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Flame Behavior During the Combustion of Premixed Kapok Oil Influenced by Oxygen and Magnetic Field

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ABSTRACT

This study aimed to determine effect of oxygen enrichment and magnetic field direction on the flame behavior kapok oil combustion. Experiment was carried out to obtain flame evolution, temperature and height. Kapok oil (600 ml) was put in the boiler, and heated to 300°C. A burner chamber is placed for the reaction between kapok oil vapor with air from compressor and oxygen. Two permanent magnets of neodymium nickel grade N52 with intensity 1.1 Tesla were placed on side of burner tip. Results showed the magnetic field produce more transparent, slimmer flames with highest temperature of 679°C, lowest flames height of 5 mm. Magnetic fields produce a Lorentz force that breaks the fuel chemical chain and creates magnetic pulses in the flames. Oxygen contained in air around the burner coupled with oxygen enrichment create excessive oxidizing gas to separate and release electrons. Excessive oxygen results in a higher flame temperature due to faster combustion reaction. The magnetic fields around flames induces flow air which magnetically cause heat transfer around the flame, resulted variable flame height. This combustion produces different flame evolution, temperature, and height.

1. INTRODUCTION

Energy has an important role on driving economic of growth, causing demand on fossil fuels to increases every year. However, petroleum reserves are decreasing. The use of fossil fuels causes greenhouse gas emissions, pollutants like CO, CO_2, NOx, SOx, and heavy metals. Vegetable oils are abundantly available in natural from variety of sources, easily renewable quickly and biodegradable (Ali *et al*., 2015). However, its use directly in diesel engines still causes problems, including high viscosity and flash points making the fuel difficult to burn (Yilmaz *et al*., 2018). In addition, incomplete combustion produces carbon deposits in combustions chamber (Che Mat *et al*., 2019). Higher viscosity of results on imperfect atomizations, low evaporation rates, and incompletes combustion, as well as shortening life of fuel filter (Yilmaz & Vigil, 2014). Vegetable oils come from edible and no edible such as soybeans, coconut, sun flower, jatropha, pongamia pinnata, kapok, neem, rubber seeds etc. To overcome the shortage of vegetable oils, a number of researchers apply vegetable oil derivative fuels such as biodiesel, biodiesel with diesel, a mixture vegetable oils with diesel and vegetable oils mixed to bioethanol. One of the non-edible oils that has the potential to be used as fuel is kapok (*Ceiba pentandra*) oil. Kapok oil consists of a mixture of glycerol triesters and fatty acids which are generally called triglycerides. Most of the constituents of kapok oil are composed of 15–20% saturated and 80–85% unsaturated fatty acids (Yuniwati, 2012). Kapok seeds have a higher oil yield (26.4% w/w) than vegetable oils such as soybeans (18–22%). Because of these properties, kapok is a promising source of non-vegetable oil for biodiesel production (Kusumaningtyas *et al*., 2019). A number of researchers have conducted research using kapok oil biodiesel fuel in diesel engines. Kapok oil biodiesel (B20, B30, B40 and B100) blends with diesel were tested to diesel engine, finding performance of B30 to be similar diesel compared to B20, B40 and B 100. Brake specific fuel consumption (BSFC) and exhaust gas temperature (EGT) are 1.9% and 3.1% higher respectively than diesel. Meanwhile, the brake thermal efficiency (BTE) of all mixtures is close diesel. Without a mixture of diesel (B 100), carbon monoxide (CO) and hydrocarbon (HC) decrease respectively by 23.33% and 40% compared diesel (Asokan *et al*., 2016). Variable compression ratio engine (VCRE) type diesel engine with mixture of kapok oil biodiesel (B10, B20, B30 and B40), it was found that an increase in compression ratio (CR) caused an increase in BTE for the B10 fuel mixture. At CR 18, CO_2, HC and NOX increase with longer ignition delay time (Rathinasamy, 2016). Kapok oil biodiesel (B25, B50, B75, and B100) is used in single cylinder diesel engines under full load conditions with a constant CR of 17.5:1. The B25 blend shows an increase of 6.27 in BSFC and a decrease in BTE, CO, HC, NOX and suggests that B25 biodiesel blend to be used as substitute fuels for diesel (Panneerselvam *et al*., 2016). Research by Silitonga *et al*. (2013) on diesel engines burning kapok oil biodiesel (B10) have been found an increase on torque, brake power (BP) and BSFC. Engine performance is achieved an engine speed of 1900 rpm under fulled loading condition. BSFC in kapok oil biodiesel is 22.98% higher while CO_2 and CO have decrease compared to diesel. Process of converter pure vegetable oils to biodiesel, such as transesterification (Liu *et al*., 2017), esterification (Leevijit *et al*., 2016) and partial hydrogenation (Thunyaratchatanon *et al*., 2016), has disadvantages because it requires additional energy, materials, equipment, and costs, causing fuel production costs from this process to become an obstacle (Sonthalia & Kumar, 2019). These factors limit biodiesel production and demand, so several researchers have reviewed potential of vegetable oils as alternative fuel (Yilmaz *et al*., 2018).

