The Influence of NaCl dissolved on biodiesel of used cooking oil on performance and its degradation of main components of diesel engine

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Abstract. Biodiesel has been developed both domestically and abroad. Various studies have been conducted to determine the feasibility and capability of raw materials used cooking oil is replacing diesel oil in the future. The salt content in the raw material for biodiesel (new cooking oil and used cooking oil) could have a negative impact or even do not have a significant effect on the rate of wear of metal on the main components of the diesel engine. Through durability tests, the effect of salt (NaCl) on the main components of diesel engines has been tested. The new cooking oil biodiesel is used as a reference in examining the damage level of the main components of diesel engines. Results of the experiments showed that there is a difference between the use of biodiesel fuel from used cooking oil with new cooking oil such as lower diesel engine performance, carbon deposits generated higher, and degradation of metal elements on the main component in the diesel engine lubricating oil is higher

Keywords: biodiesel of use cooking oil, biodiesel of cooking oil, salt content (NaCl), durability test

1. Introduction
Alternative fuel for diesel engines that have been developed in Indonesia is biodiesel, made from used cooking oil. [1] Used cooking oil is waste oil that can be derived from the types of oils used for frying including palm oil, corn oil, vegetable oil, and so on. However, in terms of their chemical composition, used cooking oil contains compounds that are carcinogenically formed during the frying process.[2]. Very different case if the raw material for biodiesel is derived from cooking oil. Cooking oil does not receive heat treatment and mixing with chemicals contained in food, as happened in the used cooking oil. So the content of salt (NaCl) in biodiesel from cooking oil is smaller than with biodiesel from used cooking oil.

In the process of biodiesel production (transesterification) there is a strong alkaline compound (such as KOH or NaOH) is used as a catalyst in the production process of biodiesel via transesterification reaction. This strong base compound is composed of chemical elements that exist on the periodic table of the chemical elements that belong to the group IA and IIA metal shaped. These elements if reacts with the chemical elements of group VIIA (in the table of the periodic system
of chemical elements) contained in a solution of cooking oil in the form of non-metals forms a salt compound.[3]

Salt compounds (acidic) if it reacts with the metal element, the electrochemical reaction occurs in which the metal is corroded. If the concentration of salt in the biodiesel is relatively large, the rate of corrosion of metal components of the diesel engine will be faster and will cause the diesel engine component to experience wear and corrosion causes a reduced lifetime of the diesel engine. If it is alkaline, the salt will act as a lubricant on the main components; thus causing the lifetime of the diesel engine it will be longer. [4][5][6]

2. Material Description

2.1 Biodiesel

The most common scientific sense of the term biodiesel fuel is made from biological resources or biomass. But biodiesel also has a composition consisting of alkyl esters of fatty acids. Biodiesel is fuel from vegetable oils that have characteristics such as diesel oil. Biofuels are all fuels derived from vegetable oils. Therefore, the biofuel can be biodiesel, bioethanol, and bio-oil (pure vegetable oil). Biodiesel is a form of an ester of vegetable oil after the change in chemical properties because the transesterification process requires additional methanol.[7]

Table 1. Cetane Number of biodiesel from various feedstocks and diesel oil [8]

| Vegetable Oil (VO) | Cetane Number | VO | Ester |
|--------------------|---------------|----|-------|
| canola             | 37.6          | 60 |       |
| soy                | 37.9          | 45 |       |
| palm oil           | 37            | 62 |       |
| jatropha           | -             | 51 |       |
| diesel oil         | ≥45           |    |       |

2.2. Biodiesel Form Vegetable Oil

Biodiesel can be made from vegetable oils or animal fats but is commonly used vegetable oil as feedstock. Vegetable oil from biodiesel is classified into organic compounds called ester fatty acids. However, vegetable oil is fatty acid comprising triglyceride with glycerol, while biodiesel is a monoester of fatty acid with methanol. Differences in molecular form important consequences in the assessment as fuel for diesel engines:

1. Vegetable oil (triglycerides) large molecular weight is much greater than biodiesel (methyl ester). Consequently, triglycerides relatively easily experience cracking into a variety of small molecules when heated without contact with air (oxygen).
2. Vegetable oil (triglycerides) has a large molecular weight that is much greater than biodiesel (methyl ester). Consequently, triglycerides are relatively easily experience cracking into a variety of small molecules when heated without contact with air (oxygen).
3. Vegetable oil molecules are relatively more branched than the methyl esters of fatty acids. Consequently, the cetane number of vegetable oil is lower than methyl esters. Cetane number is a measure of the capability of the fuel burned in the combustion chamber of the diesel engine.

