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Analysis of Mixed Premixed Combustion Characteristics of Biodiesel Candlenut Oil (*Aleurites Moluccana*) With Biodiesel Fuel

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Abstract. Candlenut biodiesel meets the characteristics of biodiesel standards that have been determined according to the criteria of Indonesia's national standard parameters (SNI) such as density, viscosity, Cetane number, flash point, and fog point. The premixed combustion test on candlenut biodiesel oil aims to determine the characteristics of biodiesel and the characteristics of the combustion fire. The examination was carried out by comparing the characteristics of pure biodiesel fire (B100), pure candlenut biodiesel (B0), with a mixture of 10% (B10), 20% (B20), 30% (B30) and the equivalent variation of ratio (ϕ) 1.5 , (ϕ) 1 and (ϕ) 0.5. This examination aims to analyze the effect of mixing on the resulting fire characteristics, including the flame color, the height of the flame cone, and the temperature of the flame. The examination and measurements of the flame temperature showed a decrease in flame temperature on each addition of candlenut biodiesel from each variation. In the results of the measurement of flame color with variations $\phi = 1$ and $\phi = 0.5$, there is a decrease in the percentage of blue flame in each addition of candlenut biodiesel. In the results of fire cone measurements with variations $\phi = 1.5$, $\phi = 1$ and $\phi = 0.5$, there is a decrease in the height of the fire cone in each addition of 30% pecan oil biodiesel. The decrease in each flame characteristic was caused by the effect of adding candlenut biodiesel oil, which resulted in increasing fuel density so that the fuel was difficult to burn and reduced the result characteristics of the flame.

INTRODUCTION

Indonesia is a vast country within many island and potential of energy. For example, the potential of biodiesel in Indonesia used candlenut. Candlenut plant in Indonesia can be found in the tropical area such as Sumatra, Sulawesi, Maluku, and Nusa Tenggara islands. Candlenut can growth in the area 170,000 hectares di Indonesia and can produce the candlenut seeds about 60,000 ton within a year [1].

According to the criteria of Indonesian national standard parameters (SNI), the candlenut oil should be passed on a characteristic of biodiesel standards such as density, viscosity, cetane number, flash point, and fog point. Generally, the combustion process will occur if the fuel and air mixture, then burned with the help of the initial heating energy or lighter. Combustion can take place in two conditions, namely with a flame or without using a flame. There are two types of flame modes that can be produced in combustion, namely premixed flame and diffusion flame [2].

In the combustion process using a bunsen burner, the composition of air and fuel or an air-fuel ratio (AFR) is also a parameter that determines whether combustion that occurs can take place optimally. According to In the premixed combustion, there are two parts of the resulting fire cone namely the inner cone (fire premixed) which is blue and the outer fire cone (diffusion flame) is yellow or faded blue [3]. To determine the quality of biodiesel, then it is necessary to test the characteristics of premixed fire by mixing biodiesel of candlenut oil on biodiesel using a bunsen burner, with the aim to determine the effect of adding biodiesel to biodiesel fuel on the characteristics of premixed fire such as flame color, flame cone height and the flame temperature.

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Candlenut Biodiesel

Candlenut oil has many contents of unsaturated fatty acids such as linoleic acid, linolenic acid, and oleic acid as well as vitamins A, C, and E as antioxidants. The main component in the composition of candlenut oil is unsaturated fatty acids, but there is also a saturated fatty acid content with a relatively small percentage. In one candlenut can contain 2 to 3 candlenut seeds. In the seeds, there is fruit flesh or kernels that contain oil reaching 55 to 65% [1]. In its use, biodiesel that has been formed must have quality standards so that later it can be applied to diesel engines. The quality standard of biodiesel is determined by the Indonesian National Standardization Agency (SNI). Biodiesel quality standards based on SNI 7182: 2015 can be presented as in Table 1 as follows.