To overcome of shortcoming vegetable oils mentioned above, increased efficiency and reduces combustion emission, addition of magnets has been used by several researchers. Properties of fuel will improve better by adding a magnetic field so that it can balance and direct the hydrocarbon molecules. A number of studies are investigated influence of the magnetic fields to diesel and petrol engines on pollution, emissions and energy (Chaware & Basavaraj, 2015). Four magnetic fields with different intensities (0 G, 3200 G, 4800 G and 6400 G) applied to a diesel engine were found to increase thermal efficiency by 3.9% and fuel consumption decreased by 13.8% (Oommen *et al*., 2020). The magnetic tubes was install of fuel inlet on generator in idle condition with constant speed of 1800 rpm, with loading variations of 50% and 25% respectively. Specific fuel consumption (SFC) and BSFC were reduced an average of 15% and 3.5%, while BTE increased around 3.5%. CO, particulate matter (PM), hydrocarbon and CO_2 were reduced around, 5.4–11.3%, 21.9–33.3%, 29.4–64.7% and 2.68–4.18% (Chen *et al*., 2017). Research was also carried out on diesel engines with variations in 1,000 to 2,500 rpm with addition of magnetic fields with intensity of (7000 G, 9000 G and 18000 G) and without magnet, finding that addition of magnetic field result in reduction on SFC of around 15.71%, BSFC 15.71% and HC 29.82%, but CO_2 increased by 33.04% (Kurji & Imran, 2018).

Flame characteristics play very important role in engine performance which was influenced by combustion stability, but very few have been studied. 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. Premixed combustion is the process of mixing fuel and air in a mechanical mixing chamber. Premix combustion with additional magnetic fields and oxygen enrichment requires special attention. Continuously study was needed, mainly regarding the effect of magnetic field directions and oxygen enrichment of completed combustion, resulting in shortness combustion and optimum energy. This research aims to provide discussion of role of variations in direction of repulsive magnetic fields, attractive magnetic fields, without magnets and oxygen enrichment in premix combustion of kapok oil fuel on characteristics combustion chamber.

2. MATERIALS AND METHODS

2.1. Materials

Kapok oil was used as fuel in this research, obtained from products from Balittas Malang, East Java. Fatty acid compositions, physical, chemical properties, glycerol, gum and water of vegetable oils have been shown on previous research (Perdana *et al*., 2018).

