Droplet Combustion Characteristic of Biodiesel Produced from Waste Cooking Oil

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Abstract. Waste cooking oil is a good candidate as a diesel engines fuel substitution. Its abundant availability because it is unused waste, and its physical properties similar to diesel oil make the waste cooking oil more preferable as diesel fuel substitutes compared to other types of vegetable oil. The purpose of this study is to determine the percentage effect of waste cooking oil mixture in biodiesel fuel on droplets combustion characteristics of biodiesel that include flame visualization, ignition delay and burning rate. In this study, a mixture of waste esterified cooking oil was varied in 0% to 100%. The results showed that in the mixture of waste cooking oil biodiesel below 50%; the higher the biodiesel content in the diesel fuel mixture, the higher the maximum temperature of droplet combustion. Whereas the biodiesel cooking oil content above 50% to 100% showed a temperature that tends to be constant. In addition, the droplet combustion speed will be lower along with the increase in waste cooking oil content in biodiesel. The greater waste cooking oil content in biodiesel causes high droplet flame becomes higher. The water content in waste cooking oil biodiesel causes microexplosion in droplet combustion of biodiesel mixture of waste cooking oil and diesel.

Keywords: Combustion, droplet, biodiesel, waste cooking oil, characteristic.

1. Introduction
The depletion of petroleum reserves in the world as well as in Indonesia, one of the triggers is caused by our dependence on energy consumption from petroleum. This situation is also driven by the increasing demand for oil energy in the transportation sector and the growth of the industrial sector in Indonesia. This forces us to seek, utilize, and develop new renewable energy sources in lieu of petroleum fuels. One of these renewable energy alternatives is Biodiesel. Indonesia has great potential as a biodiesel producer because biodiesel producing sources of sugar cane, cassava, sweet potato, castor bean and so on are widely available and easy to grow in Indonesia. As an alternative renewable energy, biodiesel can help minimize the world's dependence on fossil fuels.

The main source for biodiesel production is vegetable oil obtained from plants that can or cannot be eaten, beef fat, etc. However, the main problem in making biodiesel is the raw materials cost, the vegetable oil raw materials scarcity, and the converting process of biomass to biodiesel. The production high cost has caused the producing cost of biodiesel from biomass around 1.5 times higher for diesel oil [1]. Several efforts continue to be conducted to minimize the raw materials cost, and currently one of the low-cost raw materials is biodiesel made from waste cooking oil. Waste cooking oil is currently the best candidate as a raw material for biodiesel production. Therefore, the use of
waste cooking oil as a substitute for crude oil, to produce biodiesel, is an effective method to reduce raw material costs.

Cooking oil waste refers to vegetable oils that have been used to cook food, and which are not suitable for intended use. A large number of waste cooking oil is available throughout the world. Large amounts of cooking oil are produced locally by the hotel industry during food preparation. Waste cooking oil thus creates a significant challenge due to disposal problems. The main quantity is disposed of illegally into landfills and rivers. Therefore, the use of this waste as raw material for biodiesel synthesis not only helps in disposal but also reduces production costs.

Some researchers have conducted research on the possibility of using biodiesel from waste cooking oil as a substitute for diesel fuel in diesel engines. Abed et. al, examined the effect of waste cooking oil biodiesel content on diesel blends on diesel engine performance and its exhaust emissions. The results of his research show that fuel consumption is greater in cooking oil biodiesel compared to pure diesel oil, while the HC and CO content is lower. The results of the study are in line with the research conducted by Osmano, et al., Parvaneh et al., Nantha et al., Enweremadu et al. Özer et al. Muralidharan et al., Ash et al. Joonsik et al. and Rasi et al. Addition of waste cooking oil in diesel oil by 20% can reduce engine power by 3.38%, while fuel consumption increases by 6.7%. Waste cooking oil biodiesel in a mixture of diesel oil causes fuel motor efficiency to decrease because the heating value of cooking oil is lower than diesel.

Actually, combustion that occurs in the internal combustion engine is spray combustion from a collection of fuel droplets in the combustion chamber. To see the detailed effects of adding waste cooking oil biodiesel to diesel engine combustion, knowledge of the mechanism and characteristics of droplet combustion mixtures between waste cooking oil and diesel oil is needed. For this reason, this study aims to determine the effect of adding waste cooking oil to the droplet combustion characteristics that include ignition delay time, flame visualization (dimensions), flame temperature, and burning rate.

