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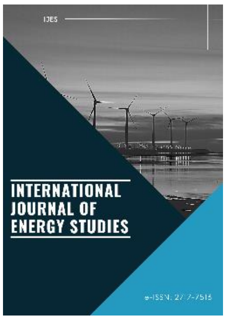

Review Article

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A review of magnetic field assisted combustion

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Highlights

- Impact of Magnetic Fields on Combustion Processes.
- Fuel Atomization and Homogeneous Fuel-Air Mixtures.
- Potential for Emission Reduction.

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ABSTRACT

Since the early 1980s, research on magnetically enhanced combustion has garnered significant attention and importance. These studies have primarily focused on investigating the influence of magnetic fields on the combustion process of fuels. During this period, studies that highlighted the potential to alter molecular structures and properties through powerful magnetic fields emerged as significant contributors to the field. Simultaneously, the effects of magnetic fields on flame formation, behavior, and propagation have been thoroughly explored through various combustion models and experiments. The significance of these investigations lies in their contribution to a better understanding of the effects of combustion on energy efficiency and emission profiles. The capability of strong magnetic fields to modify molecular arrangements can enhance fuel atomization, promoting the creation of a more homogeneous fuel-air mixture. Additionally, the potential of magnetic fields to influence the reaction rates and behavior of gas molecules holds promise for achieving improved combustion and reduced emission production. Investigations have also focused on how chemical reactions of fuels are altered under magnetic fields and how these changes translate into motor performance. Specifically, research has highlighted how chain reactions such as gas combustion and explosion can be altered under magnetic fields, potentially reducing the production of harmful emissions like carbon monoxide, hydrocarbons, and nitrogen oxides. In this context, a comprehensive exploration of various aspects such as flame formation, engine performance, emissions, and explosion intensity under the influence of magnetic fields is of paramount importance. Future endeavors can potentially yield a more profound and precise understanding of the effects of magnetic fields on combustion processes and enable the utilization of this knowledge for more efficient and cleaner energy production across different industrial applications.

Keywords: Combustion in magnetic field, Pollution emissions, Combustion instabilities

1. INTRODUCTION

Energy is an essential part of the economy and everyday life, playing a crucial role in the future of societies and nations [1]. Between 1960 and 2020, the world population increased from 3.03 billion to 7.75 billion, marking a 254% growth [2]. With this population surge, the supply and demand for energy are also changing. In 2020, while oil and natural gas production reached 4.296 million tons, the total demand recorded was 4.070 million tons, resulting in an imbalance of 226 million tons between supply and demand [3].

The combustion process holds a significant role in generating thermal and mechanical energy. However, the emission gases resulting from this reaction pollute the environment. An array of emissions, encompassing nitrogen oxides, hydrocarbons, carbon dioxide, water vapor, sulfur oxides, particulates, and assorted compounds, are discharged into the atmosphere Incomplete combustion releases CO gas, while complete combustion yields water vapor. These reactions occur due to the interaction between hydrogen in the fuel and oxygen in the air. The adverse effects of combustion are observed both locally and globally [4].

In recent years, hydrogen has drawn attention as an alternative energy source, alongside various hydrocarbons. Particularly, the synthesis of gaseous fuels in combination has intrigued researchers [5]. At the same time, the discovery of the effects of powerful magnetic fields on molecular structures and their capacity to modify properties on a molecular scale has emerged. This discovery has directed researchers to explore the characteristics of fuels under magnetic fields, such as combustion efficiency, flame temperatures, and emission releases [6].

Magnetic fields find applications across various disciplines, including energy and combustion fields. They can influence chemical reaction rates [7,8], and magnetic fields can also induce combustion reactions and explosions [9]. Technology aimed at reducing global carbon emissions has made significant strides in recent years. Utilizing magnetic fields in fuel engines has the potential to diminish explosion emissions and improve combustion efficiency. The behavior of fuels during combustion can be affected by molecular-level magnetic interactions. For instance, the spin orientation of hydrogen can influence molecular behavior, and magnetic fields can alter this spin orientation. Additionally, magnetic fields can influence thermodynamic factors like binding energy and enthalpy, thereby directing fuel consumption [10-14].

This review provides a comprehensive exploration of the influence of magnetic fields on combustion flames and internal combustion engines. By discussing the findings of pioneering studies in this field, our aim is to guide future researchers in this area.

2. EXPLORING THE INFLUENCE OF MAGNETIC FIELDS ON FUEL STRUCTURE AND THEIR EFFECTS ON FLAME DYNAMICS

The effects of magnetic fields on the hydrocarbon structure, properties, and flame behavior will be discussed below. According to the results of research conducted on different types of fuels, the effects of magnetic fields on combustion processes have been examined.

