Pressure Effect in Droplet Combustion of Blended Fuel on Ethanol and Kemiri Sunan (Reutealis Trisperma (Blanco) Airy Shaw) Biodiesel

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Abstract. Bio oil from seeds of Kemiri Sunan (reutealis trisperma (Blanco) airy shaw) plant is particularly attractive to be studied since its high potential as alternative of biodiesel. This paper describes the results of a fundamental study of the combustion characteristics of a single droplet of blended fuel of Kemiri Sunan (reutealis trisperma (Blanco) airy shaw) biodiesel and ethanol in various levels of ambient pressure. The ambient pressures of the burning chamber were varied at 1, 3, and 5 bars. The fuels were prepared by mixing the biodiesel with the ethanol at concentrations of 0%, 10%, 20%, and 30% vol/vol. The single droplets of blended fuels were suspended using micro-syringe on a tip of the thermocouple. It was ignited and combusted using an electrical heater. The ignition and combustion processes of the single droplets were recorded using a high-speed camera. It was found that the ignition delay of the droplet decrease with the increase of ambient pressure and the concentration of ethanol in blended fuels. Also, the burning rate of blended droplets increased with increasing biodiesel concentration and pressure. The maximum droplet temperature slightly increased during the combustion with the increasing ethanol concentration, but not with increasing ambient pressure.

1. Introduction
The use of petroleum diesel fuels in industrial and transportation in the long-term faces problems because of the limited resources and the harmful effects on the environment from its pollutant emission [1,2]. Like fossil fuels, petroleum diesel also contributes to greenhouse gas emissions (CO₂) that become serious problems for human life and environment due to their global warming impact [2, 3]. Therefore, exploring sustainable and environmentally friendly alternative renewable fuels is urgent to replace fossil fuels [4]. Biofuel is one of potential sources of alternative fuels for fossil fuels substitution and will play more and more important roles worldwide. It has wide sources of production, renewable nature, and potential of reducing CO₂ emissions. Compared to petroleum diesel, biodiesel also can be used to reduce emissions of pollutants. Biodiesel is an oxygenated fuel which contains 10–15% oxygen by weight, and studies have shown that the formation of the pollutants can be reduced by including oxygenated fuels on diesel blends [1-3]. Biofuels can be derived from animal fats and vegetable/seed oil. One of the new potential plants in Indonesia that can produce biofuels is Kemiri Sunan (reutealis trisperma (Blanco) airy shaw). Kemiri Sunan seeds have a high content of crude oil, about 50% of their mass. The more interesting is that from crude oil of Kemiri Sunan consists of 88% of fatty acid and 12% of glycerol so it is relatively quiet efficient as a raw material of biodiesel [5].
Biodiesel is usually mixed with pure diesel and can be used in a diesel engine without substantial modification since it has relatively close physical and chemical properties of petroleum diesel. Many works reported that the oxygen content in biodiesel results in improvement of its combustion efficiency as well as reductions of carbon monoxide and unburned hydrocarbon because the oxygen in biodiesel fuel promotes combustion. But, at the same time, it produces higher NOx emissions [6-9]. Biodiesel also has some various problems associated with higher viscosity, density, and cetane number but lower heating value.

There were some investigations related to the performance and combustion characteristics of a direct injection diesel engine with biodiesels [6-10]. It was reported that the engine performance was slightly weakened and the combustion characteristics such as carbon monoxide, unburned hydrocarbon, and smoke capacity changed slightly compared to pure diesel fuel [10]. However, it could be compensated by blending biodiesel with pure diesel or alcohols. There have been relevant investigations of combustion using such mixtures of biodiesel and petroleum diesel that performed directly for engines [11,12]. The results showed that the emissions of CO and HC were significantly reduced compared to pure petroleum diesel. Many investigations also have studied the impact of blending various oxygenates additives such as alcohols with biodiesel fuel on engine performance and emission characteristics of Diesel engine [13]. Zhu et al. [14] investigated the effect of the used of ethanol-biodiesel blends in direct injection Diesel engine. The results indicated that when compared with biodiesel, the combustion characteristics of ethanol-biodiesel blends changed and the engine performance has improved slightly with ethanol in biodiesel. It is known that diesel fuel and alcohol have difficulties in mixing and exhibit tendency to phase separation but biodiesel is known to be miscible with alcohols. Many researchers have proposed adding biodiesel as a solvent for ethanol in diesel fuel. Though performing experiments on biodiesels directly for the engine is practical for realistic application, however, it is difficult to clearly identify the combustion process inside the engine. Understanding the burning characteristics of these fuels is also important in combustion research. In order to understand the burning characteristics of biodiesel in a fundamental manner, several works were done on the combustion of a single droplet [15].

