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Experiment Investigation on the Effect of Oxygen Percentage on Combustion Characteristics of Waste Cooking Oil Biodiesel

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Abstract: In making biodiesel, the main problems are the raw materials cost and scarcity for producing vegetable oils, and the process of converting biomass to biodiesel. One effective method for reducing raw material costs to produce biodiesel is by using of waste cooking oil. This study aimed to find out the effect of oxygen percentage on the combustion features of biodiesel waste cooking oil premixed spray flame. The features of combustion discussed here comprise flame dimension, lift-off, flame visualization, and flame stability indicated by the percentage of oxygen on the oxidizer during extinction. Diesel spray flame's combustion was also recorded for the purpose of comparison. In this study's experiment, the oxygen percentage in the oxidizer stream ranged from 50% to 100%. Also, the total flow rate of oxidizer ranged from 7 liters/minute to 10 liters/minute. In addition, the flow rate of waste cooking oil was kept at a constant 14 mL/minute. The spray of biodiesel was carried out using a water atomizing nozzle with a diameter tip of 0.5 mm. The results showed that the height and width of the spray flame decreased with increasing variation in oxygen percentage. The height and the width of diesel flame are greater than that of biodiesel made from waste cooking oil. The height of biodiesel spray flame tended to decrease as the percentage of oxygen increased. The percentage of blue flame color increased with the increase of oxygen percentage in the biodiesel fuel. On the other hand, the flame of the diesel spray became yellow. In order to maintain stability of the cooking oil flame, greater oxidizing flow rate resulted in a smaller percentage of oxygen needed for extinguishing.

Keywords: Waste cooking oil, spray combustion, oxygen percentage, biodiesel

1. Introduction

Global energy demand which continues to rapidly increase every year-coupled with the growth of the world economy—causes the depletion of world oil reserves. This prolonging issue has compelled us to explore, make use, and develop new sources for renewable energy as a more sustainable substitute for petroleum fuels. One alternative for renewable energy is Biodiesel. Biodiesel is an alternative energy substitute for petroleum extracted from plant oils or animal fats. Vegetations with high oil content, for instance palm oil, jatropha carcass, and coconut are our last resort when petroleum is not available anymore. As an alternative source of renewable energy, biodiesel can encourage the reduction global dependence on fossil fuels.

The production for biodiesel mainly sources from vegetable oils of edible or non-edible plants. The non-edible oils, such as jatropha, microalgae, neem, rubber seed, mahua, silk cotton tree, etc., are accessible in developing countries and are very economical comparable to edible oils such as rapeseed, soybean, sunflower, and palm. However, major issues in process of making biodiesel lie at the raw materials cost and scarcity for producing vegetable oil, and the process of converting them from biomass to biodiesel. High production costs cause the cost of converting biomass to biodiesel to rise around 1.5 times higher than that of diesel oil [1]. Attempts have been made to decrease the cost of raw materials. To date, one of the cheap raw materials for biodiesel is waste cooking oil. To date, waste cooking oil is

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considered as the best contender as a biodiesel production raw material. Therefore, the use of used cooking oil as a substitute for crude oil in the production of biodiesel is an effective method for reducing raw material costs. Waste cooking oil contains triglycerides comprising glycerol and esters of fatty acids. These fatty acids need to be modified so that shorter carbon chains are achieved in order to yield biodiesel. Despite the fact that WCO displays higher viscosity and density in comparison to diesel oil, its characteristics—as a fuel blend—are very much similar to pure diesel oil, including in terms of its flash point and combustion properties. In addition, since it has high oxygen content, WCO has the potential of being a better contender for cutting down emissions in diesel engines.

By definition, waste cooking oil is described as vegetable oils having been for cooking food and not suitable for its intended use. Abundant quantities of used cooking oil are available worldwide and are produced locally by the hotel industry during their food preparation. Waste cooking oil have resulted in profound dilemma in regard to its disposal. A large amount of which are illegally discarded into landfills and rivers areas. Therefore, the use of the waste as a raw material for biodiesel synthesis does not only help resolve its disposal issue, but also minimize production costs.

Studies have been carried out on the possibility in finding the use of biodiesel made from waste cooking oil as a substitute for diesel fuel in diesel engines. Abed et. Al, [2] examined the impact by the content of biodiesel made from waste cooking oil on diesel blends in regard to diesel engine's performance and exhaust emissions. The results of his research revealed that fuel consumption was found to be higher in biodiesel cooking oil compared to pure diesel oil, though HC and CO content were lower. In keeping with a study conducted by Osmano et al. [3], 20% addition of used cooking oil in diesel oil can reduce engine power by 3.38% while simultaneously increasing fuel consumption by 6.7%. Fuel motor efficiency decreases when waste cooking oil biodiesel is mixed into diesel oil due to the heating value of cooking oil being lower than that of diesel [4–11].