TABLE 1. SNI biodiesel quality standards

No	Parameters	SNI 7182:2012
1	Density at 40 ºC (kg/m^3)	850 – 890
2	Kinematic Viscosity at 40 ºC (cSt)	2.3 – 6.0
3	Cetane number	Min 51
4	Flashpoint (ºC)	Min 100
5	Acid (mg-KOH/g)	Max 0.8
6	Iodine (%-mass (g-12/100g))	Max 115

The combustion process is a chemical reaction between a fuel and an oxidizer accompanied by the production of heat and light in the form of phosphorescence or fire. Fuel (fuel) is any substance that releases heat when oxidized. Fuels generally contain elements of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). While oxidizing agents are all substances that contain oxygen. Dry air consists of about 21% oxygen and 79% nitrogen [4]. For combustion to take place, oxygen is taken from the free air. In the air component, the only compound which reacts to combustion is oxygen, while the other elements do not exert any influence and are inhibitors (slowing down). The ratio between the amount of air and fuel is called the air-fuel ratio (AFR) [5]. Based on stoichiometric calculations, for an ideal combustion reaction in biodiesel fuel, 14.86 moles of air and 1 mole of biodiesel fuel are needed. While in its application, to be able to find out the actual fuel ratio, an equivalent ratio (ϕ) is needed. The equivalent ratio is the ratio between the stoichiometric air-fuel ratio and the actual air-fuel ratio (AFR) [6].

METHODOLOGY

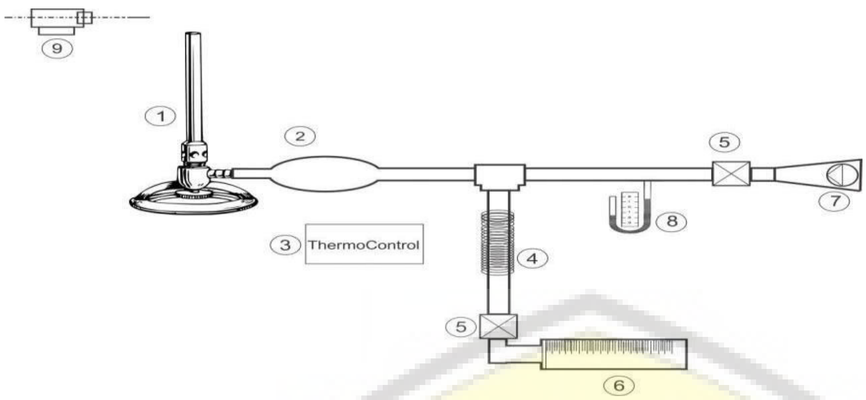
In this research used an experimental method to verify the effect of candlenut biodiesel oil mixed by biodiesel fuel (from PT. Pertamina) due to premixed flame characteristics used a bunsen burner. Then, the flame characteristics will be compared by pure biodiesel, mixed biodiesel fuel with 10%, 20%, 30% of candlenut biodiesel, and pure biodiesel fuel.

A. Material

The materials must be prepared for candlenut biodiesel production such as candlenut seeds, potassium hydroxide (KOH), methanol, vinegar 25%, and water. The materials must be prepared for the examinations of the combustion characteristics such as candlenut biodiesel and biodiesel fuel (from PT. Pertamina).

B. Equipment

The equipment must be prepared for the examinations of the combustion characteristics is bunsen burner following the Figure 1.



Note:

1. Bunsen burner
2. *Mixing chamber*
3. Thermocontrol
4. Heater
5. Valve
6. Burette
7. Flowmeter
8. Compressor
9. Camera

FIGURE 1. The equipment to examinates flame characteristic

C. Procedure

The procedure should be followed for the independent variable used pure biodiesel (B0), pure candlenut biodiesel (B100), biodiesel mixture candlenut biodiesel 10%, 20%, and 30%. The fuel mixing process is done using magnetic stirrer. The equivalent ratio (ϕ) which used are 1.5, 1, and 0.5 with discharge fuel flow 2 ml/min, meanwhile for air discharge obtained from calculations using each equivalent ratio (ϕ). After the fuel mixtures, then the premixed combustion examination testing was carried out to get the characteristic flame data. The bunsen burner used to examinates the candlenut biodiesel which are mixtures with biodiesel fuel.

