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Experimental Investigation of Combustion Characteristics of Waste Cooking Oil Methyl Ester and its Blends in Compression Ignition Engine

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ABSTRACT: The high energy demand in the industrialized world as well as the pollution problems caused due to the use of fossil fuels make it increasingly necessary to develop a new renewable energy source. This work transesterified waste cooking oil with methanol and investigated combustion characteristics of the resulting methyl ester and its blends in a compression ignition engine. The methyl ester and its blends were combusted in a direct injection single cylinder four-stroke air cooled diesel engine one after the other and the combustion characteristics such as combustion temperature, cylinder pressure, heat release rate and ignition delay were investigated at different loads of 0.0, 20.0, 40.0, 60.0, 80.0 and 100.0% with full throttle speed of the engine. Results obtained showed that the combustion temperature, cylinder pressure and heat release rate increased as the load increased for each blend. And for each load, the combustion temperature, cylinder pressure and heat release rate increased as the percentage of methyl ester in the blends increased. While ignition delay reduced as the load increased but increased as the percentage of methyl ester in the blends increased. The study concludes that waste cooking oil methyl ester and its blends compare favorably with petroleum diesel and possessed combustion characteristics very close to that of fossil diesel in terms of combustion temperature, cylinder pressure, heat release rate and ignition delay when combusted in a compression ignition engine.

KEYWORDS: Biodiesel Blends, Combustion Characteristics, Glycerol, Methyl Ester, Transesterification.

1 INTRODUCTION

Majority of the world's energy needs are supplied through petrochemical sources (fossil fuels). All these sources are finite and with time, usage rates will be consumed shortly. The high energy demand in the industrialized world as well as the pollution problems caused due to the use of fossil fuels make it increasingly necessary to develop a new renewable energy source. Methyl ester (Biodiesel) has created great awareness in different countries all over the world because of its renewability, improved gas emissions, better combustion characteristics and its biodegradability. The fuel modification is mainly aimed at reducing the viscosity to get rid of flow and combustion-related problem. For these modifications in fuel characteristics, there are mainly four processes named as dilution or blending, micro-emulsification, transesterification and pyrolysis. Among all these techniques, the transesterification seems to be the best choice, as the physical characteristics of fatty esters are very close to those of diesel fuel and the process is relatively simple. The commercial method used for the biodiesel production is the transesterification also known as alcoholysis [1]. Transesterification is the process of using an alcohol of low molecular weight (e.g. methanol, ethanol, butanol), in the presence of a catalyst such as sodium hydroxide or potassium hydroxide, to break the molecule of the raw renewable oil chemically into methyl or ethyl esters of the renewable oil with glycerol as a byproduct. Methyl ester refers to a vegetable oil-or-fat based diesel fuel consisting of long chain alkyl esters. It is an attractive alternative to fossil fuels; it is biodegradable, non-toxic and has low combustion and emission profiles as compared to petroleum fuels. Biodiesel can be produced from vegetable oils, animal fats or waste cooking oils by transesterification with an alcohol in order to substitute fossil fuels [2], [3], [4]. Many works have used methanol [5], [6], [7], [8] as alcohol reactant which is mainly produced by oxidation processes of methane, a natural gas component, hence, a non-renewable energy.

Methanol is preferable to ethanol because it is very cheap and due to its dissolving power for vegetable oils, it has low toxicity and renewable origin. Various factors such as Free Fatty Acid (FFA) content, water content, amount/type of catalyst, vegetable oil to alcohol molar ratio or temperature can affect the process [9], [10], [11]. Methyl ester can be blended with petroleum diesel. In the case of mixtures, the respective proportion of methyl ester in petrol diesel should be indicated. E.g. B20 means a mixture of 20% methyl ester and 80% petroleum diesel; B75 means a mixture of 75% methyl ester and 25% petroleum diesel while B50 means 50% methyl ester and 50% petroleum diesel. B100 means pure methyl ester and B0 means pure petroleum diesel.

