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Experimental Study of the Compression Ignition Engine Performance Using Various Bio Diesel Blends

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ABSTRACT

The purpose of this study is to experimentally investigate the performance of compression ignition engine using a biodiesel extracted from waste cooking oils (WCO), such as, falafel frying palm oil, chicken frying soybean oil, and fresh oils, such as soybean and olive oils. After producing biodiesel from WCO and fresh oils, the mixtures were blended with pure diesel in two percentages as follows: B20 (20% biodiesel from each type, 80% pure diesel) and B10 (10% biodiesel from each type, 90% pure diesel). The biodiesel blends were used as an alternative fuel for diesel engine. The ignition performance of the fuel blends was compared with that of pure diesel B00 (0% biodiesel, 100%pure diesel). To analyze the effect of biodiesel on engine performance, the engine was operated at variable load from 0 to 6 kW and constant speed at 2000 RPM. For engine performance, brake power, brake specific fuel consumption and brake thermal efficiency were analyzed. The results showed that pure diesel produces higher brake force (BP) than all biodiesel blends. The highest value for brake specific fuel consumption (BSFC) at variable load is for B20-F (20% biodiesel from falafel frying oil, 80% pure diesel) is equal to 0.243426 gm/kW.s. The highest value for brake thermal efficiency (BTE) is for B10-S (10% biodiesel from soybeans oil, 90% pure diesel) is equal to 27.6%.

Keywords: biodiesel, compression ignition engines, engine performance.

INTRODUCTION

As the population around the world is increasing rapidly, the technological sector is developing consistently. These changes make the matter of energy a top priority. Because of the large number of vehicles on the road, the transportation sector is the primary factor of fuel depletion (Yasin et al., 2013). Although various alternative fuels have been proposed to replace mineral diesel in diesel engines, the expensive cost of engine modification remains an issue. Biodiesel fuel, on the other hand, has long been regarded as a unique alternative fuel that can be utilized in a diesel engine with little or no modification (Norhafana, et al., 2019).

According to the ASTM fuel standard, the qualities of biodiesel from various sources varies in general depending on the feedstock source. One of the most frequent approaches for introducing biodiesel as a fuel for direct use in a diesel engine is to blend it with mineral diesel (Shahabuddin et al., 2012).

Vegetable oil has been suggested as an alternative fuel, but it has one disadvantage which is the high viscosity that affect the engine (Verma & Sharma, 2015). To address the problem, the chemical (transesterification) of vegetable oil has been used to reduce viscosity and to produce biodiesel.

Biodiesel seems very suitable for many reasons. Firstly, it is a renewable source, secondly, it is the least toxic and most biodegradable. Moreover, it is reasonable for boilers and compression ignition engine (CI) without major modifications. Comparing to diesel, biodiesel has more cetane number. Also, it does not contain aromatics or sulfur. Approximately, 10 to 11% of its weight is oxygen. These biodiesel properties reduce the carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) emissions in the exhaust gas as compared to diesel fuel. but the biodiesel will increase the amount NOx (Pullen and Saeed, 2014).

The engine performance of diesel fuel and a diesel fuel mixed with 0, 25, 50, 75, and 100 percent sunflower oil was analyzed. The results show that torque and power are maintained at the same levels for all fuels, although brake specific fuel consumption (BSFC) rises within acceptable limits. (Moreno et al., 1999). Puneet and Sharma [2015] investigated the performance characteristics of a biodiesel-fueled diesel engine. They discovered that biodiesel has a higher thermal efficiency and a lower BSFC. Gaurav et al. examined the performance of diesel engines utilizing biodiesel derived from various oils.

Ramana et al. [2015]. investigated the performance of engines employing biodiesel blends in an experimental setting. By reducing fuel consumption and managing exhaust pollutants, they were able to achieve environmental safety. Liaquat et al. studied engine performance utilizing biodiesel made from non-edible oil in an experimental setting. They concluded that biodiesel blend fuels may be used in CI engines without requiring any engine modifications, and that they provide benefits in terms of emissions reduction and alternative diesel fuel.

The purpose of this study was achieved through experimental verification. It aims at exploring the effect of the biodiesel blends on the performance of the diesel engine. In particular, the experiment is designed to study the following sub-objectives:

1. To Utilize waste cooking oils and fresh oils to produce biodiesel fuel, using as an alternative energy source and to maintain energy security.
2. To investigate the effect of biodiesel blends on the performance of the internal combustion engine.