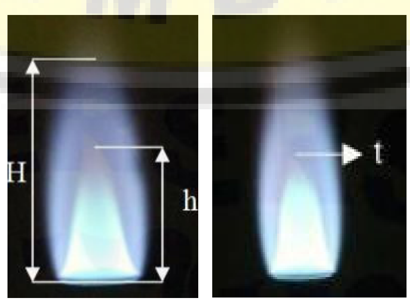
D. Analysis

The analytical method used to determine the fire characteristics such as the flame color, the height of the flame cone, and the temperature of the flame. The examination of the flame color done by recording the flame using the camera. Then, the result of the picture was examined by software image-J to get Red Green Blue (RGB) value. RGB value can be calculated by Equation 1 below to calculate the percentage of the color.

$$p = \frac{R(b)}{R(b)+R(a)} x100 \qquad \text{(i)}$$

Where:
p = color percentage
R(b) = RGB blue color
R(a) = RGB red color

The measurement of flame cone height used a bunsen burner and image-J. The measurements are carried out on inner and outer cones as in Figure 2 (a). Then, the measurement of fuel temperature used a bunsen burner and thermocouple. The measurements are carried out on the point *t* of the reaction zone, which has the highest temperature as in Figure 2 (b). After all the measurement and collect data done, then an analysis of the results obtained.



(a) (b)

FIGURE 2. (a) The measurement of height cone flame, (b) The measurement of flame temperature

RESULTS AND DISCUSSIONS

A. Analyzed the flame color

From the results of the characteristics of the flame premixed combustions on pure biodiesel fuel (B100), pure candlenut biodiesel (B0) and mixtures of biodiesel – candlenut biodiesel are 10% to 30% biodiesel composition, with variations of equivalent ratio $\phi = 1.5$, $\phi = 1$ $\phi = 0.5$, the flame color data was collected with the aim of finding the red, green, and blue (RGB) values to determine the percentage of the variations in the composition of the fuel mixture with each equivalent ratio (ϕ). The following of the composition of variations equivalent ratio $\phi = 1.5$, $\phi = 1$, $\phi = 0.5$ the pictures of the flame color will be shown in Figure 3 (a), Figure 3 (b), and Figure 3 (c).