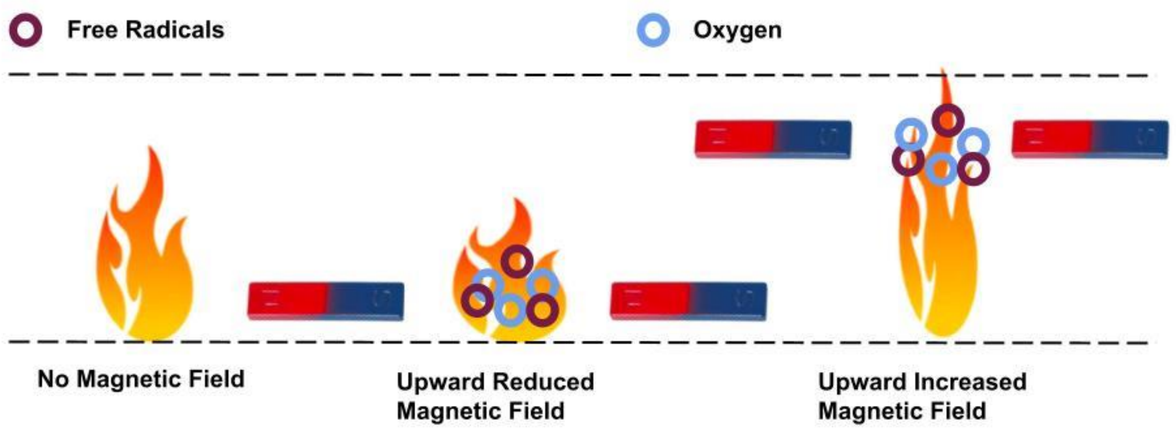

Figure 1. Schematic Representation of the Behaviour of The Combustion Flame Under Magnetic Field

Shoogo et al. [15-17] investigated the influence of magnetic fields on flame structure and gas flow for fuels such as methane, propane, and hydrogen. Despite the use of different fuels, they concluded that the magnetic field significantly altered the shape of the flame and increased the combustion rate. It was observed that the combustion rate increased depending on the gradient of the magnetic field. Additionally, it was determined that the combustion temperature and rate changed depending on the magnetic field. The combustion temperature of methanol in a magnetic field has been thoroughly investigated over time. The findings indicate that varying magnetic field intensities reduce the flame temperature. Specifically, a 0.9 Tesla magnetic field has been determined to completely extinguish the flame.

Guo et al. [18] investigated the influence of magnetic fields on the viscosity of hydrocarbon fuels. They observed that increasing magnetic field strength increased viscosity change, especially noting a more pronounced decrease in viscosity with an increase in the number of carbon atoms, particularly in normal paraffinic hydrocarbons. The same study also revealed that magnetic fields reduced the surface tension of hydrocarbons.

Research conducted by Wakayama [19-22] investigated the dynamics of gas flow in air under a gradient magnetic field ranging from 0 to 1.5 T. Observations revealed that the magnetic field exhibited fluctuations corresponding to changes in oxygen concentration, with higher oxygen levels correlating to increased magnetic force. Analysis of methane diffusion flames indicated that a negative gradient field heightened the burning velocity of diffusion flames, whereas its impact on premixed flames was negligible. Moreover, non-uniform magnetic fields were observed to stimulate combustion reactions within diffusion flames and augment gas flow in inclined regions.Magnetic fields can also create convective airflow and support combustion under microgravity conditions.

Fujita et al. [23] explored the impact of magnetic fields on the behavior of laminar jet diffusion flames in a microgravity environment.In a study conducted under low (approximately 0 mT) and high (approximately 215 mT) magnetic fields, the effects of the magnetic field on flame shape, length, brightness, and color were evaluated. It was determined that with an increase in the magnetic field, the flame length decreased, and the flame color turned yellow with increased temperature.

Morozov et al. [24] studied how a steady magnetic field changed the propagation conditions of the combustion wave. In their study, it was observed that combustion speed increased by 30% in a 0.27T magnetic field. It was noted that the increase in combustion speed was related to the degree of compression created by the magnetic field. The ionization of reactants at the combustion front resulted in the development of combustion electromotive force.

Baker and Varagani [25] studied the behavior of laminar diffusion slot flames when subjected to non-uniform magnetic fields. Slot flames were specifically chosen for mathematical modeling purposes because of the ease in establishing a symmetrical magnetic field.This study observed a decrease in maximum flame temperature.

onducted numerical simulations to investigate the impact of a magnetic field on airflow at the inlet. Their findings indicated that the magnetic field augmented the airflow, resulting in a twofold increase in pressure difference.Tung et al. [27] addressed how magnetic forces affected the fluidity of crude oil and demonstrated the effect of magnetic fields on viscosity through electron microscopy analysis.

Loskutova et al. [28] examined the effects of magnetic fields on the properties of resin, asphaltene, and paraffin hydrocarbons, showing their impact on factors like viscosity, antioxidants, and paramagnetic properties. Tao's studies [29,30] observed that strong and pulsed magnetic fields could reduce the viscosity of gasoline and diesel.

Numerous researchers have extensively investigated the impact of magnetic fields on the performance of fuel combustion systems, yielding significant findings in this field. Saksono's research [31] examined the influence of multiple factors—such as magnetic density, pole orientation, fuel flow rate, and the distance between the magnet and the burner—on the efficiency of kerosene stoves. This study emphasized the potential of magnetization to enhance the efficiency of kerosene stoves. Chang and Weng's work [32] contained an important finding on how an increasing magnetic field affected hydrogen bonds in liquid water. This study proposed an interesting suggestion that magnetic fields could control the size of molecular clusters.

