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Research Article

The Role of Magnetic Field Orientation in Vegetable Oil Premixed Combustion

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This study observed the influence of magnetic field orientation on the premixed combustion of vegetable oil. The results show that the magnetic field increased the laminar burning velocity because the spin of electron became more energetic and changes the spin of hydrogen proton from para to ortho. The increase of flame speed became larger on vegetable oil with stronger electric poles. The attraction magnetic field gives the strongest effect against the increase of flame speed and makes flame stability limit wider toward lean equivalence ratio. This is because O_2 with the paramagnetic nature is pumped more crossing flame from the south pole (S) to north pole (N) whereas the heat energy carried by H_2O from the reaction product with the diamagnetic nature is pumped more crossing flame in the N pole to the S pole. This made the combustion close to Lewis number equal to unity, whereas in the repulsion magnetic poles, S-S, more O_2 is pumped into the flame while more heat is pumped out of the flame, and thus, combustion in the flame is leaner and reactions are not optimal. Conversely, at N-N poles, more heat carried by H_2O was pumped into the flame while more O_2 was pumped out of the flame. As a result, combustion in the flame is richer and the reaction is also not optimal. As a consequence, the velocity of the laminar flame at the repelling poles is lower than that of attracting poles.

1. Introduction

Oil is the largest source of energy consumed by the world's population, surpassing natural gas, coal, nuclear energy, and renewable materials. Due to the reduction in petroleum resources coupled with increased energy consumption and the negative environmental impact of the use of fossil fuels, there has been a shift towards alternative, renewable, sustainable, efficient, cost-effective, and pollution-reducing energy sources [1, 2]. On the other hand, engineers and researchers have been struggling to improve engine performance through improved combustion processes to improve efficiency and reduce emissions.

There are many studies on the characteristics of vegetable oil combustion or its derivatives and its use in diesel engine has been carried out for four decades. These studies have shown vegetable oil behavior is similar to diesel oil behavior [3–7]. However, the use of pure vegetable oil for diesel engines is still problematic due to high viscosity and low volatility which can cause large deposits on the engine and injectors and stick to the piston rings [8, 9]. Such problems have been explained in the literature such as clogged filters and deposits in combustion chambers [10]. Various solutions are proposed:

(i) Mixing vegetable oil with diesel oil in different proportions
(ii) Heating vegetable oil
(iii) Exhaust gas recirculation (EGR)
(iv) Modifying the combustion chamber (piston, injector, etc.)

A number of vegetable oils such as caramel oil, rapeseed oil, rice bran oil, cottonseed oil, sunflower oil, and castor oil have been investigated as diesel engine fuels [11–13]. Studies have shown, over a short period of time, vegetable oil works satisfactorily on unmodified diesel engines. Vegetable oil has a high viscosity due to molecular weight and large molecular structure [14]. The viscosity of liquid fuels influences the flow properties as well as spray atomization, evaporation, and formation of air/fuel mixtures. Higher viscosity also has an adverse effect on the combustion of vegetable oils on diesel engines, fuel pumps, and injectors. Vegetable oils have a higher percentage of oxygen, density, and viscosity. Vegetable oil must be heated before it is used in combustion [15]. Experimental results have shown that pure jatropha oil which is heated has combustion characteristics that are close to diesel fuel [16].

Because of the shortcomings experienced when using vegetable oils, some researchers have focused and worked on applying magnetic fields to diesel engines to reduce pollution emissions and save fuel. The effect of the magnetic field increases engine efficiency and reduces pollution emissions caused by increases in fuel atomization [17]. Previously, several studies have evaluated the effect of magnetic fields on the performance of diesel engines and gasoline engines in terms of pollution and energy emissions [18–22], while other pollution control devices are placed in further combustion areas, using magnetic fields placed in the fuel lines before combustion. The content value of NOx, HC, and CO_2, respectively, decreased by 8%, 27.7%, 30%, and 9.99% in fuel consumption, when using a 2000 gauss magnetic field on a four-cylinder one-stroke diesel engine [22]. The use of a 5000 gauss magnetic field achieved a reduction in HC and CO emissions of 12%, 22%, and 7% in fuel consumption, but an increase in NOX and CO_2 of 19% and 7%, respectively [23]. The increase of the magnetic field up to 9000 gauss reduces CO and HC to 30% and 40%, respectively, and fuel consumption to around 9 to14%, however, CO_2 increases up to 10% [19]. A magnetic field with an intensity of 1000 gauss on a compression engine affects fuel ionization, thereby reducing pollution emissions and increasing thermal efficiency caused by increased combustion efficiency [24]. The effect of the magnetic field on the performance of a four-stroke one-cylinder compression ignition engine was observed by installing a 5000 gauss intensity magnet on the outer surface of the fuel pipe. The results show that magnetic fields reduce HC and CO emissions but increase CO_2 and NOX [25]. The magnet is mounted on a fuel pipe which has an intensity of 2000 gauss reducing fuel consumption and emissions (CO_2, CO, NOX, and HC) [21]. The role of the magnetic field intensity of 1000–4000 gauss in the effectiveness of a single-cylinder compression ignition engine was observed experimentally. Magnets are placed on the outer surface of the fuel pipe. The best results were obtained on 3000 gauss where there is a decrease in consumption of fuel, exhaust gas temperature, and CO_2, CO, HC, and NOX emissions [26]. Combustion of diesel fuel is a major driver in industrial furnaces and is likely to remain the same for the foreseeable future. Maintaining the use of these fuels is very important to increase fuel consumption and pollution emission character [27].