In real conditions, during the process of combustion in motorized vehicles, fuel is sprayed into the combustion chamber directly or through the intake manifold using a nozzle, after which oxygen is mixed with the fuel. After the two have been incorporated, activation energy will be given to the fuel by the spark plug (for gasoline engines), or high compression (for diesel engines) which will result in a combustion reaction inside the engine. Combustion that takes place in the internal combustion engine is spray combustion originating from a collection of fuel droplets in the combustion chamber. To closely observe the detailed effects of waste cooking oil biodiesel addition into diesel engine combustion, knowledge on the mechanism and features of the combustion mixtures between waste cooking oil and diesel oil is needed.

Corresponding to previous description of the background, the features of WCO combustion should be investigated thoroughly prior to its usage on engines. Therefore, this study's objective was to look into the features of spray combustion of WCO fuel and conduct comparison related to its performance with pure diesel engine. The method of combustion spray flame was used to test the combustion quality of used cooking oil biodiesel. The features of combustion are illustrated by the resulted droplet size, flame visualization, and the oxygen percentage when the flame is in a state of extinction.

2. Experimental Method

The waste cooking oil used in this research was collected from the local restaurant which is only used two times in the frying process. The conversion from used cooking oil to biodiesel is carried out in Malang State Polytechnic Engineering Laboratory. The research scheme on burning spray flame of waste cooking oil was shown in Figure 1. The droplet spray of WCO was generated by using a special WCO atomizing nozzle with a diameter tip of 0.5 mm. WCO fuel was located in a tank which is placed two meter above the atomizer and flowed gravitationally into the nozzle. The flow rate of WCO fuel flowed into the nozzle was controlled by using a flowmeter (KOFLOC). On the other hand, an oxidizer which is a mixture of nitrogen and oxygen gas is supplied from the gas cylinder. The flow rate of all supplied gases to the nozzle was controlled individually by flowmeters. The percentage of the amount of oxygen in the oxidizer contributing to the spray flame can be varied by adjusting the flow mass of oxygen and nitrogen gas. In the experiment, the percentage of oxygen in the oxidizer stream was varied from 50% to 100%. The total flow rate of oxidizer was also varied from 7 LPM to 10 LPM. Whereas the flow rate of waste cooking oil was kept constant at 14 ml/min. The digital camera was placed parallel to the tip of the nozzle with a certain distance to observe and record visualization data and combustion characteristic of the spray flame. The combustion characteristics included the dimension of flame, lift-off, visualization of the flame and flame stability

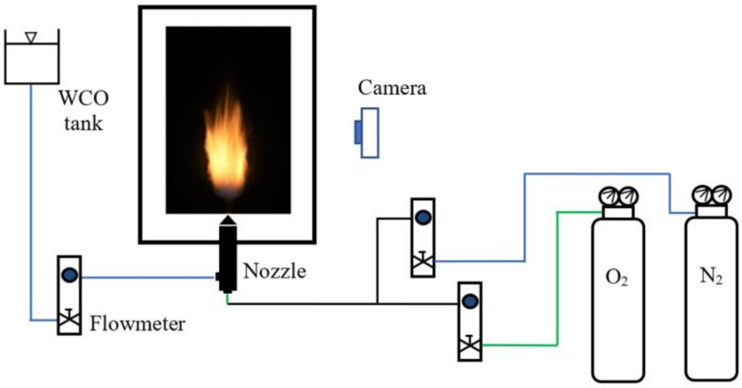

Fig. 1 - Schematic of experiment apparatus

The stability limit of the spray flame produced from the combustion of WCO was indicated by the minimum amount of oxygen in the oxidizer when the flame approaches extinct due to the lack of oxygen. The extinction of the flame was obtained by reducing the oxygen concentration in the oxidizer stream while keeping the total oxidizer flow constant until the flame were extinguished. The minimum value of the oxygen concentration needed by the flame before it extinguished becomes the stability limit of the flame.

