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Research Paper

Experimental Study on the Effect of Magnetic Fields on Combustion Characteristics of Biodiesel from Nyamplung (*Calophyllum Inophyllum*)

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Abstract

Nyamplung (*Calophyllum Inophyllum*) is an environmentally friendly alternative fuel that can be used to replace the consumption of fossil fuels. The purpose of this experiment was to analyze the effect of magnetic fields on the premixed flame of biodiesel from *Calophyllum Inophyllum*, the experiments were carried out on a bunsen burner. Fuel evaporation uses a temperature of 473 K and the equivalent ratio used is between ϕ 0.7; 0.8; 0.9; 1.0; 1.1 and 1.2. This experiment used a modified magnet that has magnetic force in 11.000 gausses with magnetic variations N-S, S-N, N-N, and S-S. Experiments revealed that magnetic fields have a significant effect to increase the value of laminar flame speed on magnetic variations point at S-S 3.8%; N-N 4.8%; S-N 17.09%, and the highest laminar flame speed were at point N-S 20.7%. The enhancement value of laminar flame speed indicated more optimum combustion processes. The magnetic fields can influence the O_2, and H_2O and change the orientation of the hydrocarbons which makes it easier for O_2 and fuel to carry out the oxidation process, resulting in more optimal combustion.

Keywords: Biodiesel; Premixed flame speed; Magnetic fields; Bunsen burner

1. Introduction

Fossil oil is non-renewable energy so its production and utilization cause environmental pollution. Therefore, in recent decades, global researchers have focused on developing renewable fuels, such as biogasoline and biodiesel [1]–[3]. Biodiesel is mono-alkyl ester fuel from long-chain fatty acids that can be synthesized from plant oil or animal fat [4]–[6]. Biodiesel is an alternative fuel that is environmentally friendly because its high product range has a good impact on the environment [7]. The application of biodiesel in diesel engines (compression-ignition engines) results in lower CO_2 emissions than petro-diesel [8].

Nyamplung *(Calophyllum Inophyllum)* is a potential second-generation biodiesel raw material that could be developed for large-scale production [9]–[11]. *Calophyllum Inophyllum* produces a high oil yield of 65,8%, higher than palm oil and castor oil which is only 40-60% [12]. *Calophyllum Inophyllum* biodiesel has identical characteristics to petro-diesel so its application on diesel engines does not require any modification. Biodiesel in a diesel engine produces low carbon emissions than petro-diesel [13]–[17].

Quality of fuel is generally confirmed by engine performance, fuel consumption, and emissions produced. Calophyllum Inophyllum has the potential to produce incomplete combustion because it has a higher viscosity, density, and flash point compared to diesel fuel [6]. High viscosity can also determine spray atomization, evaporation, and air-fuel homogeneity [18], [19]. In addition, biodiesel contains a higher oxygen content, resulting in higher NOx emissions [16]. Then, mixing biodiesel and petro-diesel can be an alternative to produce better combustion quality and also produce lower emissions [20].

Several studies on the addition of additives to fuel have been investigated and resulted in longer flame stability [9], [14], [21]. An attempt to reduce the fuel viscosity is by using a preheating method to fuel which is carried out before being placed in the combustion chamber to increase the atomization of the fuel spray [22]. Meanwhile, another important parameter is the ignition delay which affects the quality of combustion to obtain targeted engine performance and emissions [23]. The ignition delay is the time between the first drop of fuel and the slightest flash point. Ignition delay time is determined by engine speed, engine load, and fuel temperature [24]. As it is known that combustion is a combination of physical and chemical processes [25]. Ignition delay in physical processes is determined by fuel spraying, evaporation, and fuel mixing. Meanwhile, chemically, combustion is determined by the composition of the fuel, aggregation, and the oxidation-reduction process.

To improve combustion, the addition of a magnetic field to the fuel line has been tested in diesel engines to reduce fuel consumption as well as to reduce carbon emissions [26]. The magnetic field is able to change the orientation of the hydrocarbons from the para state to the ortho state [27]–[29]. This makes the distance between the hydrocarbon atoms wider so that it can bind oxygen more easily and produce optimal combustion.

