WOB100 depending on the CRs of the engines (14.5-18.5). The following is the formula that is used in the determination of the brake specific fuel consumption (SFC) of the diesel engine.

Table 2: Technical Specifications

Limits	**Limits value**
Engine stroke /cylinder	4/1
Higher FIP	230 bar
Speed	1500 rpm
Dimension of bore/stroke	87.5/110 mm
Advanced fuel injection timing	24.0° b TDC
Compression ratio	14.5-18.5
Method of cooling	Water

$$\mathrm{BSFC} = \frac{\text{mass flow rate of fuel in kg/s} \times 3600}{\text{brake power in kW}}\ \mathrm{kg/kWh}$$

The engine that was run at 1500 rpm demonstrated an increase in SFC of 3.5% and 3.1%, respectively, for BF80WOB20 and BF0WOB100 when operated at CR17.5.

3.2. Experimental Error Analysis

There are a variety of factors that might cause the results of an experiment to be inaccurate. One of them is the inaccuracy that arises from the instruments that are employed throughout the research to account for its various constraints. If π_1, π_2……. π are inaccuracies with separate limits, then Eq. (1) H. Hazar et al [10] can be used to estimate the experiment total error (πr). Table 2 shows how far off the estimates of the parameters were. In Table 3, you can see how uncertain each of the measured metrics is. Also, 2.56% is set as the total amount of uncertainty in all of the tests.

$$\textbf{Error analysis } \%(\pi_r) = \sqrt{\left(\frac{\partial r}{\partial x_1}\pi_1\right)^2 + \left(\frac{\partial r}{\partial x_2}\pi_2\right)^2 + \left(\frac{\partial r}{\partial x_3}\pi_3\right)^2 + \ldots\ldots\ldots\ldots \left(\frac{\partial r}{\partial x_n}\pi_n\right)^2}$$

Table 3: Error in Experiments

Apparatus	**Error**
Encoder	±0.2%
Burette measurements.	±1.0%
Speed	±1.0%
Load cell	±0.2%
Measurement of the heat value	±1.0%
Pressure	±0.5%
CO_2	± 0.5-1.0%
NO_X	± 0.5-1.0%
Smoke	± 1.0%
Temperature	±0.5%

At CR17.5 and 100% load, the SFC values of BF80WOB20 by 0.259 Kg/kWh and BF0WOB100 by 0.2617 Kg/kWh were higher than those of BF by 0.2533 Kg/kWh. The basic fuel had a higher calorific value than the BF80WOB20 and BF0WOB100 fuels, both of which had lower calorific value numbers. When calculating SFC, the calorific value of a fuel is a crucial component to take into account. The information presented in Table 1 reveals that WOB and blends had less calories than BF. The engine has to burn through a lot more biodiesel to get the same power out to the output shaft because of the alternative poor calorific value and other unfavorable qualities including its high density and viscosity. As compared to BF, the SFC values of biodiesel fuels were proven to be substantially greater M. Akcay,H. Hazar, H. How et al, [9]-[11]. By boosting the CRs, we were able to reduce fuel consumption to its absolute minimum A. Hasan et al,[14].