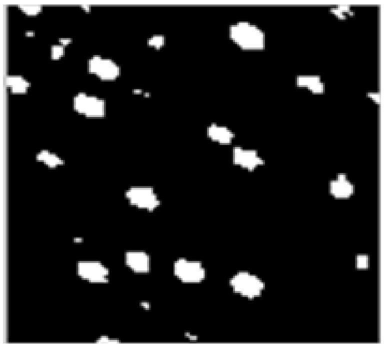

Fig. 2 - Photograph of spray

Droplet Size Measurement

The first step of this study was to measure the size of fuel droplets. In order to do this, droplet stream from lower duct was sprayed on a flat glass placed on the top of duct, perpendicular to the droplet stream. Next, a digital camera (Nikon D5000) was used to photograph droplets attached on the glass. Picture of the distribution of water droplets on the glass were then analyzed to identify the real diameter of droplets. Due to the spray being a polydisperse spray, the water droplet distribution is considered random. As a result, Sauter mean diameter (SMD) was employed to characterize the water droplets in order to simplify water droplet size distribution. Fig 2 shows the picture of processed water spray depicted in black and white. White area represents the water droplets. The diameter of each droplet could then be measured more easily and the mean diameter of droplet in the spray was able to be calculated.

3. Result and Discussion

Figure 3 and 4 show a typical photograph of a burning behavior of flame spray from WCO and diesel fuel. The percentage of oxygen in the oxidizer varies from 50 to 100%, while the total flow of the oxidizer is varied into 3 differences value such as 7, 8 and 10 LPM. the flowrate of WCO and diesel fuel was kept constant at 14 ml/min. It can be seen from these pictures that there is a significant difference in the burning behavior of spray flame when the oxygen concentration in the oxidizer was changed. The flame spray of both WCO and diesel fuel appears to be a smaller size when percentage of oxygen in the oxidizing stream is increased. On the other hand, the effect of flow rate of the oxidizing stream on the visualization of spray flame of WCO and diesel fuel showed a slightly different trend. For WCO fuel, the spray flame tends to decrease if the oxidizing flowrate was increased from 7 to 10 LPM. Whereas, the diesel spray flame tends to increased slightly when increasing the flow rate of oxidizer. The difference tendency in the visualization of the spray flame between WCO and diesel above will be explained in more detail in the next figure in this paper (Fig 5 and 6).