From the literature studied, analysis of the effects of magnetic fields on diesel engines discusses more about engine performance, fuel consumption, and emissions. Meanwhile, the observation of flame characteristics which play a major role in the quality of combustion has not been a concern in previous studies. Therefore, this paper discusses the effect of the magnetic field equivalent ratio on the flame speed characteristics of premixed biodiesel from Calophyllum Inophyllum. Bunsen burner is used to measure the speed of a laminar flame [30]. The laminar flame speed is determined by the equivalent ratio and the characteristics of the fuel [31]–[33]. Increasing the value of the laminar flame speed indicates a more optimal combustion process. The results of this study are expected to be a reference for further modification and development of the combustion quality of biodiesel from Calophyllum inophyllum and can also be applied to future technologies.

2. Methods

2.1. *Fuel Preparation*

This study uses mixed biodiesel from Calophyllum Inophyllum methyl ester (CIME) and petro-diesel (D100). Nyamplung seed was harvested from Banyuwangi, East Java, Indonesia. Nyamplung was extracted in Jember University Laboratory by degumming, esterification, and transesterification of triglycerides. Then, petro-diesel was obtained from PT. Pertamina Tanjung Wangi, Banyuwangi, Indonesia.

2.2. *Properties Testing of CIME Biodiesel*

Figure 1 shows the result of the CIME biodiesel GCMS test in the Jember Polytechnic Bioscience Laboratory. From the GCMS test, it can be seen the composition of each fatty acid component shown in **Table 1**. It can be seen that the content of CIME biodiesel compounds in this study was dominated by 43.77% methyl palmitate and 45.82% methyl oleate. Methyl oleate is a free fatty acid that plays an important role in biodiesel because it can improve low-temperature performance and has a positive impact on the oxidation stability of biodiesel [34]. The content of methyl oleate in this research was higher than the content of biodiesel in castor oil (38.108%) and palm oil (42.72%) [35]. This shows that CIME biodiesel has good quality for further development. Of all the chemical compounds contained in biodiesel, it can be seen that the stoichiometric combustion reaction is shown in Eq. (1). After obtaining the combustion reaction of chemical compounds, then the stoichiometry AFR of CIME 13.2 biodiesel can be determined by using Eq. (2). In contrast, diesel fuel (D100) has a higher AFR of 14.59. This is because biodiesel compounds already contain oxygen, so biodiesel requires less air in combustion compared to diesel fuel whose chemical compounds do not contain oxygen.

2.3. *Experiment Setup*

The premixed flame characteristics test uses a bunsen burner made from stainless steel with a Y-Junction shape. The dimension of the bunsen burner is 0.6 cm in inner diameter and 0.7 cm in outer diameter. This experiment used a modified magnet that has magnetic force in 11.000 gausses. Figure 2 shows schematic tools of bunsen burner. During the observation process, fuel flowed using a syringe pump with constant pressure. Fuel and air are heated to a constant temperature of 473 K which aims to process the evaporation of the fuel. Air is circulated using a pressurized compressor and the flow is regulated using a flowmeter with a flow rate of 1 liter/minute. The equivalent ratio of air and fuel using variations of 0.7; 0.8; 0.9; 1.0; 1.1 and 1.2. Magnets are placed on both sides of the flame at a distance of 0.3 cm, the magnetic field using variations of N-S, S-N, N-N, and S-S. The flames were recorded using a camera with full high definition specifications, 1080p, 64 megapixels. To obtain valid data, the distance between the camera and the flame is set at 18 cm.