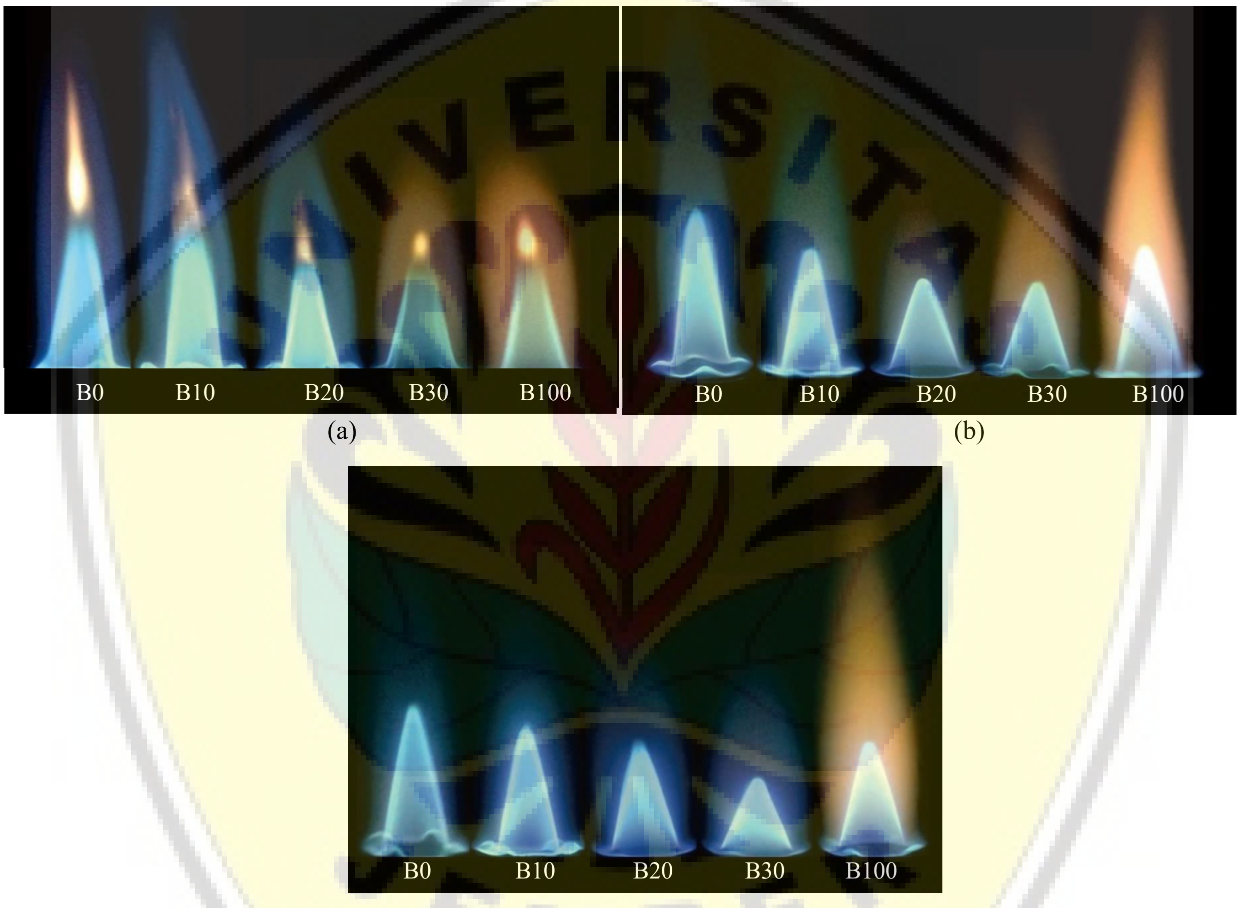


FIGURE 3. The transformation of *premixed* flame (a) with the equivalent ratio (ϕ) = 1.5, (b) with the equivalent ratio (ϕ) = 1.0, (c) with the equivalent ratio (ϕ) = 0.5

The data from each equivalent ratio (ϕ), the blue color percentage will be calculated by RGB value as the equation 1. The result is shown in Figure 4. As presented in Figure 4 it can be seen that the fuel that has the highest percentage of blue flame color is pure biodiesel fuel at 74.94% with $\phi = 1$, while the fuel which has the highest percentage of red color is biodiesel pure hazelnut oil at 62.98% with $\phi = 1$. For material fuel which has the lowest blue flame percentage, namely pure biodiesel hazelnut oil by 37.03% with $\phi = 1$, while the fuel that has the lowest percentage of red color is pure biodiesel fuel by 26.40% with $\phi = 1$. From the graphic results $\phi = 1$ and $\phi = 0.5$, the color of blue flame has decreased more stable than $\phi = 1.5$. The composition of air and fuel influences this at $\phi = 1.5$. The flame tends to be unstable because the mixture of air is poor, and the fuel is richer, so the combustion process is not ideal, and the color of the resulting fire also changes. From the results of the graph with $\phi = 1$ and $\phi = 0.5$ with the increasing of the biodiesel composition in the fuel mixture shows that the percentage of the color of the blue flame was decreased. The equivalent ratio affects the optimal or failure of a combustion process. While the decrease in the percentage of blue color in the fire is caused by the high density of biodiesel. With the addition of biodiesel to biodiesel, resulting in increased density of fuel, this makes it more difficult to burn fuel and the combustion heat produced is also decreasing. The blue color indicates that combustion is near ideal or perfect (stoichiometry), the more combustion is near perfect (stoichiometry), the more fuel is burned, causing the combustion heat and the temperature is rising.