From all of these studies, the stability of combustion that really determines engine performance has not been discussed. Therefore, further research is needed especially regarding the role of the magnetic field in stabilizing the combustion process. This research provides data on combustion stability in a magnetic field which strongly supports the combustion process of vegetable oil in the engine to be more efficient.

The purpose of this paper is to reveal the role of magnetic fields in premixed combustion in various orientations of the magnetic field in pure vegetable oil fuels with various equivalence ratios.

2. Literature Review and Problem Statement

Many studies have shown that magnetic field has a positive effect on the process of combustion, and thus, it would repair the system performance. Combustion engines represent the main section of hydrocarbon fuel consumption. Generally, fuel for internal combustion engines is hydrocarbon molecule substance. Every molecule consists of a number of hydrogen and carbon atoms. Hydrogen atom has one proton with one electron orbiting around the proton, whereas carbon atom has a nucleus with six electrons orbiting around the nucleus. Ionization and reorganization are achieved through the use of the magnetic field [28]. Magnetic field is used to ionize fuel to be baited to combustion devices, ensuring that the combustion is perfect, saving fuel and maximizing efficiency.

The magnetic field tends to break the hydrocarbon fuel molecules giving rise to shorter molecules leading to better combustion. Magnetic field tends to induce fuel molecules to improve the mixing of oxygen with fuel [19]. Magnetic field induces electron that tends to make molecules have positive and negative electrical charges. Therefore, magnetic orientation could organize the charge that allows fast binding with oxygen. As a result, combustion of hydrocarbon fuels becomes more complete and faster [29]. Liquid fuels consist of chemical compounds of carbon and hydrogen atoms. A very stable fuel structure does not allow oxygen atoms to penetrate into the interior during the air-fuel mixing process. Therefore, there is an incomplete combustion process [30].

Hydrogen atoms in fuel are arranged in two forms of para and ortho isomers. Effective arrangement of hydrogen atoms leads to efficient combustion. The ortho state of hydrogen atom is developed by placing a strong magnetic field into the fuel lines [31]. In the para state, the rotation of one atom relative to the other is in the opposite direction, whereas in the ortho state, the rotation of one atom relative to the other is in the same direction. Usually, the fuel is in the para state; however, the magnetic field converts it into the ortho state [18]. When a strong magnetic field is applied to the fuel, the hydrocarbon changes its orientation and changes from the para state to the ortho state [19]. Ortho causes a considerable reduction in intermolecular forces that increase the space between hydrogen. Consequently, more oxygen penetrates into the fuel resulting in complete combustion of the fuel in the combustion chamber [21]. Fuel molecule decomposes to be smaller and easily combined with oxygen [31]. Positive ionization allows hydrocarbon fuels to attract and bind negatively charged oxygen and cause more complete carbon/oxygen bonding and efficient combustion [32]. This results in better fuel atomization and better fuel-air mixing. Fuel-saving, better fuel economy, and reduction of exhaust emissions such as hydrocarbons, carbon monoxide, and carbon dioxide could be acquired under the influence of the magnetic field [33].

The stability of the premixed flame in high-speed flow has become an important discourse of observation in the study of combustion for several decades. The stability of flame is a great issue when alternative or renewable energy is used in many applications such as in internal combustion engine, gas turbine, and industrial oil burner. Special attention needs to be given on the study of alternative fuel influenced by the magnetic field for improving combustion reaction and flame stability. In this study, the premixed combustion process and premixed flame stability are observed under four magnetic field orientations. The transport of oxygen and heat energy brings by H_2O, and the spin of electron and hydrogen proton under various magnetic orientations and their impact on flame speed and stability are discussed.

3. Materials, Methods, and Model of Research

Vegetable oil tested includes coconut oil and jatropha oil. All vegetable oils were obtained from commercial products. The composition of fatty acids, physical properties, glycerol, sap, and water from vegetable oils has been shown in our previous research [34].

The experimental equipment is shown schematically in Figure 1. Vegetable oil of 600 ml was fed into the boiler (2) and then was heated with a gas stove (1) to evaporate at 320°C and the pressure of 3 bar was kept constant. The fuel inlet valve (3a) was opened and the air inlet valve (3b) was closed. The next process was the air inlet valve (3b) was opened slightly and the difference in water level was noted on the flow control (4b). The water level difference in the fuel flow control (4a) was recorded and kept constant. With a gradual increase in the air inlet valve opening, each water level difference in the airflow controls was recorded. The vegetable oil vapor from the boiler is mixed with air from the compressor (11) in the burner chamber (5). The reactant mixture then flew into the nozzle with an inner diameter of 6 mm, and then, the flame was ignited at the tip of the nozzle to form a diffusion flame. By increasing the amount of air in the mixture, the flame would gradually change to a premixed flame. The flame was then given magnetic field from magnetic bar (7a and 7b) each with north (N) and south (S) pole. The orientation of the magnetic bars was changed in four conditions, namely, S-S, N-N, S-N, and N-S as shown in Figure 2. The magnetic bars were each made of N45 grade nickel plated neodymium permanent magnet with a magnetic field intensity of 1.1 T (11000 gauss) with dimensions of 40 mm × 25 mm × 10 mm. The magnetic bars were placed on a holder made of aluminum plates and tightened by bolts and nuts so that it can be removed and reassembled to change the direction of the S-S, N-N, S-N, and N-S magnetic fields as shown in Figure 2. In 12 mm gap between the two magnets, a burner (5) with a diameter of 6 mm and a length of 200 mm made of stainless steel pipe was placed. Premixed flame (8) formed at the rim of the nozzle was recorded until the flame goes out using a high-speed camera (6) with a speed of 320 fps. Thermocouple of K type (9) was connected to the data logger to record the measured temperature into computer memory (10) by placing the sensor in the reaction zone position with a distance of 2 mm above the end of the burner as in Figure 3.

