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THE EFFECT OF WASTE COOKING OIL BIODIESEL TO THE DIESEL ENGINE PERFORMANCE

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ABSTRACT: The non-renewable fossil energy and petroleum are the core of the energy source of the vehicles whose availability increasingly limited. The issues of the energy crisis and environmental pollution as the effects of the emission products of the burning fossil oil have become the global main problems. This study was conducted experimentally method, starting from the fuel characterizations, combustion process, engine emission, and engine performance. The fuel characterizations are based on Indonesia's national standardization for the used waste cooking oil biodiesel fuel. The characterizations of the combustion, the performance and the engine emissions were undertaken by adjusting the degrees of the injection time, namely, advanced and retarded by 3^0 and 6^0 CA (Crank Angle) respectively. The results indicated that use of 100% cooking oil biodiesel reduce the duration of ignition delay until 4 degrees, the duration of premixed combustion is up to 2 degrees, the total heat release is up to 26%, the amount of soot emissions is up to 30% and the increase of the duration of diffusion combustion is 3 degree compared with the fossil diesel. The measurement of the engine performance indicated that the addition of the percentage of the cooking oil biodiesel into the mixture decreases on performance (torque, power, B_{mep} and thermal efficiency) of 1 - 4% for each 25% increase in used cooking oil biodiesel on the mixture and the B_{sfc} increase 3-5% for each 25% increase in used cooking oil biodiesel on the mixture. The measurement of the engine emissions designated that the addition of the percentage of cooking oil biodiesel into the mixture of a resulted in the reduction of the soot particle emission of 4-6% for each 25% increase in the used cooking oil biodiesel. The results of the visualization of the deposit of the used waste cooking oil biodiesel are greater than the fossil diesel. The changes in the degree of the injection time both retarded and advanced 3^0 CA provided significant changes to the characterization of the combustion.

Keywords: Waste cooking oil biodiesel, Degree of injection time, Combustion, Characterization, Performance, and Engine emissions

1. INTRODUCTION

The fossil fuel or widely known as petroleum is the fuel that cannot be renewed and is expected to run out if it is continuously exploited on a large scale. Moreover, alternative energy is incredibly required as a substitute for fossil fuel. The oiling experts have been able to develop it. The result of the development is often referred to the environmentally friendly biofuel and expected to reduce and replace the fossil fuel whose supply or availability about to promptly run out. Previous studies mention that there are several numbers of the plants types that have been proven to be used as green energy sources [21-23]. One of which is used for the biodiesel production. The use of the biodiesel is intended to support the government programs towards the use of renewable energy or alternative energy as diesel fuel.

There is much researcher that studies the use of biodiesel fuel that has been carried out especially since the energy crisis in the 1970s. However, the biodiesel fuel that currently exists still has shortcomings. The conclusions from the numerous studies relating to the biodiesel fuel as described in [18]. Nitrogen oxide (NOx) exhaust emissions generally increase with the increase in the concentrations of the biodiesel compared to other diesel fuels. Exhaust emissions, hydrocarbons (HC) and carbon monoxide (CO) decrease along with the increase in the concentrations of the biodiesel compared with the fossil diesel fuel. The specific fuel consumption value tends to increase along with the increase in the biodiesel concentration compared with other diesel fuel.

The combustion of the diesel motors in principle is the unsteady turbulent diffusion combustion which is determined by the process of mixing between the fuel and the air in the combustion chamber [3, 6, 7]. Therefore, the characteristics of the fuel spray and the airflow have a large-scale influence on the process of mixing the fuel-air in the combustion chamber, in addition to the combustion chamber geometry [5, 9]. Whereas [2] explained that the atomization process and the penetration of fuel sprays affect the emission formation process. While the characteristics of the fuel spray are influenced by the physical property of the fuel in the form of the density, viscosity and surface tension. For the ambient atmospheric pressure spray, the higher the physical property of the fuel (in the form of viscosity, density and surface tension) will produce the longer penetration of the spray [8]. Finally, the pressure increase and ambient temperature cause the liquid spray phase to be shorter and thinner [17]. It caused by the increase in momentum and heat transfer from the droplets to the ambient air [24].