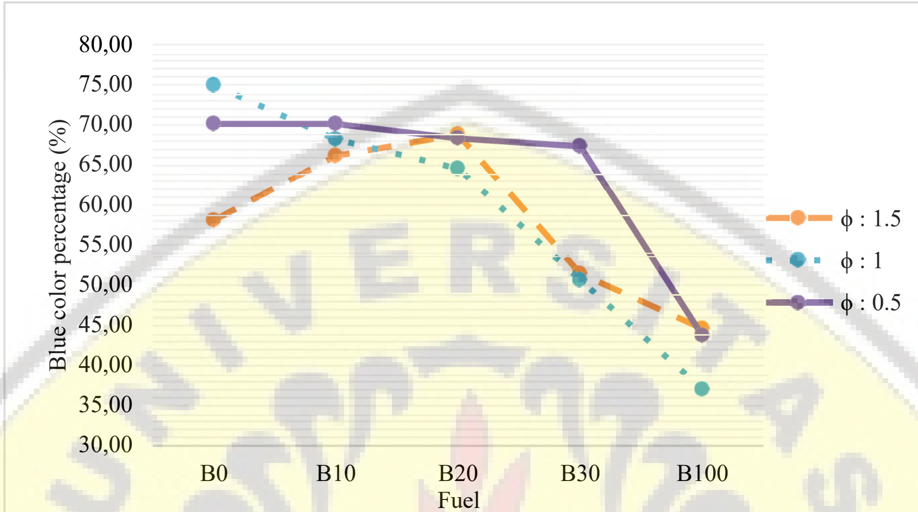
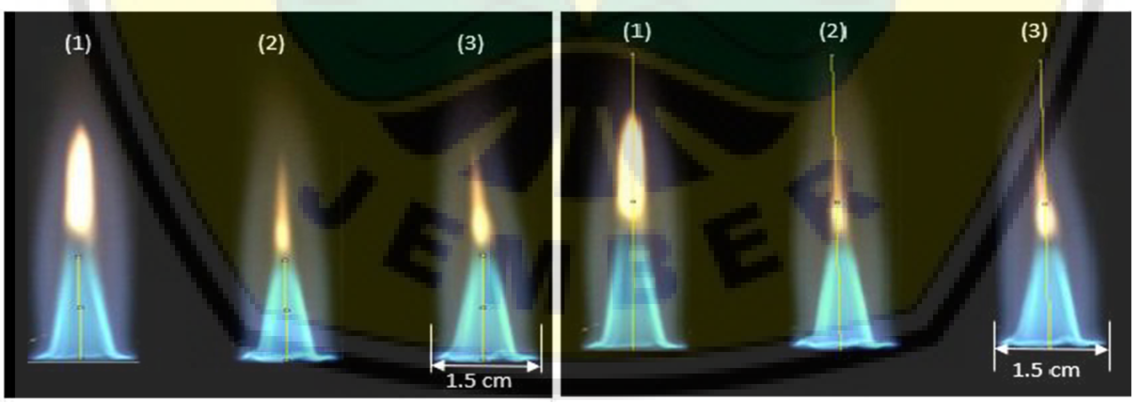


FIGURE 4. Blue flame color percentage with variation in equivalent ratio (ϕ)

B. Analyzed the flame cone height

From the results of research on the characteristics of pure biodiesel premixed fire, pure biodiesel, biodiesel mixture biodiesel composition of 10% - 30% with variations ϕ = 1.5, ϕ = 1, ϕ = 0.5, the height of the inner cone height (h) and outner cone height (H). Following are examples of measurements of the height of the inner cone (h) shown in Table 2, 3, and 4 following the variation of equivalent ratio (ϕ). The inner (h) and outer cone (H) shown by Figure 5 on pure biodiesel fuel (B0) equivalent ratio (ϕ) = 1.5 with three examinations.