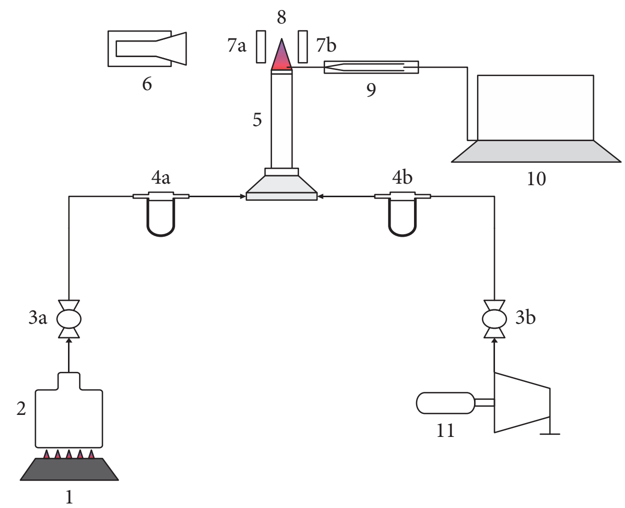


Figure 1: Experimental Apparatus: (1) Stove; (2) boiler; (3) valve; (4) flow control; (5) burner type cylinder; (6) high-speed camera; (7) permanent magnet; (8) flame; (9) thermocouple; (10) data logger; (11) compressor.

4. The Results of the Investigation of the Magnetic Field Orientation Influence on Vegetable Oil Premixed Combustion

4.1. Stability and Characteristics of Flame on Various Equivalence Ratios and Orientations of Magnetic Fields. Figures 4 and 5 show a premixed flame from coconut and jatropha oil. Coconut oil can burn at an equivalence ratio that is leaner than jatropha oil. Premixed coconut oil flames lift off and then blew off at an equivalence ratio below 0.83 while premixed jatropha oil flames lift off and then blew off below 0.85. This shows that coconut oil is more difficult to evaporate than jatropha oil because the pole of coconut oil is more stronger than that of jatropha, so it requires more air to burn [35, 36]. Weaker polar jatropha is more volatile, so the combustion reaction became faster and the laminar flame speed was slightly higher than that of coconut. As seen from Figures 4 and 5, reaction zones on jatropha flame were thicker than reaction zones on coconut flames. This indicates the diffusion speed of fuel in jatropha flame is faster than the reaction speed. This happened because at a weaker electric pole the fuel molecule was freer to move. Conversely, in coconut molecules, it was more difficult to move because the stronger electric pole molecular attractions were stronger so the reaction speed was faster due to stronger polarity. Giving the magnetic field to the flame as a whole increased the combustion reaction which can be seen from the reaction zone which was getting thinner and the

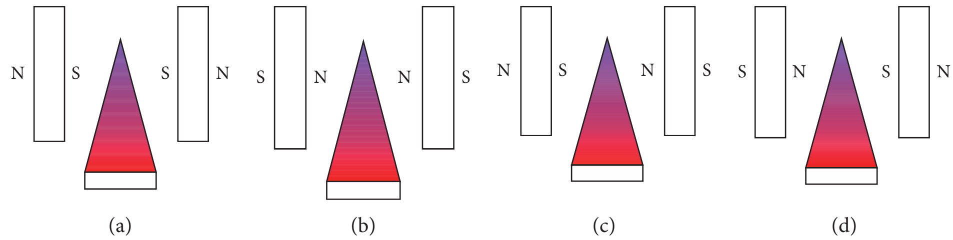


Figure 2: Magnetic field orientation. (a) S pole from the two magnets is facing inside the flame (S-S). (b) N pole from the two magnets is facing inside the flame (N-N). (c) S left magnet pole is facing inside the flame whereas N right magnet pole is facing inside the flame (S-N). (d) N left magnet pole is facing inside the flame whereas S right magnet pole is facing inside the flame (N-S).

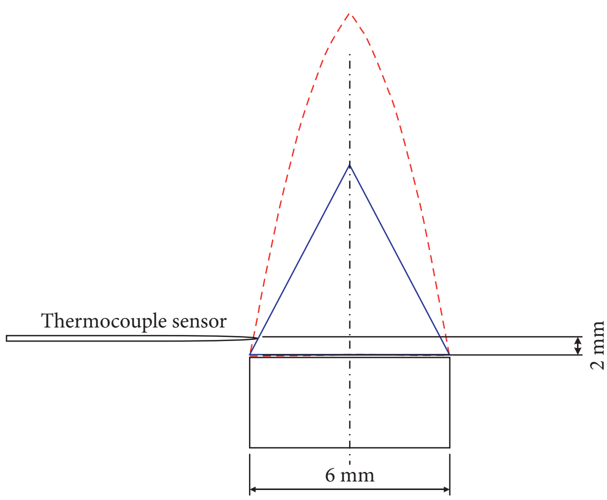


Figure 3: Thermocouple positions.