MATERIAL AND METHODOLOGY

Because of the nature of manufacturing, biodiesel can be produced from many kinds of vegetable oils, whether these are waste or fresh oils. Choosing the type of oil used to produce biodiesel is extremely important, as the raw materials constitute 75% of the production cost (Cordero & Schellenberg, 2018). Therefore, using WCO as a raw material contributes to reduce the cost of biodiesel production, and helps in preserving the ecosystem by reducing pollution.

Biodiesel is produced from fresh oils and WCO. Fresh oils are soybean oil and olive oil. The WCO are falafel frying oil; originally from palm oil, chicken frying oil; originally from soybean oil. The crude oils were obtained from different places: soybean oil from local market, olive oil from local production, falafel frying oil and chicken frying oil from local restaurants. The amount of crude oil used is 10 liters of each type.

The principal method of producing biodiesel is transesterification process. This method was used because it is the most effective way to reduce the viscosity of biodiesel, also it has low production cost, and returns good yields of biodiesel (Sidhu, 2018). Transesterification process is a chemical reaction between vegetable oils and alcohol, such as methanol (CH_3OH) with the help of catalysts, such as sodium hydroxide (NaOH), also known as FAME, to produce biodiesel and glycerin as a by-product (Shahid & Jamal, 2011).

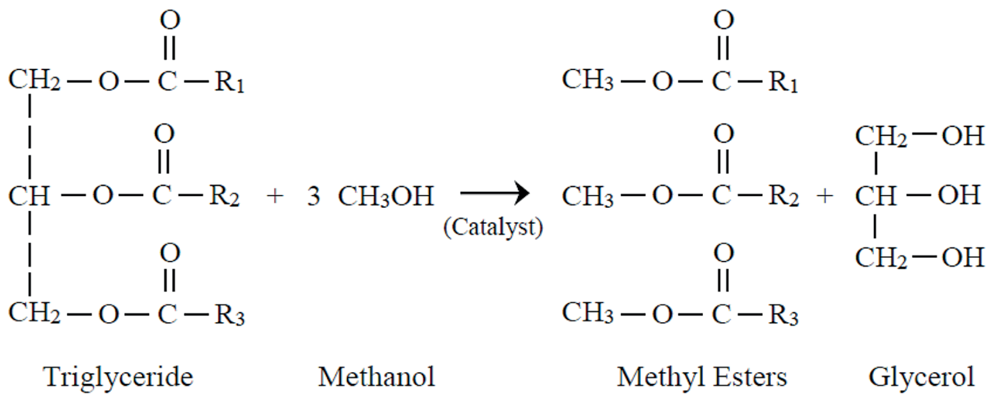

Fig. 1. Transesterification process reaction (Liu, 2014)

The transesterification process is affected by many factors which influence the yield, conversion, and purity of the product esters. These factors are:
- reaction temperature,
- reaction time,
- ratio of alcohol to oil,
- catalyst type and concentration,
- mixing intensity.

To have good production rate and high quality, these factors must be controlled according to previous studies and research.

A transesterification method was used to produce biodiesel. All equipment has been used to produce biodiesel, and it consists of the following:

Raw material (falafel frying oil, chicken frying oil, soybean oil and olive oil); methoxide (methanol / NaOH mixture); hotplate to heat the reactants; blender to mix reactants; Infrared thermometer; filter; bottle to store biodiesel. The following steps were used to make biodiesel:
- Step 1 – preparing WCO to produce biodiesel by heating on a hotplate to 35 °C, and then filtering by using several layers of cheesecloth placed in a funnel;
- Step 2 – removing water from the WCO by heating the oil at a temperature of 60 degrees Celsius for about a quarter of an hour, then pouring the oil into another container, and leaving it until settles for 24 hours, then repouring the oil into another container, considering not to pour the water that will be stagnant at the end of the container;
- Step 3 – preparing 1000 cc of all kinds of oils and heat up to 65 °C;
- Step 4 – preparation of methoxide solution (methanol / sodium hydroxide). When adding to WCO (falafel frying oil and chicken frying oil), mix 7gm of sodium hydroxide with 220 cc of methanol per liter of WCO. When adding to fresh oils (soybean and olive), mix 5gm of sodium hydroxide with 200 cc of methanol per liter of fresh oils;
- Step 5 – adding the methoxide solution to the oil and mixing in a blender for about 30 minutes;
- Step 6 – putting the mixture in a bottle and waiting for 24 hours, and two layers will form, a dark layer at the bottom which is glycerin, and a light layer at the top which is diesel;
- Step 7 – pouring biodiesel into another container and adding a small amount of distilled water to it and turning the bowl upside down several times for several minutes until the water draws a white soap;