Extensive research on the use of alternative input products, such as rape oil, soybean oil, sunflower oil, waste cooking oil (WCO) and tallow oil in the production of methyl ester have been conducted. Based on exhaustive engine tests, it can be concluded that methyl ester can be adopted as an alternative fuel for existing conventional diesel engines without requiring any major modifications in the mechanical system of the engines. Various studies have shown that methyl ester made from WCO can be used in different types of diesel engines with no loss of efficiency [12] and significant reductions in CO emissions [13], [14] and total hydrocarbon (THC) emissions [15], [16] when compared with emissions from conventional fossil diesel fuel. Murillo et al. [17] tested a four-stroke diesel outboard engine running on conventional diesel, conventional diesel blended with certain amounts of WCO methyl ester (10, 30 and 50%), and pure methyl ester and proved that the bio-diesel blends are environmentally friendly alternatives to conventional diesel. They found some reduction in power of approximately 5% with B10 and B30, and 8% with B50 and B100 with respect to the power obtained from conventional diesel. The methyl ester from WCO was tested by Meng et al. [18] on an unmodified diesel engine and the results showed that under all conditions, the dynamical performance remained normal. In another study, waste cooking oil from restaurants was used to produce neat (pure) methyl ester through transesterification, and this converted biodiesel was then used to prepare biodiesel/diesel blends. The authors of the study concluded that B20 and B50 are the optimum fuel blends in terms of emissions [19].

In this study, the performance of WCO methyl ester blended with diesel fuel in ratios of 25% (B25), 50% (B50) and 75% (B75) was investigated and compared with that of regular diesel 0% (B0) and pure methyl ester 100% (B100) in terms of combustion in a four stroke direct-injection diesel engine. The research deals with the experimental investigation of combustion characteristics of variable torque engine for different proportion of blends of biodiesel (methyl esters of waste cooking oil) with standard diesel for varying conditions. Load is one of the parameters which influence the performance of an engine. The combustion parameters such as variation of combustion temperature, cylinder pressure, heat release rate and ignition delay with reference to the speed and for different loading conditions are discussed in detail.

2 Methodology

2.1 Methyl Ester Production

The process employed was transesterification because it was a simple and fastest way of producing methyl ester as recommended by Van Gerpen [20] and almost all the literature consulted supported the use of the method in producing methyl ester. Transesterification of oil was carried out with methanol at a molar ratio of 1 to 6 (1:6) in the presence of potassium hydroxide (KOH) as a catalyst and 65^0c reaction temperature. One hundred gram (100g) of oil was weighed into 250 mL flat bottom flask fitted with a condenser. The oil was preheated for about thirty minutes (30 mins) to increase the reaction of the oil with methanol. 1% KOH (by weight of oil) was dissolved in 21.7g of methanol (equivalent to 1:6 of oil to methanol) in a separate beaker to give potassium methoxide. This solution was added to the preheated oil and stirred for two hours on a magnetic stirrer. The condenser was placed on top of the mixture setup to condense any vaporized liquid (such as methanol) back to liquid which consequently returned into the mixture as liquid methanol. After two hours, the entire mixture was poured into a separating beaker and left for twelve hours to separate into two phases, where the glycerol settled at the bottom of the separating funnel and the methyl ester at the top of the funnel as shown in figure 1. This is possible because the two liquids have different densities. The physicochemical properties of produced methyl ester and its blends are shown in table 1.