2. Methodology
2.1 Research installation
The research installation can be seen in detail in the schema of Figure 1. A biodiesel droplet was placed on a droplet holder, above a heating element. The droplet holder is a type K thermocouple that functioned doubles as a droplet attachment, as well as a measuring sensor for droplet temperature and combustion temperature. Thermocouples were connected by an analog to digital converter that converts analog signals from thermocouple to digital signals, which then measure the data stored and processed on the computer. Visualization of burning biodiesel droplets was observed using a digital camera with data recording speeds up to 240 fps. The video camera data is then processed to determine the biodiesel droplets combustion characteristics. The combustion characteristics include flame dimensions, ignition delay and droplet combustion burning rate.
After the camera was positioned and started recording, the next step was fuel heating process, this to provide activation energy to the droplet so that the droplets evaporate and react with oxygen that it can burn. The heating process began by connecting transformer to the power source; the transformer used has an output specification of 9 volts and 1 ampere. The electricity produced by the transformer was flowed towards the heating element; it made of nichrome with a length of 5 cm, a diameter of 0.2 mm, and requires power of 9 watts to produce a temperature of 800 °C. The heating element was placed about 1 mm from the droplet so that heat can still move to the droplet but the heating element did not have direct contact with the droplet. The heat energy produced by the heating element will trigger the droplet combustion process; when the droplet starts burning, the heating process was stopped. Thermocouples will measure the flame temperature then translate it into an analog signal. The analog signal was sent to data logger that functions to convert analog signals into digital signals which will then be read on the laptop through a program called WaveScan. The data in form of temperature values is one of the combustion characteristics needed for processing data later. After the flame goes out, the camera recording process was stopped, then the video file result was saved.

From the recording results, several droplets combustion characteristics will be seen namely the time needed for the fuel to burn starting from the beginning of the heating process or the combustion pause, then the time needed for burning out fuel starts from the first time the fuel burns or burning rate, and visualization of the flame. The droplet combustion process will be performed in a combustion chamber made of cardboard and rectangular shape with dimensions of 30 cm high, 30 cm long, and 30 cm wide; this aims to reduce wind disturbances during the combustion process. On one side of the combustion chamber, a window will be made that serves as a gap to see and record the combustion process that occurs.

In this study, two main procedures were performed, namely the test specimens creation and data collection. The first procedure was making test specimens starting with preparing a specimen container, in this test 11 test containers in the form of glass bottles that have a volume of 50ml were needed, each container will be filled with diesel fuel which will be mixed with biodiesel at 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%. After the mixture was obtained, the label was given to each container with a B sign followed by a percentage value of biodiesel mixture, for example B0 or pure diesel, B10 mix of 10% pure biodiesel and 90% pure diesel, B20 mix 20% pure biodiesel and 80% pure diesel, and then up to B100 or pure biodiesel, this is intended to avoid errors when collecting data due to errors in the use of specimens.

After all samples had been prepared, the next step was the droplet test. This was performed by taking a sample using a syringe, then positioning the syringe in the condition that the needle is facing down then pressing the pressure point so that the droplets begin to form, the droplets tested must have a volume of 0.5µl. After the 0.5µl volume droplet was formed, the next step was to photograph the droplet shape so that the droplet dimensions formed can be seen, this can be done by using a ruler as the photo background and the photo was processed using ImageJ software so actual droplet size can be obtained. After the results of one specimen were obtained, cleaned the microsyringer and did the same steps for all the research specimens.

After the procedures for making specimens and measuring droplet dimensions were performed, the next step was data collection, the data collection process began with positioning all research tools in accordance with the scheme where the droplet was placed on the top of the combustion chamber with the needle facing down, then the thermocouple was positioned at the tip of the needle syringe where the droplet was formed, then under the needle was placed a heating element, the camera was focused on the droplet location so that when the droplet was burned-all the processes that occur can be observed clearly from the recorded video. Thermocouples were connected to a data logger and connected to a laptop, and run the Daqlab 2.0 application to record data generated by thermocouple.