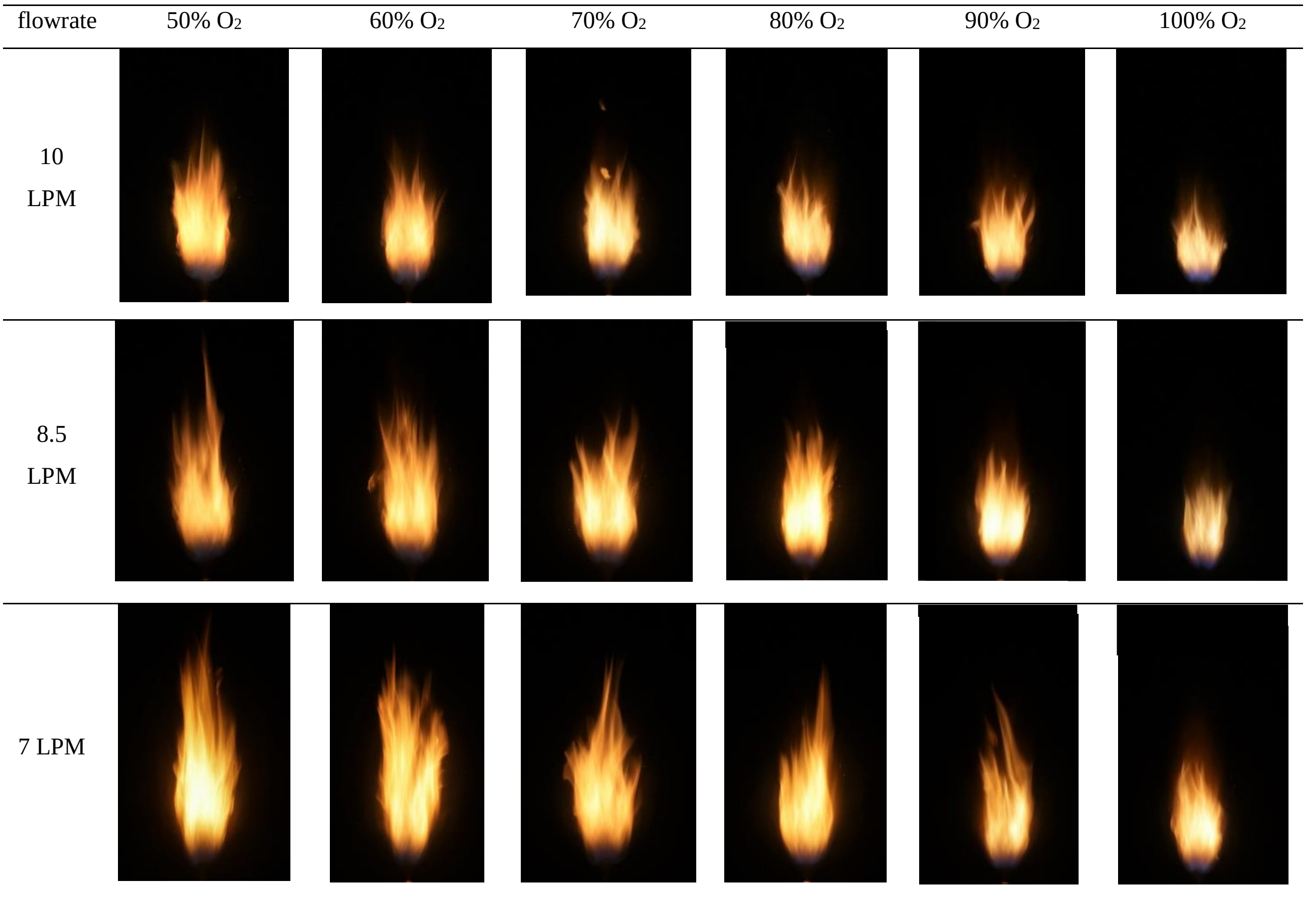

Fig. 3 - Visualization of WCO fuel spray

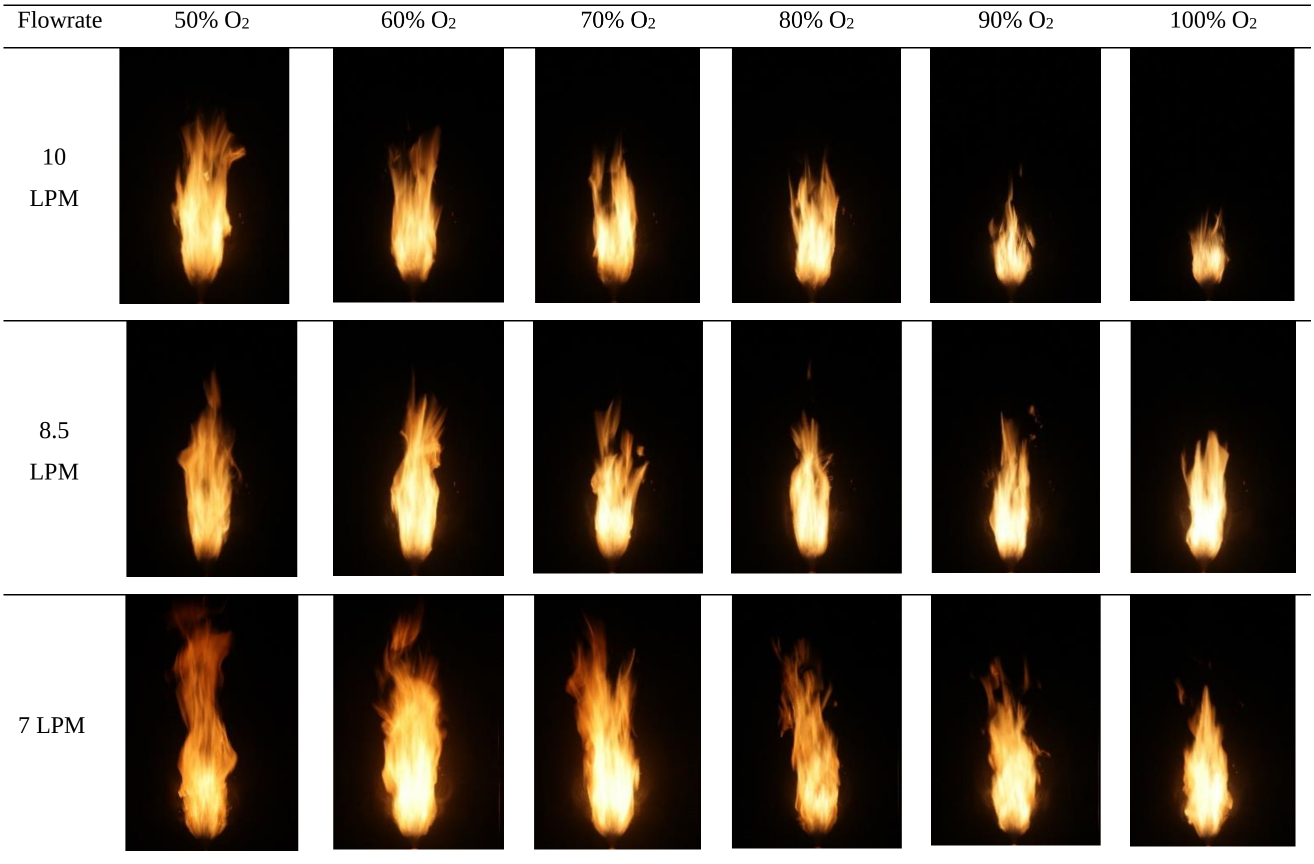

Fig. 4 - Visualization of diesel spray flame

Figure 5 and 6 show the data on the dimensions of flame spray such as height and wide flame in several variations of research that have been done. Figure 5 depicts the effect of oxygen concentration in the oxidizer on the height of spray flame of WCO and diesel fuel. The oxygen concentration was varied from 50 to 100% and the total flow rate of oxidizer was varied at 7, 8.5 and 10 LPM. As seen in the Fig 5, the diesel spray flame has a higher flame dimension compared to WCO fuel. It is because the diesel fuel has a much lower viscosity value compared to WCO. Fuels with lower viscosity will be easier to be atomized so that the size of the droplet produced in the spray stream becomes smaller