Influence of Mixture Composition Between Soybean Oil and Diesel Fuel on Characteristic of Droplets Combustion

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Depleting oil reserves has encouraged many researchers to search for new energy resources. Of many alternatives, soybean oil has been proposed as biodiesel. In this study, influence of mixture composition of soybean oil and diesel fuel on the droplet combustion characteristics was investigated. These characteristics included Ignition delay time, fire visualization, flame temperature and burning rate. The mixture comprises 10 to 50% soybean oil while the rest are Pertamina Dex diesel fuel. The study shows that flash point temperature, ignition delay time and burning rate increase as soybean oil content increases. In contrary, the flame height decreases with increasing soybean oil content.

Keywords: *Soybean Oil, Flash Point, Burning Rate, Ignition Delay Time.*

1. INTRODUCTION

Depleting oil reserves and increasing fossil fuel demand since the past few years have encouraged many industries, governments, and researchers to search for new alternative energy. Of many promising alternatives, biofuel use has become more interesting [1]. Indonesia has still great dependence on fossil fuels. To address this issue, biodiesel has been widely used in the transportation and energy sector to decrease fossil fuel consumption [2]. Biodiesel is competitive in price, carbon-neutral, and biodegradable resource which is expected to fulfill global energy demand [3]. Biodiesel can be produced from animal fat or as the first derivative of plants oil, e.g. soybean, canola, hazelnut, corn, and sunflower seed [4,5].

In Indonesia, there are more than 60 oil-producing plant species which is potential to be developed as biofuel [6]. Of those, soybean has an interesting potential since it can easily grow in Indonesia and is widely used as traditional food, e.g. tempe, tofu, and soybean sauce. In addition, oil extracted from its bean can be used as the alternative fuel for renewable energy [4]. Transesterification process involving alkaline as catalyst transforms soybean oil into fuel and it has similar properties to diesel [7]. Like other biodiesel produced through by transesterification process, soybean fuel is structured by mono-alkyl esters of higher fatty acids [8]. To increase the efficiency of soybean oil transformation into biodiesel, high quality soybean oil is beneficial since it does not require any additional process to decrease free fatty acids prior to transesterification process [9].

Biodiesel is expected to decrease hydrocarbon emissions like CO and CO_2 [4]. In addition, biodiesel has low sulfur content which can decrease SO_2 emissions as a source of acid rain. Much attention has been dedicated to investigating the biodiesel use as an alternative fuel for combustion in an engine. Zang *et al*. [11] studied the combustion of biodiesel droplets comprised of 50% n-butanol and 50% biodiesel. Sitorus *et al*. [12] analyzed off-gas and temperature of combustion room of engine fueled by 100% soybean oil. A challenge exists since soybean oil, like other biofuels, has high viscosity leading to poor atomization during its injection [10]. Study on combustion characteristics of an engine fueled with the mixture of soybean oil and diesel is therefore important.

This study investigates the combustion characteristics of an engine fueled with a mixture of soybean oil and biodiesel. The investigated characteristics were maximum combustion temperature, flash point, ignition delay time, burning rate, and combustion visualization. Combustion temperature was used also to estimate combustion energy and its efficiency [1]. The ignition delay time was an interesting point in this study since it strongly influences performance and off-gas emission from the engine [13]. Burning rate,

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determined from the beginning until the end of combustion, also influences combustion efficiency. Higher droplet size whose higher mass requires a longer duration for a complete combustion process [2]. Flame temperature is the highest temperature by assuming adiabatic condition. This property is important to investigate maximum heat energy can be produced during combustion. Combustion commences when flash point temperature is achieved [13].