The study of the vegetable oil application in the diesel motors has been directly studied and carried out [2, 4]. The results showed that the use in the short-term in general can be done well while the long-term use shows the limitations of the fuel against the lubricant contamination, deposits on the surface of the engine components and the injection problems, which will affect the durability and performance of the engine. The free fatty acid content makes the vegetable oil corrosive, the phosphorus content will produce the crust in the combustion chamber while the injection problem is due to the higher viscosity of vegetable oil than diesel.

Chemically, modification of vegetable oil into small molecular weight, low viscosity and high flash point number of fuels can be carried out through a transesterificatio process using alcohol. This process produces alkyl esters of fatty acids (fatty acid methyl ester, FAME, and commonly referred to biodiesel) as the main product and glycerin [10].

The performance test and the exhaust emissions of diesel engines using biodiesel fuel have been conducted. Generally, the results designated that the specific fuel consumption (SFC) for the biodiesel fuel is higher than the fossil diesel and the HC emissions for the biodiesel fuel is lower than the fossil [1, 4, 11, 13, 14]. Scholl et al [15], and [16] examined the combustion process of Soybean Methyl Ester (SME) on the diesel motor direct injection systems with the variations in the nozzle diameter [19, 20].

The pressure and the increase in pressure rate inside the cylinder for the SME fuel are sensitive to the variations in nozzle diameter than the fossil diesel. The ignition delay period for the SME fuel is less sensitive to the variations in nozzle diameter than the fossil diesel. The fossil diesel fuels have a longer ignition delay and a higher maximum combustion rate during "premixed" combustion.

The purpose of this study is to examine the characterization of performance and emissions of a direct injection diesel engine fueled by a mixture of diesel fossil and used waste cooking oil biodiesel by adjusting the degree of the fuel injection time, which is advanced and retarded respectively 30 and 60 CA.

2. BASIC THEORY

2.1 Characteristics of the Biodiesel Fuel

The following Table 1 describes the comparative properties of the biofuels (biodiesel) and diesel fuel.

Table 1 Comparative properties of the biofuels (biodiesel) and the diesel fuel

Properties	Unit	Fuel	
		Biodiesel	Fossil Diesel
Density	Kg/m^3	860	848
Kinematic viscosity	mm^2/s	3,8	3,3
Flash point	°C	145	70
Lower Heating Value	KJ/Kg	39.540	44.844
Cetane Number	-	64	42

2.2 Burning Stages in Diesel Engine

For the occurrence of combustion in the combustion chamber, there are some conditions that must be fulfilled. Among others, areas a mixture can be burned, something that ignites the burning, stabilization and propagation of fire in the combustion chamber.

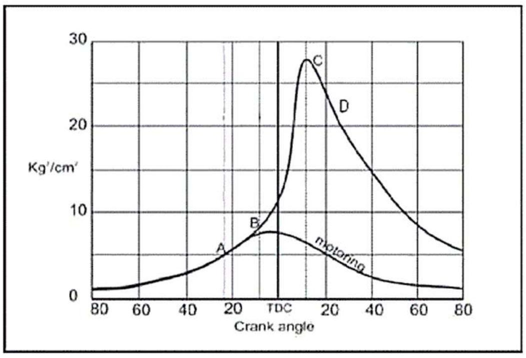


Fig. 1 Combustion process on the diesel engine [17]

The combustion process in a diesel engine has several stages described in the *P-θ* diagram as in Fig. 1 the combustion stages [17]:

Phase 1

Ignition delay period is the time when the fuel is burned but has not been ignited. Ignition delay is calculated from the start of the injection to the point where the *P-θ* curve separates with the air pressure curve only. The delay period is indicated by point A-B.

Phase 2

The rapid or uncontrolled combustion (can be classified as a pre-mixed flame) occurs after the ignition. In this second stage, the pressure increases rapidly because during the delay period, the soft grains of the fuel has had time to spread themselves to large areas and they have gotten fresh air around it.

Phase 3

Controlled combustion, the second period of the rapid or the uncontrolled combustion is followed by the third stage of controlled combustion. At the end of the second stage, the temperature and pressure make the soft grains of the injected fuel at the final injection stage burn instantly, and the increase in pressure can be controlled by the means of the pure mechanism which regulates the injection rate. The controlled combustion period is assumed to end at the maximum temperature of the cycle.