Besides the three differences that give an important consequence of the above, either vegetable oil or biodiesel equally have the main component constituent fatty acids. In fact, the process of transesterification of vegetable oils into biodiesel generates viscosity as diesel, has a higher cetane number, and is more stable against cracking. [8]. Table 1 is a difference of cetane number in some feedstock on originally of vegetable oil and after produced into biodiesel. The cetane number of diesel oil is added in table 1 as a reference.
2.3 Composition in the Vegetable Oil

The composition contained in the vegetable oil consists of triglycerides and fatty acids (having the highest content in vegetable oil, account for about 95%), free fatty acid (commonly abbreviated as FFA), mono and diglycerides as well as some other components such as phosphoglycerates, vitamins, minerals, and sulphur. According to Anam [7], raw materials biodiesel are:

a) Triglycerides, which is the main component of various fats and oils
b) Fatty acids are by products of the industrial refining of fats and oils.

2.3.1 Triglycerides

Triglycerides are triesters of glycerol with fatty acids, namely carboxylic acids having carbon atoms 6 to 30. Triglycerides are much oil and fat contained in the vegetable oil, which are the largest components. Besides triglycerides are also monoglycerides and diglycerides. The molecular structure of the three kinds of glyceride can be seen in figure 1.

![Molecular structure of monoglyceride, diglycerides, and triglycerides.](image)

2.3.2 Free Fatty Acid

The free fatty acid is a fatty acid that is separated from triglycerides, diglycerides, monoglycerides, and free glycerol. This case is caused by heating and the presence of water as the result is causing the hydrolysis process. Oxidation can also increase the levels of free fatty acids in vegetable oils. The process of conversion of triglycerides into alkyl esters through a transesterification reaction with free fatty acid alkaline catalyst must be separated; or converted into an alkyl ester first, because the free fatty acids require a catalyst. The content of free fatty acids into biodiesel resulted in the formation of acidic conditions which can lead to corrosion in the fuel injection equipment, blockage in the filter, and sedimentation in the injector [7].

2.4 Production Process of Biodiesel

Transesterification (commonly called alcoholizes) is the stage of conversion of triglycerides (vegetable oil) into the alkyl ester by reaction with the alcohol and produces by-products that glycerol. Among the alcohols that a candidate sources the alkyl group, methanol is the most commonly used because they are cheap and most high reactivity (so-called reaction methanalysis). Most of the world's biodiesel production use is Fatty Acid Methyl Ester (FAME). In the transesterification process is necessary to use a catalyst in the reaction. Without a catalyst, the resulting conversion is not the maximum because the reaction is very slow [7]. The catalyst used in the transesterification reaction is an alkaline catalyst since these catalysts can accelerate the reaction.

2.5 Properties Biodiesel

As a fuel, biodiesel must meet the ASTM requirements. One of the important parameters to determine the quality of fuel is a cetane number. Cetane number is a measure of the combustion quality of the fuel in the combustion chamber of the diesel engine. Cetane number is a function of the number of CH3 and CH2 in fuel composition. [10]. The cetane number range is 1 to 100. The value of the fuel with a cetane number of 100 is cetane (hexadecane), fuel with a cetane number is the lowest value 2.2.4.4.6.8.8 heptamethylnonane, with a value of cetane number 15. [11]. Cetane number can be determined based on the physical properties of the fuel, such as density and kinematic viscosity;
however, the determination of cetane number by their chemical properties is considered better [12]. One of the formulas that can be used to calculate the cetane number is shown in equation (1):

\[
\text{Cetane number} = -0.057(H_3) + 0.935(H_2) - 0.454(H_1) - 9.718(\text{HA}) + 0.102 \text{ HD}
\]  

(1)