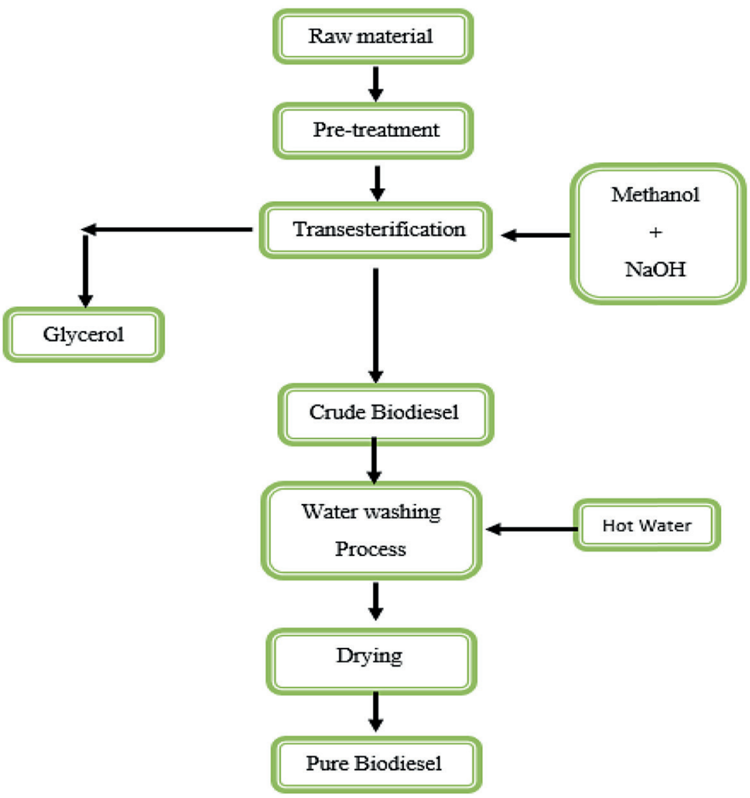

Fig. 2. Scheme showing the steps for producing biodiesel

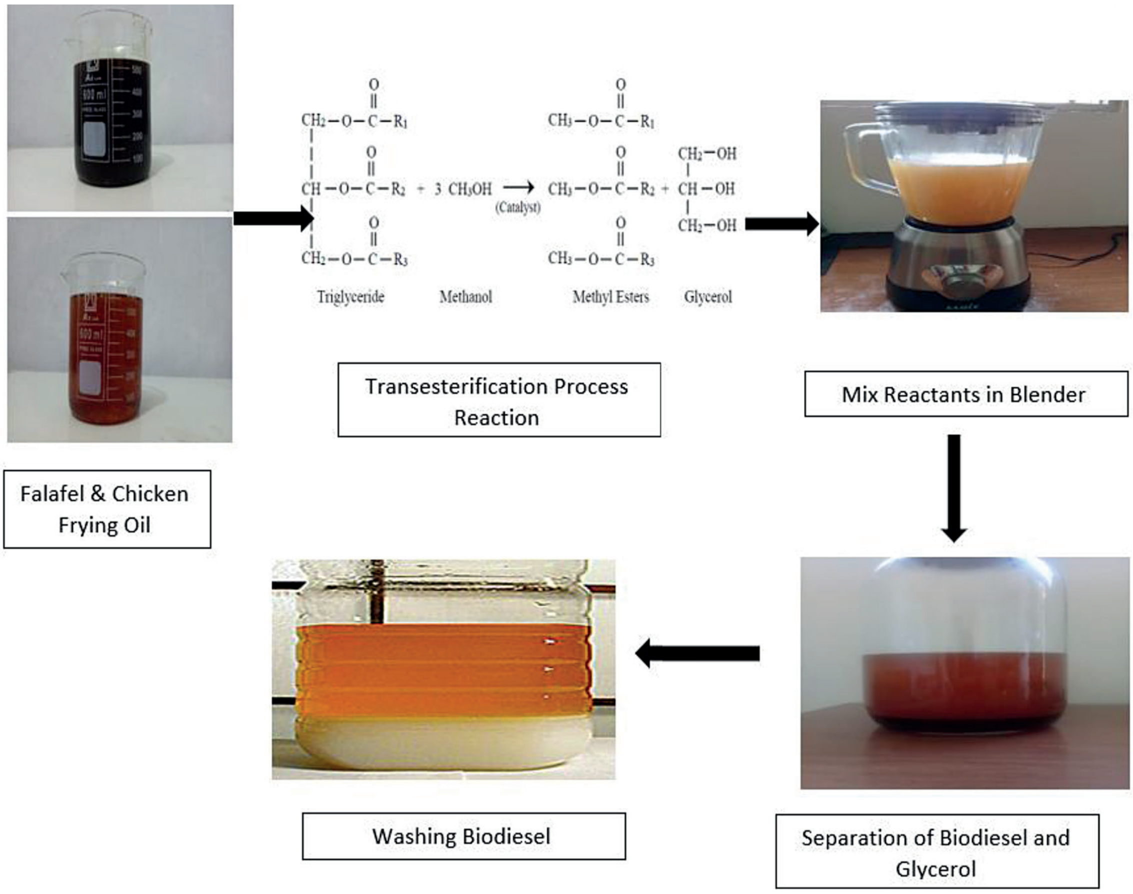

Fig. 3. Steps of producing biodiesel

- Step 8 – repeating the washing process 3 to 4 more times until the water becomes opaque, to make sure that all unwanted components have been removed, the washed biodiesel samples are dried at 110 °C for 1 hour.

The following figures 2 and 3 summarized the methodology and steps of biodiesel production. There are some physical properties of biodiesel that have a great impact on the performance and emission of (CI) engines. Table 1 shows the physical properties of pure biodiesel that is produce from the various vegetable oils.

After producing biodiesel from (olive oil, soybean oil, falafel frying oil, and chicken frying oil), eight biodiesel blends were prepared with the following ratios: B20-S (20% biodiesel from soybean oil, and 80% fuel Diesel), B20-O (20% biodiesel from olive oil, and 80% diesel fuel), B20-F (20% biodiesel from falafel frying oil, and 80% diesel fuel), and B20-C (20% biodiesel from chicken frying oil, and 80% diesel), and B10-S (10% biodiesel from soybean oil, and 90% fuel Diesel), B10-O (10% biodiesel from olive oil, and 90% diesel fuel), B10-F (10% biodiesel from falafel frying oil, and 90% diesel fuel), and B10-C (10% biodiesel from chicken frying oil, and 90% diesel), and use it as an alternative fuel for the diesel engine, and compare it with pure diesel B00 (00% biodiesel and 100% diesel), to analyze the impact of biodiesel on the performance of engine.