Phase 4

This fourth stage does not occur in all cases of burning the CI motor after burning. Theoretically, the combustion process is expected to end after the completion of the third stage. However, due to the poor distribution of the fuel particles, the combustion continues in the remaining expansion steps. Moreover, the name after burning or the fourth stage was developed. The total heat until the end of the combustion is 95% -97% while the remaining heat, 3% -5% goes to the exhaust system as the unburnt fuel.

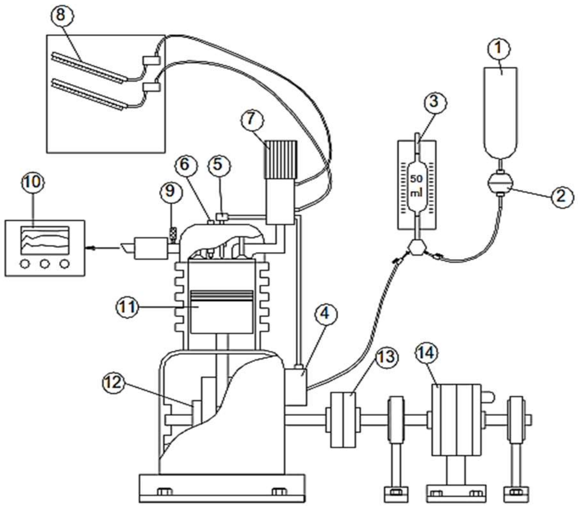
3. RESEARCH METHOD

3.1 Experimental Design

A single cylinder direct injection diesel engine is used in the experimental application. The engine specifications are shown in Table 2 and the experimental procedure is shown in Fig.2.

Table 2. Test machine specifications

Item	Specification
Mark	YANMAR
Model	TF 65 R-di
Type	Horizontal, water-cooled 4-cycle diesel
No. of cylinder	1
Bore x stroke	78 mm x 80 mm
Displacement	382 cc
Max power	6.5 PS/ 2200 rpm
Max power	5.5 PS/ 2200 rpm
Compression ratio	18: 1
Cooling system	Radiator
Combustion system	Direct injection



1. Fuel tank
2. Fuel filter
3. Burette
4. Fuel pump
5. Injector
6. Cylinder headcover
7. Air filter
8. Air temperature
9. Oxygen sensor
10. Four gas analyzer
11. Piston Cylinder
12. Crankshaft
13. Coupling set
14. Generator set

Fig.2 Experimental Design

Table 3. Operating conditions

Injection timing	11, 14, 17, 20, 23 BTDC
Engine speed	2200 rpm
Engine load	20%,40%; 60%; 80%; 100%
Fuel	B0, B25, B50, B75, B100

Table 4. Comparison of the fuel properties

Properties	Unit	Fuels	
		Biodiesel	Fossil diesel
Density	Kg/m^3	860	848
Kinematic viscosity	mm^2/s	3,8	3,3
Flashpoint	°C	145	70
Lower Heating Value	KJ/Kg	39540	44844
Cetane Number	-	64	42

3.2 Operating Conditions

In this study, the engine was at the constant speed at 2,200 rpm with the standard injection time (17 Before Top Dead Center, BTDC), advanced 3^0 and 6^0 CA (28 and 30 BTDC) and retarded 3^0 and 6^0 CA (24 and 22 BTDC). The engine load is regulated using a water brake dynamometer, starting from a low load (10%) to a high load (100%). The fuel used was the fossil diesel and the used waste cooking oil biodiesel and a mixture of both (expressed in percent volume). Further operating conditions are shown in Table 3.

The particulate emissions are measured by using Bosch type smoke meters. Table 4 shows the properties of both types of diesel fossil fuels and the waste cooking oil biodiesel. The fuel property tests showed that the waste cooking oil biodiesel differences in the physical properties such as density, viscosity and surface tension compared to fossil diesel.

4. RESULTS AND DISCUSSION

The combustion characteristics of the diesel engine are divided into 3 phases, as ignition delay, premixed combustion, and diffusion combustion. The identification of the combustion characteristics is based on measuring the gas pressure in the combustion chamber. Further processing of the gas pressure data in the combustion chamber into the heat release diagram provides the estimation of the combustion characteristics, the performance, and the engine emissions. The characterization of the performance and the engine emissions are carried out by setting the advanced and retarded injection time levels of 3^0 and 6^0 CA respectively.