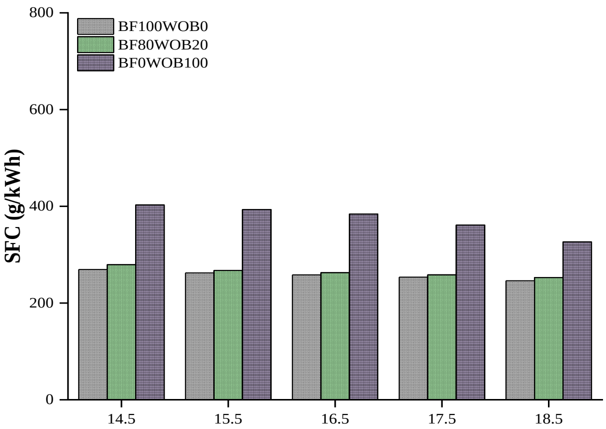

Fig. 4. Specific Fuel Consumption with CRs

3.2.2. Brake Thermal Efficiency (BTE)

Figure 5 illustrates the difference in braking torque between the BF100WOB0, BF80WOB20, and BF0WOB100 at different engine CRs (14.5-18.5). The following is the formula that is used in order to calculate the BTE of the diesel engine: BTE =(brake power in kW)/(heat supplied by the fuel in kJ/s)× 100 %. When operating at 1500 rpm, the engine demonstrated a reduction in BTE of 3.4% and 3.2% for BF80WOB20 at CR14.5 and CR17.5, respectively. At CR17.5 and 100% load, the BTE values of BF80WOB20 by 32.5% and BF0WOB100 by 26.8% were lower than those of BF by 33.6%. The ratio of the quantity of energy that is taken from the fuel to the amount of energy that is extracted from the generation of electricity is one definition of thermal efficiency S. Mohite et al [15]-[16]. This effect is brought about as a consequence of increased mass flow rate and lower heating value of the injected fuel S. Mohite set al, [17] [18]. Rajak, U et al, [19]. Calculate the fuel energy content using its mass flow rate and lower heating value. A little increase in BTE was seen with the biodiesel due to reduced fuel atomization in the burning space. One possible explanation for this is the higher viscosity of alternative compared to diesel I. Veza, J. Gao et al [20]-[21]. At full load, the BF BTE was found to be 33.6% higher than the BF80WOB20 BTE, the BF0WOB100 BTE, and the BF0WOB100 BTE.

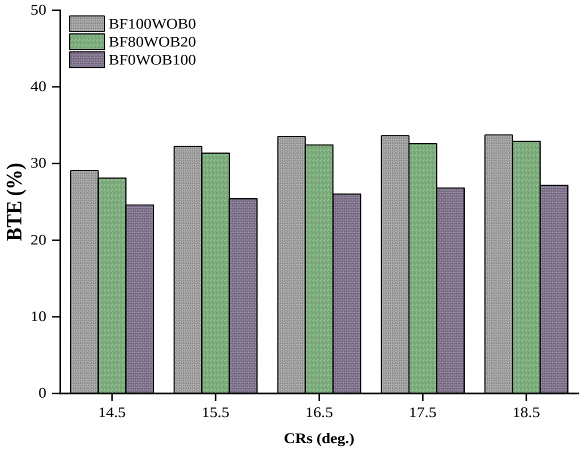

Fig.5. BTE with CRs

3.3. Maximum Cylinder Pressure (Max.CP)

The contours of the maximum cylinder pressure (Max.CP) are depicted in Figure 6 for the BF100WOB0, BF80WOB20, and BF0WOB100 with their respective engine CRs (14.5-18.5). It was discovered that the Max.CP was greater for base fuel thasn for WOB and mix while the engine was operating at maximum load. At CR17.5 and 100% load, the Max.CP values of BF80WOB20 by 96.0 bar and BF0WOB100 by 68.9 bar were lower than those of BF by 98.0 bar. This was because base fuel had a larger calorific value than WOB and blend. Discovered greater cetane number of B20 feedstock blends owing to early combustion processes by N. Krishaina et al. [22], U. Rajak et al. and [23]. As the compression ratio (CR) is increased, there is a corresponding increase in the Max.CP for both the diesel blend (B20) and the base fuel that was tested. This is because a higher intake air temperature permits better oxidation and fuel atomization with air, which in turn accelerates the entire combustion process.

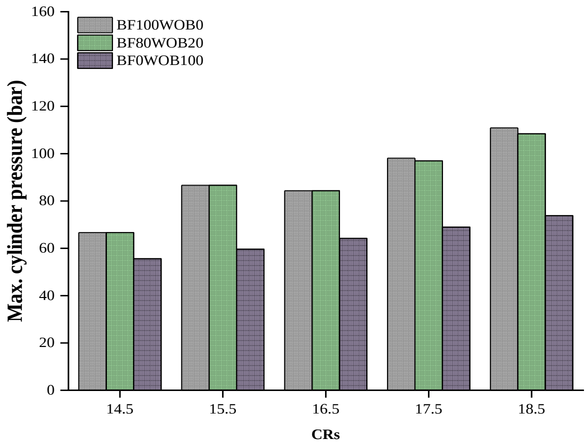

Fig.6. Cylinder Pressure with Engine CRs

3.4. Ignition Delay

Figure 7 illustrates how the ignition delay (ID) varies depending on the engine CR for the BF100WOB0, BF80WOB20, and BF0WOB100 (14.5-18.5). When operating at 1500 rpm, the engine demonstrated a reduction in ID of 2.7% and 14.5% for BF80WOB20 at CR14.5 and