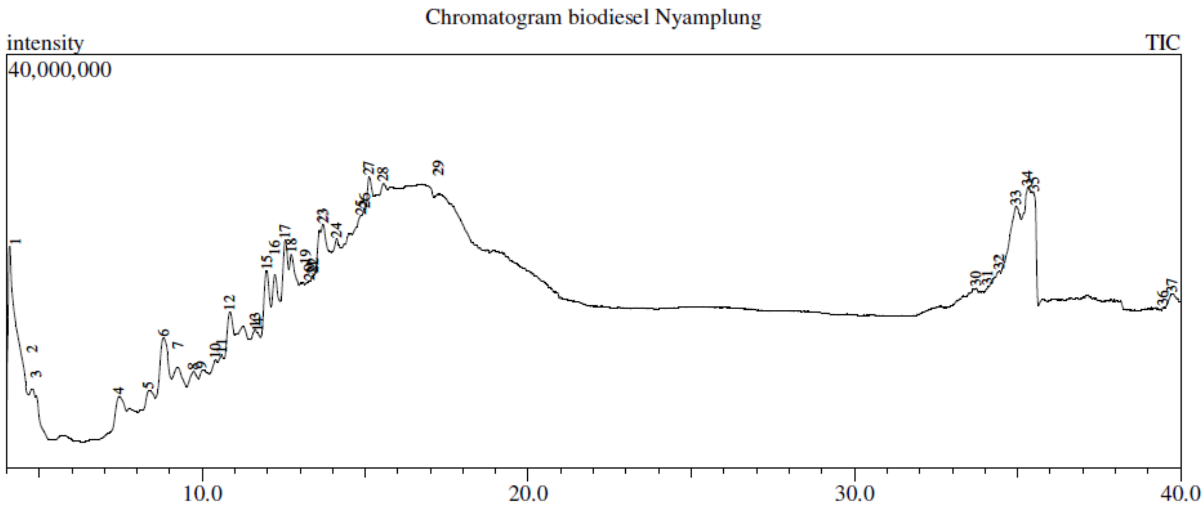

Figure 1. GCMS of CIME biodiesel

Table 1. Precentage of molecules compositions of CIME from the chematography test

No	Trivial Name	Molecule formulas	%	%
1	Methyl oleate	$C_{19}H_{36}O_2$	45,82%	0,4582
2	Methyl palmitate	$C_{17}H_{36}O_2$	43,77%	0,4377
3	Methyl myristate	$C_{15}H_{30}O_2$	2,97%	0,0297
4	Methyl arachistate	$C_{21}H_{42}O_2$	2,71%	0,0271
5	Methyl linoleate	$C_{19}H_{34}O_2$	2,25%	0,0225
6	Methyl arachidonate	$C_{21}H_{34}O_2$	1,44%	0,0144
7	Methyl laurate	$C_{13}H_{26}O_2$	0,62%	0,0062
8	Methyl margarate	$C_{18}H_{36}O_2$	0,41%	0,0041

Combustion Reactions:

$$0.4582C_{19}H_{36}O_2 + 0.4377C_{17}H_{36}O_2 + 0.0297C_{15}H_{30}O_2 + 0.0271C_{21}H_{42}O_2 + 0.0225C_{19}H_{34}O_2 + 0.0144C_{21}H_{34}O_2 + 0.0062C_{13}H_{26}O_2 + 0.0041C_{18}H_{36}O_2 + 27.00685(O_2 + 3.76N_2) \longrightarrow 18.0456CO_2 + 17.9225H_2O + 101.545568N_2 \quad (1)$$

$$\begin{aligned} \textit{AFR stoichiometry} &= \frac{\textit{air mass}}{\textit{fuel mass}} \\ &= 27.00685(O_2+3.76N_2) \,/\, 0.4582C_{19}H_{36}O_2 + 0.4377C_{17}H_{36}O_2 + 0.0297C_{15}H_{30}O_2 + 0.0271C_{21}H_{42}O_2 + 0.0225C_{19}H_{34}O_2 + 0.0144C_{21}H_{34}O_2 + 0.0062C_{13}H_{26}O_2 + 0.0041C_{18}H_{36}O_2 \quad (2) \\ &= 3{,}707.49/280.75 \\ &= 13.2 \end{aligned}$$