flame getting shorter. This happened because the magnet made the electrons in the reactants become more energetic due to the spin of electrons that were accelerated by the magnetic field. At the same time, the hydrogen proton spin tends to change from the para to ortho state. The magnetic field gives a stronger effect on the coconut because the coconut has a stronger electric pole than jatropha [36]. The orientation of the magnetic field has the same trend of influence both on coconut oil and on jatropha oil. The magnetic fields of S-S and N-N fields do not change the stability of the flame. From the image of flame, it can be seen that at the S-S pole (Figures 4(b) and 5(b)), the flame became clearer or leaner, whereas at N-N pole (Figures 4(c) and 5(c)) the flame was thicker or richer. This happened because oxygen that was paramagnetic would move in the orientation of the field while H_2O products that carry heat were diamagnetic which tend to move against the orientation of the magnetic field. At S-S pole, the orientation of the magnetic field exited the pole, pushing O_2 into the flame while H_2O, which carries heat energy, being pulled out of the flame. Conversely, at N-N pole, the magnetic field lines entered the magnet making O_2 drawn out of the flame while H_2O which carries heat was pushed into the flame. Both of these events made chemical reactions not optimal. The orientation of magnetic field S-N and N-S gave a stronger effect. The flame became more stable towards leaner equivalence ratio, from 0.83 to 0.74 in coconut flame while in jatropha from 0.85 to 0.79. In addition, the secondary flame became thinner which indicates that the combustion reaction in the reaction zone becomes stronger. This happened because O_2 was pumped across the flame from S to N poles while H_2O as a heat source was pumped across the flame from N poles to S. This cross heat and mass transfer makes a maximum reaction. But if seen from Figures 4(d), 4(e), and 5(d), N-S poles provided a stronger effect possibly due to the influence of the global magnetic orientation.

4.2. Speed of Premixed Combustion on Various Equivalence Ratios and Orientations of Magnetic Field. Figures 6 and 7 show the laminar burning velocity of the coconut oil and jatropha oil estimated from Figures 4 and 5. The maximum laminar burning velocity occurs at an equivalence ratio slightly above one. Jatropha's maximum burning velocity occurs in a mixture richer than that of coconut. This is because the electric pole of jatropha is weaker, so it is more volatile, but its electric pole was weaker attracting O_2 while the electric pole of coconut is stronger so it was difficult to evaporate but attracts stronger O_2. Because it was difficult to evaporate, the burning velocity of coconut flame without magnets is lower than that of jatropha. The burning velocity decreased when the fuel-air mixture got richer or leaner. Coconut is more stable in leaner mixes because of its ability to attract stronger O_2. Giving a magnetic field makes the laminar burning velocity increase because the electrons become more energetic and proton spin tends to change to the ortho state. A greater increase occurs in coconut flame because of its stronger electric pole compared to jatropha oil. Magnetic fields make laminar burning velocity increase greater in leaner mixture regions and tend to become more stable towards leaner mixture region at attracting magnetic pole (N-S and S-N). This shows that magnets help pump oxygen that is paramagnetic and control the heat carried by more diamagnetic H_2O to the flame. The difference in orientation of the magnetic poles has a different effect on the speed of combustion. As explained before, the repelling magnetic poles exert a smaller effect than the attraction magnetic poles. The repelling magnetic pole in N-N produced a higher burning velocity than S-S because N-N pumps more heat that H_2O brought to the flame while S-S removes H_2O which carries the heat of the product out of the flame. As a result, the combustion reaction becomes

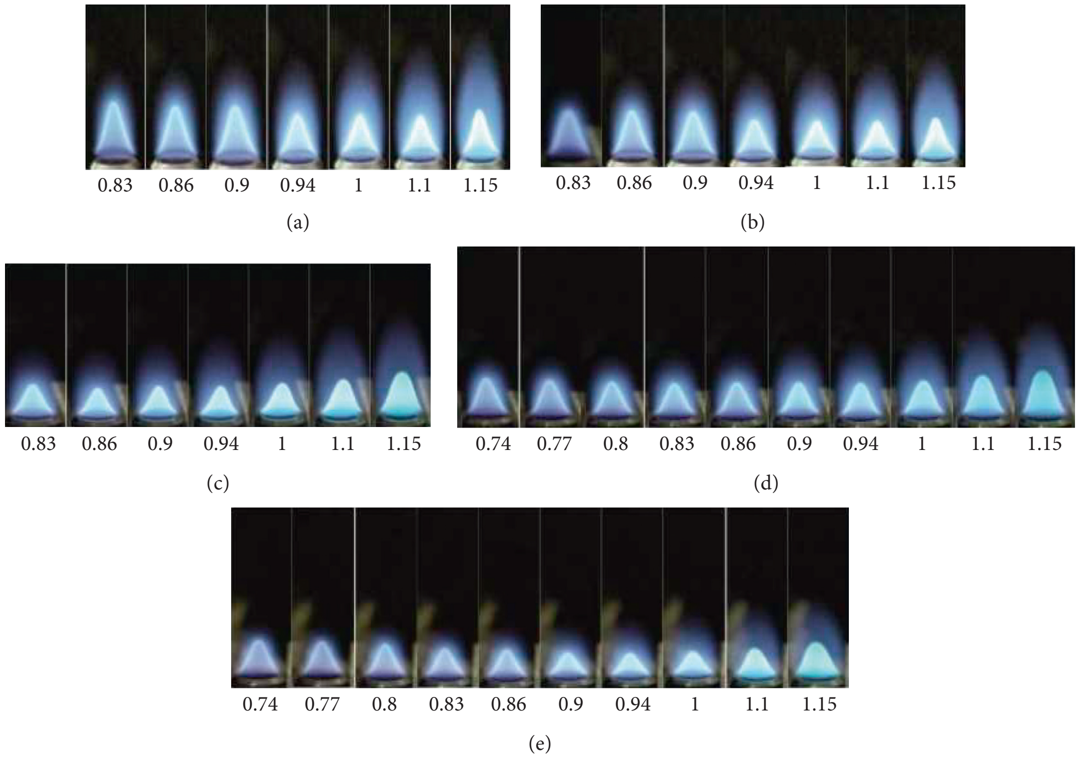


Figure 4: Stability and shape of the flame of coconut oil at equivalence ratio: (a) without magnet; (b) magnet S-S; (c) magnet N-N; (d) magnet S-N; (e) magnet N-S.

