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Analysis of Calophyllum Inophyllum Biodiesel Combustion with Variations of Magnetic Field Strength

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ABSTRACT

The problems facing the world today are limited fossil fuels and increasing global warming due to fuel emissions. Therefore, there is a need to transition from fossil energy to alternative energy that is environmentally friendly and renewable. Biodiesel is an alternative material that can be used as a substitute for diesel fuel. This research aims to improve the combustion quality of calophyllum inophyllum biodiesel using the magnetic field influence method. The combustion test method uses a Bunsen burner and variations in magnetic strength of 4000 gauss, 8000 gauss and 12000 gauss are given. The equivalent ratios used in combustion analysis are 0.6:1, 0.7:1, 0.8:1, 0.9:1, 1:1, 1:1.1, and 1:1.2. The fuel and air flowing in the Bunsen pipe are heated to a constant temperature of 250°C for the fuel evaporation process. Then the resulting flame was analyzed for its combustion characteristics with RGB color variables, laminar burning velocity, and flame height. The research results show that the stronger the magnetic field effect, the more optimal the combustion quality will be. This is indicated by the increasingly strong magnetic field effect exerted on the flame, causing the red color intensity to decrease, the laminar burning velocity to increase, and the flame height to decrease. This is because the magnetic field can influence the movement of O_2 molecules and cause a change in the orientation of the hydrocarbon from para to ortho. As a result, diffusion combustion becomes minimal and the combustion reaction becomes faster.

1. Introduction

The increase in industry and transportation has caused the demand for fossil energy to increase. Fossil fuels are a limited and non-renewable energy source that takes hundreds of years to regenerate. In addition, burning fossil fuels results in the release of gases containing large amounts of carbon dioxide, a gas that increases global warming. Therefore, alternative fuels that are renewable and environmentally friendly are urgently needed as a substitute for fossil fuels. Second generation biodiesel is an alternative fuel that has the potential to replace fossil fuels [1-3]. Biodiesel is a mixture of methyl esters with long chain fatty acids made from non-toxic biological raw materials such as vegetable oils and animal oils [4,5]. Biodiesel as an alternative fuel for diesel engines offers

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several advantages, including its properties being almost the same as diesel fuel and can be used directly in diesel engines [6]. The first generation of biodiesel has been successfully tested in diesel engines and is produced on a large scale for the needs of the transportation and industrial sectors [7]. Indonesia and Malaysia are some of the largest palm oil biodiesel producing countries in the world. However, the use of first generation raw materials competes with food raw materials so that their use in the long term will disrupt food stability. Therefore, it is necessary to focus on developing biodiesel using non-food raw materials, one of which is calophyllum inophyllum seeds [8-12].

Calophyllum inophyllum biodiesel is produced from calophyllum inophyllum seeds which are then extracted to obtain pure Calophyllum inophyllum oil. Calophyllum inophyllum seeds have a high yield value, namely around 65%, higher than the yield of oil palm which is only around 60% [13]. From pure oil, then proceed with the esterification and transesterification processes. This process produces a reaction between triglycerides and methanol in the presence of a catalyst to produce glycerol and esters [14]. In the process of making biodiesel, it is possible that there is unreacted glycerol in the biodiesel produced in the transesterification process [15]. As a result, it can affect the properties of biodiesel such as viscosity, flash point, density and volatility which are higher than diesel fuel [16]. This can cause problems in the biodiesel combustion process. Fuel with high viscosity will produce less spray atomization, thereby affecting the ignition delay time in the combustion process [17]. A high flash point makes it more difficult for fuel to evaporate so it takes longer to burn. This causes engine performance to decrease and the resulting emissions to increase.

Several researchers have stated that biodiesel fuel in diesel engines produces exhaust emissions that are more environmentally friendly [18-20]. Biodiesel can be applied with various other oil mixtures to obtain optimal results between performance and lower emissions [21-23]. One of the parameters that indicates optimal combustion is the ignition delay time in a diesel engine combustion. Several researchers stated that biodiesel has a good ignition delay time [17]. However, some ignition delay problems are influenced by the physical properties of the fuel, such as viscosity, density, temperature, pressure, and fuel cetane number [24,25]. In other research, it was stated that the interaction of the catalyst with triglycerides changes the bond angles of the molecular chains, which causes the atomic bonds to get extra space to move, thereby increasing combustion performance [26,27].