2.2. Experimental Procedure

Laboratory experiment was applied in this research using instruments shown schematically in Figure 1. Kapok oil with a volume of 600 ml was filled in a boiler heated to a stable temperature of 300°C. Addition of a concentration of 25% oxygen as a solvent from the concentration of kapok oil vapor. The evaporation of kapok oil from boiler was then reacted with oxygen and air from the compressor on the burner chamber, which went to a nozzle diameter of 20 mm. When the inlet valve of fuel vapor was opend and oxygen kept constant then the level in the U pipe (flow control) was observed while air inlet valve was in the closed position. At the end of the burner, a flame feeder was provided so that a diffusion flame was formed. After flame was formed, the air inlet valve was periodically opened by noting the height difference on the flow control. The mas flow rate of air ($\dot{m}_{air}$), oxygen ($\dot{m}_{oxygen}$), and fuel ($\dot{m}_{fuel}$) were obtained by multiplying the density and the flow rate after passing through flow control. The air mass flow rate was repeated by increasing the air volume until the flame extinguished, while the mass flow rates of oxygen and fuel were kept constant to obtain the different air fuel ratios (AFR). A permanent magnet neodymium (N52) with magnetic field inten-

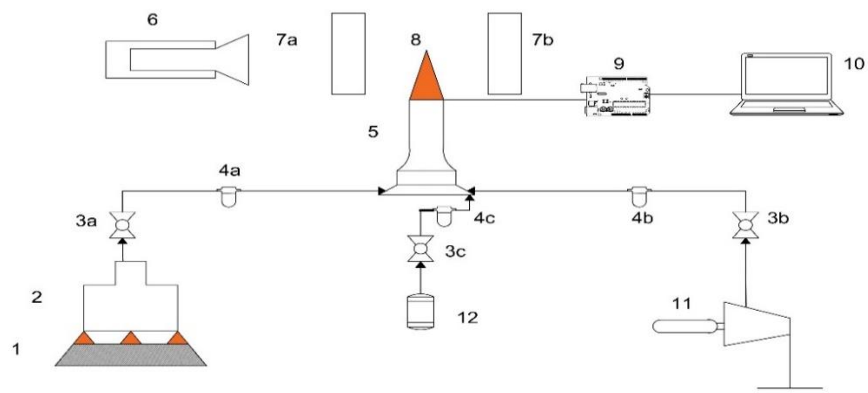

Figure 1. Research premix combustion installation: 1. Stove, 2. Boiler, 3. Valve, 4. Flow control, 5. Burner, 6. High speed camera, 7. Magnet permanent, 8. Flame, 9. Thermocouple connected to data logger, 10. Laptop, 11. Compressor, 12. Oxygen

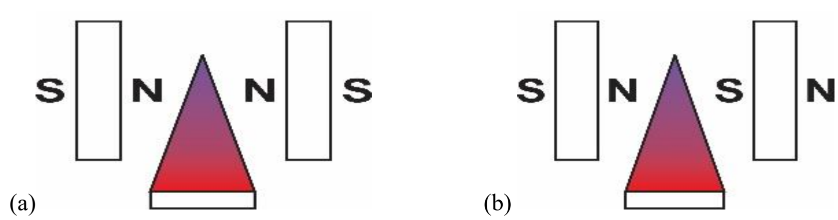

Figure 2. Field direction position; (a) repulsive (N-N), (b) attractive magnetic field (N-S) (Perdana *et al*., 2020)

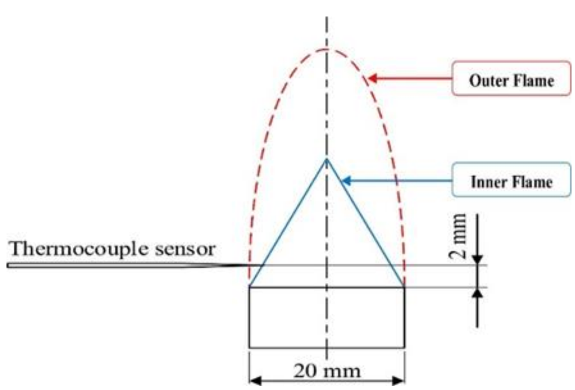

Figure 3. Thermocouple position (Perdana *et al*., 2020)