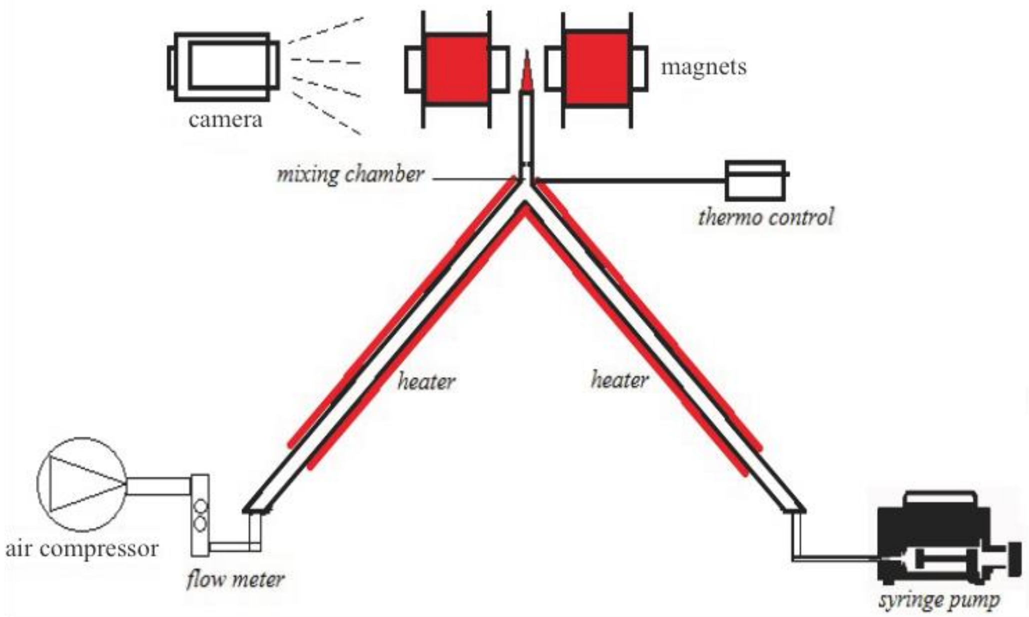

Figure 2. Experiment setup

2.4. Data Processing

Experiments were carried out using equivalent ratios of 0.7; 0.8; 0.9; 1.0; 1.1 and 1.2 defined by Eq. (3). The stoichiometric AFR is known and the equivalent ratio has been determined so that it can be used to calculate the actual AFR. After the fuel and air discharges are known, the reactant velocity can be calculated using Eq. (4). The primary data is obtained by measuring the angle of the bunsen flame which is illustrated in **Figure 3**. Then, the primary data is converted into laminar flame speed using Eq. (5).

$$\varphi = \frac{AFR_{stoic}}{AFR_{actual}} \tag{3}$$

Where,

φ : Equivalent ratio
AFR_{stoic} : Stoichiometry AFR
AFR_{actual} : Actual AFR

$$Uo = \frac{Q_{fuel} + Q_{ar}}{A_d} \tag{4}$$

Where,

Q_{fuel} : Fuel flow rate (cm^3/s)
Q_{ar} : Air flow rate (cm^3/s)
A_d : Burner cross-sectional area (cm^2)

$$SL = Uo \sin \alpha \tag{5}$$

With:

SL : Laminar flame speed (cm/s)
Uo : Speed of reactants (cm/s)
Sin α : Half of the bunsen burner flame angle (°)

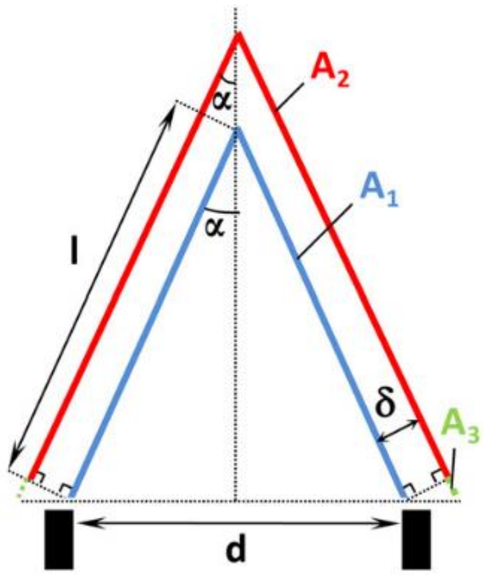

Figure 3. Ilustration of cone bunsen flame angle [36], [37]

3. Results and Discussion

3.1. Laminar Flame Speed SL (cm/s)

Laminar flame speed is obtained by multiplying the reactant velocity by half of the premixed flame angle. The evolution of the CIME biodiesel flame under the influence of varying magnetic fields are shown in **Figure 5**. When the point of flame was close up to stoichiometry point shown a two-zone reaction, first, inner premixed flame where fuel is converted to CO and H_2; second, an outer diffuse flame where CO and H_2 are further oxidized to run the combustions [32].