(a) (b)

FIGURE 5. Measurement of the fire cone with an equivalent ratio (ϕ) 1.5 (a) outer cone height (H), (b) inner cone height (h)

The measurement results of the inner (h) and outer (H) cones characteristics of pure biodiesel premixed fire, pure biodiesel, biodiesel mixture biodiesel composition of 10% - 30% with variations ϕ = 1.5, ϕ = 1, ϕ = 0.5 are then presented in Table 2, 3 and 4 below. And the inner flame cone height with the variations of an ekuivalent ratio (ϕ) can be see in Figure 6.

TABLE 2. SNI biodiesel quality standards

Fuel	Examination 1		Examination 2		Examination 3		Rate	
	h (cm)	H (cm)	h (cm)	H (cm)	h (cm)	H (cm)	h (cm)	H (cm
B0	3.208	8.569	2.938	8.203	3.010	8.601	3.052	8.458
B10	2.596	6.442	2.780	6.426	2.585	6.407	2.654	6.425
B20	1.981	4.503	1.921	4.442	1.881	4.456	1.928	4.467
B30	2.071	5.240	1.860	4.654	1.799	4.695	1.910	4.863
B100	2.200	4.691	1.998	4.407	1.983	4.692	2.060	4.597

TABLE 3. SNI biodiesel quality standards

Fuel	Examination 1		Examination 2		Examination 3		Rate	
	h (cm)	H (cm)	h (cm)	H (cm)	h (cm)	H (cm)	h (cm)	H (cm
B0	2.580	5.634	2.560	5.662	2.674	5.780	2.605	5.692
B10	2.000	5.414	2.022	4.739	2.109	5.196	2.044	5.116
B20	1.603	3.436	1.603	3.492	1.595	3.445	1.600	3.458
B30	1.586	4.953	1.532	4.996	1.651	5.072	1.590	5.007
B100	1.954	5.547	2.086	5.578	2.029	5.547	2.023	5.557

TABLE 4. SNI biodiesel quality standards

Fuel	Examination 1		Examination 2		Examination 3		Rate	
	h (cm)	H (cm)	h (cm)	H (cm)	h (cm)	H (cm)	h (cm)	H (cm
B0	2.208	4.026	2.166	3.381	2.177	4.462	2.184	3.956
B10	1.847	3.530	1.928	3.727	1.840	3.798	1.872	3.685
B20	1.789	3.300	1.754	3.227	1.820	3.384	1.788	3.304
B30	1.203	3.561	1.369	4.032	1.088	3.437	1.220	3.677
B100	1.733	6.017	1.767	5.569	1.601	5.967	1.700	5.851