sity of 1.1 Tesla was placed between the tips of the nozzle with the positions of North-North (repulsive) and North-South (attractive) magnetic fields, as showed in Figure 2. The magnet rods were put in place 20 mm. A high-speed camera Fuji ZR of 250 frames per second (fps) was used to record images of the flames. The images were captured 3 times from the time until the flame extinguished. Free video to jpg converter was used to process recorded images so that several flame photo frames were produced with a time size of milliseconds (ms). A CorelDraw application was used to get data on the evolution and height of the flame. A K type thermocouple was placed 2 mm above the nozzle to measure temperature, as shown in Figure 3. Thermocouple which shows temperatures change signal during combustion was connected to an Arduino UNO R3 Atmega 328 data logger with a frequency of 0.01 Hz by send flames temperature signal to laptop.

3. RESULTS AND DISCUSSION

3.1. Flames Stability and Shape

Shown in Figure 4a-4c is stability and shape of premix combustion flame with variations in the AFR magnetic field of repulsion, attraction and without the addition of oxygen. The flame formed is divided into two zones, namely the inner and outer flame cones. Without a magnet, the flame color results in a hazy color. However, when the droplet combustion the color of flames is yellow-red (Perdana *et al*., 2023a). While the repulsive and attractive magnetic fields produce a clearer color, this is caused by the lorentz force with eddy currents continuously rotating and breaking the flame itself, causing polarized lighting waves. These results are an accordance with previous researched by Perdana *et al*. (2020) on burning premixed coconut oil. Without magnet on flame is most stable compared to repulsive and attractive magnetic field, this is proven by the AFR from 3.51 to 13.59 showed in Figure 4a. Then followed by repulsive and attractive magnetic fields with AFR 3.51 to 10.61 and 3.51 to 9.36 respectively. shown in Figure 4b-4c. These different flames characteristic are caused by, first: reactant speed will affect on fuel diffusion, when speed of the reactants is higher, fuel diffusion occurs more rapidly. Addition of magnetic fields to combustion reaction causes more complete combustion as evidenced by the very short flame time. More energetic reactions result in fuel compound becoming smaller elements so they react easily and faster. In a repulsive magnetic field, one of the O_2 or H_2O will be pumped out following the direction of magnetic fields (Perdana *et al*., 2023a). This causes O_2 as a paramagnetic gas tend to move in direction of magnetic field, but H_2O as a diamagnetic gas will moves against direction of magnetic field. It's possible that O_2 as a paramagnetic gas will tend to move in the direction of magnetic field, but H_2O as a diamagnetic gas will move against the direction of magnetic field. This causes chemicals reaction during combustion to be less than optimal as seen in Figure 4b. Repulsive of magnetic field produces less perfect combustion, as evidenced by the formation of a diffusion flame (yellow flame) at AFR 3.51 to 4.99. It is possible that when the direction of magnetic field repels H_2O that is pumped in across flame while the O_2 is pumped out. However, on the