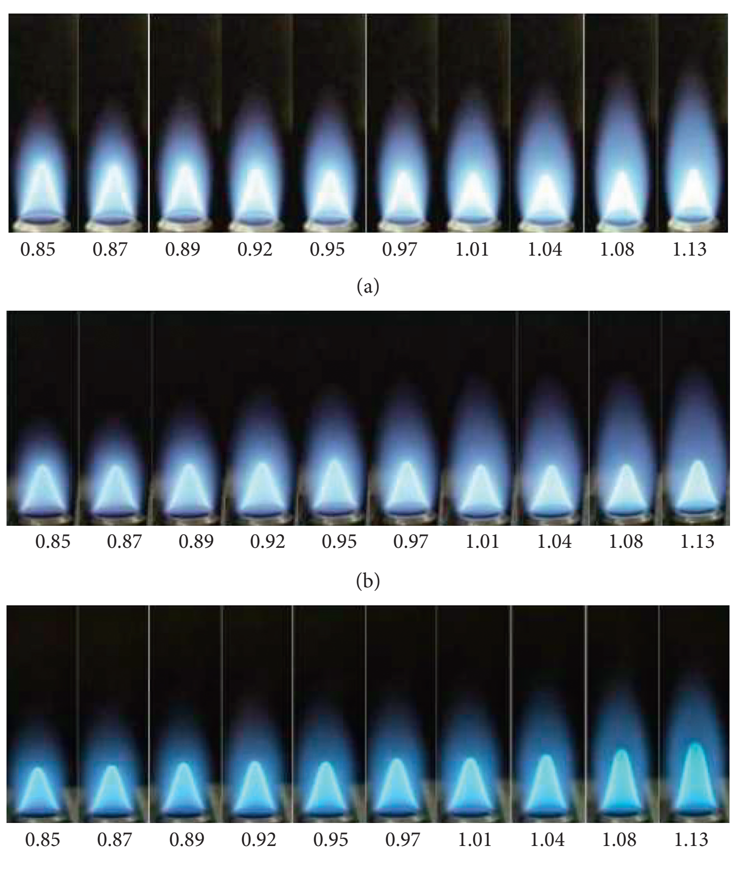
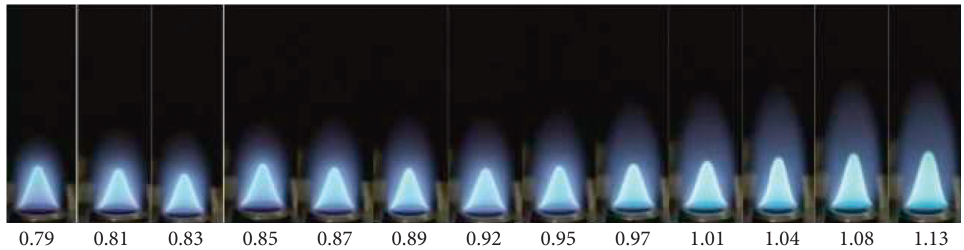
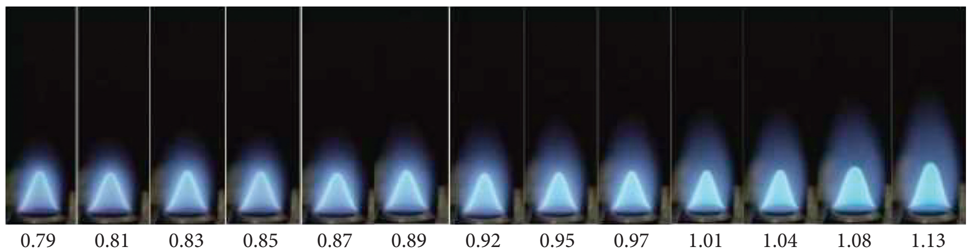


Figure 5: Continued.



(d)



(e)

Figure 5: Stability and shape of the flame of jatropha oil at equivalence ratio: (a) without magnet; (b) magnet S-S; (c) magnet N-N; (d) magnet S-N; (e) magnet N-S.

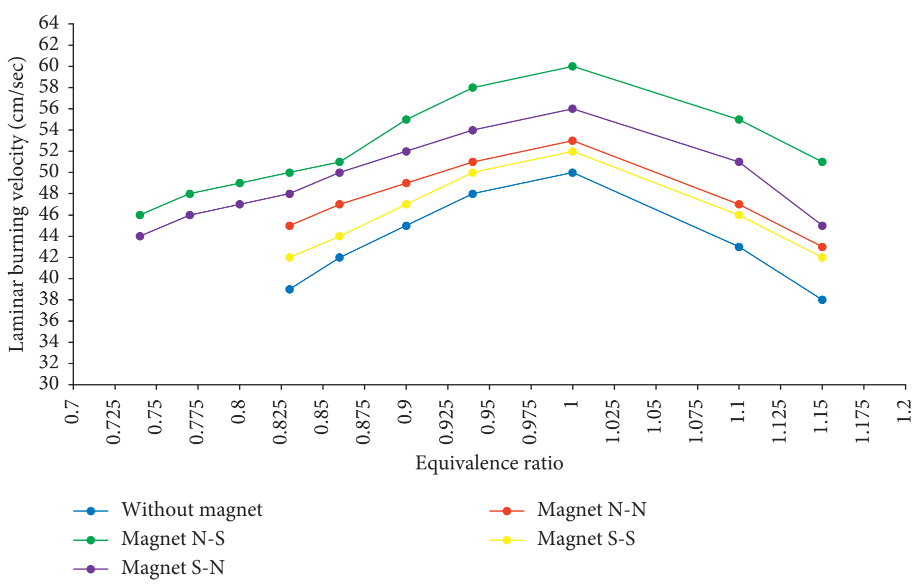


Figure 6: Laminar burning velocity of coconut oil versus equivalence ratio at various magnetic field orientations and without magnetic field.

faster at N-N pole. Changes in the burning velocity due to changes in the direction of the magnetic poles on the coconut are larger, indicating that the heat of the product in H_2O that is pumped by a magnet becomes an important factor in burning coconut to overcome stronger intermolecular attractions due to stronger electric pole for the evaporation process.