4.1 Engine Power

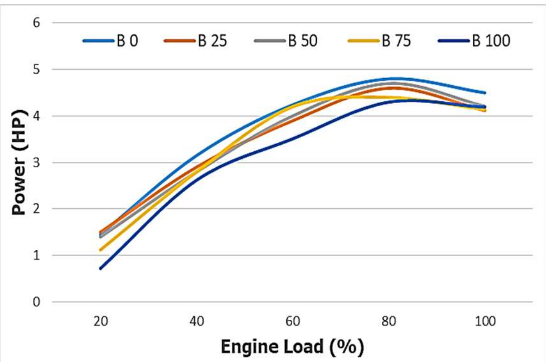


Fig.3 Engine power vs engine load

The core purpose of engine speed is to get the driving force in the form of the engine power, where the power of the engine will be directly proportional to the torque. Fig.3 shows that the higher the load addition, the higher the power produced. At the time of loading 87.5%, the amount of power experiences the peak, then it will decrease simultaneously. The increase in power is caused by increased fuel injection so that the combustion is increased.

The percentage addition of the waste cooking oil biodiesel in the fuel mixture has a tendency to reduce the power at each change in load. This is related to the heating value of the waste cooking oil biodiesel, which is smaller than the fossil diesel. In addition, the power reduction is also caused by setting the fuel injection time, which is less than optimum. As it is known that used waste cooking oil biodiesel has a higher burning point compared to the fossil diesel which requires a shorter ignition period delay.

The experimental measurement results showed that the use of B100 mixture (purely used waste cooking oil biodiesel) at the low load (25% load) showed that higher output power. This was related to the heating value. The lower waste cooking oil biodiesel compared to fossil diesel. Whereas in the middle to the upper load, the low heat value is helped by the perfection of the combustion process due to the oxygen content in the used waste cooking oil biodiesel, so that the increase in power has a close tendency to the fossil diesel.

4.2 Specific Fuel Consumption

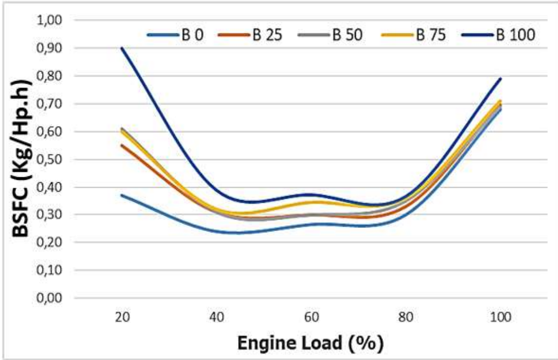


Fig.4 BSFC chart vs engine load

Fig.4 shows that the graph of the usage of the specific fuels towards the increase in load. The experimental measurement indicated that the use of the specific fuel tends to decrease at the low loads (load 10.0% ~ 37.5%), tends to be constant at the moderate loads (37.5% ~ 87.5%) and rises at the high loads (87, 5% ~ 100%). This downward trend is caused by the mixture of fuel and air that is too thin. As a result, it produces 1 horsepower in 60 minutes. This means that it just requires less fuel. At certain times, the chart trend will rise due to the amount of consumption the machine requires to produce the 1 horsepower in 60 minutes.

Large-Scale fuel consumption will cause the mixture to become rich. This is caused by the mechanism in the diesel motor that the amount of the mass flow air is relatively constant in all operating conditions. The rich mixture also causes the after-burning stage not to burn all the fuel so that there is some unburned fuel that is wasted. The unburned fuel is wasted and does not become useful energy. As a result, it causes an increase in specific fuel consumption.

The addition of the percentage of the used waste cooking oil biodiesel in the fuel mixture has a greater tendency to use specific fuel. This is due to the lower heating value of used waste cooking oil biodiesel than the fossil one so that it will produce the same power which requires greater fuel consumption.