Table 1. The physical properties of pure biodiesel (López et al., 2014; Hossain et al., 2010; Ullah et al., 2014; Silva et al., 2010)

Fuel type	Cetane number	Heating value kJ/kg	Density gm/cc
Diesel	47	43.400	0.855
Bio (olive)	58	40.49	0.908
Bio (soybean)	55	37.300	0.877
Bio (falafel frying oil)	54	39.658	0.901
Bio (chicken frying oil)	47.17	38.034	0.863

Table 2. The physical properties of biodiesel blends

Fuel type	Cetane number	Heating value kJ/kg	Density gm/cc
Diesel	47	43400	0.8550
B20 (olive)	49.20	42818	0.8656
B20 (soybean)	48.60	42180	0.8594
B20 (falafel frying oil)	48.40	42651	0.8642
B20 (chicken frying oil)	47.03	42326	0.8566
B10 (olive)	48.10	43109	0.8603
B10 (soybean)	47.80	42790	0.8572
B10 (falafel frying oil)	47.70	43025	0.8596
B10 (chicken frying oil)	47.02	42863	0.8558

The properties of biodiesel blends are calculated according to the following equation:

$$Pmix = \sum mi * Pi \quad (1)$$

where: $Pmix$ – the properties of the mixture;
mi – mass fraction of component *i*;
Pi – property of component *i*.

Table 2 shows the physical qualities of biodiesel blends.

Experimental setup

The type of engine used in this research is a Lister, single cylinder, four strokes, water cooled, computer controlled. Table 3 explains the technical specifications of the engine. The testing engine is depicted in Figure 4.