and easier to diffuse with the surrounding oxidizer, especially axial diffusion of the fuel [12]. It can also be seen from the Fig 5 that the greater the oxygen content in the oxidizer, the length of the flame spray becomes shorter for all research parameters. The high concentration of oxygen in the spray accelerates the process of mixing fuel droplets with oxidizing to reach stochiometric proportions so that the mixing distance becomes shorter. This condition causes an increase in combustion speed of resulting in a shorter flame.

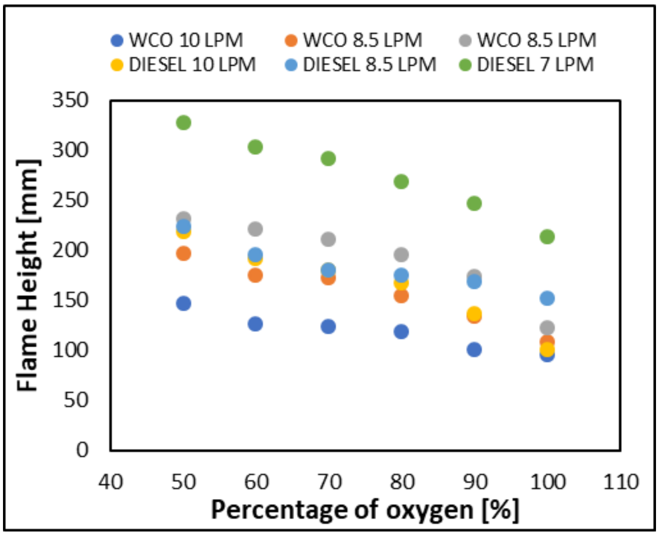

Fig. 5 - The dependence of flame height on the percentage of oxygen for different fuel and total flow rate of the oxidizer

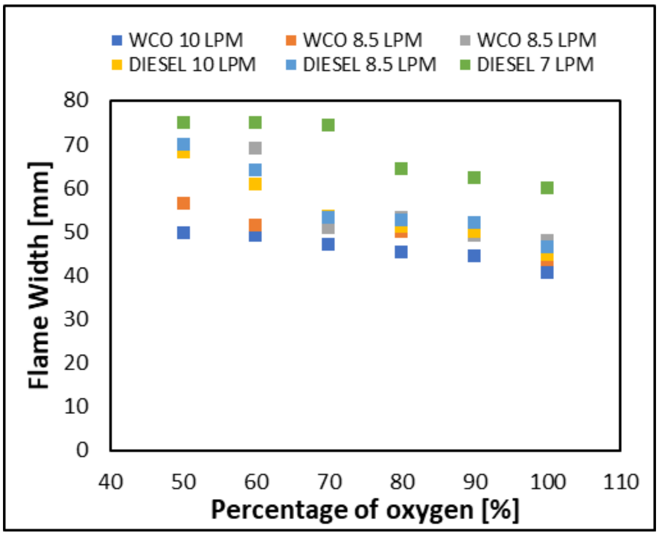

Fig. 6 - The dependence of flame wide on the percentage of oxygen for different fuel and total flow rate of the oxidizer