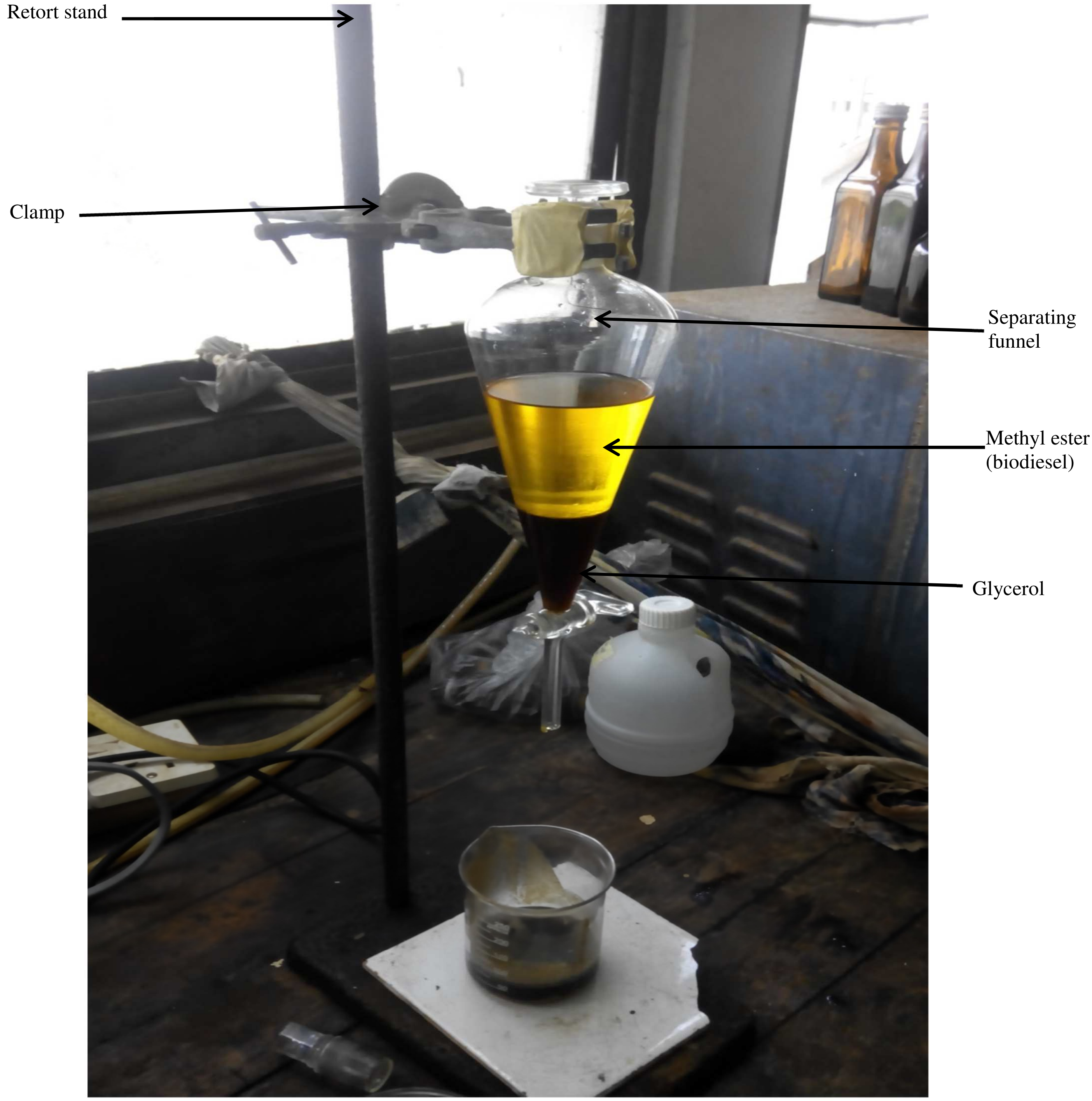

Figure 1. Methyl Ester Separation Using Separating Funnel during Experiment

Table 1. Physicochemical Properties of Produced Methyl Ester and its Blends

S/N	FUEL PROPERTY	UNIT	Bo	B25	B50	B75	B100
1.	Ester Content	% (m/m)	-	-	-	-	89.93
2.	Density at 40^{0}C	Kg/m^3	830	844	849	859	860
3.	Viscosity at 40^{0}C	mm^2/s	3.91	4.00	4.80	5.50	6.00
4.	Flash Point	^{0}C	65	95	110	130	178
5.	Cetane Number	-	65.80	66.72	67.09	67.40	68.63
6.	Acid Value	mgKOH/g	0.70	1.12	1.12	1.25	1.40
7.	Iodine Value	I/100g	115.75	114.49	113.33	112.67	111.67
8.	Smoke Point	^{0}C	45	50	70	80	95
9.	Saponification Value	mgKOH/g	119.85	118.20	117.90	117.50	115.01
10.	Peroxide Value	mgKOH/g	9.00	7.00	4.00	2.00	1.50