The experimental investigation was performed on a biodiesel blend (B10 and B20) that was produced from (olive oil, soybeans, falafel frying oil, chicken frying oil) and comparing it with B00 (00% biodiesel, 100% pure diesel) to see the extent of the effect of biodiesel on engine performance.

The experimental investigation carried out for each blend of biodiesel in variable load and constant speed. The readings (current, voltage, fuel consumption time, power, load, and speed) are taken at a constant speed (2000 rpm) and changing the load as load 0, load 2, load 4, and load 6.

Table 3. Engine specification

Model	Diesel engine
Type	Lister, four stroke (CI) diesel engine, water cooled
No. of cylinders	Single cylinder
No. of strokes	4
Bore	114.3 mm
Speed	2000 rpm
Power	6 kw
Stroke volume	1.433 L

When conducting an experiment, firstly, operating diesel engine for 15 minutes to warm up the engine before running by B10 and B20 blends. The fuel consumption rate was determined by using the glass burette and stopwatch.

To calculate the engine parameters, the following equation was used.

1) Torque (N·m):

$$T = \frac{L}{1000} * F \quad (2)$$

where: T – torque (N·m);
L – length of the piston's arm needed to calculate the torque (mm) and equals to 220 mm as given in the experiment;
F – force (N).

2) Brake power (kW):

$$\text{Brake power } (BP) = T \times \omega$$
$$P = \frac{T}{1000} * \frac{2\pi N}{60} \quad (3)$$

Fig. 4. Internal combustion diesel engine (Test set up)

where: P – brake power (kW);
ω – the angular velocity (The engine speed equal to the generator speed divided by 2.4 is used).

Brake specific fuel consumption (gm/kW.s):

$$BSFC = \frac{mf}{BP} \quad (4)$$

where: the $BSFC$ is brake specific fuel consumption (gm/kW.s);
mf is the amount of fuel consumed (gm/s);
BP is brake power (kW).

Brake thermal efficiency:

$$\mu = \frac{outputpower}{inputpower} = \frac{brake\ power}{thermal\ power} \quad (5)$$

$$\text{Thermal power} = m_f \times c.v\ \text{(kW)} \quad (6)$$

where: the (μ) – brake thermal efficiency,
m_f – the amount of fuel consumed (gm/s),
$c.v$ – is the calorific value (kJ/kg).

RESULTS AND DISCUSSION

From the collected data during each experiment, brake power, brake specific fuel consumption, and brake thermal efficiency were analyzed, and were plotted versus variable load with engine constant speed.

Figures 5 and 6 show the brake power BP as function of load. It is clear from both figures that the brake power BP increases with increasing in load for all biodiesel blends and pure diesel until load 2, after that it begins to decrease. The highest BP in figure 5 is for B20-S which is equal

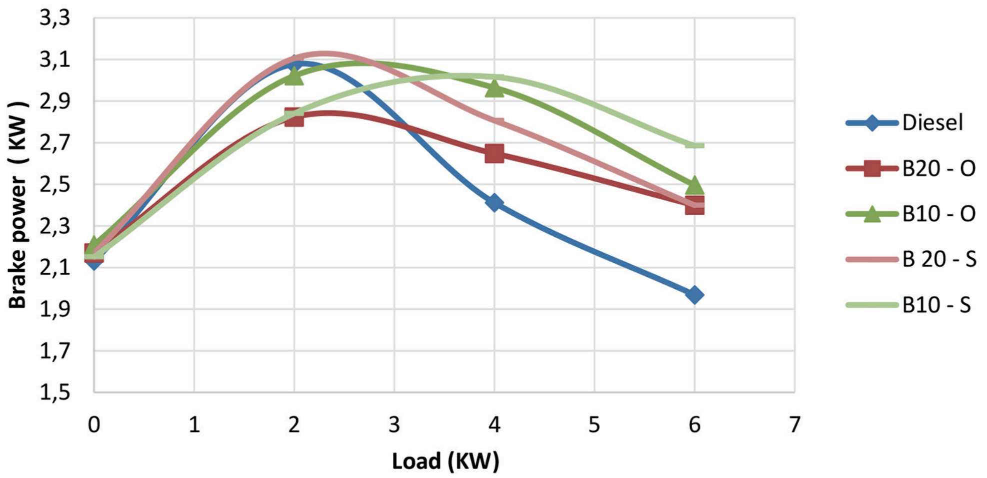

Fig. 5. Brake power resulting from using (Diesel, B20-O, B10-O, B20-S, B10-S) as a function of variable load

