Research has been carried out on the effect of various preheating and the direction of the magnetic field on the flame characteristics of droplet combustion. This study is important to substitute fuel from fossils with vegetable oil that is environment friendly. The variations of the magnetic field are south-south pole, north-north pole, south-north pole, north-south pole, and without. A drop of palm oil is placed on a type K thermocouple between two magnetic rods. The high-speed camera of 120 fps from the front recorded the flame from the start until it went out. The researcher found out the influence of various preheating in palm oil and the magnetic characteristics and behavior of the flame. The direction of the north-south magnetic field had a higher magnetic field strength, caused the droplet combustion to increases resulting in a wider flame but a lower and more stable height compared to other magnetic field directions. The speed of combustion affected by the magnetic field intensity which resulted the flow rate of O_2, therefore the combustion speed happened quickly because between O_2 and the fuel molecules easily react and were more flammable. The strength of the magnetic field increased oxygen concentration and fuel molecule around the reaction zone causing a short burning, resulting in a change delay time the shorter but the flame temperature increased. Stability, shape, temperature, height, delay time and combustion duration were highly valuable to design an efficient heat generator industry with the addition of magnet field. This study provides insight into the influence of magnetic field direction in magnetic field intensity on droplet combustion characteristics for boiler combustion in the power generation system

Keywords: magnetic field, palm oil, droplet combustion, flame characteristics, flame stability

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THE INFLUENCE OF VARIOUS PREHEATING AND DIRECTION OF MAGNETIC FIELD ON COMBUSTION CHARACTERISTICS OF PALM OIL DROPLETS FOR BOILER COMBUSTION IN POWER GENERATION SYSTEM

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1. Introduction

The consumption of fossil fuel increases drastically every year across the world due to the increasing population in each country [1], thus looking for sustainable and environmentally friendly energy sources [2]. Various efforts have done by researchers to find fossil fuel substitution, one of which by using fuel from vegetable oils and animal fats [3]. Environment friendly renewable energy sources are a potential alternative solution in resolving the depletion of fuel reserves and toxic emission caused by fossil fuel [4]. Biodiesel, biofuel, and biogas are some kinds of alternative energy, the advantage of using vegetable oils is that it has properties similar to diesel fuel [5]. Otherwise, the disadvantages are viscosity and high NO_x, but CO and energy produced is lower from diesel [6]. Vegetable oils used directly cause problems because of their high viscosity [7], which causes difficulties in the operation of the machine [8]. Production of high heat energy radiation needs effective flame stability; therefore, further research is needed. This work provides combustion fact efficient and stable heat generation using preheating of vegetable oil and magnetic fields.

Single droplet combustion is low-cost and an effective analytical method for characterizing fuels based on their properties [6]. Therefore, studies that are devoted are especially regarding preheated vegetable oil fuels and the influence of magnetic fields in stabilizing the combustion process so as to produce high thermal in power plants are scientific relevance.

2. Literature review and problem statement

Many researchers review fuels from vegetable oils such as biodiesel which has been studied by several authors [9], pure or mixed vegetable oil in [10]. The paper [11] biomass such as bio-alcohol, was used in the internal combustion engine were reported in [12]. In the author's work [13] in the operation of a diesel engine, the fuel used was palm oil. However, direct usage caused large problems, especially in the filter blockage, injection pumps damage, and carbon deposits on the engine such as the combustion of chamber walls, cylinder head, and injector nozzles the authors of [14]. The author's work [15] shows the most frequently proposed solutions were: preheating vegetable oil to reduce its viscosity to similar to diesel fuel, vegetable oil mixed with diesel in various ratios are reported in works [16], and adding additives to biodiesel from those studied in works [17].

Several researchers have carried out the use of palm biofuel in diesel engines, reviewing engine capabilities and exhaust emissions. The authors of the works [18] palm oil (PO) was heated first and blended with diesel (PO20, PO30, and PO40) in diesel engines. The find was 5.1 % BTE and 7.1 % lower pressure, while BSFC was 11.4 % higher than diesel. In the work of the author [19] oxygen molecules in vegetable oil decreased pollutants such as carbon monoxide, and hydrocarbons, low calorific value also decreased BSFC than diesel fuel. The paper [20] on a mixture of 20 % palm oil in diesel engines, found that ignition delay time reduces pressure. A mixture of diesel-crude palm oil (CPO) fuel with different concentrations of palm oil was used in four-cylinder diesel engines. It was found pressure, HRR, and delay time was decreased. On the other side, hydrocarbon and nitrogen oxide was reduced, but BSFC and carbon monoxide emissions increased compared to diesel fuel the authors of [21].

Magnetic fields had positive effects on fuel during the combustion in [22], this was due to the influence of changes in some of its physic-chemical properties are reported in works [23]. Some researchers thought that the installation of a permanent magnet or magnetic conditioner (MC) in channel fuel in a combustion engine (CE) may increase the combustion efficiency and decrease the gas emission the authors of [24]. One of the most common methods was the installation of the magnetic field in the fuel line, right in front of the injection of the diesel engine given in the works [25]. In the work of the author [26] magnetic field decreased the viscosity due to hydrocarbon molecule de-clustering, therefore resulting in better atomization and efficient combustion in the fuel-air mixture, this increased BTE and decreased SFC in diesel engines. Research also has been conducted on diesel engines affected by the magnetic field, diesel engine speed was varied (1000 to 2500) rpm without and with magnetic field intensity (0.7, 0.9, and 1.8 T), found a reduction in fuel consumption (15.71 %), BSFC (15.71 %) and (29.82 %) HC, but CO_2 increased by (33.04 %) were reported in [27].

From the explanation above, all researches have conducted performance researches and the performance only occurred in internal combustion engine. However, the behavior of the flames that have a major influence on combustion stability cannot be studied. Main interest should be given to research on the preheating of palm oil as alternative fuels and magnetic fields. This study is needed to find out the influence of preheating palm oil and the direction of magnetic field on combustion characteristics in power plants.

3. The aim and objectives of the study

This study aims to determine the influence of variations in preheating and the direction of magnetic field on the droplet combustions characteristic. This will make it possible to the heat generation industry requires high-temperature gas and constant combustion, this is why the addition of preheated vegetable oil and the magnetic field is needed.