Gillion et al.'s study [33] thoroughly investigated the influence of an axially symmetric superconducting magnetic field on propane combustion within burners. Their study elucidated the effects of magnetic fields on combustion reactions, proposing mechanisms such as the Lorentz force, direct impacts on chemical reactions, and indirect effects on oxygen. Evdokimov and Kornishin [34] observed how magnetic fuel conditioning led to a decrease in viscosity through the separation of colloids in oil.

The research conducted by Legros and colleagues [35] explored the impact of high magnetic density on methane diffusion flames, suggesting that magnetic fields had the potential to augment instability and expand the flame's reaction zone. [36], addressing the effects of magnetic fields on molecules like n-hexane and benzene, suggested that magnetization could influence the vibration states of molecules, potentially increasing the fuel's kinetic and free energy. The work by Ugare et al. [37] explores the performance analysis of a single-cylinder, four-stroke compression-ignition engine under the influence of a magnetic field. The magnetic field was applied along the fuel line using powerful permanent magnets with a strength of 5000 gauss. Various engine load conditions were examined in experiments, and exhaust gas emissions (CO, CO_2, HC, and NO_x) were measured utilizing an exhaust gas analyzer. The application of the magnetic field resulted in a 12% reduction in fuel consumption, along with a 22% decrease in HC emissions and a 7% decrease in CO emissions. However, a notable 19% increase in NO_x levels was observed. Additionally, CO_2 emissions from the compression-ignition engine experienced a 7% rise. Kumar and Shakher [38] extensively investigated how flames produced by a butane torch behaved under the presence of a magnetic field. These studies comprehensively addressed the effects of magnetic fields on fuel combustion systems, enhancing the knowledge in this field and paving the way for future research. Research conducted to understand the effects of magnetic fields on combustion processes addresses a complex topic. For instance, many of these studies have examined various fuel types to comprehend how magnetic fields influence combustion rates. The text may include examples or specific scenarios to better understand these interactions. For example, it could provide a more detailed explanation of how the combustion temperature of methanol in a magnetic field changes over time or discuss the factors influencing the impact of a magnetic field on the combustion process of a specific fuel type. Agarwal and colleagues' study [39] extensively analyzed the influence of magnetic fields on the temperature profile of diffusion flames, noting a reduction in flame temperature attributed to the presence of the magnetic field. Elamin et al.'s research [40] addressed the effects of magnetic fields on the properties of diesel fuel and cetane number. They explored effects on density and viscosity, concluding that magnetization improved the quality of diesel fuel.

Singh's study [41] evaluated the influence of magnetic fields on flame behavior using dimensionless parameters and emphasized the importance of Froude, Grashoff, and Reynolds numbers. Wein-Fei Wu et al. [42] investigated methane combustion characteristics under strong magnetic fields and studied how magnetic fields affected flame temperature. Barmina et al. [43,44] conducted comprehensive research into the influence of magnetic forces on the combustion dynamics of wood biomass. Their investigation thoroughly analyzed the impact on flame speed, composition, temperature variations, and combustion efficiency profiles.

Similarly, Barmina et al.'s studies [45] focused on the development of rotating flame dynamics under the influence of gradient magnetic fields, demonstrating that this effect led to more effective vaporization and facilitated clean energy production. Morsi K.'s research [46] emphasized the principles and recent advancements in electrically driven combustion synthesis processes, highlighting the benefits of electric fields in these processes.

Boben, Ramnath, and Lyons [47] investigated the effect of moderate magnetic fields on the temperature of diffusion flames, finding that decreasing magnetic fields led to a significant increase in local temperature. Agarwal and Shakher [48] examined the impact of magnetic fields on the temperature profile and flow characteristics of microflames using numerical modeling and experimental studies, detailing their results extensively.

Di Renzo et al.'s study [49] explored differences in the strength of electrical failures in their experiment, and they used a thorough chemical model of methane-air combustion to pinpoint possible causes of these differences. Ramnath and Lyons [50] explored a technique involving low-strength permanent magnets to control propane diffusion flames. Marouf et al.'s work [51] examining the effects of magnetic fields on candle flames determined a positive effect on flame height and lifespan.

Perdana et al.'s research [52], focusing on the effect of magnetic field orientation on the combustion properties of vegetable oil, explained the transformation of hydrogen protons with the electron becoming energetic, indicating that stronger magnetic poles could increase the combustion rate of vegetable oil. These studies have offered new perspectives on the impact of magnetic fields on fuel combustion processes from different angles, contributing to advancements in fuel technologies. Oxygen and water vapor behaved differently under magnetic fields, affecting heat distribution and combustion. Hence, it was found that in an attractive magnetic field, flame speed was highest, whereas in a repulsive magnetic field, it was lowest.

Perdana [53] scrutinized the combustion process of olive oil droplets, exploring facets such as temperature changes, height, evolution, and ignition delay. A high-speed camera was utilized to observe the behavior of the olive oil droplet, positioned atop a K-type thermocouple, situated between two magnetic bars within a nitrogen-pressurized combustion chamber. The nitrogen pressure was tested at three different levels: 0.5, 1, and 1.5 bars. Results showed that 0.5 bar nitrogen pressure provided more stable flame evolution and stability. Additionally, it was found that 0.5 bar pressure resulted in higher temperature and shorter ignition delay compared to 1 bar and 1.5 bar pressure. This was experimentally attributed to higher nitrogen pressure hindering the collision of olive oil vapor with air.