4.3. Temperature at Various Equivalence Ratios and the Orientations of Magnetic Field. Figures 8 and 9 show the flame temperature from premixed combustion of coconut oil and jatropha oil. It is seen that the trend of temperature changes with the equivalence ratio followed by the changing trend of laminar burning velocity because the burning velocity shows the rate of the combustion reaction that is the rate of heat release. Although the magnetic field increased the temperature of the flame, a higher increase in flame speed on the coconut resulted in a lower temperature increase. This may occur because some of the heat was taken to vaporize the coconut which was more difficult to evaporate due to stronger molecular attractions due to stronger polarity. In addition, the lower heating value of coconut because of its shorter carbon chain is also a factor [34]. The decrease in temperature to leaner mixture region was steeper in jatropha, which indicates that jatropha flame is less stable in leaner mixture than

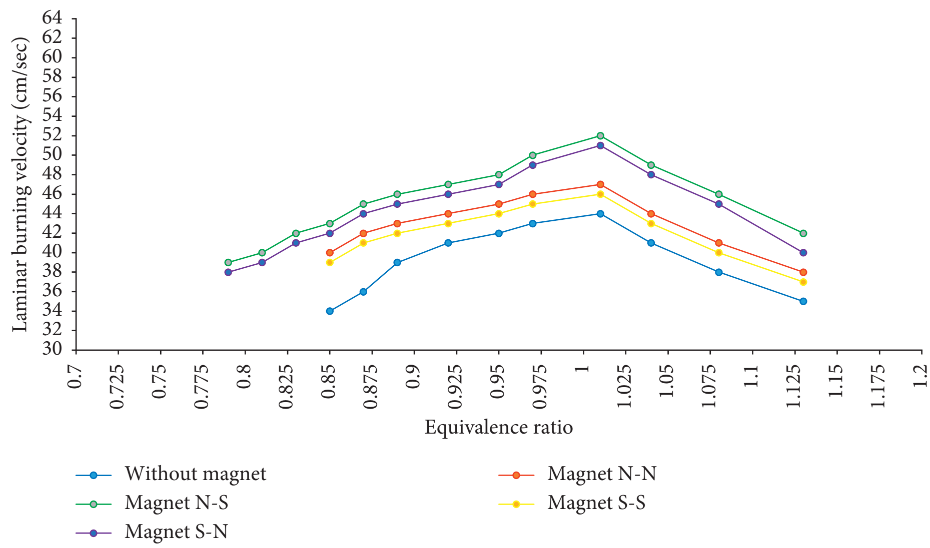


Figure 7: Laminar burning velocity of jatropha oil versus equivalence ratio at various magnetic field orientations and without magnetic field.

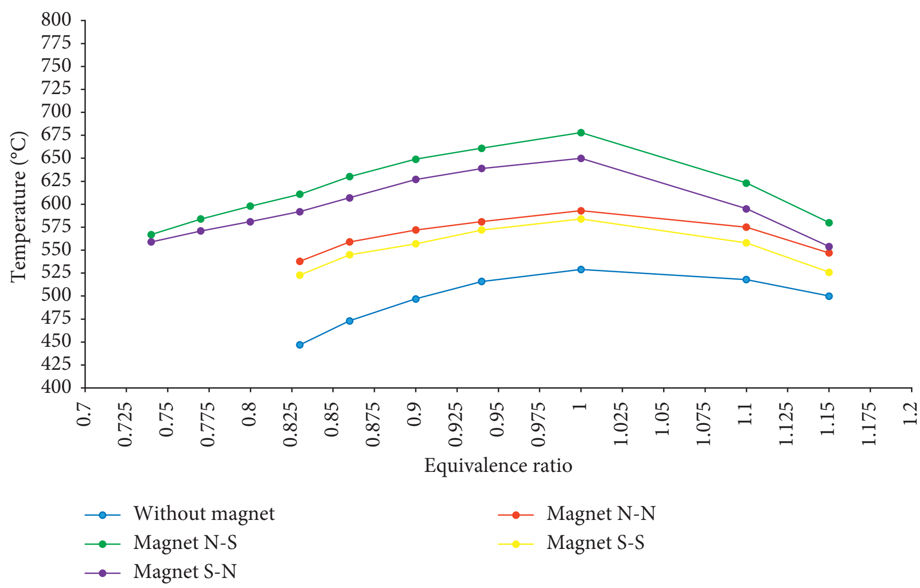


Figure 8: Flame temperature of coconut oil versus equivalence ratio at various magnetic field orientations and without magnetic field.

coconut flame. This shows that the polarity of the molecule is very influential in helping the magnetic field in stabilizing combustion.

4.4. Flame Height at Various Equivalence Ratios and the Orientation of Magnetic Field. Figures 10 and 11 show the height of flame from premixed combustion of coconut oil and jatropha oil at various orientations of the magnetic field. Jatropha flame is higher than coconut oil flame. This indicates that jatropha flame is less stable than coconut flame because the higher one shows that the flame tends to be less stable because it has a longer stretch. Magnetic fields have a greater influence on shortening flame on jatropha. This happened because the magnet makes electrons more energetic, and thus, the increase in the speed of the reaction can offset the diffusion rate of the jatropha molecule (Figure 5).