To achieve this aim, the following objectives are accomplished:

– to study the evolution and stability of flames in droplet combustion by various preheating and directions of the magnetic field;

– to study the temperature and height of flames in droplet combustion by various preheating and directions of the magnetic field;

– to study the ignition delay and burning duration in droplet combustion by various preheating and directions of the magnetic field.

4. Materials and methods

The various preheating of palm oil and directions of the magnetic field on the droplets combustion affect fuel evaporation, intermolecular attractive forces, spins electron, combustion reactions, and electrons are more energetic, causing unstable flame behaviour. The instability of this flame behaviour is characterized by different evolution, temperature, height, delay time, and flame duration. The vegetable oil tested was palm oil obtained from commercial products. The palm oil has fatty acid compositions, physicochemical properties, glycerol, gum, and water have been studied previously [28]. This study was carried out using the equipment shown in Fig. 1. A droplet of palm oil is placed on a type K thermocouple made of Pt/Rh 13 %, 0.14 mm diameter.

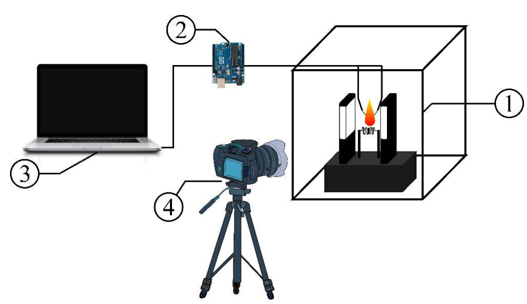

Fig. 1. Experiment apparatus: 1 – combustion chamber; 2 – data logger; 3 – laptop; 4 – high speed camera

The permanent magnet was made of neodymium of 11000 gausses with a measured 40×25×10 (mm) shown in Fig. 2. Two rectangular magnets are placed on a stand made of aluminium plate and fastened for easy removal and re-attachment changing the direction of the magnetic fields north (N) and south (S). Droplets that have been formed on the thermocouple were placed between two magnets at a distance of 15 mm. The droplet diameter is kept constant at about 0.35 mm, then ignited using an induction wire made from nichrome 0.7 mm diameter. This experiment varied the preheating temperature of palm oil at 40 °C, 50 °C, 60 °C and the magnetic field directions were south-south (S-S), north-north (N-N), south-north (S-N), north-south (N-S).

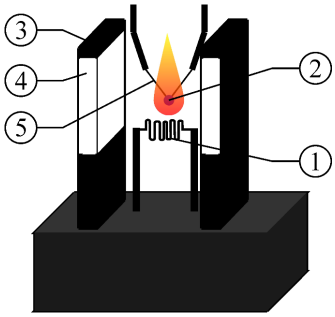

Fig. 2. Droplet and magnetic field position:
1 – heating element; 2 – droplet; 3 – magnetic holder;
4 – magnetic field; 5 – thermocouple

The collecting data was repeated 10 times with various directions of magnetic field and preheating of palm oil, then data processing was carried out. The data presented is the average value of the results of processing experimental data in all cases.

Thermocouple type K was connected with a data recorder Arduino UNO R3 Atmega 328 with the frequency of 0.01 Hz to send the signal of flame temperature to the laptop. The flames were recorded using a Fuji ZR camera at 120 fps, starting from burning until it was extinguished and stored on the sim card. Then it was processed using the application Free Video to JPG Converter. Droplet diameter, ignition delay time, height, and evolutions of the flame were measured using the Corel Draw application.

5. The results of the study of the droplet combustion characteristics of various preheating and directions of the magnetic field

5. 1. The evolution and stability of the flame

Fig. 3–5 show the stability and flame shapes in various preheating heating of palm oil and magnetic field directions. Fig. 3–5, *a* show that without magnetic fields, the flames were slimmer than the attractive and repulsive magnetic fields. On the other hand, the duration of combustion resulted in an evolution time of 1200 ms at preheat of 40 °C followed by 50 °C and 60 °C, 1139 ms and 1072 ms, respectively. With the addition of various magnetic fields, the N-S magnetic field has a significant influence on the evolution and shape of the flame as shown in Fig. 3–5, *e*.

The N-S magnetic field with preheats of 60 °C resulted in a very short evolution time of 670 ms, then followed by 50 °C of 737 ms and the longest evolution time at 40 °C of 871 ms. While the magnetic field S-N evolution time and flame stability approached N-S at various initial temperatures of 40 °C palm oil of 938 ms, followed by 50 °C of 804 ms and the shortest evolution time at 60 °C of 737 ms. The evolution time and flame stability in the S-S repulsive magnetic field are similar to that of the N-N but very different from the S-N and N-S attractive magnetic fields. The S-S repulsive magnetic field with various initial temperatures of palm oil resulted in the longest flame evolution, at 40 °C at 1139 ms then followed by 50 °C and 60 °C at 1072 ms and 938 ms, respectively. The directions of magnetic fields affected the shapes of the flames, showed by Fig. 3–5 the flames were wide or fat. This resulted from the explosion that occurred due to the water content in palm oil. The magnetic field made the H_2O molecules to break apart, thus each molecule was pulled out of in combustion.

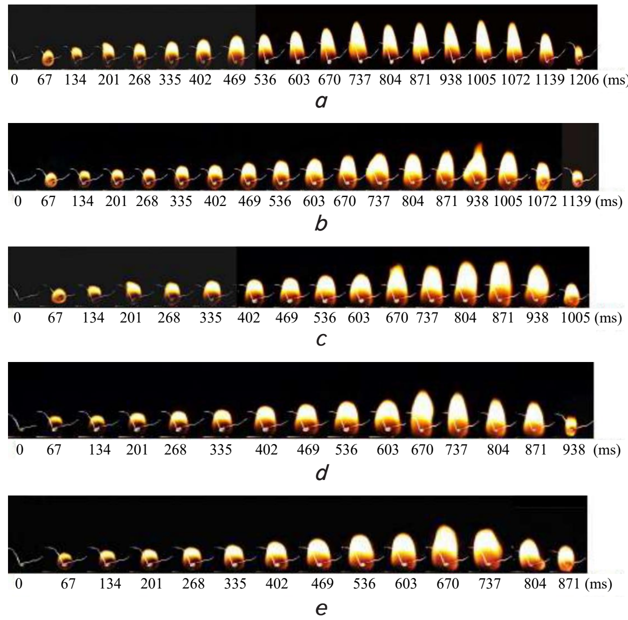

Fig. 3. Evolution and stability of the flame by preheating 40 °C palm oil: *a* – without magnetic field; *b* – magnetic field S-S; *c* – magnetic field N-N; *d* – magnetic field S-N; *e* – magnetic field N-S