2. METHOD AND MATERIAL

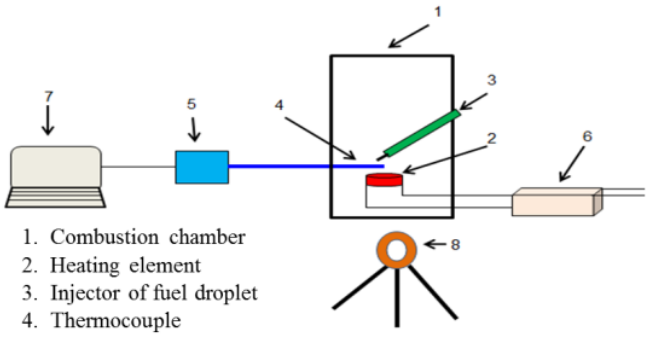
The fuel used in this study was a mixture between soybean oil and diesel fuel. In the beginning, property of soybean oil was investigated, and the result is depicted in Table 1. High flash point of soybean oil makes it easier to be safely handled and transported [14]. As a comparison, diesel oil has a lower flash point at 55 °C [15]. Diesel oil and biodiesel was mixed before being injected to a combustion chamber and the mixture composition for each case is presented in Table 2. For each case, data for flash point, ignition delay time, and the burning rate was the result from 3 experiments. Fuel was directly injected into the combustion chamber (Figure 1). Fuel droplet whose size of 1.30 mm in diameter was used in this study. One side of the combustion chamber was made of high temperature glass so that the combustion can be recorded, by a special camera, for visual analysis. The thermocouple measured the temperature inside the combustion chamber and then transmitted its signal to the data logger and computer.

Table 1: Properties of soybean oil diesel oil in this study

Property	Soybean oil	Diesel Dex [15]
Cetane number		53
Density at 15 °C	910 kg/m^3	820 kg/m^3
Flash point	172 °C	55 °C
Sulfur content		< 300 ppm
Viscosity at 40 °C	30.9 mm^2/s	2.0 mm^2/s

Table 2: Mixture composition between soybean oil and diesel fuel in this study

Case	Soybean oil	Diesel fuel
1	10 %vol	90 %vol
2	20 %vol	80 %vol
3	30 %vol	70 %vol
4	40 %vol	60 %vol
5	50 %vol	50 %vol



1. Combustion chamber
2. Heating element
3. Injector of fuel droplet
4. Thermocouple
5. Data logger
6. Transformer
7. Computer
8. Camera

Figure 1: Experiment set up in this study

3. RESULT AND DISCUSSION

3.1 Combustion characteristics

For each case, average values from 3 experiments for flash point, ignition delay time and burning rate are depicted in Table 3. The flash point of mixture increases as soybean oil content increases and its increase follows a linear correlation. The lowest flash point at 44.2 ºC occurred for soybean oil content of 10 % while the highest flash point at 66.3 ºC occurred for soybean oil content of 50%. In general, flash point temperature increases by 9-11 % with each 10% increasing soybean oil content. This result is reasonable since soybean oil has a higher flash point, i.e. 172 ºC, than diesel oil at 55 ºC. In contrary, the flame height decreases as soybean oil content increases. The highest flame height of 62.6 mm occurs for soybean oil content of 10% while the lowest flame height of 27.3 mm occurs for soybean oil content of 50% (Figure 3).

Table 3: Average value of flash point, flame height, ignition delay time and burning rate for all cases

Property	Case 1	Case 2	Case 3	Case 4	Case 5
Soybean oil content [%vol.]	10	20	30	40	50
Flash point [ºC]	44.2	48.9	55.1	59.4	66.3
Flame height [mm]	62.6	58.1	38.6	32.3	27.3
Ignition delay time [s]	4.08	4.63	5.14	6.39	7.39
Burning rate [mm²/s]	0.284	0.316	0.384	0.474	0.526

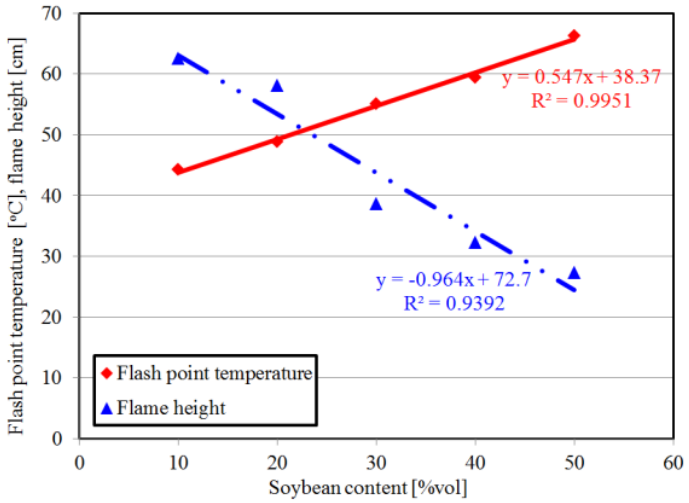


Figure 2: Influence of soybean oil contenton flash point temperature and flame height