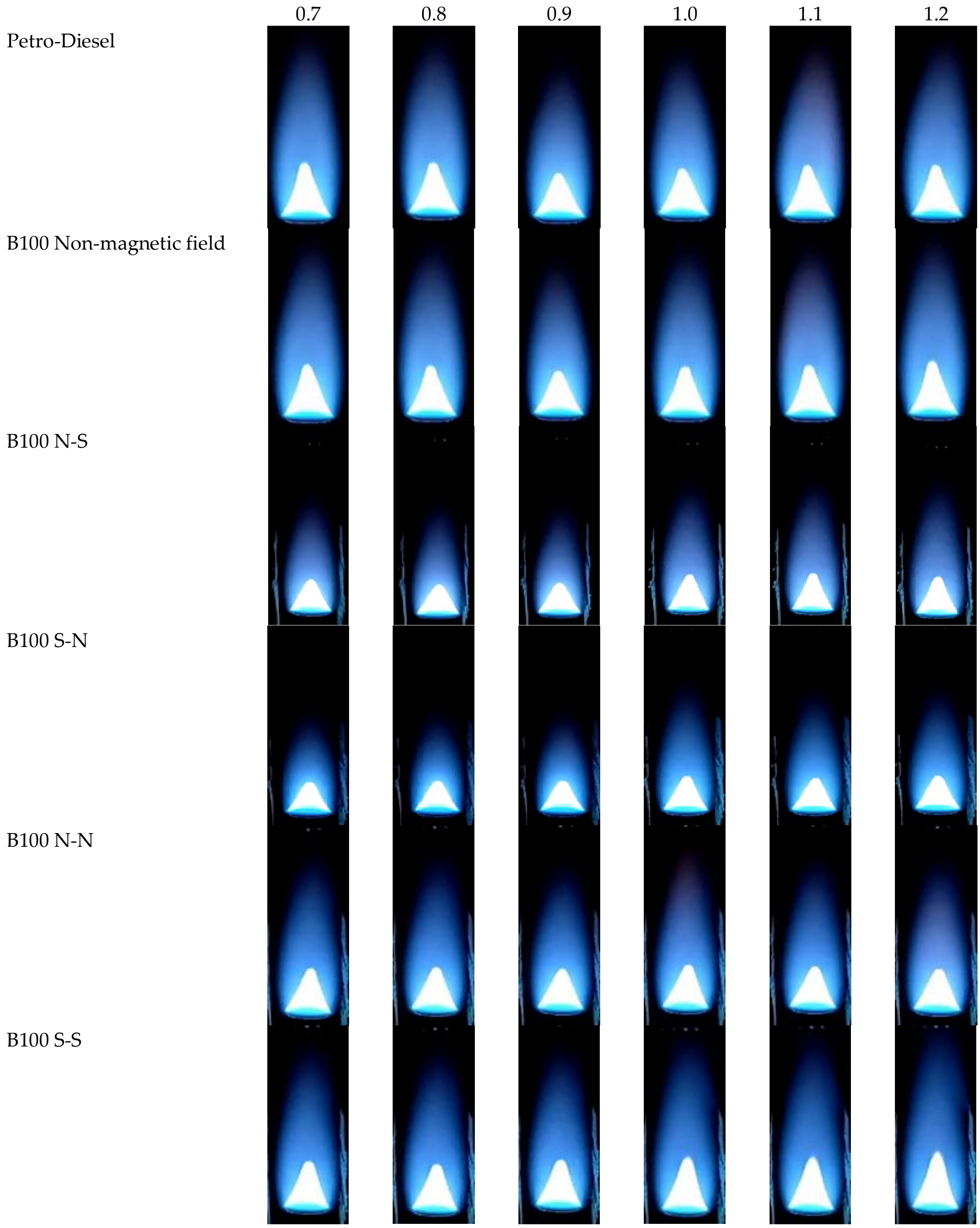

Figure 4. Flame with magnetic fields variation and equvalent ratio

Figure 5 represents the laminar flame speed graphic of CIME biodiesel and petrol fuel (D100). From the data presented, it can be seen that the trend graph of the equivalent ratio of 0.7 has increased to an equivalent ratio of 0.8, the higher point at the equivalent ratio of 0.9, and then decreased to an equivalent ratio of 1.0, 1.1, and 1.2. At an equivalent ratio of 0.7, the combustion conditions were dominated by air, so the fuel was completely burned. Whereas at an equivalent ratio of 0.9, the mixture of fuel and air approaches the stoichiometry point and produces the most ideal reaction speed and angle of flame. The data above was in line with the research before, run by Wardana [33] and Pambudi [14] which explains that premixed combustion requires air within the process (φ<1). Then, at an equivalent of 1.2, the lowest laminar flame speed was shown, because at these conditions the combustion was dominated by fuel so that the fuel did not burn completely. At an equivalent ratio of 1.2 has a higher flame structure so the flame angle becomes smaller.