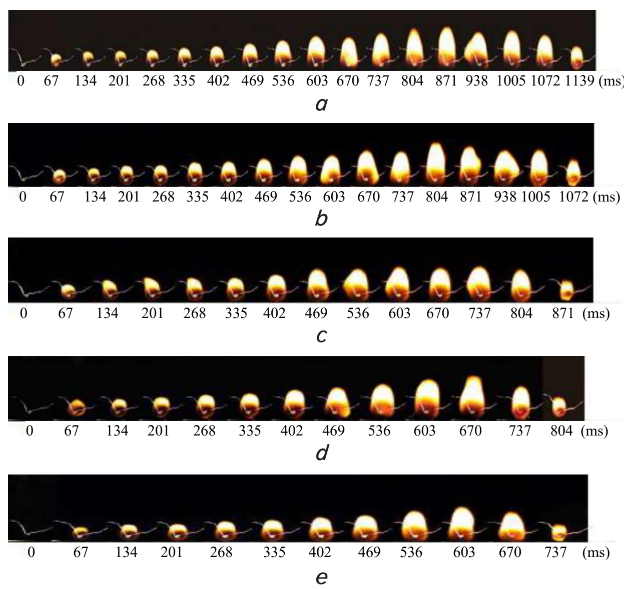

Fig. 4. Evolution and stability of the flame by preheating 50 °C palm oil: *a* – without magnetic field; *b* – magnetic field S-S; *c* – magnetic field N-N; *d* – magnetic field S-N; *e* – magnetic field N-S

The shape of the micro-explosion is spherical, this high pressure affects the release of bubbles that water vapor in palm oil. Upon exploded, the fuel vapor in the bubble did not have sufficient time to disperse and react quickly and therefore, became a spherical flame [29].

Shown in the Fig. 5, when the preheating temperature of the oil was increased, the number of micro-explosions produced were more than in Fig. 3, 4. Explosions in droplet combustion indicated by the asymmetrical shape of the flame. Fig. 3 showed the number of explosions were less that Fig. 4. The initial temperature of the palm oil affected the number of explosions in droplet combustion. The greater number of explosions, the greater energy produced.

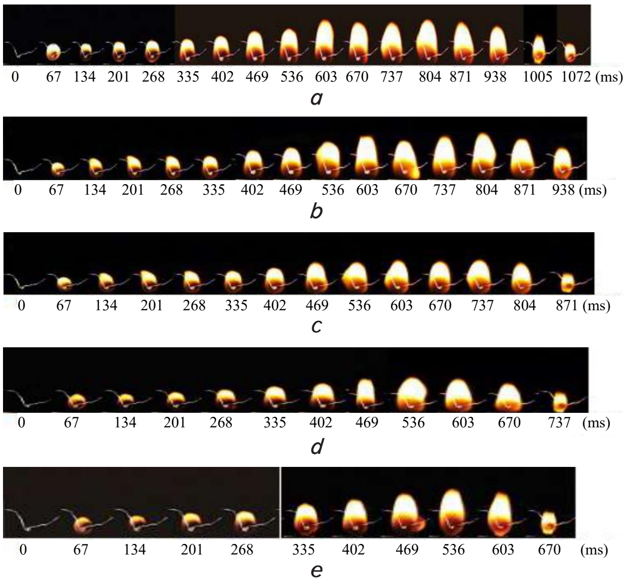

Fig. 5. Evolution and stability of the flame by preheating 60 °C palm oil: *a* – without magnetic field; *b* – magnetic field S-S; *c* – magnetic field N-N; *d* – magnetic field S-N; *e* – magnetic field N-S

drastic temperatures increase, inversely proportional to S-S, N-N and without.

The smaller intensity of magnetic direction, the smaller temperature produced due to the lack of O_2 caused the combustion reaction to be incomplete. The more complete the combustion reaction, the higher the temperature of the flame.

The difference in flame height during droplet combustion has been affected by the preheating temperature of the palm oil and the direction of the magnetic field as shown in Fig. 9–11. The highest height was 8.5 mm without magnetic field at 1005 milliseconds (ms) then the trend was down until went out, meanwhile the lowest 680 mm at 670 ms with the magnetic direction N-S shown in Fig. 9.

Shown in Fig. 9–11, the highest flame of palm oil with initial heating of 40 °C, then followed by 50 °C and 60 °C. Palm oil with initial heating of 40 °C on without magnetic field, then followed by magnetic field direction S-S, N-N, S-N, and N-S respectively 6.69 mm, 5.97 mm, and 5.89 mm with varying heights. The higher initial heating of palm oil, the lower the flame height. The difference of the flame height due to: firstly, the initial heating of palm oil resulted in lower viscosity therefore the combustion process occurred quickly.

5. 2. The flame temperature and height

Fig. 6–8 showed the flame temperature of palm oil droplet combustion by varying the direction of the magnetic field and preheating of 40 °C, 50 °C and 60 °C.

Palm oil is preheated to 60 °C in the N-S magnetic field, the highest temperature is 888.98 °C, followed by 50 °C and 40 °C with temperatures of 836.25 °C and 806.25 °C, respectively.

The attractive S-N magnetic field resulted a temperature close to that of the N-S magnet, at the highest temperature with the preheat of 60 °C palm oil at 848.72 °C followed by 50 °C and 40 °C at 805.74 °C and 789.17 °C, respectively.

The addition of an N-N repulsive magnetic field resulted in the highest temperature at the initial temperature of 60 °C palm oil at 817.39 °C followed by 50 °C and 40 °C, 789.85 °C and 777.25 °C, respectively.