Where \(H_3\) are all methyl hydrogen, except its bound directly to the aromatic group. \(H_2\) is all methylene and methylene except hydrogen which is bound directly to the aromatic group. \(H_1\) is all hydrocarbons or carbon groups are bound to the aromatic group. HA is all aromatic mono hydrogen. HD is all poly aromatic hydrogen. Another formula is closer to the regression results given by O’Conner, Forrester, and Scruller [11], namely:

\[
\text{Cetane number} = 2.34 + 35.4(\text{CH}_2/\text{CH}_3) \quad \text{linear regression}
\]  

(2)

\[
\text{Cetane number} = 1.8 + 43.8(\text{CH}_2/\text{CH}_3) - 8.1(\text{CH}_2/\text{CH}_3)^2 + 0.69(\text{CH}_2/\text{CH}_3)^3 \quad \text{nonlinear regression}
\]  

(3)

Comparing to experimental results, the formula of non linear regression results is closest. Regarding to similarity between biodiesel and diesel oil characteristics, its can be ensured that the potential of biodiesel as substitute for diesel oil.

A biodiesel production technique is only useful if the products are produced according to quality requirements that have been established and applied in the area of marketing of biodiesel. The quality a requirement of biodiesel in Indonesia has been standardized in ISO-04-7182-2006, which was approved and published by the Standard Biodiesel Indonesia (SNI) dated February 22, 2006.

| Characteristics | Units | Value                  |
|-----------------|-------|------------------------|
| Cetane Number   | min   | 51                     |
| Density         | Kg/m³ | 820-863                |
| Kinematics      | mm²/s (cSt) | 2.3 - 6               |
| Viscosity       |       |                        |
| Flash point     | °C    | min 100                |
| Cloud point     | °C    | maks 18                |
| Pour point      | °C    | maks 18                |
| Water content   | % - volume | maks 0.05             |
| Free glycerol   | % - massa | maks 0.02              |
| Total glycerol  | % - massa | maks 0.24              |
| Total Acid number | mg KOH/gr | maks 0.8              |
| Saponification number | mg KOH/gr | -                |
| Ester content  | % - massa | min 96.5               |

Source: National Standard Biodiesel Indonesia (SNI) SNI 04-7182-2006

2.6. Used Cooking Oil

Used cooking oil is the oil used to fry repeated in different time intervals (cooking oil is kept at certain periods). The use of used cooking oil to three times usage can be tolerated (not considered harmful). More use of it, especially if the cooking oil changed its colour to dark and dense, will cause harm to human health. [7]. Based on its chemical composition, cooking oil contains chemical compounds that are carcinogenic (harmful to the human body) arising during the frying process. The use of used cooking oil continuously will certainly cause diseases to the human body such as coronary heart disease and cancer.[8].
Used cooking oil is very different from new oil that has not been used for frying. In palm oil, contained about 45.5% saturated fatty acids are dominated by fatty acids palmitate and approximately 54.1% of unsaturated fatty acids which is dominated by oleic fatty acid. While on used cooking oil, saturated fatty acid numbers are much higher than the numbers of saturated fatty acids. Saturated fatty acids are very harmful to the body because they can lead to various diseases causes of death. [7]

2.7. The Salt Compound

Salt is a chemical compound composed of elements of positive ions (cations) and negative ions elements (anions) to form a neutral compound (no charged). One way is through the salt formation reaction products of acids and bases. Some other ways to form a salt compound that is through the reaction between the metal compound with a strong acid aqueous compound, the reaction between the metal compound with a non-metallic, the reaction between acid-base compound oxide, the reaction of acid compounds with oxide base, and the reaction of mixing two kinds of salt compounds differently. [13]

There are various forms of salt compounds based on their properties and solubility. The properties of the salt compounds include acids, bases, and neutral. The properties of the salt compound are dependent on the types of formation. Examples of compounds NaCl, KCl, Na2SO4 are neutral, NH4Cl and (NH4)2SO4 are acidic, while Na2CO3 and KCN are alkaline. Based on the solubility of compounds there are two kinds of salt including soluble and insoluble into water. Examples of the salt compound soluble in water are NaCl, CaCl2, KNO3, and Pb(NO3)2. While examples of the salt compound insoluble into water are AgCl, PbCl2, CaCO3, and BaCO3.