Perdana et al. [54] investigated pre-mixed combustion with coconut oil, studying different perforated plates and magnetic field orientations. They found varied plate designs significantly affected flame stability, favoring an 11-hole plate at higher reactant velocities. The magnetic field notably accelerated combustion speeds, especially at 659°C using a 7-hole plate, attributed to electron spin's role in breaking carbon chain bonds in the fuel.

In their study, Perdana et al. [55] explored the impact of magnetic fields on pre-mixed combustion using vegetable oil. Their findings indicated that the magnetic field enhanced laminar combustion speed by energizing electron spin, particularly notable with stronger electrical poles within vegetable oils. They observed that in repulsion poles, the laminar flame speed was lower compared to attraction poles.

Perdana et al. [56] studied magnetic field effects on kapok oil combustion. They found that attractive fields created brighter, hotter flames compared to repulsive ones. Magnetic fields broke bonds in the flame, promoting high-temperature combustion with increased oxygen. Additionally, they enhanced heat transfer, altering flame heights via induced airflow.

Zharfa and Karimi [57] examined the effect of a magnetic field on the reaction flow of hydrogen-methane fuel mixtures. Numerical simulations were conducted by adding obstacles to the inlet nozzles and applying magnetic fields of varying intensities, showing that the applied magnetic field significantly reduced the required preheating temperature for air in medium or heavily diluted oxygen combustion. They also observed that the applied magnetic field thickened the combustion flow and increased heat release.

In their study, Zhang and Wie [58] examined altering solid fuel combustion rates to enhance solid-fueled ramjet performance. They experimentally and numerically explored magnetic field effects on polymethyl methacrylate (PMMA) rods' regression rates, observing changes in flame structure. Experimental results showcased varied regression rates (-32.5% to 10.8%) with different magnetic field effects on PMMA. Numerical simulations aligned with gas-phase combustion and gas-solid heat transfer. Magnetic fields consistently adjusted combustion rates for paramagnetic and diamagnetic materials, suggesting potential for tailored solid-fueled ramjet performance.

Xie et al. [59] investigated the effect of vertically decreasing magnetic fields on the combustion characteristics of laminar biogas flames. They found no significant effect of the magnetic field on premixed flames, attributed to the low oxygen concentration and relatively high flow momentum of the injected gas. Varied oxygen distributions were determined to bring about better combustion and higher flame temperatures.

In their study, Gap et al. [60] researched the suppression effects of magnetic fields on alkane gas explosions. The effects of alkane gas explosions on explosion pressure, pressure rise rate, and flame propagation speed were experimentally examined. The mechanism of alkane gas explosions was explained by combining experimental results with simulation and the gradient magnetic field force. It was found that the magnetic field significantly weakened alkane gas explosions, reducing flame propagation speed and explosion pressure. This effect was observed to be more pronounced in ethane gas explosions. They explained the mechanism of the effect of the magnetic field based on altering the orbit of free radicals, thereby preventing collisions.

Zhou et al. [61] studied the impact and mechanism of magnetic fields on the explosion reaction of C_3H_8/air mixtures. They tested the explosion suppression capabilities of ferromagnetic and diamagnetic materials, noting that ferromagnetic materials exhibited greater effectiveness in suppressing explosions. Moreover, they investigated the influence of a DC magnetic field on gas explosions, concluding that magnetizing the iron surface did not enhance explosion suppression capability.

3. MAGNETIC FIELD APPLICATIONS IN ENHANCING ENGINE COMBUSTION

Numerous experimental studies consistently demonstrate that the application of an external magnetic field has the potential to enhance engine performance and mitigate pollution emissions.

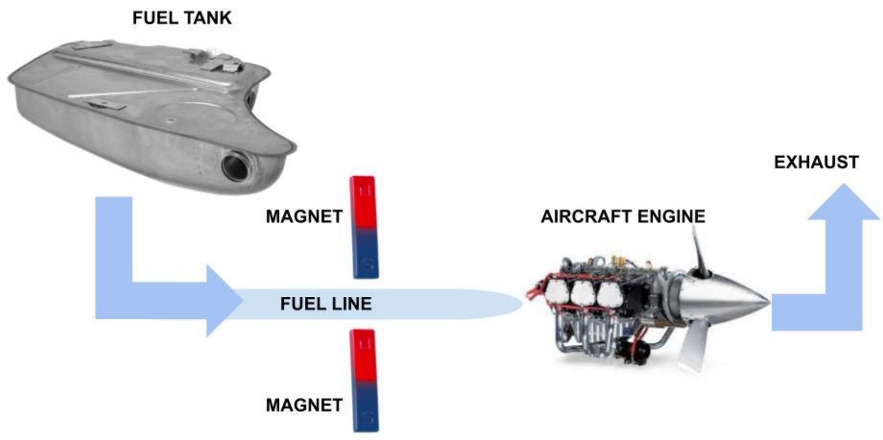

Figure 2. Placement Diagram Of The Magnetic Field On The Engine Fuel Line

Govindasamy and Dhandapani [62] delved into magnetically enhanced combustion by introducing NdFeB magnets with varying intensities into a single-cylinder two-stroke spark-ignition engine. Placing these magnets with their north pole directed towards the radiator core boosted the engine's Brake Thermal Efficiency by 3.2% and peak pressure by 6.1%, concurrently reducing unburned hydrocarbons and carbon monoxide emissions. In another study Govindasamy and Dhandapani [63], the utilization of single-pole magnetic technology amplified peak pressure per cycle in correlation with increased magnetic power. Govindasamy and Dhandapani [64] examined the impact of magnetic conditioning on Jatropha Biodiesel in a single-cylinder four-stroke diesel engine. Magnetic conditioning enhanced thermal efficiency by up to 5% and substantially reduced NO_x emissions, approaching near-zero levels.