2.2 COMBUSTION INVESTIGATION

The materials/equipment used were Compression Ignition Engine (CIE), Dynamometer with a read out meter, Thermocouple, Methyl Ester and its Blends. A combustion system direct injection diesel engine (MODEL KM 170F AIR COOLED DIESEL ENGINE) was used to carry out the investigations. The specifications of the engine are shown in table 2 while the picture of the diesel engine used for experiment is shown in figure 2. The engine was coupled with hydraulic dynamometer and controller. The dynamometer was capable of measuring the Torque (Nm), Load (%), Speed (rpm) and Combustion Temperature (^{0}C). The engine speed and load were controlled by varying the amount of water supplied to the engine. The engine was used to investigate the combustion behavior and combustion characteristics of methyl ester produced and its blends so as to compare these with petroleum diesel and to recommend the biodiesel and its blends as alternative for petroleum diesel. The combustion characteristics investigated were combustion temperature, ignition delay, heat release rate and cylinder pressure.

Table 2. Specifications of the Engine Used

Type of Engine	MODEL KM 170F Direct Injection Four-stroke Air cooled Diesel Engine.
Number of Cylinder	1
Bore Stroke	70 mm × 50 mm
Max. output	2.8 KW, 3.1 KW
Cont. output	2.5 KW, 2.8 KW
Engine speed	3000 rpm, 3600 rpm
Displacement	0.211 L