5. Discussion

From some previous research results, it is known that the magnetic field has a major role in the combustion reaction process [18, 19, 21, 29–32]. The first magnetic field strength affects the magnetic poles of electrons in molecular bonds, which means that they affect the spin electrons in molecules. With a faster spinning electron due to the magnetic field, electrons become more energetic. This is evident from the increase in laminar burning velocity from burning coconut oil and jatropha (Figures 4–7). The second role is that the magnetic field can change the spin of hydrogen protons in the fuel from para to ortho [18, 19, 21, 29–32]. Higher polarity in coconut attracts stronger electrons, so it becomes less mobile in coconut oil [36], and thus, the spin of hydrogen is para. By giving a magnetic field, the proton spin on coconut can change from para to ortho with weaker bonds,

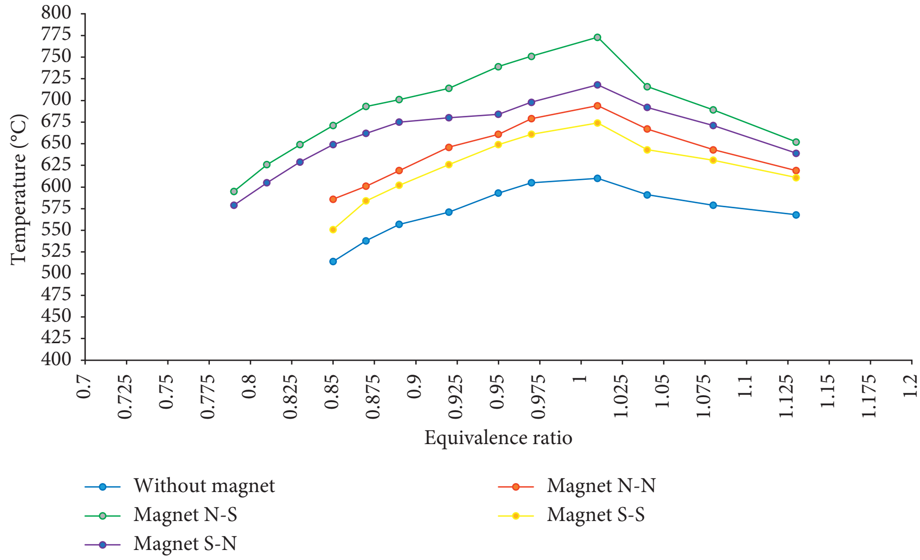


Figure 9: Flame temperature of jatropha oil versus equivalence ratio at various magnetic field orientation and without magnetic field.

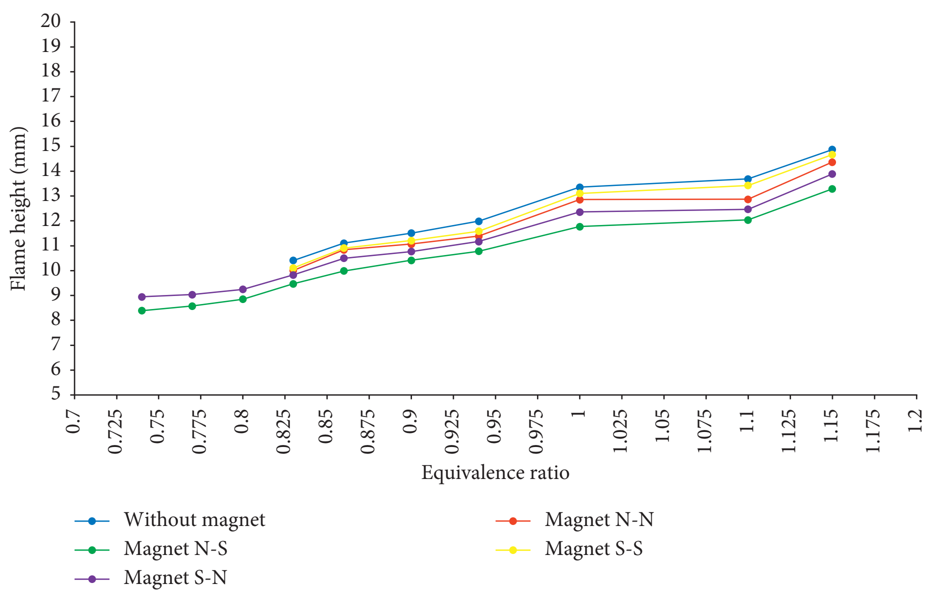


Figure 10: Flame height of coconut oil versus equivalence ratio at various magnetic field orientations and without magnetic field.

and thus, the combustion reaction can take place faster. The change from para to ortho is more evident in coconut where laminar burning velocity increases higher because of its stronger electric polarity than jatropha (Figures 4–7) [19]. In jatropha, this occurrence appears in the thickness of the flame from thicker to thinner (Figure 5). Thick flame is as a result of the Damkohler number principle which has a shorter reactant diffusion time and a longer reaction time. Jatropha molecule is more diffusive because it is less polar, so the diffusion time is shorter. By changing the proton spin into ortho and energizing electron spin in jatropha oil due to the magnetic field, the reaction time is shorter, so the reaction zone is thinning. The third role of magnets is to attract paramagnetic molecules which in the case of combustion are oxygen and reject diamagnetic molecules which in this case are products in the form of H_2O which carries heat as shown in Figure 12.