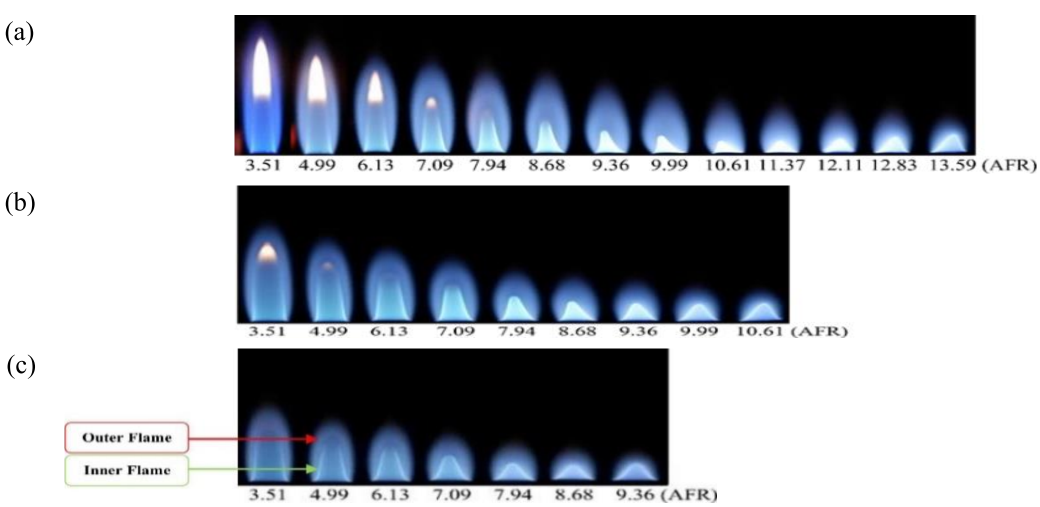

Figure 4. Correlation of AFR on flame stability and shape: (a) without; (b) repulsive; (c) attractive magnetic field

direction of attractive magnetic field, the two elements O_2 and H_2O will both be pumped in through the flame so that it does not produce a diffusion flame (yellow flame). Second; the addition of oxygen will speed up the reaction with the fuel. Negatively charged oxygen causes massive collisions with fuel molecules, resulting in a decrease in activation energy. This decrease in activation energy causes an increase in combustion speed.

3.2. Flames Temperature

Figure 5 showed that higher flames temperature in premix combustion occurs in attractive of magnetic fields, when it starts to burn at AFR 3.51 with result temperature of 437°C, as the AFR increases the trend increases until AFR 8.68 reaches the highest temperature of 679°C, then followed by a decrease in temperature of 603°C before flame extinguished at AFR 9.36. The repulsive magnetic field produce on the higher flame temperature of 619°C at AFR 9.35 then the trend decreases until the flame begins to extinguish with a temperature of 491°C at AFR 10.61. Meanwhile, the lowest flame temperature in premixed combustion without magnets was 597°C at AFR 11.37. The highest flame temperature in an attractive magnetic field allows Lorentz force to break the chemical chain of the fuel producing magnetic vibrations in the flame. Movement of electrons on fatty acid molecules is influenced by a magnetic field which causes the electrons to move out of their path, causing the bonds to break when heat energy is applied. Fatty acids only have protons and are positively charged when electrons move out of their path. Oxygen has high electronegativity so it is easy for binding electrons to migrate to oxygen. The attractive force results from negatively charged oxygen reacting with positively charged fatty acids, causing collisions between molecules so that the combustion reaction takes place quickly and produces maximum temperatures. Adding oxygen to combustion chamber tends to reduce energy required to burn the mixture. Due to enrichment of oxygen in the combustion chamber, it produces more stable, complete and higher temperature which can lead to better heat transfer.