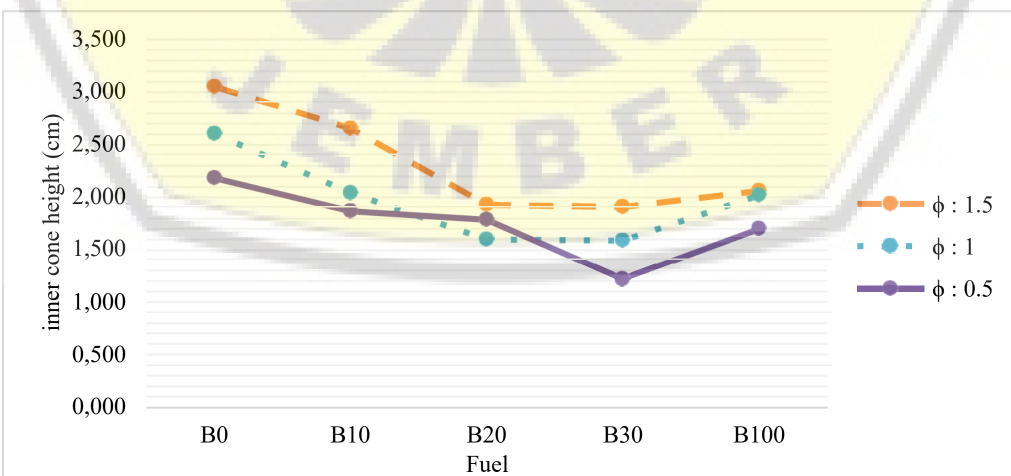


FIGURE 6. Inner flame cone height with the variations of an ekuivalent ratio (ϕ)

In Figure 6 it can be seen that the fuel that has the highest inner cone height is pure biodiesel fuel at 3.052 cm with ϕ = 1.5, while the fuel which has the highest outer cone height is pure biodiesel fuel at 5.692 cm with ϕ = 1.5. For fuel that has the lowest inner cone height, B30 (biodiesel 30% - biodiesel fuel 70%) of 1,220 cm with ϕ = 0.5, while the fuel that has the lowest outer cone height is B20 (biodiesel 20% - biodiesel 80%) of 3,304 cm with ϕ = 0.5. From the graphic results ϕ = 1.5, ϕ = 1, ϕ = 0.5, the highest height of the fire cone is obtained by the equivalent ratio (ϕ) = 1.5. That is because at ϕ = 1.5 the composition of the air is poorer than the fuel so that the combustion produced is not ideal and tends to be richer in fuel so that the resulting fire cone is high but the combustion results close to the diffusion flame. From the results of the graph with ϕ = 1.5, ϕ = 1 and ϕ = 0.5 also shows that there is a decrease in the cone of fire with increasing biodiesel composition up to 30% in the fuel mixture and an increase in the composition of pure biodiesel (B100). The increase of the fire cone on pure biodiesel (B100) is caused by the lack of optimal combustion processes due to the high density of fuel so that the combustion results tend to form a diffusion flame that has a red color.

The decrease in fire cone height in (h) in the composition B0 - B30 is caused by the characteristic density of biodiesel, which is higher than biodiesel. This causes the combustion process is not optimal because of high density, making fuel more challenging to vaporize and burn so that the energy produced in combustion will decrease. The increase in combustion energy is directly proportional to the increase in the height of the inner fire cone. The lower the equivalent ratio, combustion will be more inadequate combustion so that the height of the fire cone produced will also be smaller. The more equivalent to the ideal ratio (stoichiometry), the combustion reaction that occurs will be closer to perfect and the combustion results obtained are also optimal.

C. Analyzed the flame temperature

From the results of the research on the characteristics of fire premixed on pure biodiesel fuel, pure biodiesel and biodiesel mixture of biodiesel hazelnut with variations in the composition of biodiesel 10% - 30%, the fire temperature data was taken in order to determine the temperature ratio produced from each composition of the fuel mixture with Equivalent variation ratio (ϕ): 1.5, 1, 0.5. Data on the results of temperature measurements for each fire successively presented in the graph below.