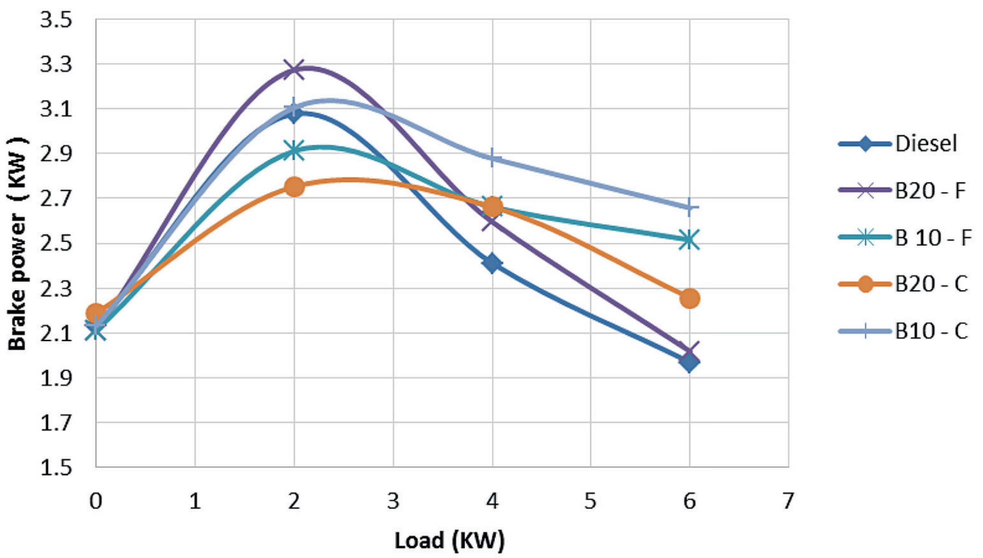

Fig. 6. Brake power resulting from using (Diesel, B20-F, B10-F,B20-C,B10-C) as a function of variable load

3.10 kW, the average increase in BP for B20-S compared to pure diesel is about 10%. Also, the highest value of BP in figure 6 is for B20-F which is equal 3.27 kW., the average increase in BP for B20-F compared to pure diesel is about 4%. The reason behind higher BP of this blends (B20-S, B20-F) is increase in fuel consumption with increased load and the oxygen content in biodiesel that lead to more complete combustion than pure diesel.

Figures 6 and 7 show the BSFC as a function of load. The BSFC is the ratio of mass fuel consumption to the brake power, it is a measure of the capability of the engine in converting fuel to brake power. It is desirable to have lower BSFC meaning that the engine uses less fuel to produce the same amount of power. In both figures the BSFC of pure diesel and all biodiesel blends increases until load 2 after that, it decreases and begins to increase slightly. The highest value of BSFC in figure 7 for B20-S is equal (0.235 gm/kW.s), the average increasing in BSFC for B20-S compared to BSFC for pure diesel is about 5.5%. Also, the highest value of BSFC in figure 7 for B20-F is equal (0.243 gm/kW.s), average increasing in BSFC for B20-F compared to BSFC for pure diesel is about 11.6% . This is because biodiesel includes oxygen which improves combustion of fuel although the calorific value of pure diesel is higher.