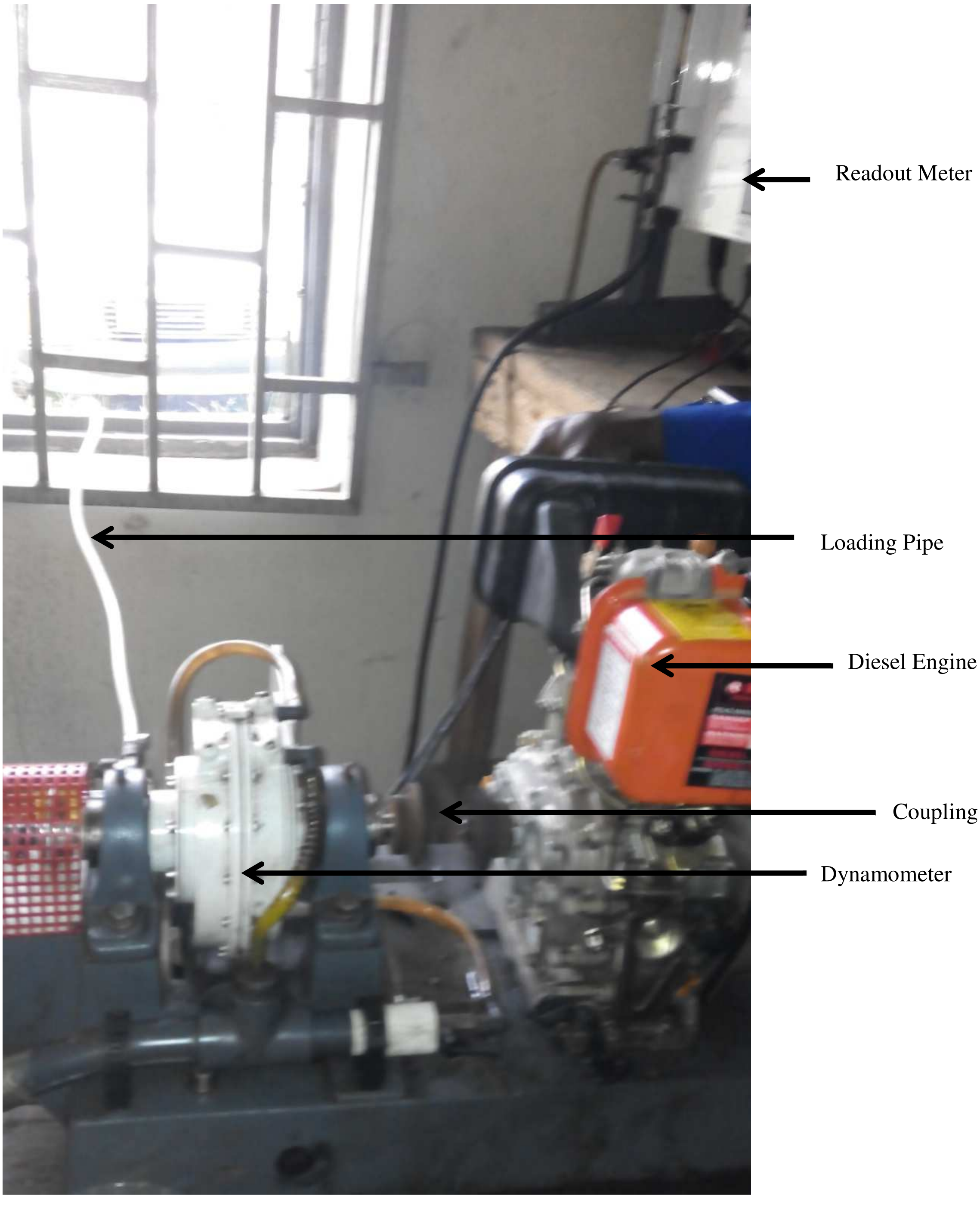

Fig. 1. Figure 2. Assembly of Diesel Engine and Dynamometer during Experiment

2.2.1 DETERMINATION OF COMBUSTION TEMPERATURE

The combustion temperatures at different loading conditions were obtained directly with the help of the thermocouple connected to the dynamometer. The load was gradually increased to obtain different values of combustion temperatures and torques while the speed was kept constant at 2500rpm throughout the experiment. Five samples of oil blends were tested one after the other and they were B0 (0% biodiesel), B25 (25% biodiesel), B50 (50 % biodiesel), B75 (75% biodiesel), B100 (100 % biodiesel). For each sample, the combustion temperature at each loading condition was examined as records were taken for six different loading conditions of 0.0, 20.0, 40.0, 60.0, 80.0 and 100.0%.

2.2.2 DETERMINATION OF IGNITION DELAY

Having discovered that the dynamometer used would not be able to give the value of ignition delay directly, equation (1) below was used to calculate the values of ignition delay for each sample of fuel blend for different loading conditions of 0.0, 20.0, 40.0, 60.0, 80.0 and 100.0%. The equation [21] was given as:

$$\tau = (22.104 \text{ x } \%B + 1131)/\, T \tag{1}$$

Where τ = Ignition Delay; T = Combustion Temperature; %B = Percentage Blend

2.2.3 DETERMINATION OF CYLINDER PRESSURE

The method applied for determining the ignition delay was taken for cylinder pressure**.** Application of equation (2) below was used to obtain the values of cylinder pressure for each sample of fuel blend for different loading conditions of 0.0, 20.0, 40.0, 60.0, 80.0 and 100.0%. The equation [21] was given as:

$$\tau = 124.3 \text{ x } e^{(0.0893 \text{ x } \%B)} \text{ x } P^{(-0.0234 \text{ x } \%B - 1.1715)} \tag{2}$$

Where τ = Ignition Delay; P = Cylinder Pressure; %B = Percentage Blend

2.2.4 DETERMINATION OF HEAT RELEASE RATE

Similar step was applied to determine the values of heat release by making use of the equation (3) below. The equation was given according to the first law of thermodynamics for an open system [22] as:

$$\frac{dQ_n}{dt} = \frac{dQ_{ch}}{dt} - \frac{dQ_{hw}}{dt} = \frac{\gamma}{\gamma-1}\, p \frac{dV}{dt} + \frac{\gamma}{\gamma-1}\, V \frac{dp}{dt} \tag{3}$$

Where P = Cylinder Pressure; V = Cylinder Volume; Q = quantity of Heat release and γ = Specific Heat Ratio which has the value from 1.3 to 1.35

3 RESULTS AND DISCUSSION

3.1 EFFECTS OF METHYL ESTER AND ITS BLENDS ON COMBUSTION TEMPERATURE

Though, the speed of the engine was kept constant throughout the experiment, it was observed that the combustion temperature increased as the load of the engine increased for each blend. And across the blends, the combustion temperature increased as the percentage of methyl ester in the blends increased for each load as shown in figure 2. The value of combustion temperature was observed to be slightly higher for methyl ester and its blends than petroleum diesel though still within the normal range. The reason for this slight increase can be explained on the basis of the presence of the oxygen molecules in methyl ester fuel that results in the air-mixed fuel in the cylinder to burn completely and consequently, increase the combustion temperature.

