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Potential Fuel Magnetisation in Droplet Combustion: A Review

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ABSTRACT
An inventive method to improve droplet combustion efficiency is fuel magnetization. The fundamental idea behind this technique is to alter the molecular structure of hydrocarbon fuels using magnetic fields, which improves atomization and promotes more thorough burning. Permanent magnets like neodymium can produce magnetic fields that can affect how electrons are distributed in fuel molecules, lessen molecular clumping, and increase the combustion chamber's air and fuel mixture's homogeneity. According to experimental research, magnetic fuels enhance combustion characteristics while improving the physical properties of the fuel. An inventive method to improve droplet combustion efficiency is fuel magnetization. For the magnetization process, a steady and powerful magnetic field is supplied by neodymium permanent magnets in the fuel line. Additionally, this procedure enhances the oxidation reaction within the combustion chamber, which has a direct impact on the resulting flame shape. Fuel magnetization is a cost effective and simple option as it does not require large energy or complex infrastructure. This method has enormous potential to improve energy efficiency and optimize combustion yields if its mechanism of action and beneficial effects are understood.

Key words : Fuel, Magnetisation, Droplet combustion, Flame, Hydrocarbon.

1. INTRODUCTION

Fuel combustion is an important process in many industrial applications, such as transport, energy generation, and internal combustion engines [1]. As the need for energy efficiency and pollutant emission reduction increases, new approaches are being implemented to improve combustion quality [2]. Biofuels are an object that need to be investigated for their combustion results as they have the potential to replace fossil fuels [3]. Vehicle exhaust emissions in China reached 5.61 Mt of carbon monoxide (CO), 1.34 Mt of hydrocarbons (HC), and 295 kt of nitrogen oxides (NOx), which accounted for 80.9%, 77.6%, and 4.8% of total vehicle emissions, respectively [4]. There is a need for innovation to modify the physical and chemical properties of fuels during the combustion process.

Most emissions consist of unburned hydrocarbons (UHC), carbon monoxide (CO), and nitrogen oxides (NOx) [5]. Hydrocarbon fuels leave natural carbon deposits thereby reducing efficiency and causing fuel wastage [6]. Unburned hydrocarbons and oxides of nitrogen react in the atmosphere and create smog. Various sustainable design improvements to to improve fuel efficiency. An approach is to apply magnetic fields to the combustion, which can vary the flame's temperature, size, radiation, pollutant production, and kinetic characteristics [7]. Droplet combustion is one method that is used a lot to determine the combustion characteristics of fuels. It allows a detailed study of evaporation, diffusion, and chemical reactions on a microscopic scale, providing a scientific basis for developing more efficient and environmentally sustainable combustion technologies.

The application of magnetic fields to increase fuel efficiency has been widely researched. A study shows that the influence of magnetic fields can increase the combustion rate of fuels because it increases the efficiency of chemical reactions and accelerates the oxidation process. Magnetic fields can affect the temperature distribution in the fuel and air mixture, resulting in more even and efficient combustion. As seen from [6] conducted a permanent magnet can improve fuel properties such as aligning and directing hydrocarbon molecules for better fuel atomization. Magnetic fields can also result in slightly decreased flame temperature due to better air convection and more heat transfer with the flame [8]. Magnetic field intensity can increase the heat transfer coefficient by up to 20% [9]. Through the magnetic force acting on paramagnetic and diamagnetic materials, the magnetic field affects the flow field, changing the form of the flame and improving the combustion rate [10]. The use of magnetic fields will result in increased O_2 concentration reaction zone area [7]. This also leads to the argument that by applying magnetic fields, combustion efficiency increases. The magnetic field changes the orientation of hydrocarbons and hydrocarbon molecules by modifying their configuration. Conducted a special fuel ionisation system with permanent magnets can reduce fuel viscosity, improve atomisation and mixing processes, and reduce soot formation and other pollutants resulting from incomplete combustion. Therefore, research on fuel magnetisation in droplet combustion has great potential and is considered one of the promising solutions to address the environmental challenges associated with fuel use.

In this journal explain the extent to which fuel magnetisation is required to enhance droplet combustion characteristics and improve fuel physical properties is described in this study. To enhance the oxidation reaction of the fuel to oxygen and promote cleaner and more effective combustion with less flue gas waste, two permanent magnets are applied facing each other to influence singel fuel droplet combustion. This study is intended to summarise previous research and analyse existing topics. From this analysis, suggestions are made for comparison and guidance in future research.