Meanwhile, the highest temperature S-S repulsion magnetic field resulted in the preheating of 60 °C palm oil at 790.5 °C, followed by 50 °C and 40 °C, 766 °C, and 756.25 °C, respectively.

The lowest temperatures in various preheating palm oil respectively were 734.68 °C, 745.75 °C and 766.75 °C on combustion of without magnetic field.

Magnetic fields of N-S, S-N at all initial heating experienced a very

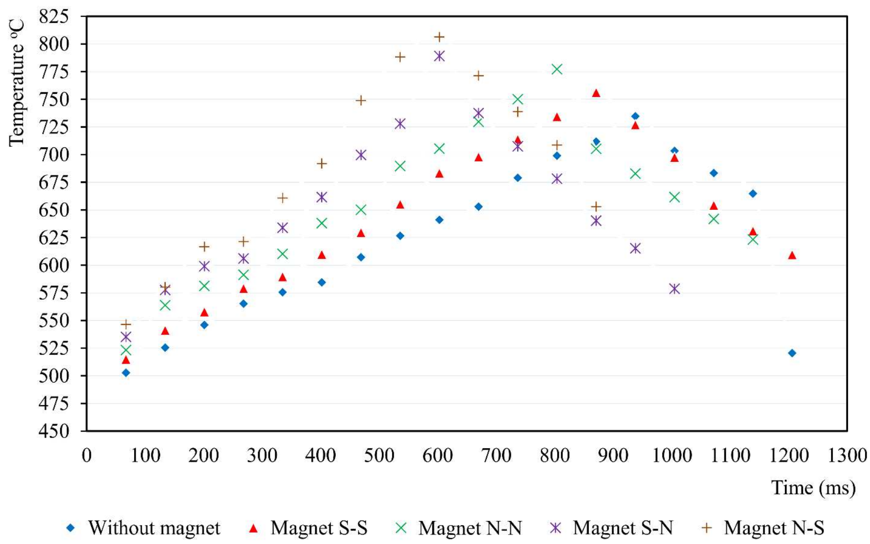

Fig. 6. Flame temperature by preheating 40 °C palm oil

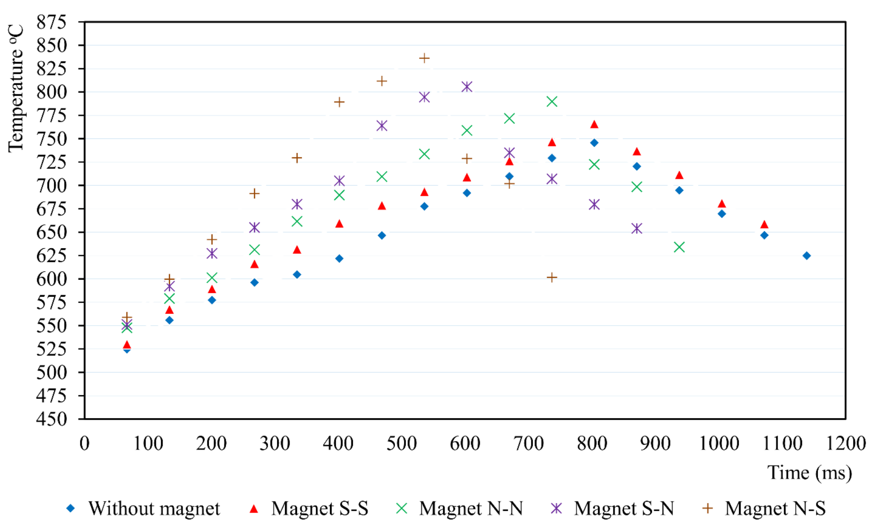

Fig. 7. Flame temperature by preheating 50 °C palm oil

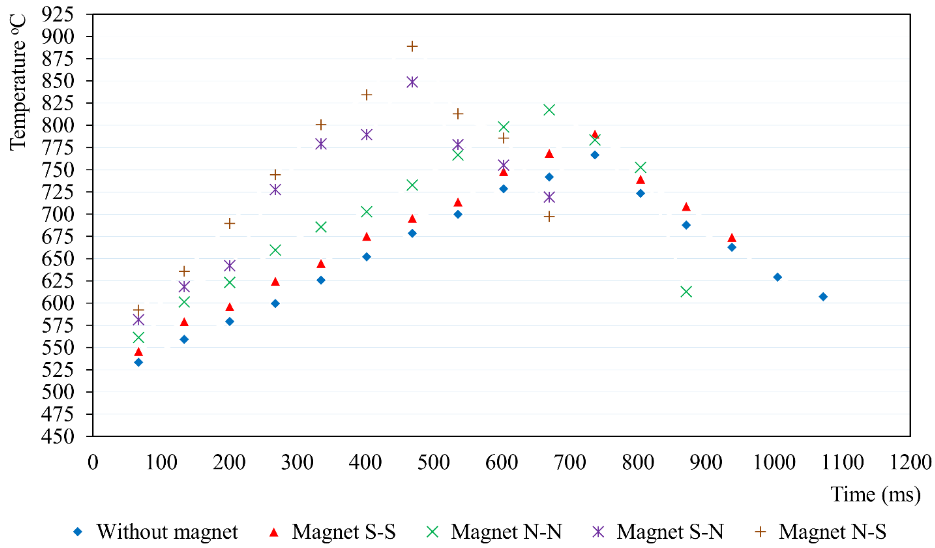

Fig. 8. Flame temperature by preheating 60 °C palm oil

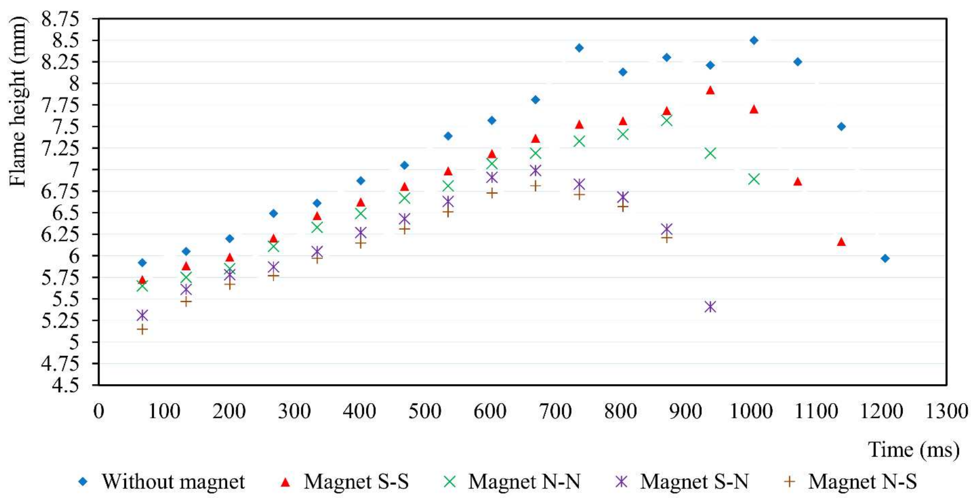

Fig. 9. Flame height with palm oil preheating 40 °C palm oil

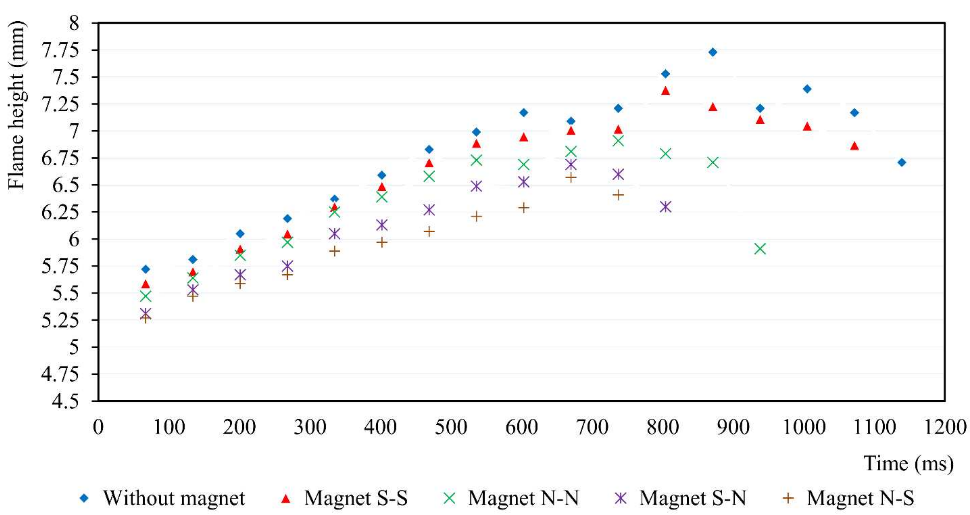

Fig. 10. Flame height with palm oil preheating 50 °C palm oil