Fatih et al. [65] demonstrated a remarkable 15% reduction in CO, HC, and NO_x emissions within a four-cylinder four-stroke gasoline engine through the application of permanent magnets. This reduction consequently led to decreased Specific Fuel Consumption (SFC). It was observed that the magnetic field increased fuel ionization, resolved carbon buildup, and extended engine life. Due to enhanced combustion efficiency, methane concentration decreased by up to 40%.

Faris et al. [66] investigated the effect of the magnetic field on the microstructure of fuel using ultraviolet and infrared absorption spectra. It was found that magnetization increased the ultraviolet absorption power of aromatic hydrocarbons, enhancing combustion efficiency by breaking bonds in aromatic rings. In tests conducted on a two-stroke spark-ignition engine, a notable decrease in specific fuel consumption of up to 14% was observed.Habbo et al. [67]

examined the effect of ignition timing on engine performance and emissions using magnetic coils. Altering ignition timing resulted in reduced specific fuel consumption and up to 8% decrease in exhaust gas temperature. Jain et al. [68] incorporated permanent magnets into both the fuel and air lines of a single-cylinder diesel engine. Tests revealed an increased reduction in fuel consumption with increasing load. Siregar and Nainggolan [69] tested electromagnetic fuel-saving devices made of plain carbon steel and copper under laboratory and road conditions. It was noted that copper cores were more effective in generating magnetic force, contrary to theoretical suggestions.

Attar et al. [70] investigated the impact of magnetic fields on fuel consumption, assessing different magnetic strengths in both a stationary diesel engine and a motorized bicycle. Approximately 7 kmpl increase was observed in the motorcycle test, although it was noted that high magnetic intensities could negatively impact engine performance. Garg et al. [71] examined the performance and emission improvements of magnetically conditioned gasoline-powered car engines. All brands showed performance and emission enhancements, with an average increase in mileage performance ranging from 15% to 25%. Vijayakumar et al. [72] investigated the impact of applying a magnetic field to a single-cylinder four-stroke diesel engine using Ni-Cu-Ni-coated magnets. The conclusion was drawn that the magnetic field increased internal energy, thereby enhancing combustion efficiency. explored the influence of magnetic fuel treatment on combustion engine performance. Their tests, involving gasoline, diesel, and natural gas, highlighted the magnetic field's greatest efficacy with gasoline. The study suggested a stronger impact of magnetic fields on liquid-phase fuels, noting a quicker decline in effectiveness within the gas phase. Patel et al. [74] investigated the impact of magnetic conditioning in conjunction with a catalytic converter on performance and emission characteristics within a diesel engine.The combination of both technologies proved effective in improving performance and emissions.

Sala & Notti [75] observed a 4.6% reduction in fuel consumption and a 14.1% decrease in CO emissions after installing an electromagnetic device on a fishing boat. Khedawan & Gaikwad [76] examined the influence of a magnetic field on hydrocarbon-based refrigerants. Their findings revealed reduced fuel consumption and exhaust concentration for the hydrocarbon-based R600, whereas no discernible effect was observed for the non-hydrocarbon-based R134A.

Mohammed Al-Rawaf [77] noted a 5.5% reduction in fuel consumption and a 13.5% increase in brake thermal efficiency in a Mercedes Benz engine running on Iraqi gasoline with magnetic fuel conditioning. Gabina et al. [78] investigated the effect of magnetic devices on improving energy efficiency in fishing vessels and observed reduced fuel consumption under laboratory conditions. Gad [79] analyzed the influence of magnetic fuel conditioning on the performance and emission traits of a single-cylinder diesel engine across diverse conditions. Chen et al. [80] investigated the performance and emissions of a diesel generator equipped with a magnetic tube attachment. They noted a 3.5% reduction in fuel consumption alongside an enhancement in brake thermal efficiency. Tipole et al. [81] studied a diesel engine integrated with magnetic flux and found the highest improvement at 9000 G magnetic intensity. Kurji & Imran [82] reported a 15.71% decrease in fuel consumption by placing permanent magnets before the injection pump in a CI engine. Sahoo & Jain [83] examined the impact of nano-fuel additives with magnetic fuel conditioning and highlighted that the magnetic field facilitated better atomization of fuel particles. Niaki et al. [84] found that magnetic fuel conditioning improved fuel economy by 4% to 12% and reduced emissions on a multi-cylinder gasoline engine.

