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Flame Characteristic Of Premix Combustion Of Jatropha Curcas Oil And Cotton Seed The Addition Of Various Magnetic Field Directions

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Abstract
This study investigates the effects of various magnetic field directions on the characteristics of premixed combustions flames. The research is important as it explores the use of environmentally friendly vegetable oil as a reserve for fossil fuel. *Jatrophacurcas* oil is mixed with cotton seeds (50% blend) as fuel. Experiments are carried out on a cylindrical type burner. Vegetable oils are loaded onto the boiler and then heated on LPG stoves, while the air is obtained from the compressor. Grade N52 nickel neodymium magnets with an intensity of magnetic fields of 1.1 T are used in this study. The combustion characteristics are identified from the flame image and the temperature signal at the burner tip. The flame image is recorded using a high-speed video camera at 120 frames per second. This research found that an attractive magnetic field produces a brighter, wider, and more stable flame compared to a repulsive magnet or no magnet at all. The magnetic field changes the orientation of the hydrocarbon from the para state to the ortho state, which leads to the breakdown of fuel molecules resulting in more complete and faster combustion, causing an increase in flame temperature but a decrease in flame height.

Keywords:
Vegetable oils, premix combustion, magnetic fields, flame characteristics, blends 50%.

1 Introduction

The growth of the global population is fueling the demand for energy resources to meet the needs of various industries, land transportation, sea transportation, and agricultural machinery. However, the use of fossil fuels has a detrimental impact on the environment, as it releases pollutants such as carbon dioxide, unburned hydrocarbons, and other toxic gases, leading to global warming, climate change, and environmental pollution[1]. Currently, fossil fuels are depleting, and researchers are actively seeking environmentally friendly alternative fuels that are domestically available and technically feasible[2]. Several techniques have been explored to reduce flue gas pollutants from internal combustion engines, including improvements in mechanical design[3]. Other options for modifying the fuel used in power generation equipment involve the use of alternative fuels such as biofuel and a blend of fossil fuels[4], as well as the use of emulsions (such as various types of alcohol)[5]. Studies have demonstrated that biofuels, such as biodiesel made from pure or mixed vegetable oils[6], and biomass fuels (such as bio-alcohol or dimethyl furan)[7], are viable environmentally friendly alternatives.

Over the past decade, biofuels have been utilized as alternative fuels in diesel engines[8]. Some vegetable oils, including cottonseed oil, castor bean oil, sunflower oil, soybean oil, rapeseed oil, and peanut oil, have an energy content similar to diesel[9]. However, the direct use of vegetable oil presents various challenges, including issues with atomization and increased particulate emissions due to its high viscosity. Consequently, carbon deposits form on combustion chamber components, such as cylinder walls, heads, valves, pistons, and injectors[10].

To overcome these limitations, researchers have explored derivative fuels derived from vegetable oil, such as biodiesel (a blend of vegetable oil with diesel), vegetable oil mixed with bioethanol, and biodiesel mixed with diesel. Jatropha biodiesel results in increased specific fuel consumption and NOx emissions, while also decreasing thermal efficiency compared to diesel[11]. Jatropha-kapok biodiesel (50%) mixed with diesel fuel reduces CO_2 and smoke plumes, but increases NOx and CO levels[12]. A blend of palm biodiesel and jatropha in various proportions with diesel was tested in a single cylinder engine under different load conditions. The results demonstrated that lower blends of biodiesel (10% biodiesel and 90% diesel) led to a 4.65% increase in Brake Power (BP) compared to diesel. Additionally, there was a slight reduction in Brake-Specific Fuel Consumption (BSFC) with lower blend ratios. Higher blends of biodiesel (80% biodiesel and 20% diesel) showed a 15% increase in Brake Thermal Efficiency (BTE)[13]. Cotton biodiesel blended with ethanol at higher loads experienced an increase in the rate of heat released and maximum pressure, while it decreased at low loads[14].