Several methods that can improve the performance of biodiesel today are the addition of additives, fuel blending, and the application of magnets. A study stated that the use of magnets in diesel engine fuel pipes causes ionization and declusterization of hydrocarbon fuel molecules, resulting in better fuel atomization [28]. This can improve combustion quality and increase fuel economy [29-31]. The magnetic method also has low costs because it only requires initial installation costs. This is different from the method of adding additives to fuel which continues to require costs during engine operation.

Many studies have been conducted on internal combustion engines, and can only analyze engine performance and residual combustion emissions. Meanwhile, to obtain a more in-depth analysis, it is necessary to observe the characteristics of the combustion flame that is formed. Several researchers have analyzed the behavior of flames using the method of magnetic field influence. This method of influencing the magnetic field is an effective method because it can increase combustion without changing the properties of the fuel. Previous research analyzed combustion characteristics with variations in the direction of the magnetic field poles and variations in the fuel used [32,33]. The results of the research state that variations in the N-S attractive magnetic pole have the greatest influence on combustion. However, differences in the strength of magnetic field effects have not been discussed and researched in depth. Therefore, this research presents an in-depth discussion and analysis of the behavior of flames under the influence of different magnetic field strength variations, namely 4000 gauss, 8000 gauss, and 12000 gauss. To determine changes in combustion characteristics, flame characteristics analysis was carried out by measuring RGB color intensity, laminar burning velocity and flame height.

2. Methodology

2.1 Calophyllum inophyllum Fuel Production

The fuel used in this research is pure calophyllum inophyllum biodiesel. The calophyllum inophyllum biodiesel production process begins with preparing old calophyllum inophyllum seeds. After that, the process of separating the seeds from the shell is carried out, which is shown in Figure 1(a). Then the seeds are dried in the sun for four days to reduce the water content in the seeds. After that, the seeds are ground using a grinding machine until they form small grains as shown in Figure 1(b). After obtaining small granules, an extraction process is carried out using a press to obtain pure calophyllum inophyllum oil.

(a) (b)

Fig. 1. Calophyllum Inophyllum seeds (a) Seeds before grinding, (b) Seeds after grinding

After obtaining crude oil, the degumming process is then carried out which aims to separate the sap and impurities in pure calophyllum inophyllum oil. The degumming process is carried out by adding 1% volume of H_3PO_4 to calophyllum inophyllum oil. Then stirred using a magnetic stirrer for 30 minutes at a temperature of 60°C and then left for 4 hours until the impurities and pure oil were separated. The next stage is the esterification process which aims to reduce the free fatty acids in calophyllum inophyllum oil. The esterification process is carried out by adding 1% H_2SO_4 by volume of calophyllum inophyllum oil. Then methanol was added in a ratio of 1:22 mol methanol. After that, it was stirred using a magnetic stirrer for 2 hours at a temperature of 60°C and then left for 8 hours so that the methanol and oil separated. The final stage is the transesterification process which aims to convert fatty acids into methyl esters. Transesterification was carried out by adding 1% NaOH by weight of calophyllum inophyllum oil. Then methanol was added in a ratio of 1:6 mol. One mole of calophyllum inophyllum oil and 6 moles of methanol. After that, it was stirred using a magnetic stirrer for 3 hours at a temperature of 60°C, and after completion it was left for 8 hours to separate the glycerol and pure biodiesel.

2.2 Calophyllum inophyllum Biodiesel Properties Test

Table 1 shows the molecular content of pure calophyllum inophyllum biodiesel as a result of the GCMS (Gas Chromatography Mass Spectrometry) test. This GCMS test aims to determine the composition of the chemical compounds of biodiesel. From the test results it can be seen that the methyl oleate compound has the highest percentage of 45.82% and methyl palmitate 43.77%. Methyl oleate is a free fatty acid which plays an important role in biodiesel because it has a positive impact on the oxidation stability of biodiesel and is good at low temperatures [34]. Methyl oleate in calophyllum inophyllum biodiesel has a higher percentage compared to the methyl oleate content in castor oil biodiesel of 38.108% and palm oil 42.72% [35,36]. The high methyl oleate content indicates that calophyllum inophyllum biodiesel has good quality so it has the potential to be developed in depth and can be produced commercially.