The magnetic field has an effect on complete combustion, this is because O_2 from the surrounding air is drawn into the combustion thereby accelerating the reaction process with fuel.

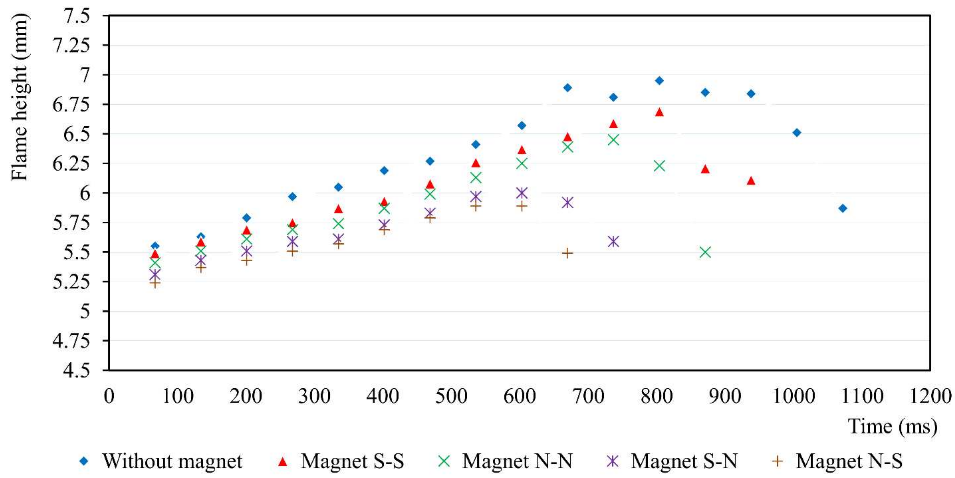

Fig. 11. Flame height with palm oil preheating 60 °C palm oil

5. 3. The ignition delay time and burning duration

Fig. 12–14 show the flame delay time in the variations in preheating of palm oil and magnetic field direction. Preheating at 40 °C without magnet field produced the longest ignition delay time of about 9297 ms, then followed by the directions of S-S, N-N and S-N magnetic fields, respectively 8271 ms, 7983 ms and 6934 ms. The fastest time of ignition by using N-S magnetic field of 6705 ms is shown in Fig. 12. As shown in the Fig. 12–14 that the flame delays trend decreased by using various directions of the magnetic field.