4.3 Soot Particle Emissions

Soot particle emissions depend on total fuel is sprayed into the combustion chamber. The richer the fuel sprayed by the injector, the greater the emission value of the soot particles and vice versa. From Fig.5 it is shown that the amount of the soot particle emission increases with increasing load. If the load is added, the amount of the fuel injected into the combustion chamber gets bigger, which causes the insufficient time to burn the fuel. So that at the after-burning stage, there are some unburned fuels or called unburnt fuel. This unburnt fuel becomes smoke and its thickness is measured which is then converted to soot particle emission values.

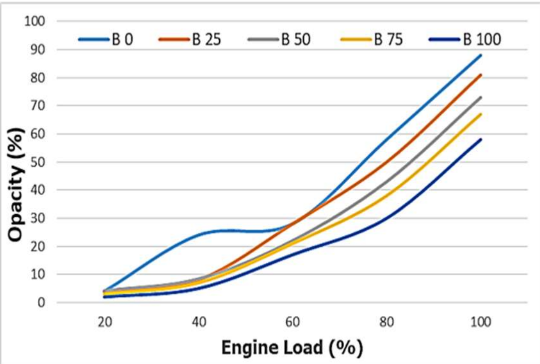


Fig. 5 Soot particle emissions vs engine load

The addition of the percentage of the used waste cooking oil biodiesel to the fuel mixture shows a tendency towards reducing the particulate emission levels of soot. This is in accordance with the previous predictions, as it is known that the used waste cooking oil biodiesel does not contain the aromatic compounds and has little sulfur. Both compounds are contained in the fossil diesel fuel and the constituent of the particulate emissions of soot.

The essential factor in this result is that the oxygen content in used waste cooking oil biodiesel is higher than the fossil diesel. The soot particles are formed in fuel-rich zones with high temperatures and pressures. The presence of the high oxygenated waste cooking oil biodiesel molecules will reduce the fuel-rich areas and limit the formation of soot particles.

4.4 Characterization of the Performance with the Injection Time Changes

Based on the fuel property table, performance analysis, and engine emissions, it is necessary to modify the engine to increases performance and emissions optimally. This study tried to modify the fuel injection time that is advanced and retarded, each of 3^0 and 6^0 CA from the standard injection time (26 CA).