2.8. Catalysts of Biodiesel Production

Widyastuti [14] produced biodiesel from jatropha by using transesterification, previously jatropha was processed through esterification to remove free fatty acid levels that were relatively high (more than 2%). Jatropha with methanol volume ratio is 4:1, the mass of the catalyst are H2SO4 0.5% of oil weight, temperature are 60°C esterification process with a stirring speed of 500 rpm for 2 hours. The transesterification process is done by using methoxide with KOH catalysts, zeolite natural and synthetic zeolite 4A (used as a comparison against the resulting methyl ester) which produces methyl ester and glycerol. The transesterification process is carried out for 1 hour at a temperature of 75°C. The result showed that the use of catalysts KOH produces better than the use of a catalyst zeolite natural or synthetic zeolite 4A. There are two types of catalysts including homogeneous and heterogeneous catalysts. Homogeneous catalysts are in the same phase as the reactants and products. A homogeneous catalyst used in the transesterification reaction is alkaline catalyst such as potassium hydroxide (KOH) and sodium hydroxide (NaOH) [15]. The weakness of these catalysts is acidic (corrosive), harmful if direct contact with humans, is difficult to separate from the product so that is wasted during the washing process [14]. Commonly used on a laboratory scale, it is difficult to do commercially, operating in a liquid phase is limited to conditions of temperature and pressure. The second is a heterogeneous catalyst, the catalyst is solid and is widely used in liquid or gaseous reactants, for example, CaO and MgO. The advantage is that mild conditions reactant, a longer catalyst life span, low catalyst cost, environmentally friendly, can be separated from the product by filtration, reusable, and simpler construction equipment.

2.9. Durability Test of Diesel Engines with Biodiesel from Used Cooking Oil

Durability testing of the engine is recommended by the EMA (Engine Manufacturers Association) [16]:

1. Low Idle: the diesel engine is operated without a load where the minimum speed. This step is performed for 30 minutes.
2. High Idle: the diesel engine is operated with a load of 25% of the maximum torque and speed 90% of the rated power speed. This step is performed for 30 minutes.
3. Rated Power Speed: the operation of a diesel engine at maximum speed in accordance with the specifications of the motor then set maximum load. This step is performed for 60 minutes.
4. Peak Torque Speed: the operation of the diesel engine speed and load at times of maximum torque. This step is performed for 60 minutes.

The above cycle was repeated five times (15 hours) and then rested overnight. Repeat the above cycle until the operation for 200 hours is met. Then the lubricating oil sample is taken after the diesel engine is run for 200 hours.[17].

Georgan and Fry[18] conduct durability testing of diesel engines with the composition of diesel oil/soybean for 200 hours following the EMA standards of diesel engine testing with alternative fuels. Use a diesel engine with an average power engine is 41.8 kW at 2200 rpm and a compression ratio of 16.3: 1. The experimental results indicate that the diesel engine with fuel composition is better power output than diesel engines using conventional fuels (diesel oil) for a short period only. For the long term, the performance of diesel engines with alternative fuels is decreased, carbon deposit formation is higher, and damage of main components of a diesel engine can be seen visually. Probably caused by variations in loading and rotations in durability testing.

Another case with Ali and Hannah[19] use a diesel engine of Cummins N14-410 with blending fuels of diesel oil, methyl tallowate, and ethanol for durability test. The test results showed an unchanged in power and torque of the engine during the tests performed for the 200-hour EMA standards. The viscosity value of lubricating oils was also unchanged for 100 hours of testing, but during testing, there are problems in 3 pieces of injector at different times.

Through the operation of the engine for 200 hours could determine the components of diesel engines that were damaged by testing the used lubricating oil. The purpose of the test uses lubricating oil to examine the content of metals and non-metals to predict engine components that were damaged, besides that also can be estimated the lifetime of the components that can operate. [20].