2. FUEL MAGNETISATION

2.1 Droplet Combustion

Droplet combustion is an experimental approach used to understand the basic characteristics of fuel combustion on a microscopic scale [11]. In this method, a fuel droplet is isolated and burned under controlled conditions, allowing detailed analysis of vaporization, heat transfer, diffusion, and chemical reaction processes. Droplet combustion is often used to study different types of fuels, including hydrocarbons, alcohols, and biodiesel, to understand combustion behavior and its impact on pollutant emissions. The droplet combustion stage usually starts with the vaporization of fuel due to the heat received followed by the formation of air and fuel vapor around the droplet, as shown in Figure 1 [12]. The combustion reaction takes place in the flame layer surrounding the droplet. This process is affected by various factors, such as droplet size, fuel composition, ambient temperature, and external fields such as magnetic fields. The study of droplet combustion not only helps understand combustion phenomena on a small scale but also provides insights to optimize efficiency and reduce emissions in large scale combustion applications, such as in engines or energy generation systems.

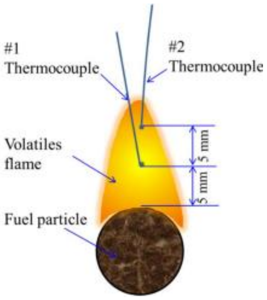


Figure 1: Structure Droplet Flame

The combustion characteristics of a droplet are highly dependent on the interaction between the vaporization process, mass diffusion, and chemical reactions occurring around the droplet [13]. When a droplet is exposed to a heat source, the fuel within it vaporizes, forming a layer of vapor that surrounds the droplet. This vapor then mixes with the oxygen in the surrounding environment and forms a reaction zone, which is often seen as a spherical flame. This process is strongly influenced by environmental factors, such as pressure, temperature, and the presence of external fields, which can alter the flow pattern around the droplet as well as the combustion speed. Droplet size also plays an important role in determining the combustion duration and vaporization pattern. Smaller droplets have a larger surface area to volume ratio, allowing for faster heat transfer and shorter combustion times [14]. In contrast, larger droplets take longer to burn completely. Research on droplet combustion is essential for studying alternative fuels such as biodiesel, which have different physical and chemical properties from conventional fossil fuels [15]. This study is also relevant in developing numerical models that can predict the combustion behavior of fuels under various operational conditions, including the effect of magnetic fields on combustion efficiency. By utilizing this method, researchers can explore the influence of various parameters, including the effect of magnetic fields, on the combustion behavior of droplets. This provides a basis for developing more efficient and environmentally combustion technologies. Droplet combustion is also relevant for understanding the application of alternative fuels such as biodiesel, which has great potential to reduce dependence on fossil fuels.

2.2 The Principle of Fuel Magnetisation

Fuel magnetization can be a technology to improve combustion efficiency and reduce emissions [16]. Hydrocarbon fuels emit unburned hydrocarbon combustion products (HC) due to incomplete combustion. HC emissions have a negative impact on the environment and indicate fuel wastage. HC emissions are caused by the following factors:

1. Poor atomization: fuel droplets are large and make combustion less optimal, thus slowing down evaporation and chemical reaction with oxygen.
2. Inhomogeneous mixing of air and fuel: lack of interaction between fuel and air leads to uneven combustion zones.
3. Low temperature combustion conditions: produces hydrocarbon residues in the exhaust gas because the temperature in the combustion chamber is not sufficient to completely oxidize the combustion.

Fuel magnetization is an innovative approach that aims to improve combustion performance by utilizing magnetic fields to influence the physical and chemical properties of the fuel. The process of fuel magnetization in droplet combustion involves using magnetic fields to change the molecular structure of the fuel. The fuel is positioned in the center, between two magnetic fields, as shown in Figure 2. This can change the density and viscosity of the fuel and improve the mixing of oxygen and fuel in the combustion chamber.