Figure 6 shows the dependences of the wide of spray flame on the percentage of oxygen in the oxidizer stream. Three different value of total flow rate of oxidizer were used here to explore its effect of the size of the spray flame. The wide of flame has the same tendency with the length of flame before. The wide of flame became narrowed when increasing the oxygen concentration in the flow, although the result was not significant compared to its effect on flame height. In addition, the size of the flame also becomes smaller when the flow rate of oxidizing is increased. in this experiment, oxidizing flow rates is not only serving as oxygen supply for the combustion process, but also function as a flow gas for atomization process of liquid fuel. In the process of fuel atomization, the droplet size tends to be smaller with increasing the atomizing gas flow rate. the smaller the size of the droplet causes the wider evaporation area of the droplet so that the evaporation rate became faster. In addition, the greater the oxidizer discharge causes the increase in oxygen concentration in the spray. So that the proportion of stoichiometric mixing between fuel droplets and oxidizing is more quickly achieved. This condition will result in a shorter mixing distance and a leaner flame. In the real engine situation, the combustion process in the cylinder occur in very shot time. Spray fuel with smaller droplet is preferable so that the rapid evaporation and mixing with oxygen result in faster and perfect combustion process. The WCO fuel is more difficult to be atomized compare to diesel due to the high of kinetic viscosity of WCO. Applying WCO to the engine, it is necessary to modify the injector so that the injector is able to produce fine droplet spray.

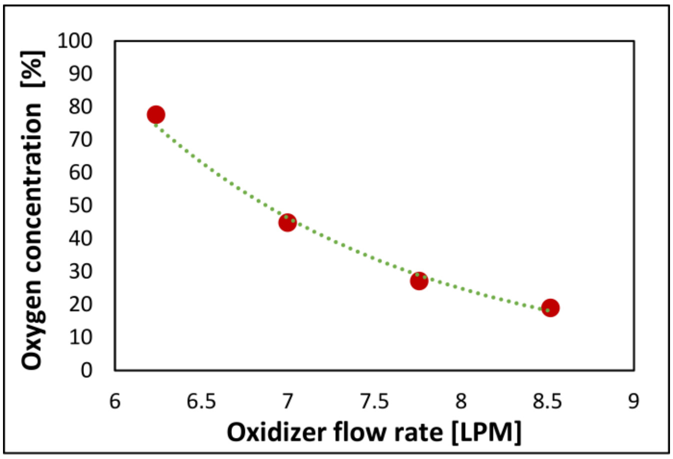

Fig. 7 - Dependence of minimum oxygen concentration on the flow rate of oxidizer

Figure 7 shows the stability limit of spray flame of WCO. The boundary of stable flame was indicated the minimum oxygen concentration on the oxidizer stream before the flame extinguished. This Figure represents the dependence of oxygen concertation on the total flow rate of oxidizer ranging from 6 to 9 LPM. As the flow rate of oxidizer increased, the spray flame requires less oxygen concentration to kept the stable flame. It is because the higher atomizing gas flow rate, the droplet size of spray will be smaller. The droplets will vaporize faster and further diffuse with oxygen resulting a more stable flame than larger droplet spray. From the Figure 7, it is also seen that, the minimum oxygen needed to produce a stable flame was still above 21% for all experiment parameters. It means that the combustion spray from WCO still could not be applied using air as an oxidizer instead of pure oxygen. Based on this result, WCO only has the potential as a mixture of diesel fuel and it could not completely replace petroleum diesel.

4. Conclusions

This experiment investigates the effect of oxygen concentration on the spray combustion characteristics of biodiesel waste cooking oil. The results can be summarized as follows:

1. The flame spray of WCO and diesel fuel appears to be a smaller size when increasing the oxygen concentration in the oxidizing stream.
2. For WCO fuel, the spray flame tends to decrease if the oxidizing flowrate was increased from 7 to 10 LPM. Whereas, the diesel spray flame tends to increased slightly when increasing the flow rate of oxidizer.
3. The percentage of blue flame color increases with the increasing percentage of oxygen in biodiesel fuel while the flame of the diesel spray becomes yellow.
4. For the stability of the cooking oil flame, the greater oxidizing flow rate results in a smaller percentage of oxygen that needed when extinction.

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