Magnetic ionization of fuels is a relatively understudied method among researchers. It has been observed that magnetic fields have a positive impact on fuel combustion [3]. Various measurement techniques have shown that the addition of a magnet affects the behavior of the flame [15]. The magnetic field induces significant changes in the flame structure [16] and temperature variations [17]. In this study, a magnet tube was placed in a fuel line diesel generator operating at a constant rate of 1800 rpm under loads of 25% and 50% respectively. The results indicate a reduction of 15% in Specific Fuel Consumption (SFC) and Brake-Specific Fuel Consumption (BSFC), while Brake Thermal Efficiency (BTE) increased by 3.5% [3]. Another study was conducted on diesel engines influenced by magnetic fields, which resulted in reductions of 3.5% in BSFC, 21.9%-33.3% in particulates, 5.4%-11.3% in CO, 29.4%-64.7% in HC, and 2.68%-4.18% in CO_2, and an increase of 1.24%-13.4% in NOx [18].

Despite the aforementioned research, little has been discussed regarding engine performance, which is determined by stable combustion. Further investigation is needed, specifically focusing on the effects of magnetic fields on stabilizing combustion. This study aims to examine the variations in the effects of repulsive and attractive magnetic fields on the combustion characteristics and flame stability behavior of premix fuel mixtures comprising jatropha oil and cotton oil (blended at a 50% ratio).

2 Materials and Methods

The experimental research is carried out directly on the object to be studied to obtain cause-and-effect data. The fuel used in this study was *Jatrophacurcas* oil and cotton seeds obtained from on-market products.Fatty acids content, physical and chemical properties of vegetable oil was studied previously[19].

2.1 Experimental Apparatus

The installation was illustrated in Fig. 1, providing a schematic representation. A blend of 0.6 liters of *Jatrophacurcas* and cottonseed oil, mixed in a 50% ratio, was introduced into boiler (2) and heated using stoves (1) until the evaporation temperature reached 300ºC. The pressure was maintained at a constant 4 bar.

The evaporation valve was temporarily opened while the air inlet valve was closed. Subsequently, the air inlet valve (3) was slightly opened, and the fluctuation in height was measured using flow controls (4). In combustion chambers (5), coconut oil was evaporated and combined with air. The fuel vapor and air mixture then passed through a nozzle equipped with a 6 mm diameter hole, resulting in ignition of the flame. Magnetic bars (7a and 7b), possessing north-south poles, were positioned near the flame. The position of the premixed flame tip (8) was captured using a camera operating at a frame rate of 120 fps (6). A type K thermocouple (9) was connected to a data logger and placed 2 mm above the burner tip to record the temperatures generated. These temperature readings were stored in the computer memory (10) and are depicted in Fig. 2.

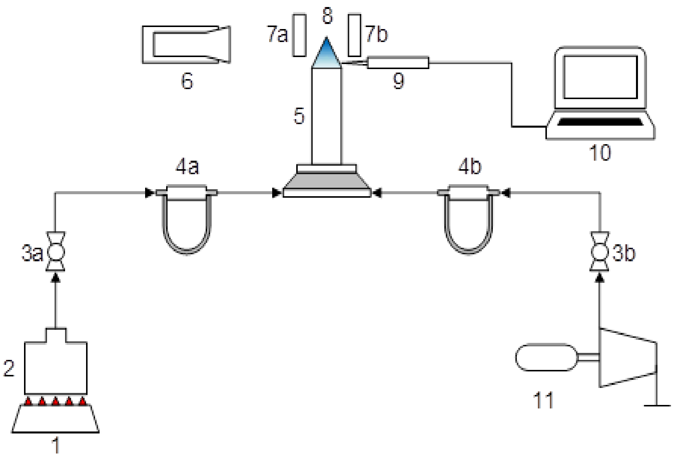

Fig. 1. Installationthe experiment is: 1)stoves, 2) boiler, 3)valves,4)flow controls,5) burner chamber, 6)highspeed camera,7)magnetic bars,8)flames,9) thermocouple type K,10)data logger,and 11) compressor [16].

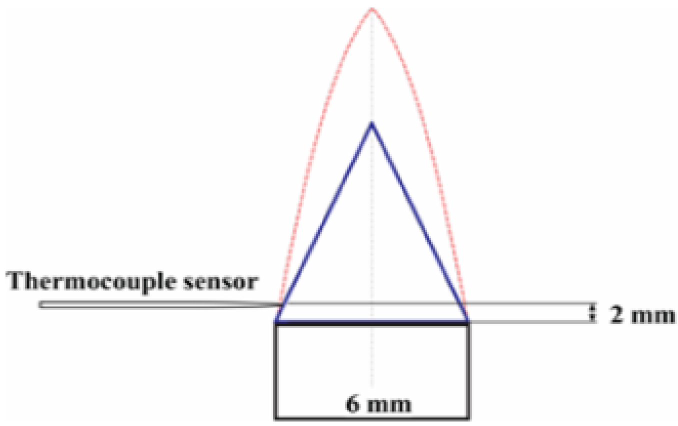

Fig. 2. Thermocouple position[16].