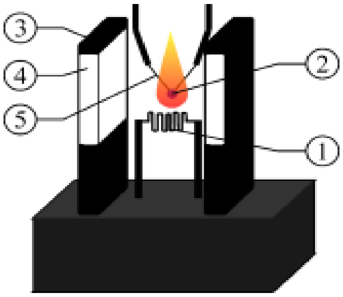


Figure 2: Magnetic Field and Droplet Position: 1-heating element; 2-droplet; 3-magnetic holder; 4-magnetic field; 5-thermocouple

The basic principle of fuel magnetization is based on the interaction of magnetic fields with the hydrocarbon molecules that make up the fuel [17]. Hydrocarbon molecules generally have weak magnetic moments that can be affected by external magnetic fields. When the fuel passes through a magnetic field, the field can change the orientation of the molecules and affect interactions between molecules, such as reducing surface tension and increasing the solubility of oxygen in the fuel. This process is believed to improve the homogeneity of the fuel and air mixture, resulting in more efficient combustion. Magnetic fields play a role in influencing the ionization of hydrocarbon molecules which contributes to improved combustion quality [18]. This enables the magnetic field to influence the fuel's molecular structure, enhancing fuel atomization and promoting more effective combustion in the combustion chamber [19].

2.3 Permanent Magnet

Permanent magnets can maintain their magnetic properties permanently without an external energy source. The structure of the material has a regular and stable magnetic domain. In magnets there is a physical phenomenon from the movement of electrons in the material [20]. Electrons have two types of movement, namely spin movement and orbital movement [21]. Both movements create magnetic moments. The magnetic moments in permanent magnets are aligned due to interactions between atoms.

Permanent magnet materials usually come from ferromagnetic materials such as iron (Fe), cobalt (Co), nickel (Ni), alloys such as Alnico (aluminum, nickel, cobalt), and rare earth magnets such as Neodymium-Iron-Boron (NdFeB) and Samarium-Cobalt (SmCo) [22]. This material has magnetic domains. When the material is magnetized, the domains align producing a strong magnetic field. Permanent magnets have several characteristics namely the first is high coercivity the ability to maintain magnetization even when exposed to an opposing external field, the second is high retentivity which is high residual magnetization after the external magnetic field is removed, and the third is a strong magnetic field at a certain distance, and good thermal stability. Some types of permanent magnets can maintain their magnetic properties at high temperatures [23].

The manufacturing process of permanent magnets involves selecting materials, heating, and cooling to rearrange the crystal structure, and magnetizing with a strong external magnetic field to align the magnetic domains. Their performance can be affected by several factors such as high temperatures which can cause demagnetization, corrosion of magnets such as NdFeB which requires a protective coating, and opposing external magnetic fields which can reduce the strength of the permanent magnet [24]. Figure 3 shows an example of Neodymium magnet. Neodymium magnets have advantages in combustion applications compared to other types. There are many different shapes of magnets, including cylinders, discs, rings, and blocks, with residual magnetic fields ranging from 1.0 to 1.4 Tesla [25].

Figure 3: Neodymium Magnet

These types produce very strong magnetic fields with high maximum energy value (BHmax) ranging from 30-52 MGOe and high coercivity (12,000 to 30,000 Oersted), so they can affect the molecular structure of the fuel more effectively [26]. The thermal stability of neodymium magnets can be applied in high temperature environments. Neodymium magnets have small sizes but high magnetic power makes them ideal for droplet combustion. Neodymium magnets are made from neodymium (Nd), iron (Fe), and boron (B) with additional elements such as dysprosium (Dy) to increase thermal stability [27]. This magnet is usually coated with materials such as nickel, zinc, or epoxy to protect against corrosion. that have curie temperature is between 310°C to 400°C [28]. The density value of this type is around 7.4 g/cm³ [29].

2.4 Magnetism Interaction with Hydrocarbons

The hydrocarbons in fuel consist of long chains of carbon and hydrogen molecules. Magnetic fields can affect the distribution of electrons in these molecules and create small changes in the molecular structure that make the fuel more reactive during combustion. Magnetization can improve the homogeneity of the fuel, and increase the dispersion of the fuel into small particles during injection, thus creating a better mixture of air and fuel [30]. The ionization of the fuel is also enhanced resulting in a more stable and efficient flame. Fuel magnetization is used to optimize combustion parameters, such as reducing ignition delay and increasing the burn rate [31]. Magnetization in the fuel can accelerate the transition of molecules to orthohydrogen thereby improving atomization and mixture formation of air and fuel. The resulting thermal efficiency will be increased and reduce emissions such as carbon monoxide and nox. Figure 4 below shows the spin isomer scheme of the para and ortho hydrogen molecular states [32].