4.5 Performance and Exhaust Gas Emissions

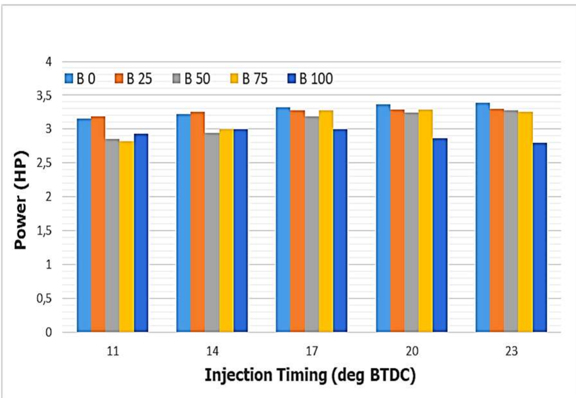


Fig. 6 Power variation with injection timing

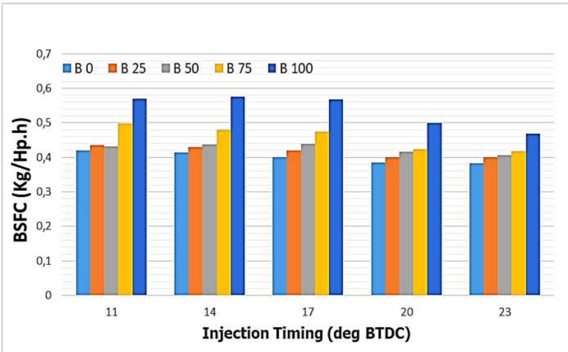


Fig.7 BSFC's with injection timing

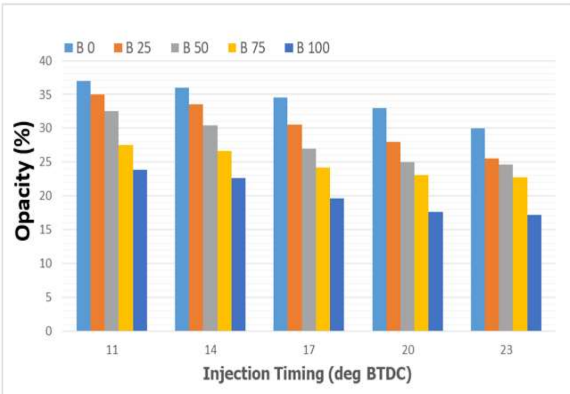


Fig.8. Soot particle emissions with injection timing

The performance characterization and exhaust gas emissions are expressed in power, BSFC, and soot emissions. The tendency obtained is that the output power engine tends to decreases with the addition of the used waste cooking oil biodiesel in the fuel mixture. This relates to the smaller content of the used waste cooking oil biodiesel compared to fossil diesel. This is the connection with the more perfect combustion process due to the oxygen content in the used waste cooking oil biodiesel so that the decrease in power is not as much as the decrease in fuel heating value [12].

As shown in Fig.6 the decrease and the increase in power in the combustion chamber with the retarded modification and the advanced 3^0 CA is higher than the retarded and advanced 6^0 CA modification. The average power decline ranged from 3.9% in retarded 3^0 CAs and 1.85% in retarded 6^0 CAs, while the average power increase was 0.15 in advanced 3^0 CA and 0.10% in advanced 6^0 CA.

The characterization of the performance and the subsequent exhaust gas emissions are the amounts of specific fuel consumption as shown in Fig.7. The trend obtained is that the amount of the BSFC tends to increase along with the addition of the used waste cooking oil biodiesel in the fuel mixture. This is related to the lower content of the used waste cooking oil biodiesel content compared to the fossil diesel, but with respect to the more perfect combustion process due to the oxygen content in the used waste cooking oil biodiesel, so the increase in BSFC is not as large as the decrease in fuel heating value.

As shown in Fig.7, the increase and the decrease of the BSFC in the combustion chamber with the retarded and the advanced modifications 3^0 CA are higher than the retarded and advanced 6^0 CA modifications. The average BCFC increase was 3.34% in retarded 30 CAs and 1.48% in retarded 60 CAs, while the decrease in BSFC averaged 6.54% on advanced 3^0 CA and 2.89% on advanced 6^0 CA.

The last is the performance's characterization and engine emission in the form of the soot particle emission as shown in Fig. 8. The tendency obtained is that the amount of the soot particle emission tends to decrease along with the addition of the used waste cooking oil biodiesel in the fuel mixture. This is related to the lower aromatic biodiesel content of used waste cooking oil biodiesel compared to fossil diesel so that it can reduce the formation of the soot particle emissions.

The following Fig.8 shows that the increase and decrease of soot particle emissions in the combustion chamber with retarded and advanced modifications 6^0 CA are greater than the retarded and advanced 6^0 CA modifications. The increase of the soot particle emission was around 10.02% in 3^0 CA retarded and 5.13% in 6^0 CA retarded, while the average soot particle emission reduction was 7% on advanced 3^0 CA and 4.3% on advanced 4^0 CA.

5. CONCLUSION

The study indicated that the use of 100% used waste cooking oil biodiesel reduces the duration of the ignition delay to 6 degrees, the duration of premixed combustion to 3 degrees, the total heat release is up to 30%, the soot emissions is up to 32% and the increase in the duration of the diffusion combustion by 3 degrees compared to fossil diesel.

The results of the engine performance measurement show that the addition of the percentage of the used waste cooking oil biodiesel into the fuel mixture results in a 1-3% reduction in performance for each addition of the 20% used waste cooking oil biodiesel to the fuel mixture and increase in BSFC of 2-4% for each addition of 20% used waste cooking oil biodiesel in the fuel mixture.

The measurement of the engine emissions shows that the addition of the percentage of used waste cooking oil biodiesel into the fuel mixture results in a decrease of the soot particle emission 5–8% for each addition of 20% used waste cooking oil biodiesel in the mixture.

The result of the visualization of the combustion chamber showed that the use of used waste cooking oil biodiesel produced a brown deposit with a more concentrated character than the fossil diesel. The changes in the degree of the injection time, both retarded and advanced 3^0 CA provide the changes (increase or decrease) to the combustion characterization, the performance and the engine emissions are greater than retarded and advanced 6^0 CA changes.

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