2.2 Magnetic Field

Permanent magnet bars neodymium N45 with 1.1 T magnetic field strength of by dimension of 40×25×10 mm. Twice magnet bars are a spaced 20 mm in two various of poles. The South-South (S-S) and North-South (N-S) magnetic fields are shown in Fig. 3.

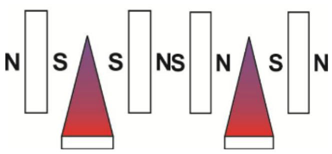

Fig. 3.Variationson the direction of magnetic fields[16].

2.3 Data Acquisition

The temperature was recorded and logged using the Arduino UNO R3 Atmega328 data logger, which was then connected to a laptop. The high-speed camera, capturing images at a rate of 120 frames per second, recorded the flames throughout the entire process - from ignition to extinguishment. This procedure was repeated five times. Video recordings were converted into images using the Free Video to JPG Converter application, with standard millisecond (ms) time measurements employed. The Coreldraw application was utilized to measure the height and evolution of the flames.

2.4 Data Processing Calculations

2.4.1 Fuel and Air Flow Rates (Q_{fuel} and Q_{air})

Q_{fuel} and $Q_{air}$are the fuel and air flow rates (cm^3/second) obtained from the orifice plate discharge coefficient (CD = 0.68); outer cross-sectional area of the orifice plate (A1 = 78.5 mm^2); cross-sectional area of the center hole of the orifice plate (A_0 = 0.785 mm^2); gravitational acceleration (g = 9800 mm/s); difference in fuel height in flow control is set at 2 mm for each process and is constant (Δh = 2 mm),while the difference in air height in flow control is varied for each additional air in increments of 4 mm (Δh = 4 mm). Calculating the fuel flow rate and air discharge using Eq. 1 and Eq. 2, the resulting Q_{fuel} = 0.1058 cm^3/s while Q_{air} = 0.1494 cm^3/s. Calculation of reactant velocity (Vu) using Eq. 3.

$$Q_{fuel} = \frac{CD\,.\,A_1\,.\,A_0\sqrt{2.g.\Delta h}}{\sqrt{{A_1}^2 - {A_0}^2}} \quad (1)$$

$$Q_{air} = \frac{CD\,.\,A_1\,.\,A_0\sqrt{2.g.\Delta h}}{\sqrt{A_1^2 - {A_0}^2}} \quad (2)$$

2.4.2 Reactant Velocity (Vu)

Where is the cross-sectional area of the nozzle hole (A_{nozzle} = 0.2826 cm^2), calculating the reactant velocity using Eq. 3 shows that Vu = 0.9 cm/s.

$$Vu = \frac{Q_{fuel} + Q_{air}}{A_{nozzle}} \quad (3)$$

3 Results and Discussion

3.1 Stability and Shapeof Flame

Fig. 4(a)-4(d) depict the stability and shape of premixed combustion under varying reactant velocities, with and without magnetic fields. The magnetic fields can either be repulsive (S-S) or attractive (N-S). The flames formed are categorized into two zones: the inner and outer flame cones. Without magnetic fields, the flames appear narrower and less stable. The results span a reactant velocity range of 0.9 to 2.5 cm/sec, as shown in Fig. 4(a). However, the introduction of repulsive and attractive magnetic fields leads to the formation of broader, more stable flames. This research aligns with the study conducted by [17] on premix combustion of coconut oil with the inclusion of a magnet. The attractive magnetic field produces the most stable flame within a reactant velocity range of 0.9 to 3.1 cm/sec, followed by the repulsive magnetic field within a range of 0.9 to 2.7 cm/sec, as shown in Fig. 4(b)-4(c). These distinct flame characteristics can be attributed to two factors. Firstly, the Lorentz force continuously twists and disrupts the flame, resulting in the generation of polarized light electromagnetic waves. Secondly, higher reactant velocities facilitate faster fuel diffusion.