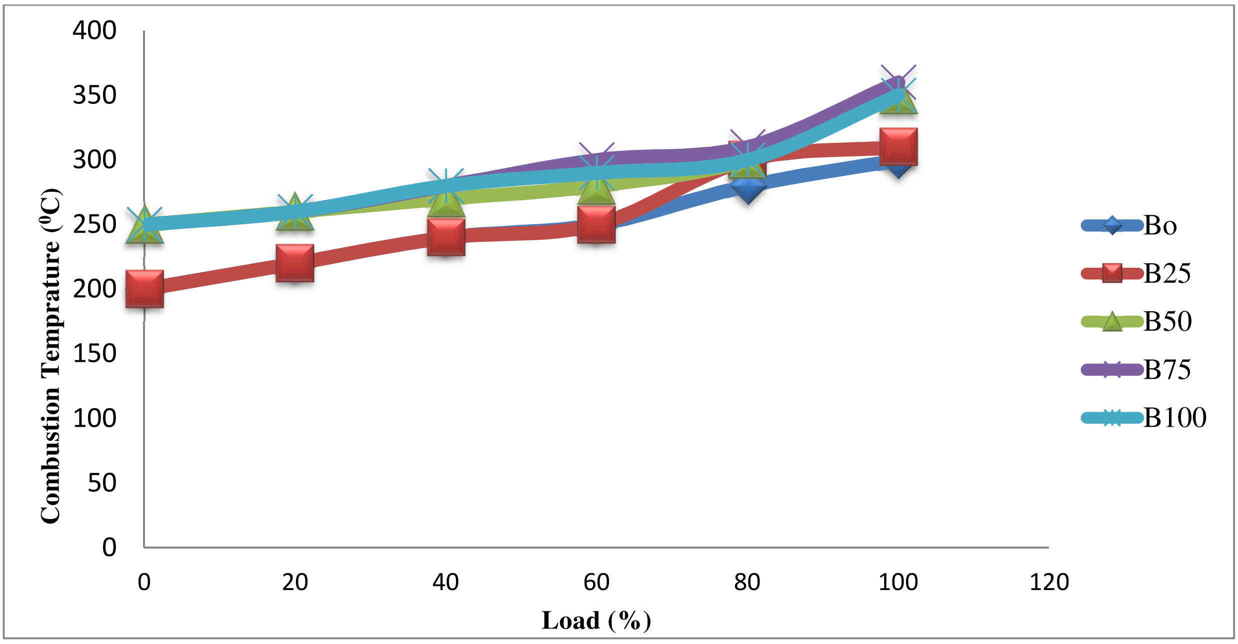

Figure 2. Effects of Methyl Ester and its Blends on Combustion Temperature

3.2 Effects Of Methyl Ester And Its Blends On Ignition Delay

The ignition delay was observed to reduce as the engine load increased for each blend but increased as the percentage of the methyl ester in the blends increased across the blends as shown in figure 3. This was observed to be as a result of increase in viscosity across the blends because increase in viscosity increases the ignition delay.