Table 1
Composition of the chemical compound biodiesel calophyllum inophyllum

No.	Name IUPAC	Name Trivial	Molecular Formula	Volume (%)
1	Asam 9-oktadekenoat	Asam oleat	$C_{17}H_{33}COOH$	45,82
2	Asam heksadekadienoat	Asam palmitat	$C_{15}H_{31}COOH$	43,77
3	Asam tetradejanoat	Asam myristat	$C_{13}H_{12}COOH$	2,97
4	Asam 9,12-oktadekadienoat	Asam linoleat	$C_{17}H_{31}COOH$	2,25
5	Asam oktadekanoat	Asam stearat	$C_{17}H_{35}COOH$	1,66
6	Asam pentadekanoat	Asam pentadekanoat	$C_{14}H_{29}COOH$	0,67
7	Asam 6-oktadekenoat	Asam petroselat	$C_{17}H_{33}COOH$	0,12

Stoichiometric combustion can be calculated using the reaction of the chemical composition of the fuel with air and combustion products using Eq. (1). Then from the stoichiometric combustion reaction, the stoichiometric AFR of calophyllum inophyllum biodiesel can be seen, which is 13.2. This AFR value is lower when compared to diesel fuel because calophyllum inophyllum biodiesel already contains O_2 molecules. This causes the air requirement to be lower in the combustion reaction process. Meanwhile, the chemical compound of diesel fuel does not contain O_2 molecules so it requires more air with a higher AFR value of 14.59.

$$\underbrace{CxHyOz + x(O_2 + 3{,}76N_2)}_{Reaktan} \longrightarrow \underbrace{xCO_2 + yH_2O + zN_2}_{Produk} \quad (1)$$

Table 2 shows a comparison of the characteristics of calophyllum inophyllum biodiesel and pure diesel. Diesel fuel has better characteristics than biodiesel. The characteristics of this fuel greatly determine the performance of the combustion engine. To overcome this problem, several researchers use a mixture of additives to improve the characteristics of biodiesel [37,38]. However, the addition of additives will reduce the lubricating properties of biodiesel so that it will have an impact on the durability of engine components. Therefore, the method of influencing magnetic fields to increase combustion needs to be considered because it does not change the characteristics of the fuel.

Table 2
Characteristics of calophyllam inophyllum biodiesel and diesel [37,38]

Fuel	Densitas 15°C (g/cm³) ASTM-D1298	Viskositas kinematik 40°C (cst) ASTM-D93	*Flash point* (°C) ASTM-D93	Nilai kalor pembakaran (Kcal/kg) ASTM-D240
Calophyllum inophyllum	0,8558	5,5	101	10.295,0
Diesel	0,84	2,84	68	10.189,0

2.3 Test Equipment Schematic

Figure 2 shows a schematic of a Bunsen burner used to analyze flame characteristics. The Bunsen burner is a tool used by several researchers to observe the characteristics of flames produced from various fuels and variables [39,40]. The Bunsen burner in this study has a T-junction geometry with stainless steel material with an inner diameter of 0.6 cm. In the operating process, fuel is flowed using a syringe pump, while air is flowed using a pressurized compressor and the flow is regulated using a flowmeter. Then the fuel and air flowing in the pipe are heated using a heating belt to a constant temperature of 250°C. The purpose of fuel heating is to evaporate the fuel, while air heating is to keep the temperature of the fuel vapor stable when mixed with air of the same temperature. The heating temperature is maintained constant using a thermocontroller.