Oommen & Narayanappa [85] explored the impact of magneticfield-supported combustion on gas and liquid phase fuels, specifically gasoline and LPG, within an automobile engine, assessing its influence on emission levels.The magnetic field positively affected combustion, reducing toxic components in both fuel types with a decrease of 20.58% in CO and 14.47% in UBHC emissions. In another study [86], they explored the interaction between magnetic field-supported LPG combustion and partial EGR. Applied magnetic fields improved LPG combustion characteristics, leading to a 13.8% fuel economy increase and a 3.9% increase in brake thermal efficiency. In their study [87], they investigated the impact of magneto-ignition on air polluting gas emitted by a multi-point fuel-injected car engin. Magneto-ignition reduced toxic emissions and restructured the hydrocarbon composition, with reductions of 23.97% in CO, 13.1% in UBHC, and 5.23% in NO_x. In a different study with a gasoline-fed engine, the authors [88] investigated combustion characteristics under a magnetic field and found decreased exhaust emissions and enhanced engine performance. In their recent study [89], they examined the charge combustion mixed with inert exhaust gas under a strong magnetic field, observing increased fuel oxidation and reduced cycle variability.

Pawar & Hudgikar [90], in their study, suggested that permanent magnets could enhance gasoline combustion, improving the performance of internal combustion engines while reducing exhaust emissions. They observed that a strong magnetic field altered the fuel structure, allowing better atomization. This effect could reduce fuel consumption while aiding in the reduction of exhaust pollutants by enhancing combustion efficiency.

4. EMISSIONS FROM ENGINES

Engines play a crucial role in modern industry and transportation; however, their operations can lead to the release of various pollutants into the atmosphere. Emission gases produced during the combustion process pose a substantial threat to both the environment and human health. This article examines the types of emission gases originating from engines and their environmental impacts. These gases primarily consist of combustion by-products, including Particulate Matter (PM), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2). Emission gases from engines can result in air pollution, acid rain, climate change, water and soil pollution, impacting living organisms. They pose a significant threat to both human health and the environment. Cleaner fuel technologies, innovative engine designs, and strict regulations offer opportunities to mitigate these adverse effects. Investments in sustainable transportation and energy sources are essential for controlling emission gases and creating a habitable environment for future generations [91-93].

4.1. Potential Applications of Magnetic Field to Combustion

Among the prospective applications of applying magnetic fields to fuels are increasing the combustion rate, enhancing engine performance, reducing emissions, and improving fuel efficiency. It has been observed that magnetic fields increase laminar flame velocity and optimize combustion processes in Calophyllum Inophyllum biodiesel [94]. Additionally, by influencing fuel molecules, magnetic fields can lead to better reactions with oxygen and improved combustion, especially in hydrocarbon fuels [95]. Furthermore, the application of magnetic fields to microalgae cultivation has shown promising results in achieving high-efficiency biomass concentration and accumulating carbohydrates and lipids, making it a viable alternative for third-generation biofuel production [96].

Research has indicated that magnetic field induction affects the characteristics of pre-mixed ethanol combustion flames, resulting in more effective and efficient flames [97]. Moreover, magnetization of bioethanol-gasoline fuel blends has been demonstrated to increase combustion energy in internal combustion engines, reduce emissions, and enhance combustion quality [98].

It has been found that magnetic fields have various effects on combustion and explosions, leading to potential industrial applications. Firstly, they can enhance fuel efficiency and engine performance by increasing the combustion rate and improving the reaction between fuel and oxygen [95]. Secondly, magnetic fields can reduce emissions by influencing the orientation of hydrocarbons and facilitating the oxidation process [99]. Thirdly, they have been shown to be beneficial for biofuel production, such as increasing the laminar flame velocity of biodiesel from Calophyllum Inophyllum [100]. Additionally, magnetic fields can improve the efficiency of gas turbines by increasing oxygen intake and reducing particulate agglomeration [101]. Finally, by influencing the behavior of chain-like aggregates and increasing flame intensity, magnetic fields have the potential to prevent explosions [102]. These findings emphasize the potential of magnetic fields in improving combustion processes and their relevance to real-world applications.

The negative effects of magnetic fields on fuel combustion are limited, but there are some potential challenges and disadvantages that need to be considered. Issues with combustion stability may arise when magnetic fields are applied [94]. Additionally, oxidation problems can occur as magnetic fields may influence the molecules involved in the combustion process [99]. Furthermore, a decrease in fuel efficiency may be observed when magnetic fields are utilized [97]. Considering the cost of additional equipment and resources required for magnetic field application, the cost of magnetization is another factor that needs to be taken into account [95]. Moreover, the natural properties of the fuel can change when exposed to magnetic fields [100]. Determining the optimal conditions for combustion when magnetic fields are present can also be challenging. In general, while magnetic fields can have positive effects on combustion, there are potential disadvantages that need to be considered.

5. CONCLUSION

This comprehensive literature review delves into the effects of magnetic fields on fuel combustion processes from a diverse array of perspectives. Various studies have demonstrated that magnetic fields augment combustion rates, alter flame structures, and influence fuel properties. Nonetheless, in some instances, the impact of magnetic fields can lead to alterations in combustion rates, flame temperatures, and fuel characteristics.