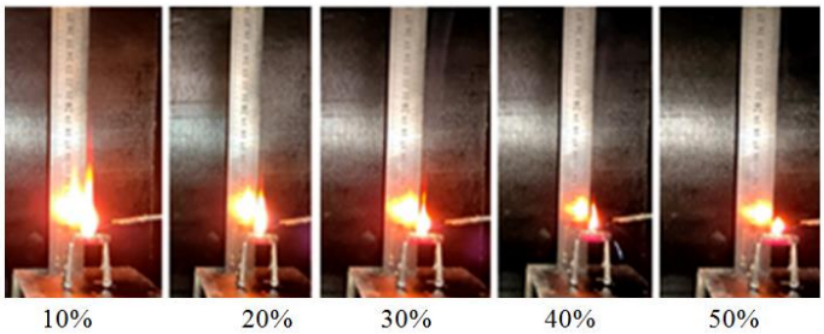


Figure 3: Flame height of each case

As soybean oil content increases, both ignition delay time and burning rate increase (Figure 3). The ignition delay time shows a nonlinear increase while the burning rate linearly increases. The lowest ignition

delay time and burning rate are 4.08 s and 0.284 mm²/s, respectively. Higher soybean oil content by 10% increases ignition delay time between 10-19%. The highest increase of ignition delay time occurs for soybean oil content increase from 30 to 40%. As soybean oil content increases by 10%, from 10 to 20%, the burning rate increases by 10%. Surprisingly, the burning rate increases by almost double, app. 18%, when soybean oil content increases from 20 to 30% and from 30 to 40%. After that, the burning rate increases only by 10% again when soybean oil content increases from 40 to 50%.

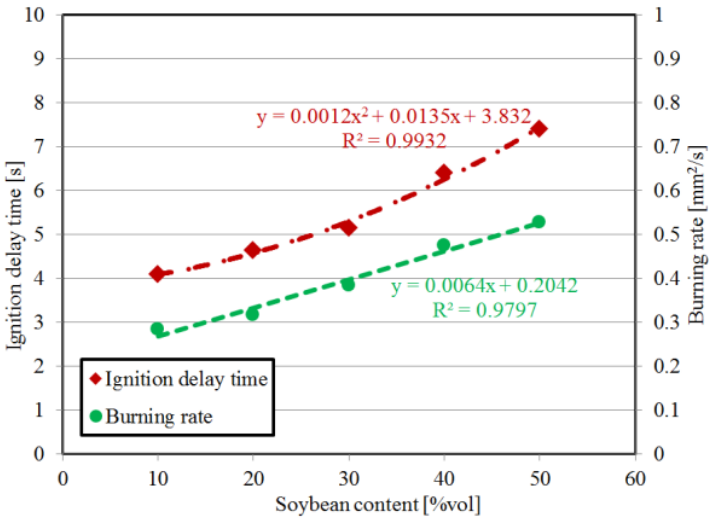


Figure 4: Influence of soybean oil contenton ignition delay time and burning rate

3.2 Flame visualization

Flame propagation during trials was photographed in this study. The main properties visualized are the beginning of flame, the maximum height of flame and the outage of flame. For all cases, the dominant flame colour is yellow. For all cases, that the flame commences after 0.17 seconds (Table 4 and Figure 5 to 9). If the soybean oil content is below 30%, the outage of flame increases as soybean oil content increases. However, the flame outage remains constant at 6.46 seconds in case soybean oil content is higher than 30%. Figure 10 shows a direct comparison of flame height for all cases. It can be seen that soybean oil content of 10% results in the highest flame at 62.6 mm while oil content of 50% results in the lowest flame at 27.3 mm.

Table 4: Result of flame visualization for all cases

Property	Case 1	Case 2	Case 3	Case 4	Case 5
Commence of the flame [s]	0.17	0.17	0.17	0.17	0.17
Maximum flame height [mm]	62.6	58.1	38.6	32.3	27.3
Outage of the flame [s]	5.78	6.12	6.46	6.46	6.46