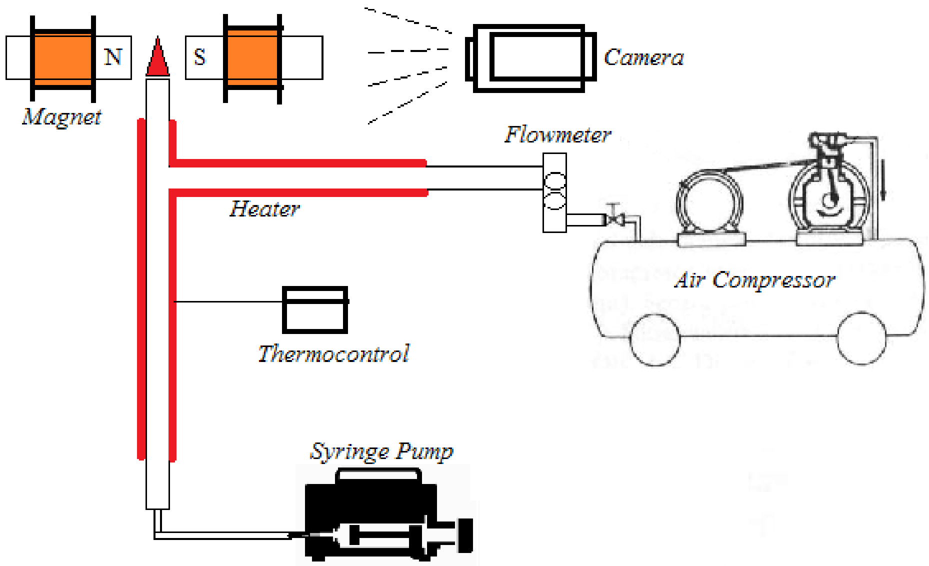


Fig. 2. Test Equipment Scheme

2.4 Magnetic Field

This research uses an artificial magnet to provide an effect on the flame of a premixed Bunsen burner. The magnetic core uses kern material in the form of a long plate. Several kern plates are then stacked to form a block and after that the kern plate block is surrounded by copper with a diameter of 1 mm. Copper is wound in 3 stages, each winding stage has a resistance of 0.7 Ohm. Then there are six copper ends where three copper ends are connected to positive current and three copper ends are connected to negative current. Two transformer units are used to change AC voltage to DC and as a 5.1 ampere current limiter in the magnetic circuit. Apart from that, the transformer also functions to regulate the electric current flowing in the copper winding, so that it can be used to change the strength of the magnetic field produced. To measure the strength of a magnetic field using a gaussmeter. The variations in magnetic field strength used in this research were 4000 gausses, 8000 gausses, and 12000 gausses. The magnetic field is placed on both sides of the flame with a distance of 0.3 cm. And then video data is taken using a high-speed camera at a distance of 18 cm. Video data was collected three times and carried out in a dark room or without light. Measurement of RGB color intensity, flame angle, and flame height using the image-J application.

3. Results and Discussion

3.1 Flame Visualization

Figure 3 shows a photo visualization of the flame at various equivalent ratios and variations in magnetic field strength. The flame formed shows two reaction zones, namely the inner reaction zone of premixed combustion and the outer reaction zone of diffusion combustion. In premixed combustion, fuel and air are mixed first in the mixing chamber before combustion occurs. Meanwhile, diffusion combustion occurs due to incomplete combustion in premixed combustion, so that some of the fuel does not burn and is then oxidized by the surrounding air to form diffusion combustion. The ideal ratio between fuel and air greatly influences the stability of the flame [39,41]. From the flame photos obtained, analysis was carried out on the RGB color formed, laminar burning velocity, and flame height.