3. Results and Discussion

3.1. The Characteristics of Biodiesel

| Parameter          | Unit  | Biodiesel CO | Biodiesel WCO | Methods          |
|--------------------|-------|--------------|---------------|------------------|
| Viscosity          | CSt   | 7.5          | 12.50         | ASTM D-445       |
| Calorific Value    | MJ/kg | 41.182       | 40.380        | ASTM D-20        |
| Flash Point        | °C    | 190          | 210           | ASTM D-93        |
| NaCl               | ppm   | 1.89         | 5.04          | Flame photometry |

The production of biodiesel from cooking oil and used cooking oil are shown in table 3. Based on the data shown in table 3 is do not very much different from the Indonesian National Standard (SNI), unless the kinematics viscosities still not meet the standard. The feedstock of cooking oil is low quality; it is estimated very high viscosity. The properties of biodiesel are affected by the quality of the feedstock. For example, cooking oil with high viscosity will produce biodiesel high viscosity as well. Patil et al [21] to produce biodiesel from waste cooking oil with a viscosity of 28.8 cSt produce biodiesel with a viscosity of 2.25 to 3.10 cSt. Ilickovic et al [22] to produce biodiesel from waste cooking oil with a viscosity of 42.54 cSt produce biodiesel with a viscosity of between 4.96-7.05 cSt. Based on these two studies provide information that raw materials with a higher viscosity will produce biodiesel with a high viscosity as well. Moreover, cooking oil depends on its usage. Is increasingly being used as a fatty meat fry the viscosity is getting thick.
### Table 4. Specification of Engine

| Model       | R 175 A |
|-------------|---------|
| Type        | Single Cylinder horizontal, 4 stroke |
| Combustion System | Indirect System |
| Bore X Stroke | 75 X 80 mm |
| Displacement | 0.353 L |
| Compression Ratio | 23:1 |
| Input Power  | 4.41 KW |
| Rotation Speed | 2600 rpm |
| Fuel Consumption | 280.2 g/KWh |
| Cooling Method | Hopper Type Water Cooling |
| Lubrication Method | Combine Pressure and Splash |
| Starting Method | Hand Cranking |
| Weight       | 65 kg |
| Dimensions   | 595 X 380 X 570 mm |

In this study, the most important property is the level of salt (NaCl) in which dissolve in biodiesel from used cooking oil. Although it is not listed on the Indonesian National Standard (SNI) or ASTM standard the salt content is very influential on the performance of diesel engines primarily on the main components of diesel engines. In table 3 shows that the new biodiesel from cooking oil contained NaCl of 1.89 ppm while biodiesel from waste cooking oil contained 5.04 ppm. The amount of the salt content of biodiesel from waste cooking oil is very difficult to identify because it is highly dependent on the period of use.

#### 3.2. Performance of Diesel Engine

Before conducting the experiment, firstly performed pre-experiment with the aim of determining the engine speeds at the time of maximum torque and maximum power. Pre-experiment is necessary because the existing performance in the engine specification has been changed. Fuel used is Diesel Oil (B5) commercial production of Pertamina as a reference. After the pre-experiment was round, resulted in 2000 rpm with a torque of 10.74 Nm and 2400 rpm with a power of 2.6 KW. Specifications of the engine can be seen in Table 4. Method of engine durability testing and the steps already described in section 2.8.

![Figure 2](image-url)  
**Figure 2.** Comparison of the maximum power of engine with biodiesel from cooking oil and used cooking oil at 200 hours durability test.
The experiments have been used diesel oil and biodiesel with composition 80:20 (B20). Experimental results showed a decrease in power and torque respectively 3.85% and 5.25% for biodiesel from cooking oil, while biodiesel from waste cooking oil fell by 13.4% and 15.2%. Figure 2 is a graph of power after the durability test for 200 hours. Trends power of the engine with biodiesel from cooking oil is very stable with an average of 2.5kW, while the engine power with biodiesel from used cooking oil fluctuated with an average of 2.25 kW.

Figure 3. Comparison of the maximum torque of engine with biodiesel from cooking oil and used cooking oil at 200 hours durability test.

The maximum torque values have been obtained at 2000 rpm. The average value of a maximum torque of 200 hours showed that biodiesel from cooking oil is greater than the biodiesel from used cooking oil. Figure 3 is a graph of torque after the durability test for 200 hours. Trends torque of engine with biodiesel from cooking oil is stable at someplace and sometimes fluctuates with an average of 10.176 Nm, while the engine torque with biodiesel from used cooking oil fluctuates with an average of 9.11Nm.