Combustion in a diesel engine is done in a high level of ambient pressure. The droplets in the liquid fuel spray ignite and burn at high temperatures and pressures. Thus, the study of droplet combustion in a pressurized environment presents a scientifically challenging problem. Based on these facts, many researchers have studied high-pressure droplet combustion [16-17]. They focused discussed on its vaporization or burning rate. However, there are few studies on the ignition delay times of droplets in high-pressure conditions. Therefore, the current study aimed to understand the ignition and combustion characteristics of a single droplet of blended fuels of Kemiri Sunan (reutealis trisperma (Blanco) airy shaw) biodiesel and ethanol in several levels of ambient pressure. The effect of ambient pressure and mixtures compositions on the droplet burning rate, ignition delay time, and the flame height were determined.

2. Experimental Materials and Procedure

2.1 Material

The biodiesel produced by esterification of Kemiri Sunan (reutealis trisperma (Blanco) airy shaw) crude oil and pure ethanol (99%) were used as the experimental materials. The ethanol and biodiesel were blended with ratios v/v (biodiesel: ethanol) of 100:0 (B100), 90:10 (B90E10), 80:20 (B80E20), and 70:30 (B7E30), respectively.

2.2 Experimental Procedure

The experiments of single droplet combustion of blended ethanol and biodiesel were carried out in a pressurized chamber. The experimental setup and apparatus are shown in Fig.1. This experimental setup consisted of a chamber with an electrical heater for droplet ignition. A high-speed camera with a frame rate of 1000 fps was used to record the combustion process and for measuring the ignition delay, burning rate, and flame dimension.
The experiments were performed in a chamber with air temperature about 30°C. A droplet was produced using a syringe and deposited on the tip of a thermocouple. The diameter of the droplet was approximately 1.5 mm. The droplet was ignited by an electrical heater, and the heater was switch off immediately after the ignition occurred. A camera was used to capture the images of the ignition and combustion processes from the moment when the droplet enters the chamber until it burned out. From the data of the camera, we can measure the ignition delay period, burning rate, and flame dimension. The ignition delay period was defined as the time from the moment when the heater is switched on until to the moment when droplet ignition occurred. The experiments were performed at 3 levels of ambient pressure (chamber pressure), i.e., 1, 3, and 5 bars.

3. Results and Discussion
3.1 Ignition delay period
Figure 2 shows the ignition delay period of droplets of ethanol-biodiesel blended fuels in various levels of ambient pressure. The ignition delay period was defined as the time from the moment when the heater is switched on until to the moment when droplet ignition occurred. It is seen that the ignition delay period of pure biodiesel droplet (B100) was longer than that of blended ethanol-biodiesel droplets. The results show that the addition of ethanol in biodiesel could shorter the ignition delay period.

Figure 1. The schematic diagram of the experimental setup and apparatus.

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Figure 2. Ignition delay periods of ethanol-biodiesel blended fuels droplet with various levels of ambient pressure.

Figure 3. Burning rates of ethanol-biodiesel blended fuels droplet with various levels of ambient pressure.
delay period reduced proportionally with the increase of the ethanol in the fuel blends. The ignition delay period of droplets consists of the time required for droplet heating, vaporization, molecular diffusion/mixing with the air and gas phase chemical reaction of the fuel with air [18]. Ethanol generally has a lower boiling point and lighter molecule than the biodiesel, so that, it is relatively more volatile and easier to diffuse/mix with the air. Rapid gasification of this lighter ethanol in ethanol-biodiesel fuel blends and thus volatile combustion compounds ignited earlier and reduced the delay period. On the other hand, the pure biodiesel usually includes a small percentage of diglycerides having higher boiling points than diesel and it often resulted in longer ignition delay period [15]. The shorter ignition delay time of biodiesel is also could be due to the presence of rich oxygen content in the ethanol-biodiesel blends.