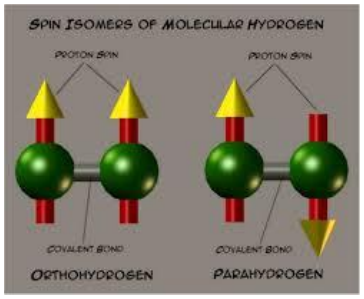
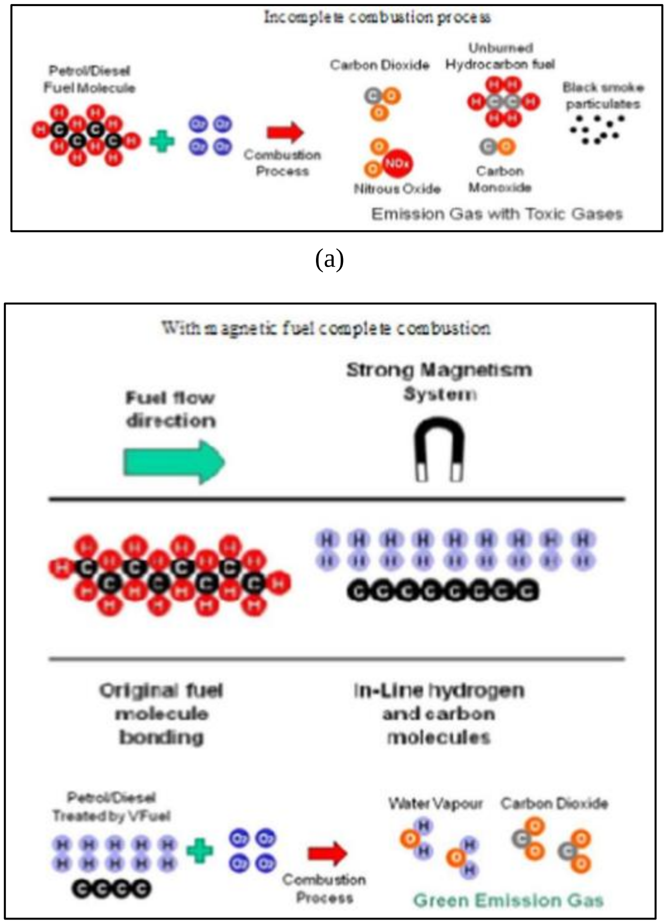


Figure 4: Schematic Spin Isomers of Para and Ortho Hydrogen Molecular States

Parahydrogen and orthohydrogen have the role of improving hydrogen fuel efficiency. Parahydrogen switch to orthohydrogen is enhanced through magnetization and results in a higher energy form of hydrogen and potentially improved combustion efficiency. Parahydrogen has stable isomer antiparallel spin, while orthohydrogen has a more energetic parallel spin and tends to be more reactive [33]. When fuels containing hydrogen and carbon burn, the paramagnetic properties of hydrogen can enhance the interaction between hydrogen and oxygen, allowing for more efficient and complete combustion. Hydrogen stimulated by a magnetic field can more easily react with oxygen, resulting in combustion that is more stoichiometric or closer to the ideal ratio of fuel to oxygen [34]. In stoichiometric combustion, the entire fuel burns completely, producing only the desired combustion products of water (H_2O) and carbon dioxide (CO_2), with no formation of harmful pollutants such as carbon monoxide (CO) or unburned hydrocarbons (HC). The following Figure 5 shows a schematic of the chemical reaction of combustion with magnetic field effects [35].



(a)

(b)

Figure 5: (a) Schematic of Combustion Reaction, (b) Schematic of Magnetic Field Effect on Combustion

Hydrogen is paramagnetic meaning that the molecule has a magnetic moment that can be aligned with an external magnetic field [36]. This paramagnetic property enhances the interaction between hydrogen and oxygen (O_2) atoms in combustion. In this condition hydrogen atoms have electron pairs with randomly directed spins. When given an external magnetic field these electron pairs can be orientated according to the direction of the field. Carbon is diamagnetic which means the electrons in carbon atoms are orientated inversely to an external magnetic field. The diamagnetic nature means carbon is unaffected by magnetic fields so combustion results in less reactive combustion.

The application of magnetic fields to fuel results in higher thermal efficiency. This effect mainly comes from the increased interaction between fuel and oxygen, which results in more complete combustion and reduced fuel consumption as well as exhaust emissions, such as CO and NOx. In some experiments, variations in the strength of the fuel magnet showed an increase in engine thermal efficiency of up to about 15%, depending on the intensity and location of the applied magnetic field [37].