In the concluding section of the article, attention can be directed toward the following key points:

Effect of Magnetic Fields on Combustion Efficiency: The studies conducted generally indicate an enhancement in combustion efficiency due to magnetic fields. This augmentation correlates with changes in combustion rates and is achieved through the intervention of magnetic fields in the combustion process.

Changes in Emissions and Environmental Impacts: Magnetic fields have the potential to reduce emissions during the fuel combustion process. This could be attributed to the promotion of a cleaner combustion process, which may have a positive impact on atmospheric pollution and environmental concerns.

Alterations in Physical and Chemical Properties of Fuel: It's observed that magnetic fields affect fuel viscosity, surface tension, and molecular structures. These effects could play a significant role in optimizing the combustion process.

Impact on Engine Performance and Fuel Economy: Several studies suggest that magnetic fields can improve both engine performance and fuel economy. They may facilitate better combustion of fuel and its more efficient utilization.

Applicability and Potential of Magnetization Technology: Research on the practical applications and industrial uses of magnetic fields underscores the potential of this technology. However, the effects of magnetic fields on different fuel types and engine systems might require further investigation.

The recommendation section can provide a framework for future research endeavors:
Further Exploration of Magnetic Fields: More comprehensive experimental studies are necessary to explore interactions between different fuel types, engine systems, and magnetic fields.

Industrial Application of Magnetic Fields: More research is needed on the practical applications of magnetic fields in industrial systems. Their impact on industrial efficiency and environmental sustainability should be evaluated.

Effects of Magnetic Fields on Emission Control: The potential of magnetic fields in emission control and reduction of atmospheric pollution needs to be more thoroughly examined.

These conclusions and recommendations could serve as a foundational basis to comprehend the effects of magnetic fields on fuel combustion processes and guide future research in this field.

SYMBOLS AND ABBREVIATIONS

°C: Celsius degrees.
%: Percent.
CH: Hydrocarbons like methane.
CI: Compression Ignition.
CFD: Computational Fluid Dynamics.
C_3H_8: Propane.
CO: Carbon Monoxide.
CO_2: Represents carbon dioxide gas.
DC: Direct current.
DNA: Deoxyribonucleic acid.
EGR: Exhaust Gas Recirculation.
G: Gauss (unit of magnetic field).
H_2: Hydrogen.
HC: Hydrocarbons.
IR: Infrared.
kmpl: Kilometers per liter
LPG: Liquified Petroleum Gas.
m: Meter.
mT: Millitesla
NdFeB: Neodymium Iron Boron
N: Newton (unit of force).
Ni-Cu-Ni: Nickel-Copper-Nickel.
NO_x: Nitrogen oxides.
O_2: Oxygen gas.
PM: Particulate Matter.
PMMA: Polymethyl methacrylate (a polymer).
ppm: Parts per million (a part in a million).
SFC: Specific Fuel Consumption.
SO_2: Sulfur Dioxide.
SO_x: Sulfur oxides.
T: Tesla (unit of magnetic field).
UBHC: Unburned Hydrocarbons.
UV: Ultraviolet.
γ: Gamma

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Ozan Öztürk: Conducted the Literature Review and Wrote the Manuscript.
Murat Taştan: Conducted the Literature Review and Wrote the Manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Sevim C. Küresel enerji jeopolitiği ve enerji güvenliği. Yaşar Üniversitesi E-Dergisi 2012; 7(26): 4378-4391.

[2] The World Bank (N.D.) World Bank Open Data: Population, Total 2022; Https://Data.Worldbank.Org/Indicator/SP.POP.TOTL

[3] International Energy Agency (N.D.) World Oil Supply And Demand, 1971-2020. IEA, Paris. 2021; Https://Www.Iea.Org/Data-And-Statistics/Charts/World-Oil-Supply-And-Demand-1971-2020

[4] İlbaş M, Yılmaz İ. Farklı ısıl güçlerdeki kazanlarda yanma ve emisyon davranışının araştırılması. Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi 2002; 18(1): 18-27.

[5] Yılmaz İ, İlbaş M. Hidrojen-metan karışım yanmasında yanma model sabitinin değerlendirilmesi. Isı Bilimi ve Tekniği Dergisi 2010; 30(1): 45-57.

[6] Saksono N. Magnetizing kerosene for increasing combustion efficiency. Jurnal Teknologi 2005; Edisi No. 2, Tahun XIX, 155-162.

[7] Bian YC, Ding W, Hu L, Et Al. Magneto-revealing and acceleration of hidden kirkendall effect in galvanic replacement reaction. Phys. Chem. Lett 2021; 12(22): 5294–5300.

[8] Alnaimat, Dagher S, Mathew B, Et Al. Microfluidics based magnetophoresis: A review. The Chemical Record 2018; 18(11): 1596-1612.

[9] Li JQ, Ma TB, Ning JG. Mechanism of explosion-induced disturbance in natural magnetic field. Chinese Journal Of Theoretical And Applied Mechanics 2018; 50(05): 1206-1218.

[10] Gilart RA, Ungaro MRB, Rodríguez CEA, Et Al. Performance and exhaust gases of a diesel engine using different magnetic treatments of the fuel. Journal of Mechanical Engineering and Sciences 2020; 14(1): 6285-6294.

[11] Chen CY, Lee WJ, Mwangi JK, Et Al. Impact of magnetic tube on pollutant emissions from the diesel engine. Aerosol and Air Quality Research 2017; 17(4): 1097-1104.