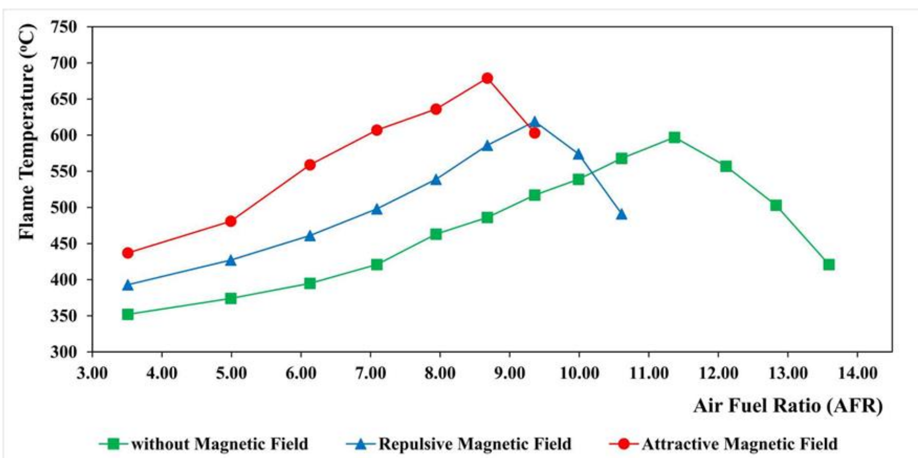

Figure 5. Correlation of AFR to flame temperature

3.3. Flame Height

Shown in Figure 6 without magnetic fields produces the highest flame of 18.2 mm at AFR 3.51. Then followed by repulsive and attractive magnets of 17.3 mm and 11.6 mm respectively. As the AFR increases, the flame height without and with the addition of a magnet tends to decrease until the flame goes out. Whereas, the lowest flame before it went out without a magnet was 7.5 mm at AFR 13.50, then followed by repulsive and attractive magnetic fields with AFR 10.61 and 9.36, respectively 8.7 mm and 5 mm. This is contrary to previous research by Maulana (2020) in premixed combustion, it was found that an attractive of magnetic field produced highest flame height compared to repulsive and without magnetic fields. This lowest higher flame indicates that attractive of magnetic field produces more stables because the higher flame is formed, greater the stretch. This means that the direction of attractive magnetic field (U-S) influences O_2 flow rate causing convection around flames, so oxygen flows to bottom of flame of both sides because attractive force of magnetic field. This flow increased concentration of oxygen and fuel molecules

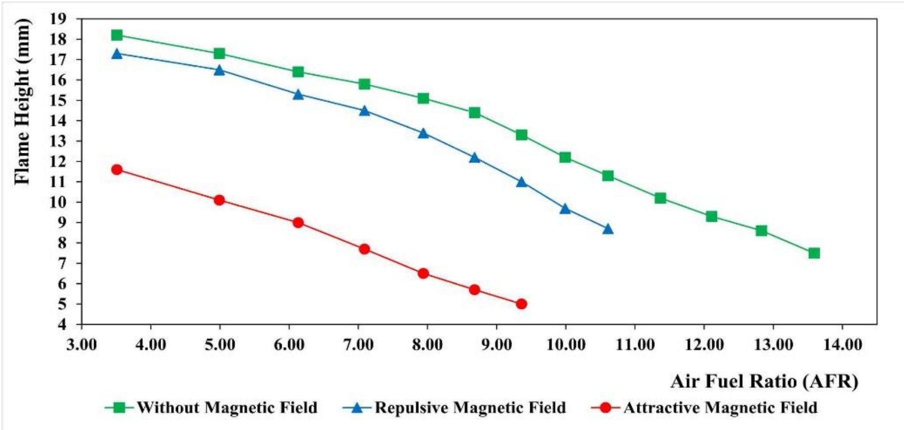

Figure 6. Correlation of AFR to flame height

around reaction zone, causing premix combustion more reactive and shorter, resulting in a large flames angle and influencing increase in flame height. Attractive magnetic field (U-S) produces a larger flame angle in the inner cones of the flame than the others, so the flame height is very short. Premix combustion in direction of repulsive magnetic field (N-N) and without takes place very slowly and for a long time so that the combustion reaction occurs above the outer cone area. Phenomenon occurs because release of oxygen and H_2O molecules are pushed out by weak magnetic field because the repulsive force between magnets around on flame, causing flame to diffuse it in the outer cone zone with the inner and outer cones of the flame being higher. Oxygen enrichment causes the combustion to be more reactive and shorter, thus affecting the lowering of the flame height. This is inversely proportional to what was done by Perdana *et al*. (2023b), who found that without oxygen enrichment the flame height was higher, temperature was lower, compared to oxygen enrichment which resulted in a low flame height but the temperature increased.

4. CONCLUSIONS

From the results of research on combustion of kapok oil premix with addition of oxygen enrichment and various magnetic field directions, it can be concluded that variations in direction of the magnetic field greatly influence the stability, shape, temperature, height and colors of the flame. The attractive (N-S) magnetic field produces the highest temperature reaching 679°C, while the flame height of 5 mm at AFR 9.36 is the lowest compared to repulsion and without, before the flame extinguished.

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