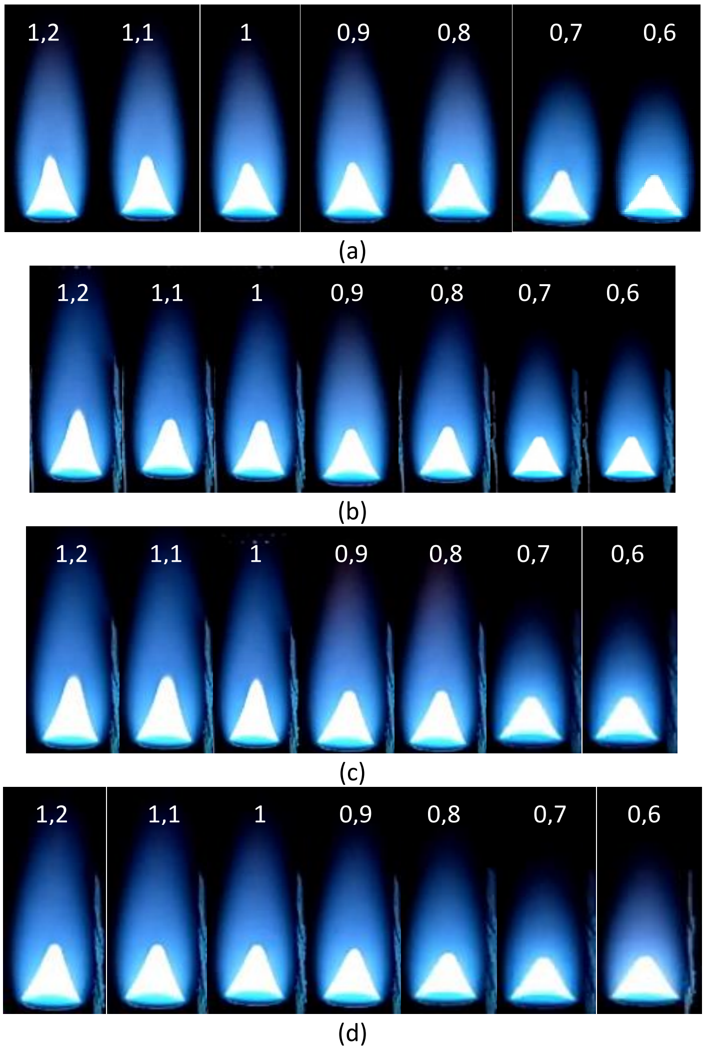


Fig. 3. Visualization of Flame with Variation of Magnetic Field Strength (a) non magnet, (b) 4000 gauss, (c) 8000, (d) 12000 gauss

3.2 RGB Color Intensity Analysis

Figure 4 shows a graph of the intensity of the red color formed in the flame. Measurement of the intensity of the color formed in the flame is carried out using the image-J application. The image-J application will detect the percentage of three colors, namely red, green and blue (RGB). From the color composition formed in this flame, it can then be used to analyze the quality of the combustion that occurs. A flame that tends to be red indicates that the fuel mixture is richer so that a lot of fuel is not burning optimally. From the graph it can be seen that the highest average red color intensity occurs in non-magnetic flames with an equivalent ratio of 1.2, and the lowest average occurs at an equivalent ratio of 0.6. This shows that at a richer equivalent ratio less complete combustion occurs. Unburned fuel will oxidize with the surrounding air and form a diffusion flame which tends to be red in color. Meanwhile, the equivalent ratio that approaches stoichiometry shows a decrease in the intensity of the red color. This is because when combustion approaches stoichiometry, the ratio of fuel and air is balanced so that the fuel is completely oxidized with the air. Meanwhile, at a poorer ratio of 0.6, the intensity of the red color formed decreases because combustion is dominated by air.