2.5 Magnetic Field Simulation under Thermal Conditions

Finite Element Method (FEM) simulations of magnetic fields can be performed under thermal conditions to analyze how temperature affects the magnetic field and system performance of permanent magnets. Demagnetization or a decrease in magnetic field strength can occur under high temperature conditions of engines or other combustion applications [38]. Based on their type, permanent magnets have different characteristics in terms of magnetization coefficient, curie point, coercivity, and other magnetic properties, all of which affect the simulation results.

The Curie temperature for neodymium (NdFeB) magnets is usually around 310-370°C. The Curie temperature is the critical temperature at which ferromagnetic materials lose their magnetic properties and turn paramagnetic [39]. In a permanent magnet field, this temperature is to determine the effective operating temperature limit of the magnet. If the temperature of a permanent magnet exceeds the curie temperature its magnetic field will weaken significantly. The magnetic arrangement in the material becomes irregular, thus reducing or even eliminating the magnetic field produced. Permanent magnet material selection should consider the curie temperature to suit applications that require magnetic field stability at high temperature conditions [40]. FEM simulations can help in determining the optimal distance and gauss strength between magnets under thermal conditions [41]. The following Figure 6. FEM simulation of neodymium magnet with ANSYS software [42].

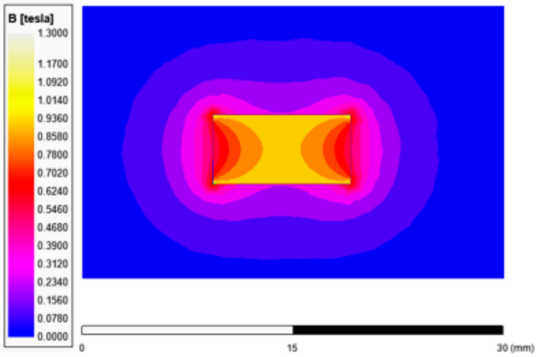


Figure 6: Flux Density Distribution of N38 Permanent Magnet

The N38 neodymium magnet with dimensions of 20 x 10 x 5 mm is simulated with a temperature of 20°C. The figure above shows the magnetic flux distribution. The magnetic simulation results show a magnetic flux distribution that reaches 540 mT in the centre of the magnet, with a decrease in flux value towards the edge of the magnet. The type of permanent magnet material greatly affects the gauss strength in the FEM simulation of the magnetic field. In another study the magnet used was a disc type neodymium magnet (NdFeB-N35) with a diameter of 15 mm and varying thicknesses of 7 mm and 3 mm [43]. The remanence for such magnets is estimated to be about 1 T. The simulation results for magnets with thicknesses of 7 mm and 3 mm show differences in the magnetic field distribution as shown in Figure 7.

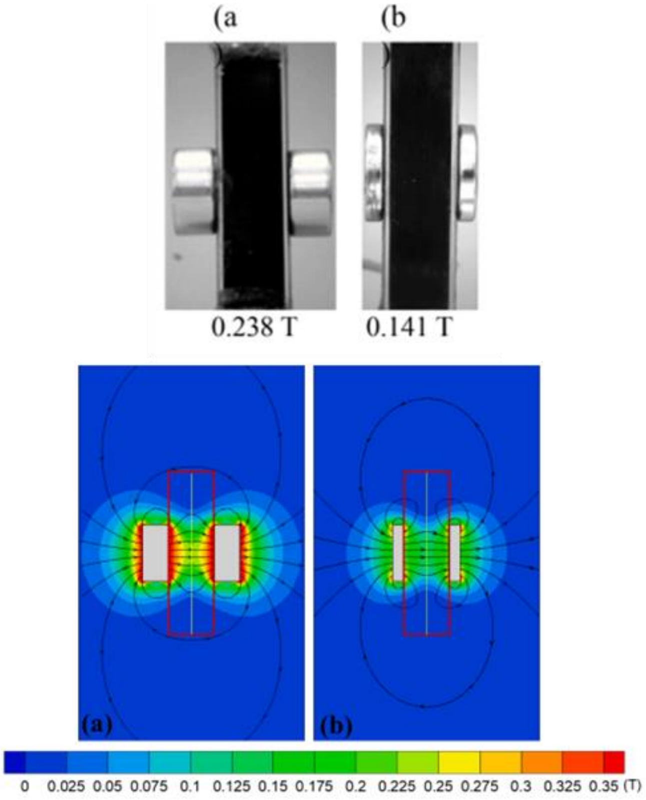


Figure 7: N35 Magnetic Field Simulation Results

This greater magnet thickness results in a stronger magnetic field. The simulation results show that by using a 7 mm magnet, there is a significant increase in flux. Whereas a 3 mm magnet, with a smaller thickness, the magnetic field generated tends to be weaker and less focused. The larger volume of magnetic material, which allows more magnetic flux lines to be generated. Thicker magnets usually produce a stronger magnetic field at a greater distance from their surface [44]. This increases the magnet's ability to impact objects from a greater distance and is more resistant to demagnetisation due to high temperatures.