The first step of the test was to form a droplet using a syringe, pressed the tip of the press so that the droplet was formed with a volume of 0.5µl then released the pressure tip and make sure there was no volume change on the syringe or droplet. After the droplet was formed, the next step clicked the start button on Daqlab application so that the recording data process from the running thermocouple
was followed by turning on the recorder button to store all data related to the flame visualization and the heating element to give activation energy for the droplet to burn. Shortly after the flame was produced, turned off the heating element and waited until the droplet combustion process completed, if the flame on the droplet combustion had been extinguished, the step to perform was to turn off the recording process and stopped the process in the Daqlab application by pressing the stop button in the application. Saved all the data obtained, namely the temperature value and the video visualization of the flame by giving the file name in accordance with the specimen used so that there is no error in processing the data later. After this process finished, cleaned all the testing tools and repeated this process for all variables that had been specified.

2.2 Biodiesel production

There are three stages in making biodiesel, namely titration, transesterification, and washing. Titration is a method used to determine the value of free fatty acids contained in waste cooking oil to be used. Titration will tell whether the oil to be used has high free fatty acids or not, if the oil has high fatty acids, it is necessary to have an esterification process before the transesterification process, which aims to reduce the free fatty acids contained, because high free fatty acids will produce biodiesel with poor quality.

The second process was transesterification. In this process, waste cooking oil was reacted with methanol and KOH, whereas for every 1 liter of waste cooking oil, it was needed of around 200cc methanol or a volume ratio of 5: 1 and 9 gr KOH, or a mass ratio of 100: 1, due to this testing the density of waste cooking oil was around 0.9 gr/cm$^3$. Mixing began with dissolving KOH into methanol, after KOH dissolved perfectly then a mixture of KOH and methanol mixed into waste cooking oil. Then the mixture was stirred in a closed container so that no gas came out, stirring about 5 minutes. After the stirring process, the mixture was left for at least 24 hours until the mixture formed two parts, namely FAME (fatty acid methyl ester) or called biodiesel and glycerol.

The last process was washing, this process began by separating biodiesel and glycerol, then the biodiesel mixed with water with a ratio of 1: 1, then washing was done using air bubbles, this is because washing should not be performed roughly because it can cause saponification caused by glycerol content which was still remained in biodiesel. This washing process will cause the water to become turbid, which indicates that the remaining glycerol contained in biodiesel moves to water, if the water becomes very turbid, water replacement must be performed. When the water does not become turbid, the washing process is considered complete, biodiesel was separated from the water, then the drying process was performed by heating to evaporate the remaining water contained in biodiesel.

3. Results

The data obtained in this study were video recordings of flame visualization and flame temperature data recorded in the data logger. The results of flame visualization data, obtained the data about flame visualization, micro explosion indication, droplet size and flame duration which will then be processed again to obtain the burning rate value using the equation:

$$D^2(t) = D_o^2 - K_c \cdot t$$  \hspace{1cm} (1)

Where D is the droplet diameter at a certain time (mm), $D_o$ is the initial size of droplet (mm), $K_c$ is the constant burning rate (mm$^2$/s), and t is burning lifetime (s).

To find out the burning rate value, the equation used was:

$$K_c = (D_o^2 - D^2) / t$$  \hspace{1cm} (2)

where $D^2$ is the final size of the droplet.
Figure 2 shows a graph of the maximum flame temperature in several variations in the percentage of waste cooking oil biodiesel in a mixture of diesel fuel. B0 indicates that the biodiesel content is 0% while B100 indicates the content of biodiesel cooking oil is 100%. From the graph above the higher the content of biodiesel in the mixture of diesel fuel up to close to 50%, the higher the maximum temperature of the droplet combustion. The content of cooking oil biodiesel above 50% to 100% shows a temperature that tends to be constant. One of the combustion temperatures was influenced by the heating value contained in the fuel. Theoretically, the greater the fuel heat value, the greater the combustion temperature. From the results of laboratory testing, the biodiesel made from the basic materials of waste cooking oil has a heat value of 9,680 kal/gr while Pertamina DEX diesel used has a heating value of 10,567 kal / gr. The results of this study indicate that the mixture of waste cooking oil biodiesel has a higher combustion temperature than diesel fuel, this seems not to be in line with the theoretical basis used.

However, if noticing to the visual comparison of droplet combustion fire between pure diesel and biodiesel with a percentage of 50% (Figure 3), combustion of Pertamina DEX pure diesel produces black smoke, while from burning pure biodiesel there was no black smoke. In the combustion reaction of diesel fuel, black smoke indicates incomplete combustion, whereas some of the fuel was not burned therefore produced black smoke. This is the cause of the combustion temperature produced not only influenced by only the heating value. Waste cooking oil biodiesel is included in Oxygenated fuel. Oxygen content in waste vegetable oil will help the droplet combustion process resulting in more perfect combustion as seen in Figure 3. The more perfect combustion droplets will further increase the flame temperature of the combustion results.