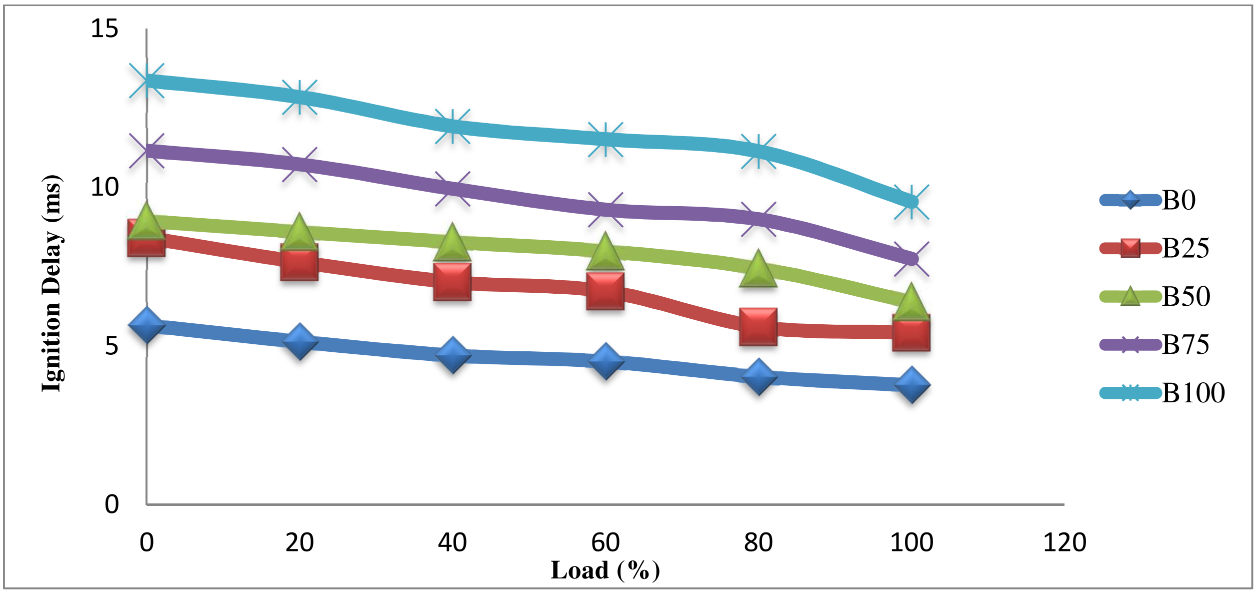

Figure 3. Effects of Methyl Ester and its Blends on Ignition Delay

3.3 Effects Of Methyl Ester And Its Blends On Cylinder Pressure

It was observed that the cylinder pressure increased as the load of the engine increased for each blend. And across the blends, the cylinder pressure increased as the percentage of methyl ester in the blends increased for each load as shown in figure 4. The value of cylinder pressure was observed to be slightly higher for methyl ester and its blends than petroleum diesel though still within the normal range. The reason for this was as a result of increase in combustion temperature.

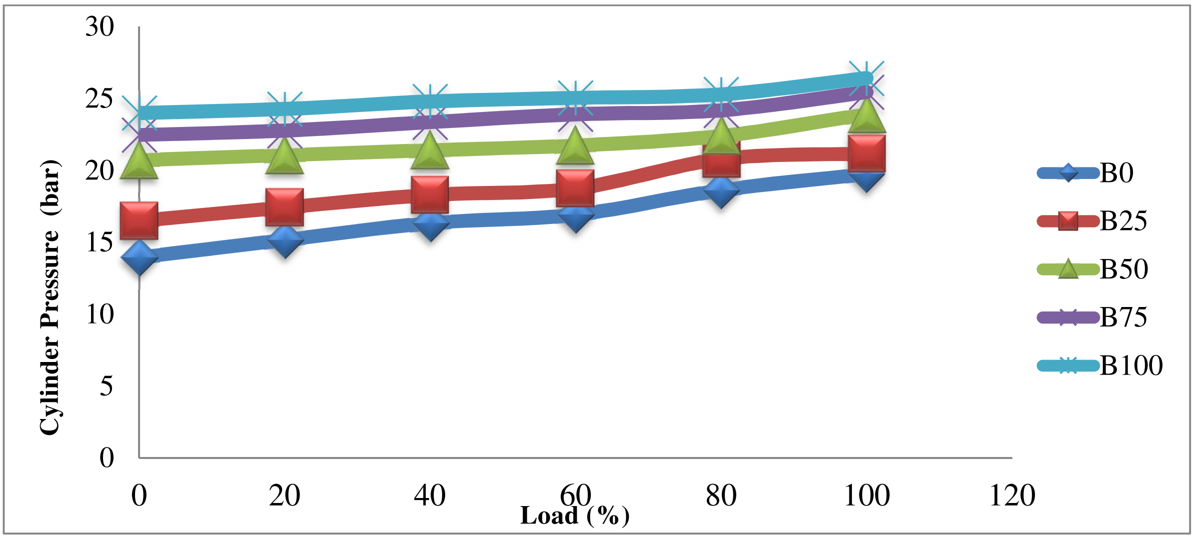

Figure 4. Effects of Methyl Ester and its Blends on Cylinder Pressure

3.4 Effects Of Methyl Ester And Its Blends On Heat Release Rate

It was observed that the heat release rate increased as the load of the engine increased for each blend. And across the blends, the heat release rate increased as the percentage of methyl ester in the blends increased for each load as shown in figure 5. The value of heat release rate was observed to be slightly higher for methyl ester and its blends than petroleum diesel though still within the normal range. The reason for this slight increase can be explained on the basis of the presence of the oxygen molecules in methyl ester fuel that results in the air-mixed fuel in the cylinder to burn completely and consequently, increase the combustion temperature and heat release rate.