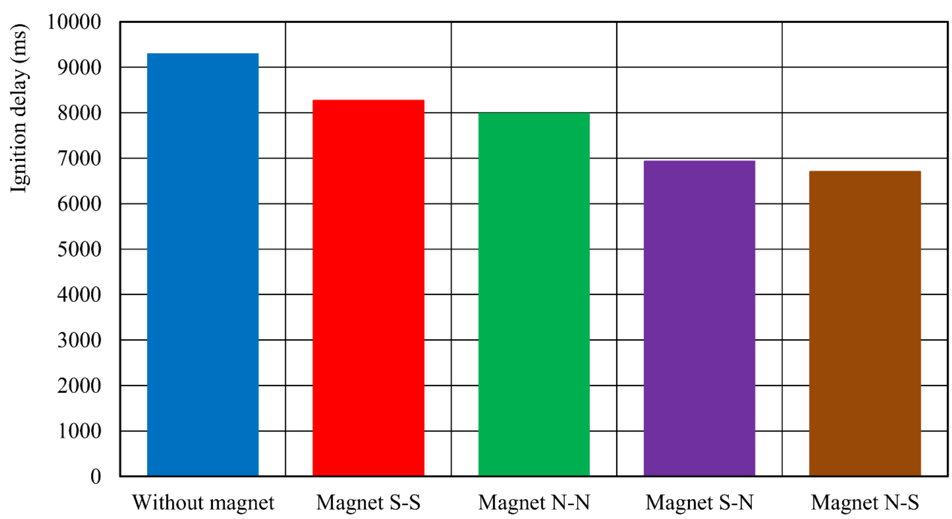

Fig. 12. The ignition delay time by preheating 40 °C palm oil

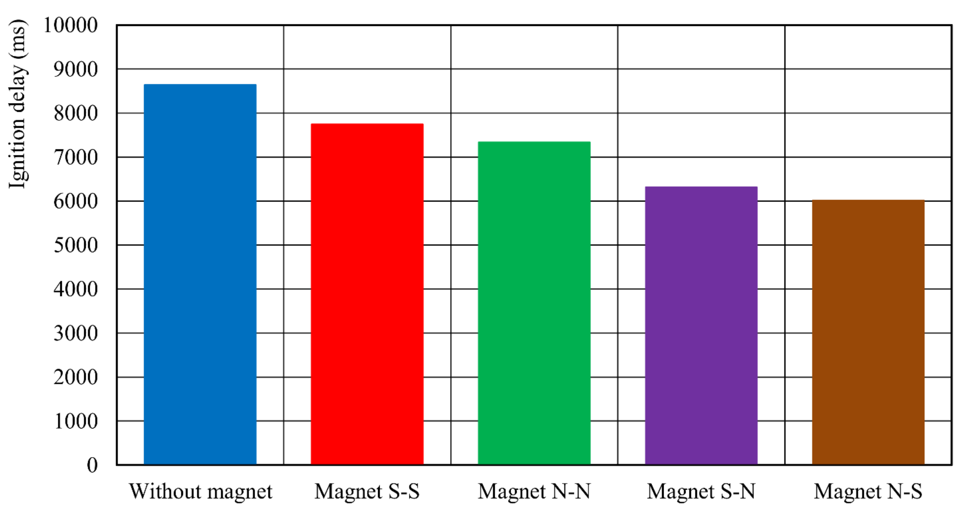

Fig. 13. The ignition delay time by preheating 50 °C palm oil

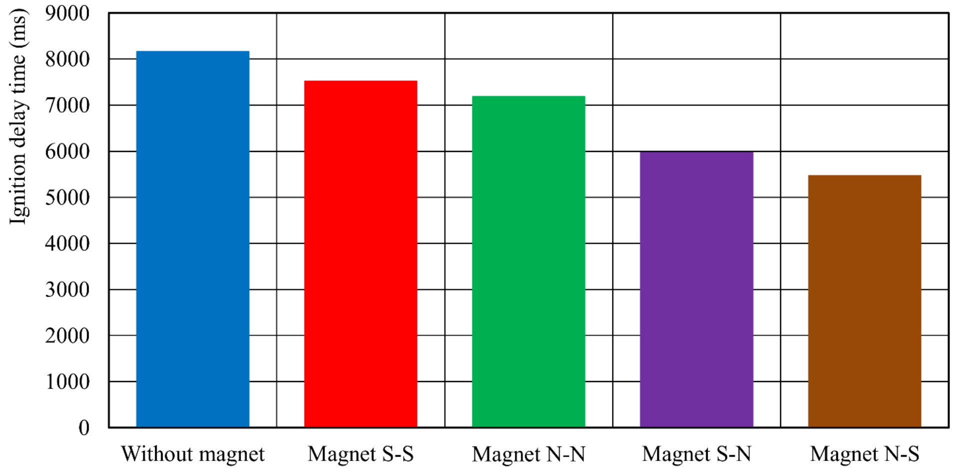

Fig. 14. The ignition delay time by preheating 60 °C palm oil

In general, there were three groups of flame delay time, the first was without magnetic field, then magnetic field directions of N-N, S-S, the second and the last was S-N, N-S. S-N and N-S attractive magnetic fields produced the shortest flame delay time, compared to N-N and S-S. The direction of the S-N and N-S magnetic fields with variations in the initial heating of palm oil, helped to improve the atomization process by increasing the formation of mixtured therefore the ignition delay time is shorter. The duration of flame with variations in the initial temperature of palm oil and magnetic field direction is shown in Fig. 15–17. Variations in preheating of palm oil and magnetic field direction affected the duration of flame combustion, without magnetic direction had a longer flame than with using magnetic field.