D100 fuel has the highest laminar flame speed value of 37.101 cm/s at an equivalent ratio of 0.9. Whereas CIME biodiesel at an equivalent ratio of 0.9 shows a laminar flame speed value of 18,360 cm/s. CIME biodiesel has a lower point of laminar flame speed than D100 because CIME biodiesel has a higher viscosity, density, and flash point, which causes the evaporation process to not run optimally and has an effect on less optimal combustion quality. Arifin [20] explains that biodiesel has lower performance than petro-diesel because biodiesel has a lower calorific value. In addition, another research by Abdulla [25] stated that biodiesel has a delay in the ignition which causes less optimal combustion. With the effect of magnetic field variation laminar flame speed of CIME biodiesel was increased. The data shows that the highest laminar flame speed occurs at the magnetic point of N-S 26.041 cm/s increase of 20.7% ± and the equivalent ratio of 0.9 and on magnetic point S-N 24.701 cm/s increase of 17.09% ±. On the other hand, on the magnetic point, N-N 20.157 cm/s increased by 4.8% ± and the lowest was at magnetic point S-S of 19.779 cm/s which is ±3.8%.

Laminar flame speed is one of the parameters used by several researchers to determine the combustion quality by the visual observation of the characteristics of flame [38]. **Figure 6** shows a comparison of the results of a current experiment with several previous experiments. Perdana [39] has researched the effect of magnetic fields on the combustion of premixed jatropha biodiesel, and the results of his experiment were that the N-S magnets provided the highest increase in laminar flame speed. Wu [40] investigated the combustion rate of CH_4 laminar using temperature variations. Pambudi [9] researched CIME biodiesel with the addition of the additive γAl2O3. The graphic shows the trend of the highest flame speed occurring among an equivalent ratio of 0.8 – 1.1 or close to an equivalent ratio of 1.

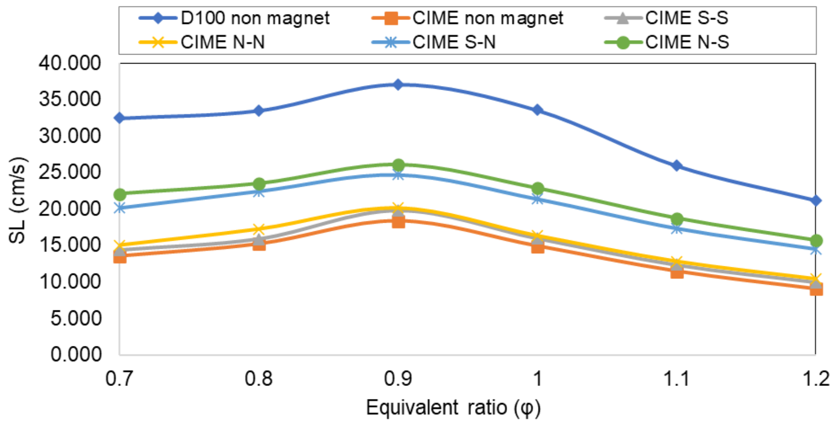

Figure 5. Laminar flame speed of premixed fuel D100 and CIME biodiesel wih the effect of magnetic field