Figure 4. Comparison of the specific fuel oil sonsumption of engine with biodiesel from cooking oil and used cooking oil at 200 hours durability test.
Figure 4 is a graphic comparison of specific fuel oil consumption (SFOC) at maximum power. Through the graph shows that the SFOC of a diesel engine with biodiesel from cooking oil is more stable than biodiesel from used cooking oil. SFOC average of the two fuels at maximum power is 393.2 grams/kWh for biodiesel from cooking oil and 448.6 grams/kWh for biodiesel from used cooking oil. The graph shows that the consumption of biodiesel from cooking oil is more efficient than biodiesel from used cooking oil.

3.3. Visual inspection of main engine components

In the inspection of the main components of diesel engines, the most appropriate methods to direct visual observation. Observations by overhaul and checking the major components in the combustion system. The data observed are cylinder head, pistons, intake valve, exhaust valve, cylinder liner, and bearing. Documentation of diesel engine components is necessary to support the evaluation of diesel engine durability. Documentation in three stages, namely at the time before the experiment, after the experiment, and after the experiment and cleaned. With this method, the carbon deposits can be compared, in addition to the physical degradation of the components can be observed with the eye senses.

Deposit carbon contained in diesel engine components (such as cylinder head, piston, intake, and exhaust valve) also needs to be analyzed. Table 7 is a summary of experiments that could include visual observation, engine performance, and analysis of used lubricant. In the case of carbon, deposits use biodiesel from waste cooking oil more than the use of cooking oil biodiesel. Total deposits for biodiesel from cooking oil is 1.48 grams, while the biodiesel fuel from used cooking oil amounted to 1.82 grams.

![Figure 5](image1.png)  
**Figure 5.** Photograph of cylinder head (a) biodiesel from cooking oil. (b) biodiesel from used cooking oil

![Figure 6](image2.png)  
**Figure 6.** Photograph of pistons crown (a) biodiesel from cooking oil. (b) biodiesel from used cooking oil
Figures 5, 6, and 7 are examples of photos for observation components visually. Through the pictures can be the observed thickness of the carbon deposits, and also frictions between metals. Figures (a) are photographs of components that use biodiesel from cooking oil, while figures (b) are components that use biodiesel from used cooking oil. Figure 6 are clear, the darkness of both pistons crown are very different, the thickness of the carbon deposits on both surfaces are very contrasting. Likewise, friction pistons with the cylinder liner walls, stripes streaks of the wall of the piston of both photos are very clear, where the scratches on the photo (b) more.

3.4. Used Lubricating Oil Examination

Degradation of the main components of the diesel engine can also be seen from the quality of used lubricating oil. In used lubricating oil also contained a metal element of diesel engine components due to abrasion. Wear and tear on the components are divided into three kinds: because of adhesive wear, wear and tear due to corrosive wear and tear because of the dust (wear friction). Adhesive wear and tear are caused by a layer of lubricating oil, corrosive wear is caused by carbon deposits, water, and acid, while the dust particles cause friction wear. The following of table 5 explains the metal elements in the used lubricating oil diesel engine according to the original source, and table 6 is condition monitoring of lubricating oil.

| No | Originally source | Metal elements | Symbol |
|----|-------------------|----------------|--------|
| 1  | Piston            | Aluminum, copper, iron | Al, Cu, Fe |
| 2  | Piston ring       | Chromium, Nickel, Molybdenum | Cr, Ni, Mb |
| 3  | Bearing           | Aluminum, Antimon, Cadmium, Cobalt, Copper, Lead, Magnesium, Silver, Tin, Zinc | Al, Sb, Cd, Co, Cu, Pb, Mg, Ag, Sn, Zn |
| 4  | Cylinder liner    | Chromium, Iron | Cr, Fe |
Table 6. Condition Monitoring of Lubricating Oil

| No | Parameters     | Restrictions                         |
|----|----------------|--------------------------------------|
| 1  | Viscosity      | maximum reduction 20% of the initial value |
| 2  | TBN            | minimum 50 % of the initial value     |
| 3  | Water Content  | maximum 0.3 %                         |
| 4  | Aluminum (Al)  | maximum 20 ppm                        |
| 5  | Iron (Fe)      | maximum 85 ppm                        |
| 6  | Chromium (Cr)  | maximum 15 ppm                        |
| 7  | Copper (Cu)    | maximum 25 ppm                        |