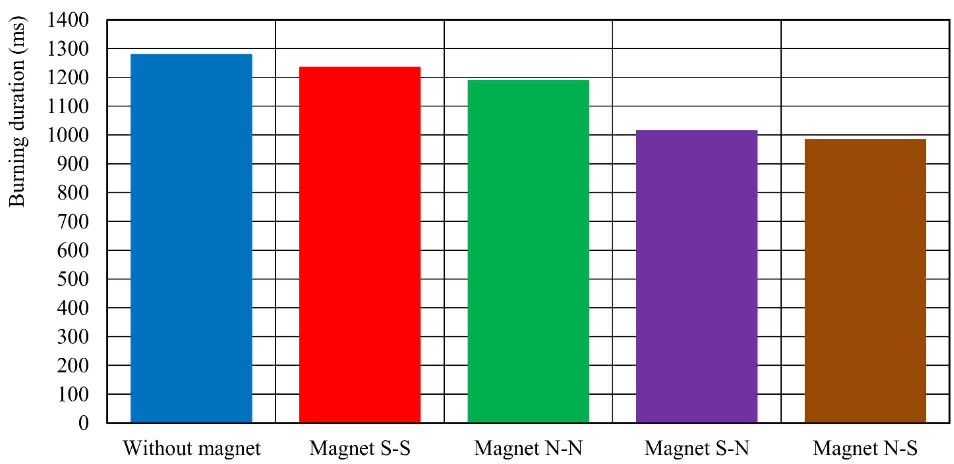

Fig. 15. Burning duration of the flame by preheating 40 °C palm oil

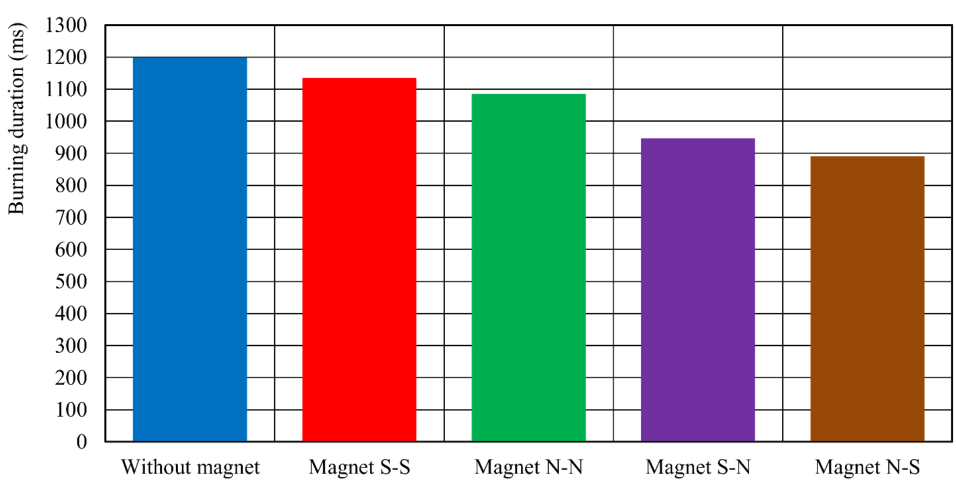

Fig. 16. Burning duration of the flame by preheating 50 °C palm oil

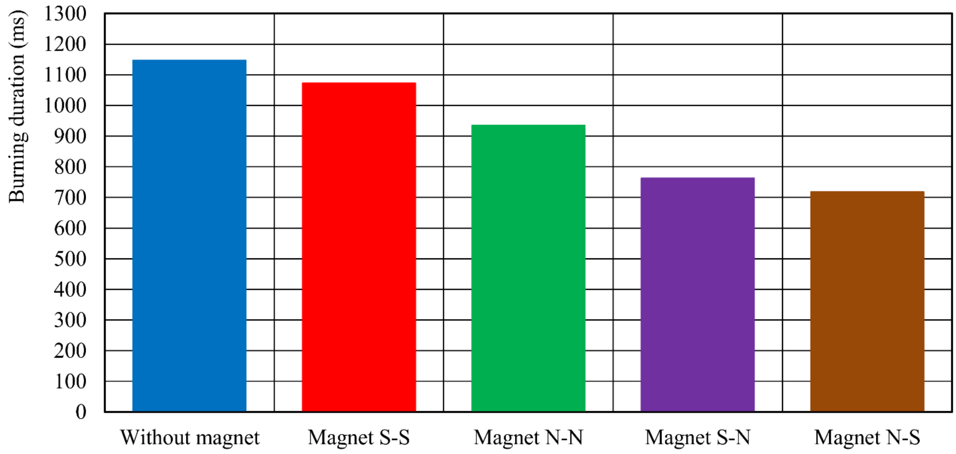

Fig. 17. Burning duration of the flame by preheating 60 °C palm oil

Fig. 15 showed the duration of flame combustion, with without using magnetic field, combustion had the longest duration of 1279 ms than repulsive and attractive magnetic fields. Magnetic field directions of S-N and N-S had a shorter duration of combustion, which respectively were 1015 ms and 984 ms than directions of the repulsive magnetic field S-S were 1235 ms, and N-N was 1189 ms.

The shown in Fig. 16, 17. The shorter combustion duration showed that the speed of reaction in fuel and oxidizing agent were faster and stable, the concentration of oxygen increased in flame reaction zone and resulted in a complete combustion.

Showed by Fig. 15–17, the duration of combustion experienced a downward trend from without to the direction of the magnetic field of attraction N-S. Variations by using either repulsive or attractive magnetic field direction affected the combustion reaction where the paramagnetic air was drawn into and held in the reaction zone, on the other hands the diamagnetic products of combustion were pushed out from the reaction zone.

6. Discussion of the results of the characteristics of the flame on the droplet combustions

The result in Fig. 4, 5 show the flame geometry widened like a mushroom at preheating of palm oil 50 °C and 60 °C, meanwhile at temperature 40 °C widens like a nail shown in Fig. 3. Palm oil is classified as high in saturated fatty acids compared to unsaturated fatty acids. The components are combustion one by one and need a longer time. This emphasizes this unsaturated are more reactive than saturated fatty acids. On the contrary, saturated fatty acids in palm oil have a high flashing point [28]. Therefore it needs a long time of evaporated and a yellow flame forms from higher thermal radiation to stabilize the flames. When the preheating of palm oil increases, the micro explosion will be more intense. Palm oil with high preheating may decrease the viscosity and density, especially unsaturated fatty acids so that it easily evaporates and reacts with oxidizing agents. The evaporation rate is a slower possible saturated acid breakdown which results in a longer flame following the diffusion flame length theory. That fast combustion can cause the flame length to become smaller, because the flame length is inversely proportional to molecule diffusion. The higher the intensity of the magnetic field, the rate of the combustion reaction increases. With the increasing rate of combustion, the shorter duration of combustion of the flame is shorter. Magnetic fields S-S, N-N, S-N and N-S effect in reducing the length dimension of the flame because it has a larger magnetic field in one atom that interferes with the movement of electrons and the bonding of palm oil molecules, therefore the electron bonds are weaker and easier to release than without magnet. Movement due to magnetic field exists in molecules and they have positive and negative electric charges. The higher the intensity magnetic field, the more easily the hydrocarbon molecules break, so there is a gap for O_2 to combine with the fuel. The magnetic field produces a repulsive force between the hydrocarbon molecules so that the optimal distance between the hydrocarbon molecules will be formed. Finally, the hydrocarbon molecules will be more oxygen reactive and more flammable.