CR17.5, respectively. At CR17.5 and 100% load, the ID values of BF80WOB20 by 11.8 deg. and BF0WOB100 by 7.6 deg. were lower than those of BF by 13.92 deg. Reduce the delay duration of the BF80WOB20 and BF0WOB100 fuels as a result of their reduced NOx emissions, which results in a lower cylinder temperature and a shorter delay period. When the compression ratio is raised, B. Wang et al. [24] found that the ID time was compact. This was because the fraction of the diffusion combustion phase was increased, which in turn considerably prolonged the length of the combustion process. A littler ID was reported by T. Nath et al. [25] when the CR was raised of 15.5 to 19.5. Besides the fact that it has the lowest cetane number, which should, in principle, result in the longest igniting delay. D. Babu et al. [26] found that a low in-cylinder temperature decreased evaporation and lengthened the delay time of the tested fuels.

Near TDC, in-cylinder temperature is greater, improving fuel evaporation and reducing delay. Fuel injection timing delayed from 21-15 °CA b TDC reduces the delay period. Delaying fuel injection lowers delay. Pre-injection increases cylinder temperature and pressure, reducing the interval between main injection and post-injection.

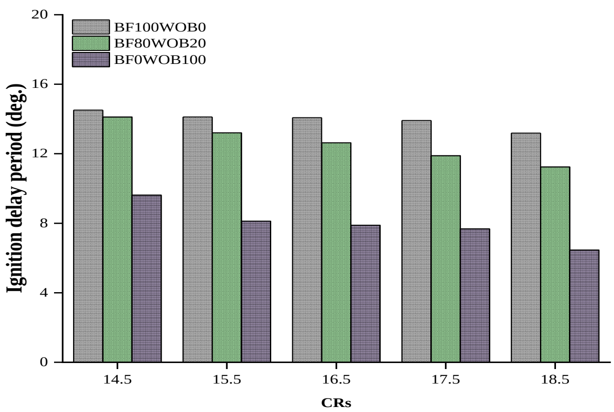

Fig.7. Ignition Delay with Engine CRs

3.5. NO_X Emission

The change in NOx emissions for the BF100WOB0, BF80WOB20, and BF0WOB100 that occurs with engine CRs is shown in Figure 8. (14.5-18.5). When operating at 1500 rpm, the engine demonstrated a reduction in NOx emission of 12.3% and 6.6%, respectively, for BF80WOB20 at CR14.5 and CR17.5. At CR17.5 and 100% load, the NOx emission values of BF80WOB20 by 2939.6 ppm and BF0WOB100 by 1770 ppm were lower than those of BF by 3148.8 ppm. The amount of NOx that is released is mainly reliant on the heat of the cylinder, the amount of time that has passed, and the amount of oxygen present. Higher combustion temperatures and increased oxygen concentrations were two of the primary factors that led to the creation of NOx. Because of the increased combustion temperature brought on by the increased amount of hydrogen, the NOx emissions are much greater than those of the plain diesel. This longer ID of the hydrogen mixture was the cause of the increased NOx emission that was produced. Because of this action, the temperature of the combustion was raised, which resulted in a greater release of NOx V. T. Vimalananth, A. Yasar et al [27]-[28].