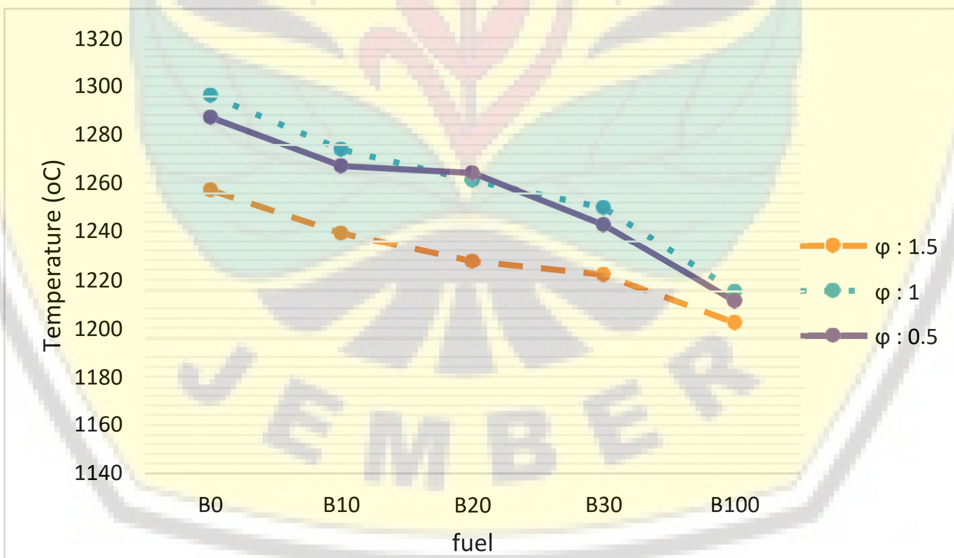


FIGURE 7. Fuel flame temperature with variation of an equivalent ratio (ϕ)

In Figure 7 it can be seen that the fuel that has the highest fire temperature is pure biodiesel fuel at 1296 ^{o}C with ϕ = 1, while the fuel that has the lowest flame temperature is pure biodiesel hazelnut oil at 1202 ^{o}C with ϕ = 1.5. From the graphic results ϕ = 1.5, ϕ = 1 and ϕ = 0.5, the highest average fire temperature is obtained by ϕ = 1 and the lowest average is obtained by ϕ = 1.5. That is because at ϕ = 1, the composition of fuel and air is close to ideal or perfect so that the premixed combustion can take place optimally, while at ϕ = 1.5 the composition of the fuel tends to be richer than air so that the resulting combustion is not ideal and the resulting fire still has fire diffusion. From the results of the graph $\phi = 1.5$, $\phi = 1$ and $\phi = 0.5$ also shows that there is a decrease in fire temperature as the composition of biodiesel increases in the fuel mixture.

From these examinations, it can see that the higher the addition of the biodiesel composition of candlenut oil to biodiesel, the temperature of the fire produced will decrease. The decrease in fire temperature occurs because biodiesel has a higher density than biodiesel fuel, thus affecting the heating value generated during the combustion process. With the addition of biodiesel to biodiesel, resulting in increased density of fuel, this makes it more challenging to burn fuel and the combustion heat produced is also decreasing. With the reduction in the heating value of the combustion, the temperature of the flame produced in the combustion process will also decrease.

CONCLUSION

Here are the following conclusion can be show from this research:

1. The temperature of the pure biodiesel fuel (B100), pure candlenut biodiesel (B0) and mixtures of biodiesel fuel – candlenut biodiesel (B10 – B30) with the variations of equivalent ratio $\phi = 1.5$, $\phi = 1$ and $\phi = 0.5$ reduced with additions of candlenut biodiesel. The reduction happens due to the calorific value of candlenut biodiesel oil lower than biodiesel fuel.
2. The flame blue color percentage of the pure biodiesel fuel (B100), pure candlenut biodiesel (B0) and mixtures of biodiesel fuel – candlenut biodiesel (B10 – B30) with the variations of equivalent ratio $\phi = 1.5$, $\phi = 1$ and $\phi = 0.5$ reduced with additions of candlenut biodiesel. The reduction happens because the biodiesel fuel has a high density so that the fuel is difficult to mix and burn. Whereas for $\phi = 1.5$, the flame color tends to be unstable because the composition of the air-fuel is not ideal, so the flame also less stable
3. The height of flame cone measurements on pure biodiesel (B100), pure candlenut biodiesel (B0) and mixtures of biodiesel fuel – candlenut biodiesel (B10-B30) with the variations of equivalent ratio $\phi = 1.5$, $\phi = 1$ and $\phi = 0.5$ decreased with every addition of candlenut biodiesel up to 30%. The biodiesel having a high density causes the reduction, so the fuel is difficult to burn.

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