The result of increasing the combustion speed is an increase in the maximum combustion temperature, which can be seen in Fig. 6–8, *e*. The flame temperature of vegetable oil is influenced by some factors, first, it is influenced by the carbon chain length and number of double bonds (indicating the degree of unsaturation). The increase in heat from combusting saturated fatty acids is indicated by an increase in the amount of carbon. These characteristics greatly affect many physical and chemical properties, such as: viscosity, density, cetane number and calorific value [30]. The high-temperature flame from the oil combustion shows the power resulting from oil combustion. The higher the flame temperature shows the greater power resulted from oil combustion. Similar to placing a magnetic field between flames, the stronger the magnetic field intensity the higher the temperature. This is due to the magnetic field disturbs the electrons' movement on fatty acid molecules resulting in the electron being ejected from its orbit therefore the fatty acids bound become weak and distancing from each other, resulting in bonds between fatty acids molecules being more easily broken when given heat energy. The electrons that are ejected from the fatty acid orbit result in fatty acids only have positively charged protons. During the combustion, the oxygen has high electronegativity therefore it can attract the electron to move to the oxygen therefore the oxygen is more negatively charged. When the negatively charged oxygen reacts with the positively charged fatty acids, it results in a massive force of attraction. The force attraction results in collision between molecules that accelerate combustion reaction.

The result in Fig. 9, 10 showed without magnetic field the maximum flame height was at 1005 ms and 871 ms, while in Fig. 11 was at 804 ms, which was calculated from the start of ignition.

The height difference is possible because of the preheating difference, the higher the preheating of palm oil, the faster evaporation occurs so that the combustion is faster after it diffuses into the air, causing a shorter flame height in the middle of the combustion. This is because more vapor resulted from the evaporation on the surface of the droplets. Next, the size of the flame drastically decreases until extinguished. The combustion of this steam produces a small fire.

Similarly, with without magnetic, S-S and N-N magnets are very slow, compared to the direction of the fast and short S-N and N-S magnetic fields that the flame height is short. This indicates that those tree conditions are very unreactive compared to the other two conditions, so the combustion is less than complete because there is some unburned fuel. Magnetic field direction N-S affects the flow rate of O_2 causing convection around the flame, so that the oxygen flows to the lower part of the flame from two sides due to the attractive force of the magnetic field. The flow increases the oxygen concentration and the fuel molecule around the reaction zone causing the combustion to be more reactive and shorter therefore results in big flame angle and affects the increase in the flame height. The greater the magnetic field (N-S), the greater angle of the flame, so the flame height is very short, on the contrary, the smaller the angle of the flame (S-S), the smaller the flame height, so the flame is higher. This phenomenon occurs due to the release of molecules of oxygen and H_2O that is ejected due to the repulsion between magnets around the flame, causing the flame to diffuse because it reacts in the cone zone with a higher flame.

A high preheating of palm oil affects the short delay time of the flame, this causes the viscosity to decrease thereby increasing the possibility of micro-explosion without changing some basic combustion parameters such as ignition delay and combustion rate. In a higher oil temperature, there is more possibility of micro explosion and the combustion process is better.

When the preheating is increased by 60 °C shown in Fig. 14, caused the unsaturated fatty acids especially oleic acid and linoleic start the evaporation first before diffusing with the oxidizing agent to form reactants and then being combusted. This shorter evaporation process causes the diffusion of the fuel with the oxidizer to occur in a narrower area.

The lowest ignition delay value occurs due to: first, the increase of the preheating of palm oil accelerates the combustion reaction because unsaturated fatty acids have a low flash point, thus accelerating the combustion reaction.

Second, the magnetic field creates an electromagnetic force that interferes with the electrons in palm oil, so that the activation energy needed to react the fuel and oxygen is reduced which causes the combustion process to be relatively faster.

The results of Fig. 17, in which the speed of evaporation of palm oil fuel increases along with the droplet temperature so that the combustion duration and speed are getting shorter. The viscosity change of the palm oil is caused by the increase in polarity molecules during the magnetization. Magnetic field intensity causes a change in molecular density on the atomic bond area or molecules and increase the dipole moment thus increase the molecules polarity. Increase in polarity have a strong relationship with de-clustering phenomenon because of the increase of dipole moment in bonds between molecules. Increased intermolecular repulsion causes a decrease in the viscosity of the fuel, creating a maximum distance between the hydrocarbon and oxygen molecules.

As a result, magnetized fuels have low intermolecular bonds, low stability, high reactivity and are easily oxidized, causing short combustion and producing higher energy than without magnet. The higher the temperature, the higher the value of the burning rate. This is due to the higher the preheating of the oil, the faster the combustion time. This is because the diffusion process in the droplets and air is getting faster, thus the diffusivity value is getting bigger. The greater the diffusivity value, the faster the droplets run out during combustion.

This study provides insight into the influence of variation in preheating of palm oil and the direction of the magnetic field on combustion characteristics for boiler combustion in the power generation system. The power generation system requires high-temperature gas and constant combustion, this is why the addition of a magnetic field is needed.

However, this research still has shortcomings related to the number of types of vegetable oils, the intensity of the magnetic field, and experimental work that is only carried out in laboratory installations with limited power generation equipment.

Further research is needed for the development and application of the machine, to obtain some data for the advancement of the power generation and transportation industries.

7. Conclusions

1. It has been found that increasing preheat of 60 °C palm oil and magnetic fields N-S attraction resulted in shorter evolution time, low flame height and wide flames. This is due to the strong attractive force between magnetic fields to attract O_2 free radicals as paramagnetic and push out the gas combustion products as diamagnetic so that it affects the combustion speed to be more reactive.

2. The high preheat of the palm oil of 60 °C and the magnetic attraction of N-S accelerates the process of evaporation of palm oil to a shorter extent causing the diffusion reaction of the fuel with the oxidizing agent to occur in a narrow area. Resulting in the highest flame temperature but a flame height shorter.

3. The combustion speed is influenced by the high preheat of 60 °C palm oil and the magnetic field of N-S so that the attraction between the oxygen molecules reacts quickly with the fuel molecules causing the combustion speed to take place quickly so that the delay time and burning duration are getting shorter.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has data included as electronic supplementary material. Data used to support the finding of this study have been deposited at https://figshare.com/account/home#/projects/154472.

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