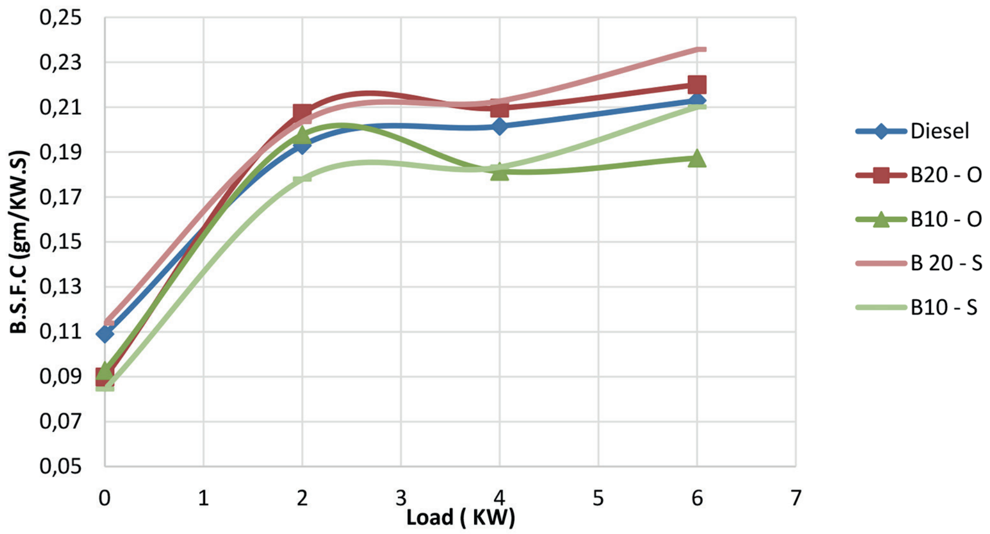

Fig. 7. Brake specific fuel consumption (B.S.F.C) resulting from using (Diesel, B20-O,B10-O,B20-S,B10-S) as a function of variable load

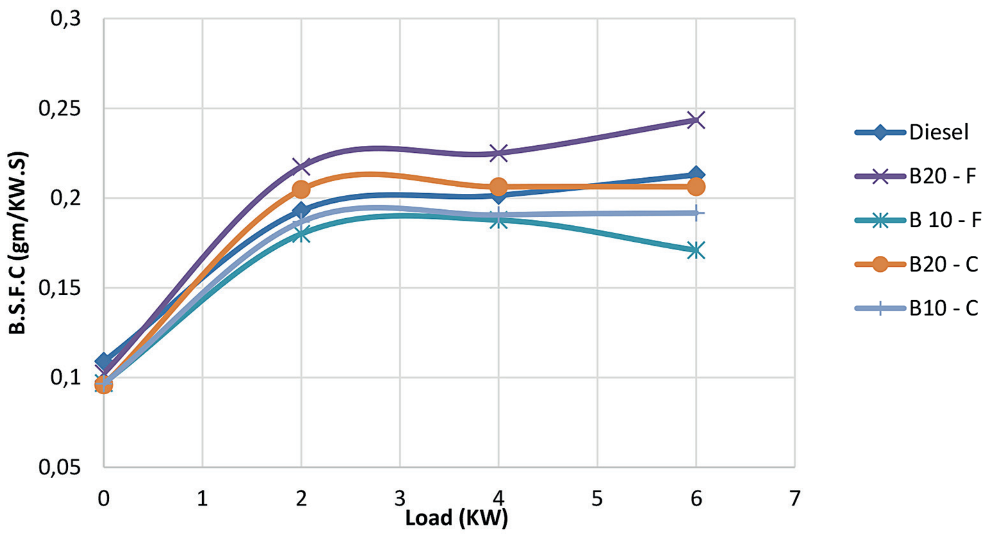

Fig. 8. Brake specific fuel consumption (B.S.F.C) resulting from using (Diesel, B20-F, B10-F,B20-C,B10-C) as a function of variable load

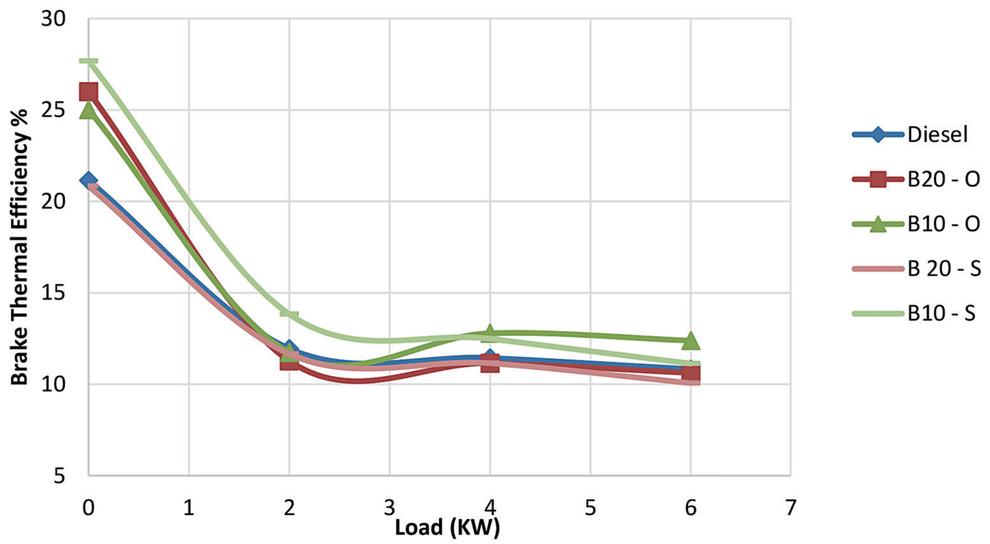

Fig. 9. Brake thermal efficiency resulting from using (Diesel, B20-O, B10-O, B20-S, B10-S) as a function of variable load