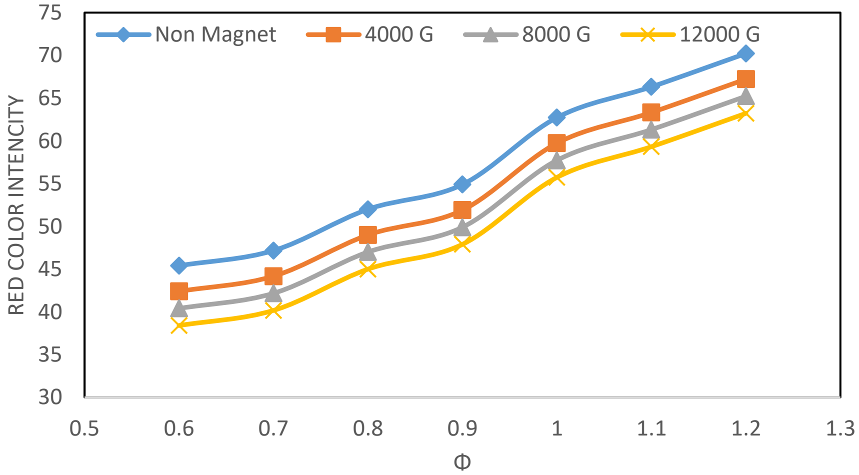


Fig. 4. The intensity of the red color

Variations in magnetic field strength were tested on a flame with a fixed equivalent ratio. The graph shows that the stronger the magnetic field, the red intensity value decreases. Decreased average value of red color intensity from variations in magnetic strength of 4000 gauss, 8000 gauss and 12000 gauss. This shows that the stronger the magnetic field provided, the more optimal the combustion that occurs. This is in line with previous research which states that the stronger the magnetic field applied to the fuel pipe, the lower the fuel consumption in a diesel engine [42]. O_2 molecules as an oxidizer have an important role in the combustion process with magnetic variations. This is related to molecular orbital theory which states that O_2 has two unpaired free electrons, so the O_2 molecule is a paramagnetic material.

Figure 5 is an illustration of the effect of a magnetic field in influencing the movement of O_2 molecules. It can be seen that the magnetic field attracts O_2 molecules that are outside the combustion reaction zone at the N pole to move towards the S pole through the flame. This causes the supply of O_2 molecules to the flame to increase. So the additional supply of O_2 molecules in the flame can oxidize fuel that does not burn completely, so that diffusion combustion is reduced. This of course can be beneficial in producing cleaner combustion, because combustion that lacks O_2 results in higher emissions [43]. Meanwhile, H_2O molecules resulting from combustion as diamagnetic heat carriers move in the opposite direction to the magnetic field. This causes the H_2O molecules to leave the combustion reaction zone more quickly. In the combustion process, H_2O is a molecule that is not needed, so the release of H_2O molecules from the combustion reaction zone quickly can provide benefits for faster and optimal combustion [33]. This is also influenced by the direction of the magnetic field used. In one study, it was stated that the direction of the different magnetic field poles greatly determines the quality of the combustion produced [32]. Where the N-S attractive magnet has the highest increase in laminar burning velocity. In this research, it can be proven that the higher the magnetic field strength, the more O_2 molecules carried into the flame will increase, so that combustion becomes more optimal.

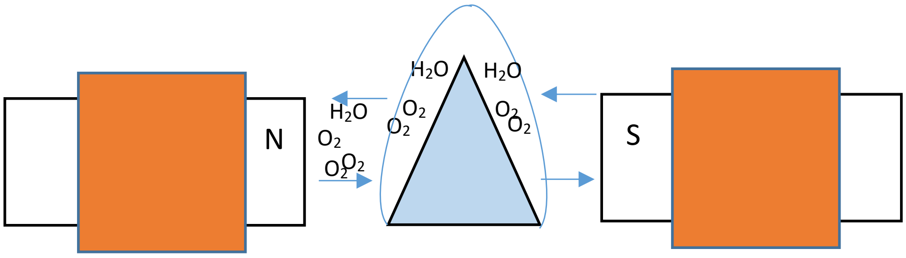


Fig. 5. Illustration of the effect of a magnetic field on the movement of O_2

3.3 Laminar Burning Velocity Analysis

Figure 6 shows graphic data of laminar burning velocity. Some researchers use laminar burning velocity parameters to determine the quality of combustion by visual observation of the flame formed [44-46]. To obtain the laminar burning velocity value, first measure the angle of the flame formed and multiply it by the reactant speed. So the speed of laminar combustion is determined by the fuel compound used and the flame angle formed. From the data presented it can be seen that the laminar burning velocity has increased due to the influence of the magnetic field. The laminar burning speed increases sequentially from non-magnetic 20.5 cm/s, magnetic 4000 gauss 22.4 cm/s, magnetic 8000 gauss 30.5 cm/s, and magnetic 12000 gauss 37 cm/s at an equivalent ratio of 0, 9. In this study, the highest laminar burning velocity occurred at an equivalent ratio of 0.9. This is in line with previous research which states that burning biodiesel requires more air so that the highest laminar burning velocity occurs at an equivalent ratio below one [37,47].