![Figure 2. Maximum temperature of the flame](image)

![Figure 3. Flame visualization; (a) pure diesel and (b) waste cooking oil](image)
Figure 4 shows biodiesel droplet burning rate in several variations in the percentage of waste cooking oil biodiesel mixture in fuel. Burning rate is obtained from the comparison between the droplet diameter and the fuel duration burns out, the longer the droplet burning flame time, therefore the slower the combustion speed. In the graph, it can be seen that the higher content of waste cooking oil biodiesel in a droplet causes the droplet combustion speed to be lower. The burning rate of burning a droplet in this study is strongly influenced by the flash point value factor possessed by biodiesel. The flash point is the lowest temperature the fuel can ignite. At this temperature the fuel will evaporate and then mix with free air and form a reactant that can burn. So that the higher the flash point value of a fuel, the harder the fuel to burn. Waste cooking oil biodiesel has a much higher flash point value compared to diesel fuel, where the flash point biodiesel in this test was 175 °C while the flash point owned by diesel was 40 °C. This is the main cause of the decrease in the burning rate as the biodiesel content increases in a droplet because biodiesel is more difficult to burn.

**Figure 4.** Burning rate of biodiesel

**Figure 5.** Dimention of the flame
Figure 5 shows the percentage variations effect of waste cooking oil in biodiesel blends on the height and width of droplet combustion fires. As shown in the figure, the larger the mixture of waste cooking oil in biodiesel, the higher the height of the fire produced, while for the width of the fire there was no significant change. In theory, this is related to the burning rate, where the combustion process that occurs quickly will produce a smaller fire size compared to the slow-burning combustion reaction [3]. In addition, the mechanism of liquid fuel can burn before going through the evaporation phase first before then diffusing with the oxidizer to form a reactant then burn. Waste cooking oil that has a higher evaporation temperature compared to diesel fuel will experience a longer droplet evaporation process compared to diesel fuel. This longer evaporation process causes diffusion of fuel with oxidizers to occur in a wider or higher area. This causes the fire that occurs in the mixture of waste cooking oil to be higher.

The mixture of waste cooking oil with diesel oil which each has a different boiling point causes the emergence of the microexplosion phenomenon in the burning of biodiesel droplets. Microexplosion is the phenomenon of an explosion originating in a droplet caused by the presence of one of the material contained in a boiling biodiesel mixture and exploding inside a droplet.

![Figure 6. Vizualisation of microexplosion](image)

In this study microexplosion occurs in all droplet combustion reactions of waste cooking oil biodiesel and diesel mixture as shown in Figure 6. Microexplosion does not occur in pure diesel droplet combustion. This indicates that cooking oil biodiesel triggers a micro explosion in droplet combustion. Microexplosion in this study is caused by the remaining water content in waste cooking oil biodiesel. In making it, biodiesel requires a washing process, there are several methods that can be performed to wash biodiesel, but the easiest method and the one used for this research is the washing method using water. This causes the biodiesel produced to still have water content, causing microexplosion (Selvaraj 2011). Microexplosion in the combustion process on the one hand is beneficial, but on the other hand it also tends to be detrimental. The positive effect of microexplosion is microexplosion can accelerate the combustion rate, this is due to the resulting explosion makes the droplets split into smaller ones, the area of contact between the fuel and oxidizer becomes wider so that the mixing of fuel and oxygen can take place better. However, the water content in the fuel will absorb much of the heat from the combustion so that it can reduce the temperature of the combustion.

### 4. Conclusion

From the research that has been conducted, the conclusions are as follows:

1. In the mixture of waste cooking oil biodiesel below 50%, the higher the content of biodiesel in the mixture of diesel fuel, the higher the maximum temperature of droplet combustion. While the content of biodiesel cooking oil above 50% to 100% indicates a temperature that tends to be constant.
2. The droplet combustion speed will be lower along with the increase in waste cooking oil content in biodiesel.
3. The greater the content of waste cooking oil in biodiesel causes the higher the droplet flame to be higher.
4. The occurrence of microexplosion in a mixture of waste cooking oil biodiesel and diesel is due to the water content that is still left in waste cooking oil which is converted into biodiesel.

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