The introduction of magnetic fields to the combustion process introduces complexity, as evident from the flame instability. In the case of repulsive magnetic fields, either O_2 or H_2O is expelled in the direction of the magnetic fields [16]. O_2, being paramagnetic, moves along the direction of the magnetic fields, while H_2O, being diamagnetic, moves against it. This results in suboptimal chemical reactions during combustion, as depicted in Fig. 4(b). A repulsive magnetic field leads to imperfect combustion, as evidenced by the formation of a diffusion flame (yellow flame) at a reactant velocity of 0.9 to 1.3 cm/sec. It is possible that when the magnetic field repels, H_2O is drawn across the flames while O_2 is expelled from the flames. On the other hand, attractive magnetic fields draw both O_2 and H_2O into the flame, resulting in the occurrence of a diffusion flame (yellow flame) only at a reactant velocity of 0.9 to 1.1 cm/sec.

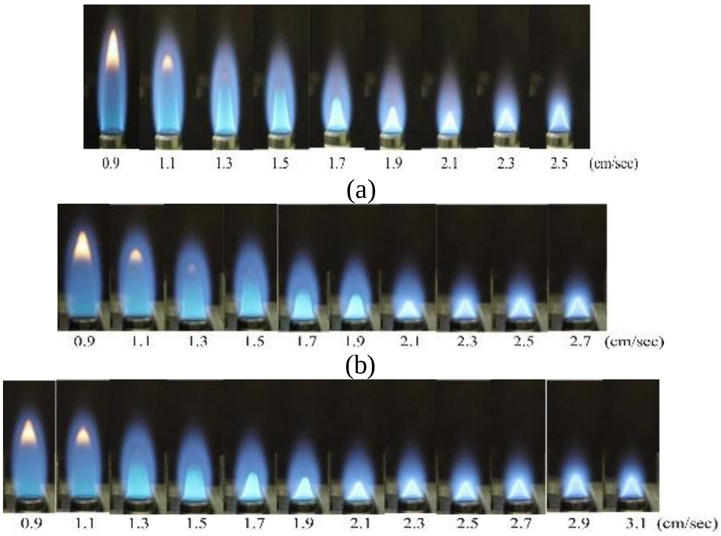

Fig. 4. Stability and shapeflameare: a) without magnet, b) repulsive magnetic fields, and c) attractive magnetic fields.

3.2 Flame of Temperature

Fig. 5 presents the relationship between flame temperature and various factors in magnetic fields during combustion. It is observed that attractive magnetic fields lead to higher flame temperatures, with a maximum temperature of 448ºC occurring when combustion initiates at a reactant velocity of 0.9 cm/sec. This trend continues as the combustion speed increases up to 2.3 cm/sec, reaching a peak temperature of 639ºC. Subsequently, the flame temperature decreases to 535ºC as the reactant velocity reaches 3.1 cm/sec, extinguishing the flames. Conversely, repulsive magnetic fields result in a peak flame temperature of 595ºC, which decreases with increasing combustion speed.

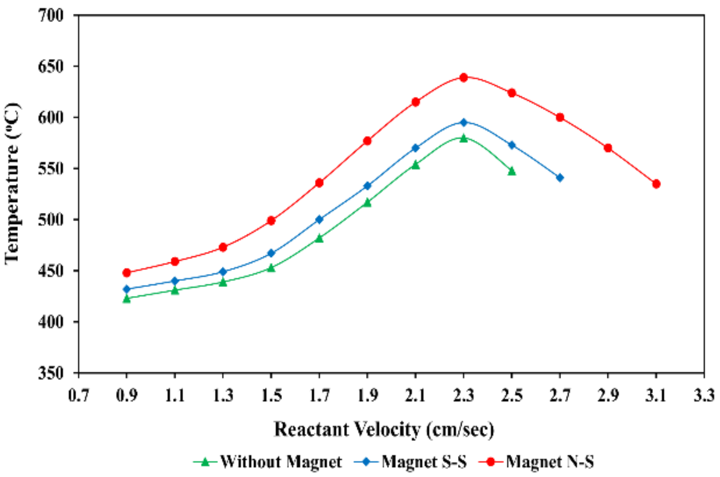

Fig. 5. Flame temperature at various magnetic field orientations and without.