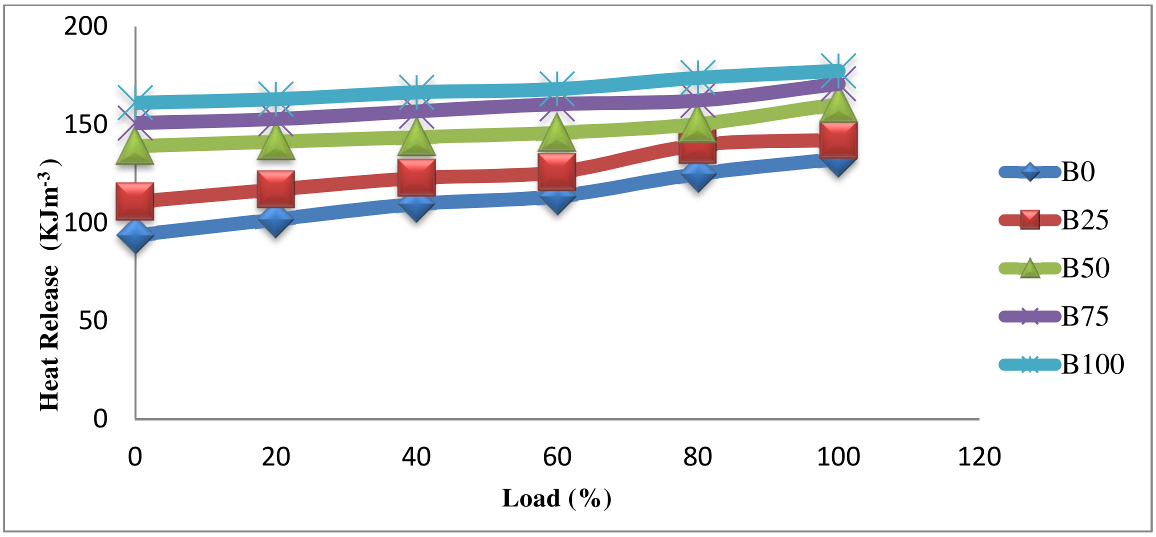

Figure 5. Effects of Methyl Ester and its Blends on Heat Release Rate

4 CONCLUSION

The production of methyl ester (biodiesel) was possible using transesterification of waste cooking oil with methanol in the presence of potassium hydroxide (KOH) as a catalyst at 65^0c. The separation of biodiesel from glycerol was done using separating funnel with the biodiesel at the top because of its lower density compared to the denser glycerol which settled at the base of the funnel. The results obtained from the combustion characteristics of methyl ester and its bends such as combustion temperature, cylinder pressure, heat release rate and ignition delay at different loads 0.0, 20.0, 40.0, 60.0, 80.0 and 100.0 % showed that the combustion temperature increased as the load for each blend. And for each load, the combustion temperature increased as the percentage of methyl ester in the blends increased. Similar results were obtained for cylinder pressure and heat release rate. But ignition delay reduced as the load increased but increased as the percentage of methyl ester in the blends increased. This might be as a result of higher viscosity of the methyl ester and its blends than that of petroleum diesel because increase in viscosity of the fuel increases the ignition timing. The study concludes that waste cooking oil methyl ester and its blends compare favorably with fossil diesel in terms of combustion characteristics and the values are within the acceptable standards. The results obtained showed that methyl ester and its blends possessed combustion characteristics very close to fossil diesel in terms of combustion temperature, cylinder pressure, heat release rate and ignition delay. Meanwhile, the values of combustion temperature, cylinder pressure and heat release rate were observed to be slightly higher for methyl ester and its blends than petroleum diesel though still within the normal range, the reason for this slight increase can be explained on the basis of the presence of the oxygen molecules in methyl ester fuel that results in the air-mixed fuel in the cylinder to burn completely and consequently, increase the combustion temperature, cylinder pressure and heat release rate.

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