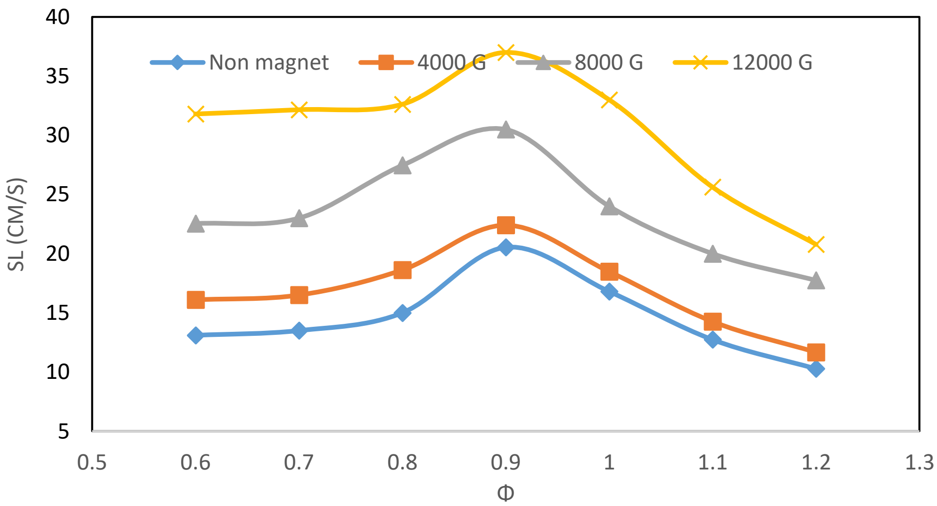
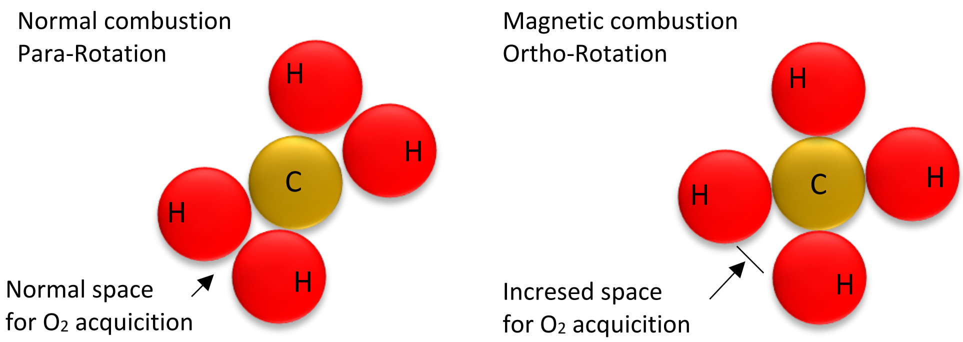


Fig. 6. Laminar Burning Velocity (cm/s)

Previous experimental analysis states that magnetic fields can influence the orientation of hydrocarbon fuel from the para state to the ortho state [30,31]. So it is very possible that the increase in laminar burning velocity in this study was caused by changes in fuel molecules. Figure 7 shows a schematic of the change in hydrogen orientation from para to ortho condition due to the influence of a magnetic field. Biodiesel is a triglyceride carbon chain consisting of hydrogen (H) and carbon (C) atoms. In Figure 7(a) it can be seen that under normal pararotation combustion conditions, hydrogen molecules have very close atomic distances. This condition makes it increasingly difficult for O_2 to bind. Meanwhile, Figure 7(b) shows combustion conditions in the presence of a magnetic field where the hydrogen orientation changes to ortho-rotation. In this condition, the bonds between hydrogen molecules weaken so that the distance between hydrogen atoms increases. This provides the advantage for O_2 to bind more easily with hydrocarbons, resulting in more optimal combustion. In addition, fuel polarity greatly influences the combustion process which is a function of the molecular mass composition and the instability of the hydrocarbon chain bonds [27]. So the magnetic field has an important role in the combustion process, because polar properties have an electric charge that is easily affected by the influence of the magnetic field. So the triglyceride chain bonds in polar fuels will be more easily affected by the presence of a magnetic attraction field, causing the Van Der Walls dispersion force to weaken, making it easier for O_2 to bind with hydrocarbons and combustion to be more optimal.