These findings align with a previous study conducted by [20] on the combustion of *Calophylluminophyllum* droplets in the presence of magnetic fields. Furthermore, it is worth noting that the lowest flame temperature recorded without the influence of a magnet is 580ºC.

The magnetic field gradient affects the combustion reaction through two main mechanisms. Firstly, the flame temperature is influenced by the oxygen's mole fraction and susceptibility to paramagnetism. Secondly, the Lorentz force affects the chemical chain fuel, inducing magnetic resonance in the flame. This resonance facilitates the separation of O_2 from the air and fuel bonds, leading to the release of electrons and an increase in oxidation number. Consequently, the flame temperature rises.

When high magnetic fields are applied to flames, a limited number of air molecules are drawn towards the burner tip, while diamagnetic gas is pushed away from the magnetic fields. As a result, all combustion products are pushed away from the reaction zone. These factors collectively contribute to enhanced combustion characteristics and behavior, ultimately resulting in higher flame temperatures.

3.3 Flame of Height

The results presented in Fig. 6 demonstrate that the flame height is 3.4 cm at a reactant velocity of 0.9 cm/sec when no magnet is present. However, when repulsive and attractive magnetic fields are introduced, the flame height varies. As the reactant velocity increases, the flame tends to decrease before extinguishing. Among the magnetic fields tested, the lowest flame height of 3.16 cm was observed with attractive magnetic fields, while a flame height of 3.31 cm was recorded with a repulsive magnetic field. These findings suggest that attractive magnetic fields contribute to more stable flames and greater flame stretch. The presence of magnetically induced air in the flame area induces convection, resulting in different flame heights. Both sides of the flame receive oxygen gas flow, leading to an increased oxygen concentration around the reaction zone [16]. The direction of the attractive magnetic fields (N-S) influences the flow rates of oxygen, causing convection around the flames. As a result, oxygen is drawn to the bottom of the flames from both sides due to the attractive force of the magnetic fields. This flow enhances the concentration of oxygen and fuel molecules around the reaction zone, promoting more reactive and shorter combustion. Consequently, a larger flame angle and increased flame height are observed with stronger attractive magnetic fields (N-S).

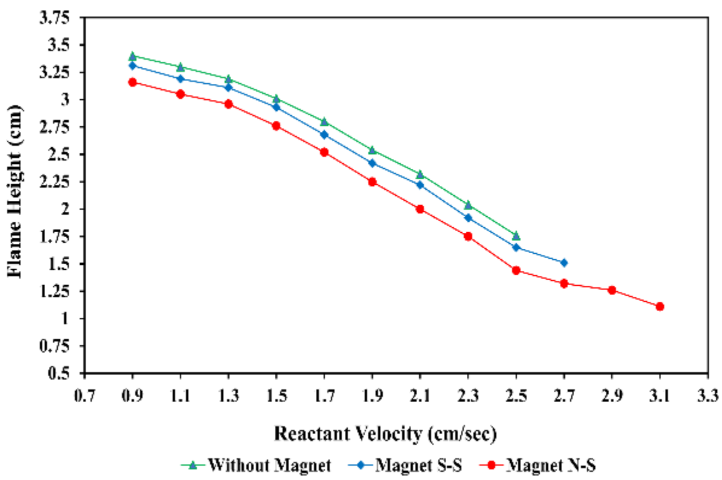

Fig. 6. Flame height at various magnetic field orientations and without.

Conversely, smaller repulsive magnetic fields (S-S) lead to a smaller flame angle and increased flame height. This phenomenon occurs due to the release of oxygen and water molecules, which are pushed out by the weak magnetic field resulting from the repulsive force between magnets surrounding the flames. This leads to a diffusion flame that reacts within the cone zone, exhibiting higher flame cones.

4 Conclusion

It can be inferred that fluctuations in the orientation of magnetic fields significantly impact the stability of the flame and the resultant flame temperature. The attractive magnetic field yields more stable flames at a high combustion rate, whereas the repulsive magnetic field results in less stable flames at a low reactant velocity. Magnetic fields play a crucial role in accelerating the reactant velocity and subsequently increasing the temperature, as the rotation of electrons speeds up and disrupts the carbon chain bonds in O_2 and fuel.

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