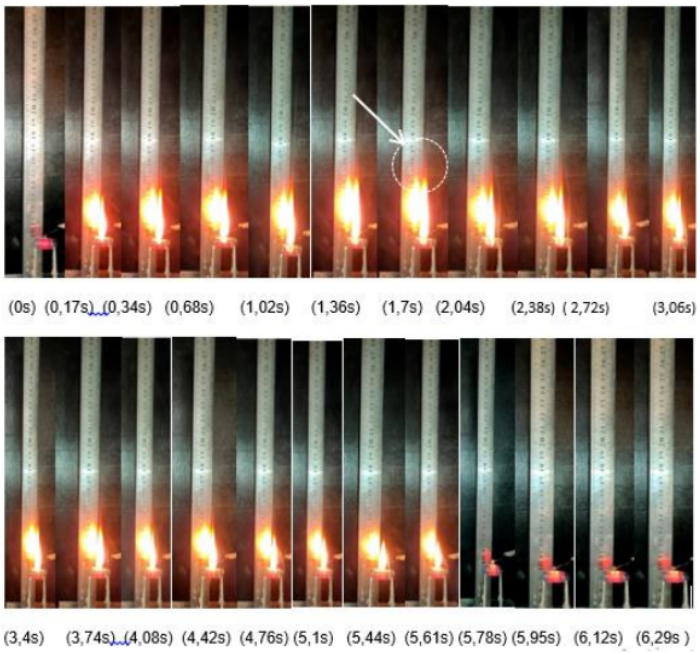


Figure 5. Flame visualization for soybean oil content of 10%

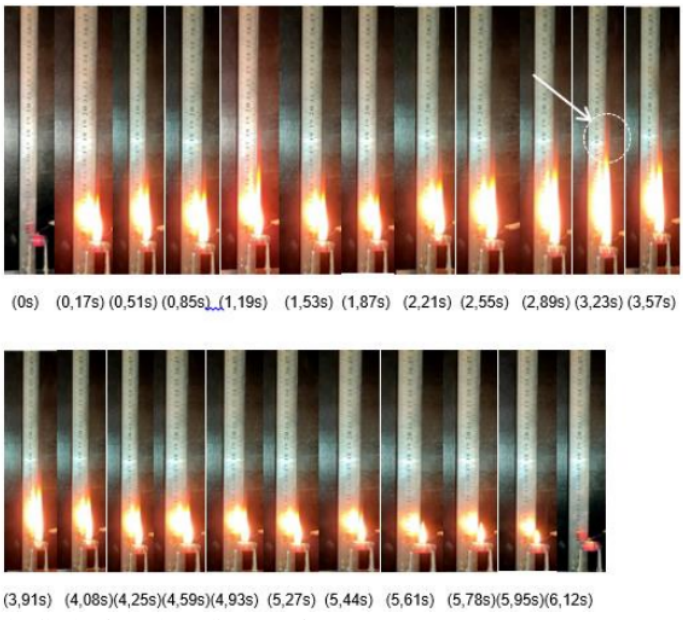


Figure 6. Flame visualization for soybean oil content of 20%

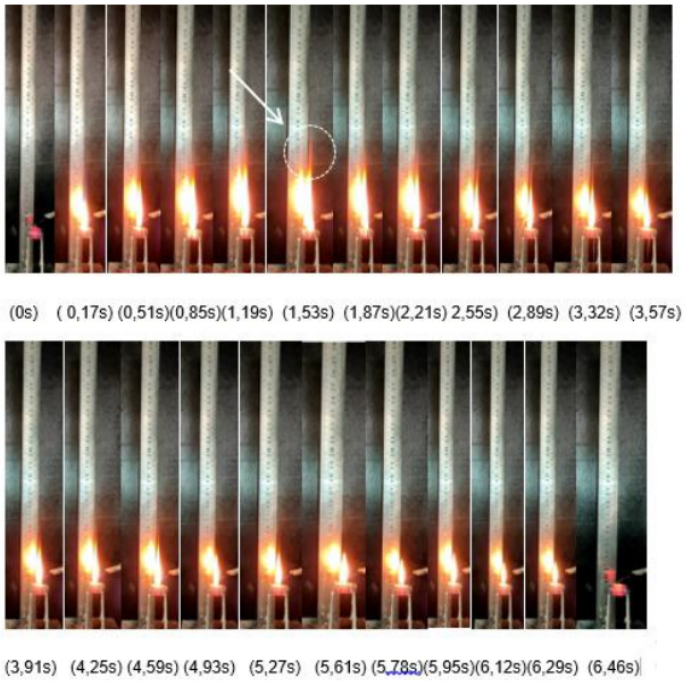


Figure 7. Flame visualization for soybean oil content of 30%

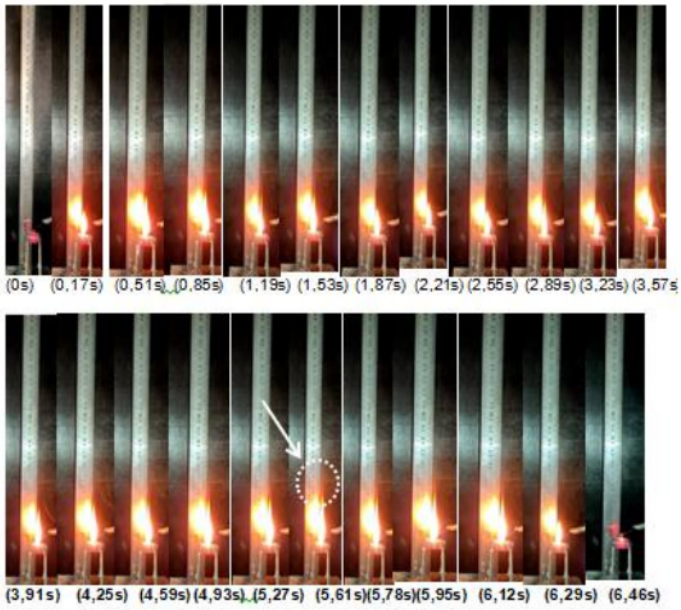


Figure 8. Flame visualization for soybean oil contentof 40%

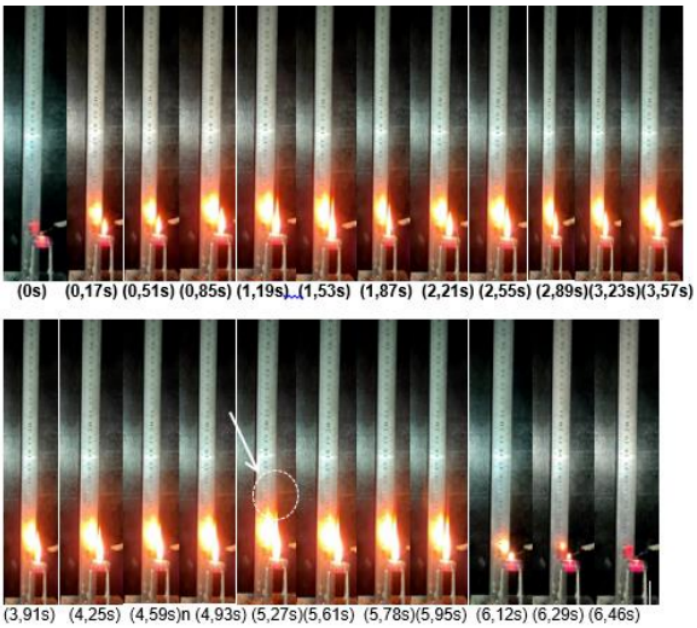


Figure 9. Flame visualization for soybean oil content of 50%

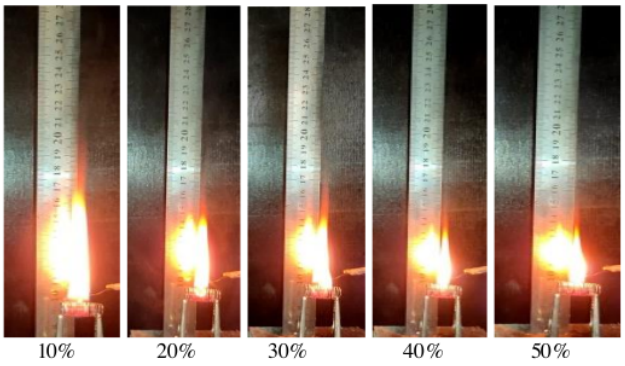


Figure 10. Comparison of maximum flame height for all cases

4. CONCLUSION

Depleting oil reserves worldwide and efforts to decrease global warming have encouraged many researches, companies and government to search for new renewable energy. In this study, renewable energy made of a mixture between soybean oil and biodiesel was investigated. The investigated mixture had soybean oil content between 10 to 50% with 10% increment. This study shows that higher content of soybean increases flash point temperature, ignition delay time and burning rate. In contrary, flame height decreases as the content of soybean oil increases.

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