Table 7. Summary of the experiment result

| Description         | Biodiesel                  |
|---------------------|----------------------------|
|                     | Cooking Oil | Used Cooking Oil |
| Carbon Deposit      |             |
| Piston              | 0.50 gram  | 0.55 gram        |
| Inlet Valve         | 0.16 gram  | 0.17 gram        |
| Outlet Valve        | 0.34 gram  | 0.47 gram        |
| Cylinder Head       | 0.48 gram  | 0.63 gram        |
| Total Deposit       | 1.48 gram  | 1.82 gram        |
| Performance (averages) |             |
| Power maximum       | 2.5 Kw      | 2.25 Kw          |
| SFOC at max power   | 393.2 gr/kWh | 448.6 gr/kWh    |
| Torque Maximum      | 9.94 Nm     | 8.96 Nm          |

Properties of used lubricating oil

| Parameters          | Biodiesel                  |
|---------------------|----------------------------|
|                     | Cooking Oil | Used Cooking Oil |
| Kinematics Viscosity, 40 °C | 66.79 Cst  | 76.35 Cst       |
| TBN                 | 8.93 mg KOH/gr | 10.71 mg KOH/gr |
| Water Content       | 0.004 %      | 0.144 %         |
| Calorific Values    | 10378 Cal/gr  | 10491 Cal/gr    |
| Sulphur (S)         | 0.05 %       | 0.098 %         |
| Iron (Fe)           | 11.20 ppm    | 20.64 ppm       |
| Copper (Cu)         | 0.01 ppm     | 0.75 ppm        |
| Lead (Pb)           | nil          | nil             |
| Chromium (Cr)       | 0.19 ppm     | 0.13 ppm        |
| Aluminum (Al)       | 10.84 ppm    | 23.37 ppm       |

According to the observation of metal elements of biodiesel from waste cooking oil greater than biodiesel from cooking oil. The content of salt (NaCl) that exist in waste cooking oil is impacting the main components of the diesel engine. Table 7 provides information that metal elements contained in the used lubricating oil are greater. Both examinations have the same trend associated with the degradation of engine components. Element of Iron (Fe) and aluminium (Al) is contained in most lubricating oils. The components of a diesel engine that contain elements of Fe and Al are pistons and bearing. Through direct observation can also be easily seen that the scratches on the walls of the piston and the bearing are very apparent, even in the main bearing layers are peeled off. Based on metal elements contained in the used oil and also direct observation, the piston and the main bearing degrade very much. Other metal elements such as Copper (Cu) and Chromium (Cr) is not too much contained in the used lubricating oil. So that the piston ring and cylinder liner is still normal.

According to condition monitoring of all-metal, elements are still within normal limits except aluminium elements on biodiesel from waste cooking oil slightly above the threshold is 23.37 ppm. When compared with biodiesel from cooking oil is only 10.84 ppm, then the NaCl salt content in cooking oil very strong influence on the components that contain aluminium (Al) including a piston component and main bearing.
4. Conclusion and Recommendation

Based on a diesel engine durability test by following the testing standards of Engine Manufacturing Association (EMA) for 200 hours the use of biodiesel fuel from used cooking oil are:

1. There was a change of performance of diesel engine, which power and torque decreased significantly and the SFOC and carbon deposit have increased.
2. Higher NaCl content does not influence the quality of lubricants, especially viscosity and TBN. Instead, degradation on the components of the engine is very noticeable especially on the components that contain elements of Al and Fe as the piston components and main bearing.

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References

[1] Pribadi A. 2020. Potential Energy Business from Used Cooking Oil. Ministry of Energy and Mineral Resources Republic of Indonesia. PRESS RELEASE. NUMBER: 388. Pers/04/SJI/2020. Date: 6 December 2020

[2] Ganesan K, Sukalingam K, and Xu B. 2017. Impact of consumption of repeatedly heated cooking oils on the incidence of various cancers- A critical review. CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION. P: 488-505

[3] Dye J.L. 2021. Alkali metal chemical element. Available: https://www.britannica.com/science/alkali-metal

[4] Xuan Phuong Nguyen and Hai Nam Vu. 2019. Corrosion of The Metal Parts of Diesel Engines In BiodieselBased Fuels. Int. Journal of Renewable Energy Development 8 (2) P: 119-132

[5] L.M. Baena J.A. Calderon. 2020. Effects of palm biodiesel and blends of biodiesel with organic acids on metals. Heliyon 6. e03735