(a) (b)

Fig. 7. Schematic view of (a) Para-Rotation, and (b) Ortho-Rotation

3.4 Flame Height Analysis

Figure 8 presents data on changes in premixed flame height due to variations in the equivalent ratio and variations in magnetic field strength. From the graph it can be seen that the flame height has an increasing trend from the equivalent ratio of 0.6 to 1.2. This is because a rich fuel mixture results in fuel that does not burn completely, thus forming diffusion combustion and making the flame structure higher [46]. In a poor fuel mixture, the flame approaches blow-off conditions because the fuel composition is less, causing the flame structure formed to be shorter [48]. Meanwhile, with variations in magnetic field strength, the flame height becomes shorter than non-magnetic variations, magnetic 4000 gauss, 8000 gauss, and 12000 gauss. The decrease in flame height due to the magnetic field indicates better combustion. The reaction of O_2 molecules and changes in hydrocarbon orientation are the main factors in reducing the flame height. This decrease in flame height is in line with the increase in laminar burning velocity with the stronger magnetic field.

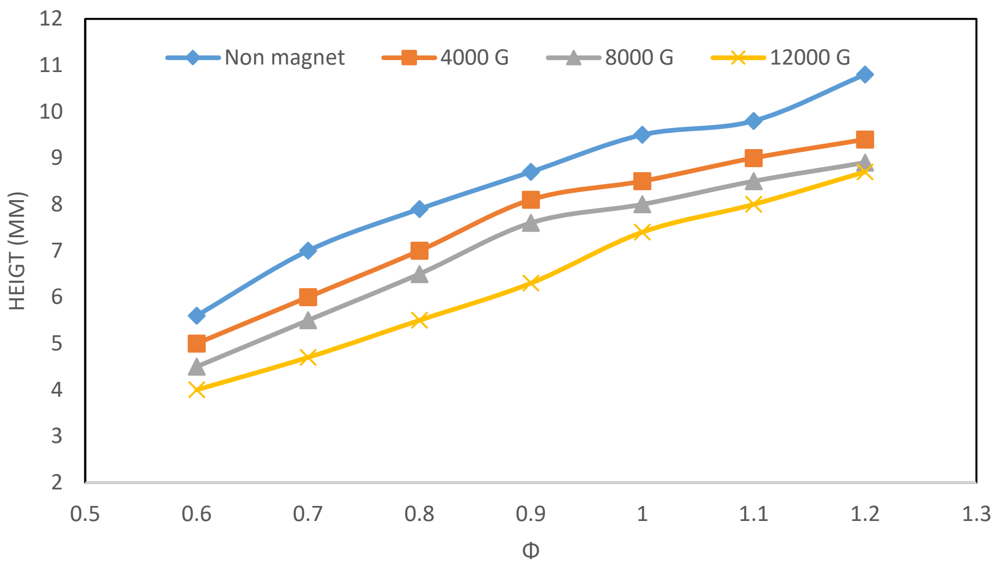


Fig. 8. Flame Height Variation

4. Conclusion

From the research and analysis that has been carried out, it can be concluded that the stronger the magnetic field effect, the better the combustion quality. This is indicated by a decrease in the intensity of the red color in the flame, an increase in the laminar burning velocity, and a decrease in flame height as the magnetic field effect increases. This change in combustion characteristics shows that the higher the magnetic field strength applied to the flame, the more optimal the combustion will be. This is because the magnetic field can influence the movement of O_2 molecules and cause a change in the orientation of the hydrocarbon from para to ortho. As a result, diffusion burning in the flame becomes minimal and the combustion reaction becomes faster. This of course can be a solution to improve combustion quality and can be applied to other combustion systems. However, this research has not analyzed combustion temperature and emissions such as CO, NOx. This data is very important for further research.

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