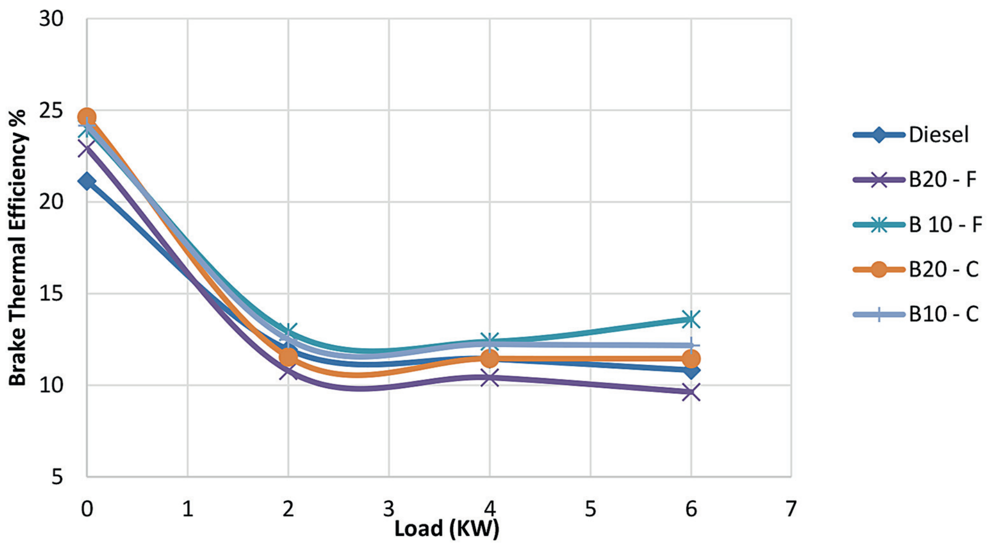

Fig. 10. Brake thermal efficiency resulting from using (Diesel, B20-F, B10-F, B20-C, B10-C) as a function of variable load

Figures 9 and 10 show the brake thermal efficiency (BTE) as a function of load. It is clear from the figures that the BTE decreases with increasing in engine load until load 2. After that, it slowly decreases with increasing in load. Because of insufficient air which causes incomplete combustion of fuel. Consequently, the BTE decreases. The highest BTE in figure 10 is for B10-S is equal 27.6%. The average increasing in BTE for B10-S compared to BTE for pure diesel is about 17.6%. Also, the highest BTE in figure 9 is for B20-C is equal 24.6%. The average increasing in BTE for B20-C compared to BTE for pure diesel is about 6.8 %. The reason for the increase in BTE of biodiesel blends is the higher oxygen content, which leads to more complete combustion and higher thermal energy production in the engine.

CONCLUSIONS

In the current study, experiments are done to investigate the performance of compression ignition engine using a biodiesel extracted from waste cooking oils. The biodiesel blends can be used as an alternative fuel for compression ignition engine without modification on it. In variable load, the highest value of BP is for B20-F, which is equal

3.27 kW, the average increase in BP for B20-F compared to pure diesel is about 4% The reason behind higher BP of this blends (B20-S, B20-F) is increase in fuel consumption with increased load and the oxygen content in biodiesel that lead to more complete combustion than pure diesel.

In variable load, the highest value of BSFC for biodiesel that produce from WCO is B20-F is equal (0.243 gm/kW.s), the average increasing in BSFC for B20-F compared to BSFC for pure diesel is about 11.6% this is because biodiesel includes oxygen which improves combustion of fuel although the calorific value of pure diesel is higher. In variable load, the highest value of BTE for B10-S is equal 27.6%, the average increasing in BTE for B10-S compared to BTE for pure diesel is about 17.6%. All biodiesel blends produce higher oxygen than pure diesel, The reason is that oxygen is found within the alkyl ester structure of biodiesel as double bonded carbonyl oxygen and single carboxylic oxygen (w11% by weight).

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