The combustion process is determined by three factors, namely, air or O_2, fuel, and heat. The fuel here is coconut oil and jatropha oil while heat is carried by H_2O. Control of these three components, namely, the withdrawal of O_2, rejection of H_2O, and changes in the spin of electrons and protons will determine the combustion process whether it becomes stable, efficient, and low emission or vice versa. The change of proton spin from para to ortho and the electron spin kinetic energy are determined by the strength of the magnetic field while the transfer of heat and mass of the fuel is determined by the orientation of the magnetic poles. The

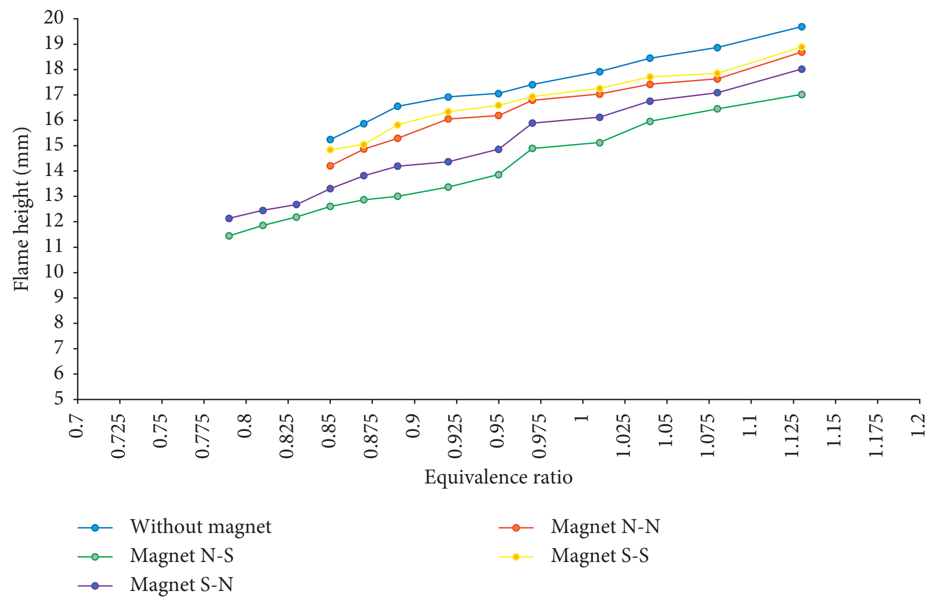


Figure 11: Flame height of jatropha oil versus equivalence ratio at various magnetic field orientation and without magnetic field.

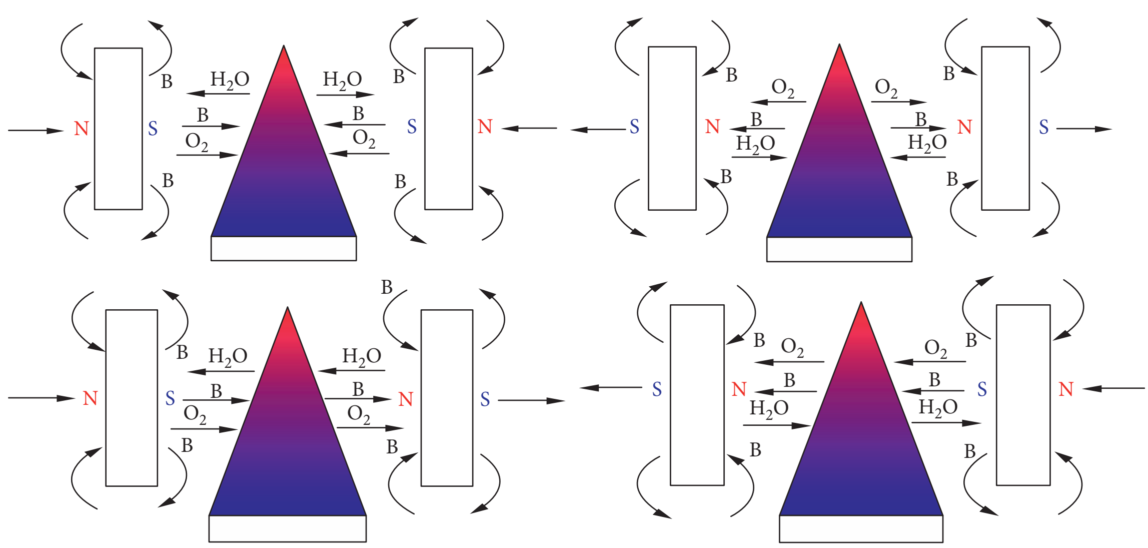


Figure 12: The role of magnetic field orientation on paramagnetic O_2 and diamagnetic H_2O in combustion product.

right combination of these two will determine the quality of combustion.

6. Conclusion

An experimental study has been carried out on premixed combustion of coconut oil and jatropha oil. The premixed combustion process is observed from combustion in a cylinder type Bunsen burner given a magnetic field in the direction of the magnetic field (N-S, S-N, N-N, and S-S). The main conclusions of this study are as follows.

The strength of the magnetic field increases the laminar burning velocity of vegetable oil through its role in increasing the spin electron and changes in the hydrogen proton spin in the fuel. This role is more clearly seen in more polar biofuels because electrons are more strongly bound to fuel molecules.

The orientation of magnetic poles plays a role in the transport of O_2 and the heat transport carried by H_2O in the reaction product which largely determines the stability and accomplishment of combustion.

The precise combination of field strength and direction of the magnetic field determines the quality of combustion.

Data Availability

The data used to support the finding of this study have been deposited in https://figshare.com/authors/Dony_Perdana/7364801.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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