[6] Zeka Angger Hartono1 , Beny Cahyono. 2020. Effect of Using B30 Palm Oil Biodiesel to Deposit Forming and Wear Metal of Diesel Engine Components. International Journal of Marine Engineering Innovation and Research, Vol. 5(1) pISSN: 2541-5972, eISSN: 2548-1479

[7] Anam, C. 2013. Pengaruh Bahan Bakar Biodiesel Dari Minyak Goreng Komersial (Baru) Terhadap Peluruhan Unsur logam Pada Komponen Motor Diesel. Final Project, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember (ITS) Surabaya

[8] Ilyas, F. 2013. Pengaruh Senyawa NaCl Pada Bahan Bakar Biodiesel Dari Minyak Jelantah Terhadap Laju Keausan Unsur logam Komponen Utama Motor Diesel. Final Project, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember (ITS) Surabaya.

[9] Elgharbawy A.S , Sadik W.A, Sadek O.M, Kasaby M.A.2021. A Review On Biodiesel Feedstocks and Production Technologies. J. Chil. Chem. Soc. Vol. 66 no.1

[10] Connemann, J., Fischer, J. 1998. Biodiesel in Europe 1998, Biodiesel Processing Technologies. International Liquid Biofuels Congress, July 19-22, 1998, Curitiba - Parana - Brazil

[11] O’connor, C.T., Forrester, R.D., Scurrell, M.S. 1992. Cetane Number Determination of Synthetic Diesel Fuel, FUEL, Vol.71. Issue : 1, p 1323-1327

[12] Henein, N. A., Fragoulis, A. N., and Luo, L. 1985. Correlation between physical properties and autoignition parameters of alternate fuels. In Combustion, emission, and analysis, Society of Automotive Engineers publication P-162, p. 243-263.

[13] Kurlansky, Mark. 2002. Salt : A World history. Walker Publishing Company

[14] Widyaustuti, L. 2007. Reaksi Metanolisis Minyak Biji Jarak Pagar Menjadi Metil Ester Sebagai Bahan Bakar Pengganti Minyak Diesel Dengan Menggunakan katalis KOH. Final Project, Dept. of Chemistry, Faculty of Mathematics and Sciences, Semarang National University, Indonesia

[15] Darmoko, D. and Cheryan, M. 2000. Continous Production of Palm Methyl Ester. J. Am.Oil Chem.Soc, 77, p 1269-1272
[16] Engine Manufacture Association. 2009. Technical Statement On The Use Of Biodiesel Fuel In Compression Ignition Engines. www.enginemanufacturers.org

[17] Baranescu R A., dan Lusco J.J. 1997. Performance, Durability, and Low Temperature Evaluation of Sun Flower Oil As Diesel Fuel Extender. American Society of Agricultural Engineering Publication, p 312-328

[18] Goering, C. E., and Fry, B. 1984. Engine Durability Screening Test of a Diesel oil/ Soy Oil/ Alcohol Microemulsion Fuel. Journal of the American Oil Chemist’s Society, Vol. 61 No:10, p1627-1632

[19] Ali, Y and Hanna, M.A. 1996. Durability Testing Of A Diesel Fuel, Methyl Tallowate And Ethanol Blend in A Cummins N14-410 Diesel Engine, Department of Biological System Engineering, University of Nebraska. www.elibrary.asabe.org/

[20] Subiyanto. 1989. Jenis-Jenis Logam Yang Terdapat Di Dalam Minyak Pelumas Bekas dan Sumber Asalnya. Lembaran Publikasi LEMIGAS No. 1, p 32-37

[21] Patil, P.D., Gude, V.G., Reddy, H.K., Muppaneni, T., Deng, S. 2012. Biodiesel Production from Waste Cooking Oil Using Sulfuric Acid and Microwave Irradiation Processes. Sci. Res., Journal of Environmental Protection, 3, p107-113, DOI: 10.4236/jep.2012.31013

[22] Ilickovic Z., Sadodinovic J., Zolic F., Redzic E. 2009. Effect of Catalyst on Transesterification of Waste Vegetable Oils from Food Processing Facility. Agric. Conspec. Sci. Vol. 74No:3, p187-190