3. EFFECT OF MAGNETIC FIELD ON FUEL DROPLET COMBUSTION 45-49

An experiment was conducted to study the impact of an attractive magnetic field inside the combustion chamber. This study aims to investigate the combustion of olive oil droplets on evolution, temperature, altitude, and ignition delay. A high-speed 120 frames per second front facing camera recorded the process from the start of ignition to extinguishment. The olive oil droplet was placed on a K-type thermocouple between two permanent magnets, as shown in Figure 8 [45]. The result, by adding an attractive magnetic field, can concentrate oxygen and fuel molecules in the reaction zone area, resulting in rapid combustion and shorter flame delay changes.

Figure 8: Magnetic Fields in the North (N) and South (S)

In another study, experiments have been conducted to determine the effect of variations in magnetic field direction on the flame combustion characteristics of coconut and palm oil droplets [46]. Two variations of magnetic field direction N-N and S-N. The results showed that the magnetic field direction affected the ignition delay time, as shown in Figure 9. The N-N magnetic field direction on palm oil produced the longest ignition delay time of about 15839.5 ms, followed by the S-N magnetic field of 11176 ms. Coconut oil with S-N magnetic field direction, produced the fastest ignition delay time of 6129.5 ms compared to palm oil. This short ignition delay time is due to viscosity playing an important role in combustion. Fuels with low viscosity lead to shorter ignition delay times. Lower viscosity accelerates the combustion reaction because unsaturated fatty acids have a low flash point. The magnetic field causes the electron spins to become more reactive towards the nuclei in the vegetable oil molecules, thus accelerating the reaction of the fuel with oxygen.

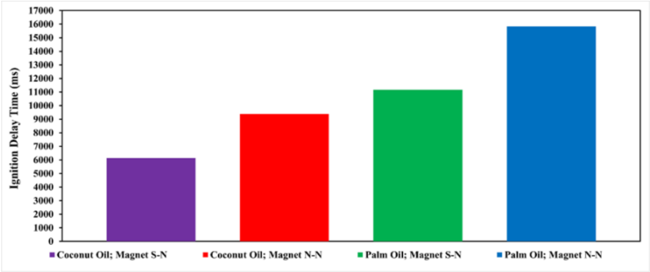


Figure 9: Ignition Delay Time of A Magnetic Field

Research has been carried out on the effect of direction magnetic field on the flame characteristics of droplet combustion in palm oil. The direction of the northsouth 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. Figure 10 show that without magnetic fields, the flames were slimmer than the attractive and repulsive magnetic fields [47]. 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.

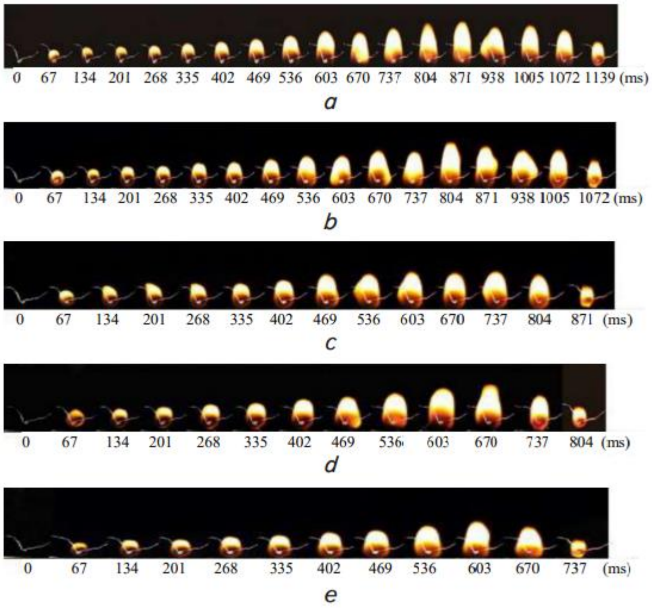


Figure 10: Evolution and Stability of the Flame: a- without magnetic field; b- magnetic field S-S; c-magnetic field N-N; d-magnetic field S-N; e-magnetic field N-S