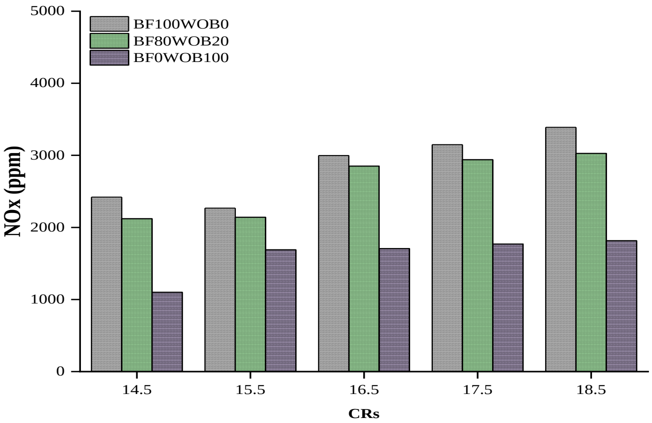

Fig.8. NO_X Emission with Engine CRs

3.6. CO_2 Emission

Figure 9 illustrates how the CO_2 emissions for the BF100WOB0, BF80WOB20, and BF0WOB100 change in response to changes in the engine CRs (14.5-18.5). When operating at 1500 revolutions per minute, the engine demonstrated an improvement in CO2 emissions of 1.2% and 2.4% for the BF80WOB20 at CR14.5 and CR17.5, respectively. At CR17.5 and 100% load, the CO2 emission values of BF80WOB20 by 845.4 g/kWh and BF0WOB100 by 1135.0 g/kWh were higher than those of BF by 825.5 g/kWh. A. Yasar et al. [28] the proportion of ethanol and methanol in the fuel mixes had an effect on the amount of carbon dioxide that was emitted. The C/H ratio, fuel mixes, and fuel usage all have a significant impact on the CO2 emissions that are generated A. Sharma, T. Nath et al [29] [30]. According to K. Duraisamy et al. [31], the presence of carbon dioxide in the exhaust is caused by the full burning of fuel in an environment with a high gas temperature. The oxygen atoms present in the plastics oil are likely to blame for the 13% rise in CO2 emissions that were caused by the mixture. These oxygen atoms may have delivered more oxygen while burning and made CO to CO_2 conversion simpler. CO_2 generation may be affected by the temperature of the combustion process, the air-to-fuel ratio, and the formation of the mixture. Under high loads, EGR raises the equivalency ratio, which in turn lowers the amount of CO2 that is produced. The presence of inert species in exhaust gases brings the temperature of combustion down, which makes CO oxidation more difficult.

4. Conclusion

In the present study, waste cooking oil biodiesel (WOB) was utilised as a sustainable compression ignition engine fuel.

- Pressure, BTE, and NOx emissions grow with CR improvement from 14.5 to 18.5. The highest values of pressure, BTE, and NOx emission all occur at CR18.5 of the BF0WOB20 blend. These values are 108.4 bar, 32.8%, and 3028 ppm, respectively.
- The increase from 14.5 to 18.5 in CR decreased SFC and ignition delay. SFC found to be 258.1 g/kWh and ignition delay found to be 11.8 at CR17.5 for BF0WOB20 blend.
- CR increased CO2 emission from 14.5 to 18.5. At CR17.5 of the BF0WOB20 blend, CO2 emissions reach 845.4 g/kWh, 825.4 g/kWh for BF100WOB0 and 1135 g/kWh for BF0WOB100.

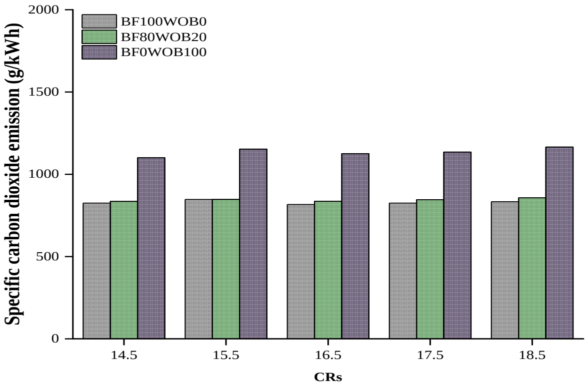

Fig.9. CO_2 Emission with Engine CRs

Abbreviations

BF	Base fuel (diesel)
BTE	Brake thermal efficiency
CI	Compression ignition
CR	Compression ratio
CO2	Carbon dioxides
ID	Ignition delay
Nox	Nitrogen oxides
Rpm	Revolution per minute
SFC	Specific fuel consumption
WOB	Waste cooking oil biofuel
WOB20	20% waste cooking oil biodiesel
BF100WOB0	100% base fuel and 0% waste cooking oil biodiesel
BF80WOB20	80% base fuel and 20% waste cooking oil biodiesel
BF0WOB100	0% base fuel and 100% waste cooking oil biodiesel

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