The effect of the air pressure in the chamber on the ignition delay period of the droplets combustion also can be seen in Figure 2. The results show that increasing of ambient pressure reduced the ignition delay time of all droplets. The elevated ambient pressure was found to reduce both the enthalpy of vaporization and the liquid density due to increased gas absorption; these two effects could be responsible for the reduction of the droplet lifetime at elevated ambient pressures [14]. It reduced the droplet lifetime by increasing the rate of vaporization. Therefore, with the same heat input, the fuel droplet will be more evaporated and burned faster at higher ambient pressure.

3.2 Burning times
The influences of ambient pressure in the combustion chamber and mixture ratio on the burning rate of droplets have been plotted in Fig. 3. Figure 3 shows that the burning rates of all the fuel droplets increased with increasing air pressure in the chamber. Increasing ambient pressure to 5 bars increases the burning rate of all the droplets. It already explains that increasing ambient pressure will reduce the enthalpy of evaporation of the fuel droplets. The droplets will be easier to vaporize and diffuse with the air. The high air pressure also increases the air absorption to the fuel, so it enriches the oxygen in the fuel. Thus, the fuel will be burned faster. The increase in the fuel boiling temperature with pressure would increase the droplet heat up time for a fixed ambient temperature. However, this effect is largely compensated by an increase in the droplet heat up time [9].

Figure 3 also shows the effect of the addition of ethanol in biodiesel on the burning rate. It was found that the burning rate of the droplets of ethanol-biodiesel blended fuels was relatively faster compared to the droplet of pure biodiesel (B100). The burning rate increased proportionally with the increasing ethanol in blended fuels. The rapid gasification of the lighter ethanol in ethanol-biodiesel fuel blends is believed to be responsible for the increasing burning rate of the droplet combustion. The duration of combustion is shortening for all biodiesel and blended fuels also can be attributed to the oxygen content increases in the blends [15].

![Figure 4. Temperature history of droplet combustion measurement using k-type thermocouple](image_url)
3.3 Droplet temperature
The measurements the temperatures were done on the center of the droplets as shown in fig. 4. The data was then plotted in fig. 5. This figure shows the history temperature of droplets during the combustion in 3 levels of ambient pressure. The results indicated that there were no significant effects of pressure to the maximum temperature of droplets. The maximum temperatures of the droplets were about 600°C. However, the droplets temperature increased faster when the biodiesel was added with the ethanol. The higher rate of the temperature increase occurred due to the faster reaction in blended fuels of ethanol-biodiesel. The droplets were burned faster at higher temperature, and then the combustion supplied the heat to the droplets. Therefore the droplet temperature increases faster at higher ambient pressure.

The Fig. 5 also indicated that the addition of ethanol in biodiesel increase the rate of temperature increase. The ethanol addition also increased the maximum temperature of the droplets during the combustion. Those could be due to ethanol has little bit higher thermal conductivity and heat abortion compared to biodiesel. Ethanol is also more volatile, so it can be burned faster than the pure biodiesel. Thus, when there is heat supply from the fuel combustion, the temperature of blended fuels droplets increased faster than that of pure biodiesel.

4. Conclusion
The combustion characteristic included ignition delay, burning rate, and temperature history of single droplets of blended biodiesel and ethanol were studied using the high-speed camera in 3 levels of ambient pressure. The results show that the increase of ambient pressure and ethanol concentration in blended fuels reduce the ignition delay and increase the burning rate of droplets combustion. Increasing ambient pressure and ethanol concentration also increased the rate of temperature rise. The maximum temperature of droplets did not change significantly with the increasing ambient pressure, however, it slightly increased with the addition of ethanol concentration.

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