Figure 11 shows the flame temperature of the coconut and jatropha oil blend B50 [48]. It can be seen that the trend of temperature change with an equivalent ratio follows the trend of flame speed change. Since the flame speed expresses the speed of combustion reaction which is the speed of heat release. Although the magnetic field increases the flame temperature, a higher increase in flame speed in the absence of a magnetic field results in a lower increase in temperature. This could be because some of the heat is taken to vaporize the B50 blended oil which is harder to vaporize due to its stronger molecular attractive force. This suggests that molecules play a very important role in assisting the magnetic field in stabilizing combustion.

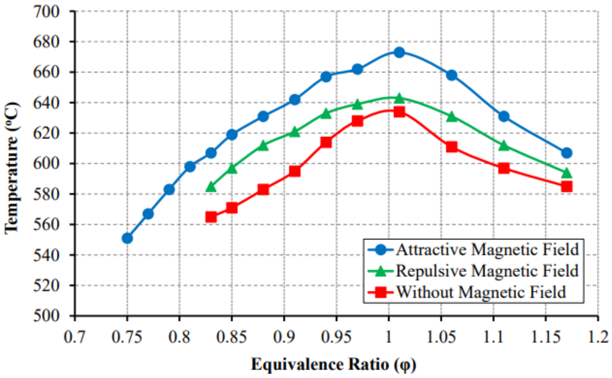
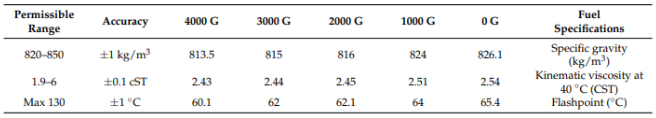


Figure 11: Temperature of Flame

The application of magnetic fields can affect combustion efficiency by modifying the physical properties of the fuel [49], as shown in Figure 12. This interaction can reduce viscosity and improve fuel atomisation. Fuel density tends to decrease as the magnetic field strength increases. The magnetic field increases the dispersion of hydrocarbon molecules and reduces interactions between molecules, resulting in a tighter molecular structure [50]. The volume of the fuel may increase as the density decreases. The magnetic field also changes the orientation and reduces the tension between molecules. The fuel will become more volatile and flammable resulting in a lower flash point. With better atomisation, combustion becomes more efficient and results in fuel savings.



Permissible Range	Accuracy	4000 G	3000 G	2000 G	1000 G	0 G	Fuel Specifications
820–850	±1 kg/m^3	813.5	815	816	824	826.1	Specific gravity (kg/m^3)
1.9–6	±0.1 cST	2.43	2.44	2.45	2.51	2.54	Kinematic viscosity at 40 °C (CST)
Max 130	±1 °C	60.1	62	62.1	64	65.4	Flashpoint (°C)

Figure 12: Physical Properties Of Fuels Under Influence Of Magnetic Fields

4. CONCLUSION

The magnetic field helps create a more stoichiometric combustion, maximising the use of oxygen and fuel. This contributes to improved combustion efficiency, reduced exhaust emissions and more effective fuel utilisation. Fuel magnetization has been shown to have significant potential in improving combustion characteristics through the improvement of fuel physical properties. Magnetic fields can reduce viscosity and lower surface tension. These changes have a direct impact on important combustion parameters. Magnetization not only accelerates the combustion process by reducing ignition delay time, but also results in more even and stable combustion, characterized by optimal temperature distribution and flame shape.

Finite Element Method (FEM) based simulations enable in-depth analysis of the interaction of magnetic fields with fuel materials. With FEM, various parameters such as magnetic field strength, optimal installation distance, and the influence of magnet dimensions and types can be determined. Simulation results show that optimising the magnetic field strength and proper magnet placement can maximise the benefits of magnetic fields. The use of magnetic field in combustion is an innovation for energy efficiency, operational cost reduction, and environmental sustainability. Variations in magnetization parameters, such as intensity, direction, and type of magnetic field, need to be explored to determine the most effective configuration in improving combustion characteristics. the use of alternative fuels such as biodiesel or bioethanol is also important to study, given their great potential in supporting a more sustainable energy transition

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