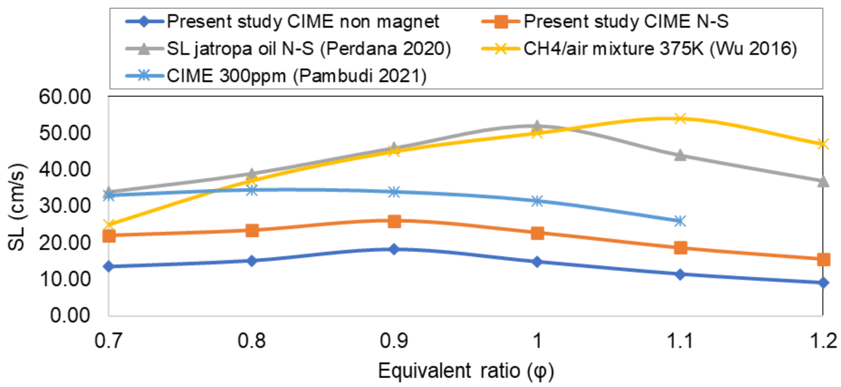

Figure 6. Laminar flame speed: current and previous experiments

3.2. *Effect of Magnetics Field on Combustion Process*

From several previous studies, it has been stated that the magnetic field has a significant effect on improving the quality of combustion [28], [41]–[43]. The combustion process was determined by three factors that are oxidator (O_2), fuel, and heat. Based on molecular orbital theory, O_2 is a non-metal compound that is paramagnetic because it has two unpaired free electrons. While the magnetic field can affect other objects that are paramagnetic or objects that are electrically charged. In addition, the magnetic field have a North (N) and South (S) point which can cause attractive and repulsive forces shown in **Figure 7**. The magnetic field force always points to the N toward S. It can be seen in the magnetic variations of the N-S and S-N, O_2 which is around the N point movement follows the direction of magnetic field force towards the S point and passes through the combustion reaction zone. The additional supply of O_2 from outside the combustion reaction zone, allows O_2 to oxidize unburned fuel and optimizes the combustion. Based on research conducted by Sahoo [28], the magnetic field effectively breaks down the fixed valence electrons that participate in the process of binding fuel compounds.

Meanwhile, the H_2O produced from the combustion process is a source of heat from a flame that is diamagnetic. H_2O tends to move in the opposite direction of the magnetic field. Repulsive magnetic point N-N produces a higher burning rate that S-S, because N-N point pumps more of the heat that H_2O brings to the flame while S-S removes H_2O which carries the heat out of the flame. Point S-N shows the values of combustion speed are higher than point N-S. It can happen because of the effect of the earth's magnetic poles during the process, the magnetic point N-S are in the line direction as the earth's poles, thereby strengthening the magnetic power, while the S-N point is opposite to the earth's magnetic poles, so the magnetic power has a different value. Moreover, the magnetic point of S-S and N-N shows a not significant increase in combustion speed, this is because the attractive force has higher power than the repulsive force.

The use of a magnetic field in this research causes the electron's rotations and hydrogen protons to be affected and have movement changes from para to ortho [27], [43], [44]. Hydrogen has two different isomeric forms namely the para form which usually occurs in fuels and the second ortho which is achieved by applying a magnetic field. These two forms are characterized by a different rotation of the opposite nucleus. In the para hydrogen, molecules occupy an anti-parallel rotation, on spin condition of a relative atom to the other atom are in opposite directions, therefore they are diamagnetics. Meanwhile, on ortho molecules that occupy parallel rotational levels, on spin condition of a relative atom to the other atom is in the same direction, therefore it is paramagnetic [45]. When the fuel is passed through a magnetic field, the orientation of the carbon will change and convert from the para to the ortho isomeric forms. In the ortho condition, the intermolecular energy is much reduced and increases the space among the hydrogens [27]. This electron spin increased causes the bonds among hydrocarbon molecules to weaken during the combustion process and expands the empty space among hydrocarbon atoms. Therefore, it makes it easier for O_2 to have hydrocarbon bonds which causes combustion to be more optimal [43].

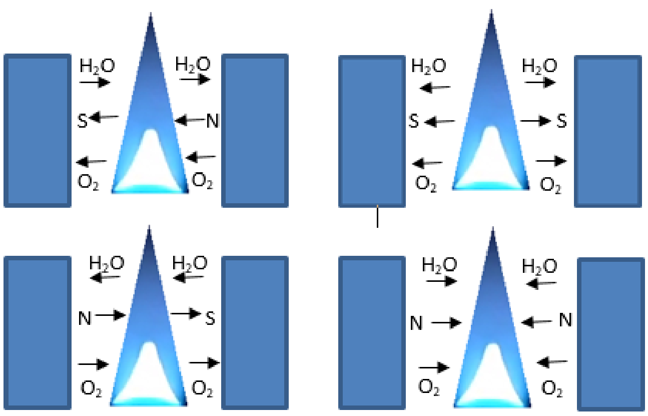

Figure 7. Movement illustration of O_2 and H_2O due to influence of a magnetic field

4. Conclusion

The main objective of this research was to analyze the effect of magnetic fields on the laminar flame speed of Calophyllum Innophyllum methyl ester (CIME). The laminar flame speed value has increased with the effect of magnetic fields. The magnetic point is S-S 3.8%, point N-N 4.8%, point S-N 17.09%, and the highest increased value was on point N-S 20.7%. Hence, the increasing laminar flame speed value indicates the optimal process of combustion. The magnetic field effectively influences O_2, and H_2O and is able to change the orientation of hydrocarbons which would make it easier for O_2 and the fuel to oxidize, so that it can make optimal combustion.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript

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All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

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