[12] Al-Rawaf MA. Magnetic field effects on spark ignition engine performance and its emissions at high engine speeds. Journal of Engineering and Development 2015; 19(4): 37-48.

[13] Kumar V, Rastogi V, Agarwal S, Et Al. Investigation of temperature profile and temperature stability of micro diffusion flame under the influence of magnetic field by use of a holo-shear lens-based interferometer. Optical Engineering 2020; 59(6): 064107.

[14] Ueno S, Harada K. Experimental difficulties in observing the effects of magnetic fields on biological and chemical processes. IEEE Transactions on Magnetics 1986; 22(5): 868-873.

[15] Ueno S, Harada K. Effect of magnetic fields on flames and gas flow. IEEE Transactions on Magnetics 1985;21(5).

[16] Ueno S, Harada K. Combustion process under strong DC magnetic fields. IEEE Transactions On Magnetics 1987; 23(5): 2752-2754.

[17] Ueno S, Esaki H, Harada R. Magnetic field effect on combustion. IEEE Translation Journal on Magnetics in Japantjmj1987; 2(9).

[18] Guo H, Chen Y, Yao R. A study of magnetic effects on the physicochemical properties of individual hydrocarbons. IEEE Transactions on Magnetics 1986.

[19] Wakayama N. Behavior of gas flow under gradient magnetic fields. Journal of Applied Physics 1991; 69: 2734–2736.

[20] Wakayama N. Effect of a gradient magnetic field on the combustion of methane in air. Chemical Physics Letters 1992; 188: 279-281.

[21] Wakayama N. Magnetic promotion of combustion in diffusion flames. Combustion and Flame 1993; 93: 207-214.

[22] Wakayama N, Ito H, Kuroda Y, Fujıta O, Ito K. Magnetic support of combustion in diffusion flames under microgravity. Combustion and Flame 1996; 107: 187-192.

[23] Fujita O, Ito K, Chida T, Nagai S, Takeshita Y. Determination of magnetic field effects on a jet diffusion flame in a microgravity environment. Twenty-Seventh Symposium (International) on Combustion/The Combustion Institute 1998; 2573–2578.

[24] Morozov YG, Kuznetsov MV. Effect of magnetic fields on combustion electromotive force. Combustion, Explosion and Shock Waves 1999; 35(1): 18-22.

[25] Baker J, Varagani R. Models and experiments on laminar diffusion flames in non-uniform magnetic fields. Seventh International Workshop on Microgravity Combustion and Chemically Reacting Systems 2003; 317-320.

[26] Iwata N, Tsubuki S, Takaki Y, Watanabe K, Sekiguchi, M, Hosoki E, Saido TC. Identification of the major aβ 1–42-degrading catabolic pathway in brain parenchyma: suppression leads to biochemical and pathological deposition. Nature Medicine 2000; 6(2): 143-150.

[27] Tung H, Cédric D, Anne V, Agnès J, Gilles L. A global tool for environmental assessment of roads–application to transport for road building. In European Conference of Transport Research Institutes The Hague 2010.

[28] Loskutova O, Walker TR, Crittenden PD, Dauvalter VA, Jones V, Kuhry P, Pystina T. Multiple indicators of human impacts on the environmentin the pechora basin. North-Eastern European Russia. Ecological Indicators 2009; 9(4): 765-779.

[29] Tao R. Investigate effects of magnetic fields on fuels. Department of Physics, Temple University, Philadelphia 2004.

[30] Tao R, Xu X. Reducing the viscosity of crude oil by pulsed electric or magnetic field. Energy & Fuels 2006; 20: 2046-2051.

[31] Saksono N. Magnetising kerosene for increasing combustion efficiency. Jurnal Teknologi 2005; 2: 155-162.

[32] Chang KT, Weng CI. The effect of an external magnetic field on the structure of liquid water using molecular dynamics simulation. Journal of Applied Physics 2006; 100: 043917.

[33] Gilard V, Gillon P, Blanchard JN, Sarh B. Influence of a horizontal magnetic field on a co-flow methane/air diffusion flame. Combustion Science and Technology 2018; 180(10-11): 1920-1935.

[34] Evdokimov IN, Kornishin KA. Apparent disaggregation of colloids in a magnetically treated crude oil. Energy & Fuels 2009; 23(8): 4016-4020.

[35] Legros G, Gomez T, Fessard M, Guibert P, Torero J. Magnetically induced flame flickering. Proceedings of the Combustion Institute 2010; 33: 1095-1103.

[36] Jalali M, Ahmadi M, Yadaei F, Azimi M, Hoseini H. Enhancement of benzine combustion behaviour in exposure to the magnetic field. Journal of Clean Energy Technologies 2013; 1: 224-227.

[37] Ugare V, Dhoble A, Lutade S, Mudafale K. Performance of internal combustion (CI) engine under the influence of strong permanent magnetic field. Journal of Mechanical and Civil Engineering 2014; 3: 11-17.

[38] Kumar M, Agarwal S, Kumar V, Khan G, Shakher C. Experimental investigation on butane diffusion flame under the influence of magnetic field by using digital speckle pattern interferometry. Applied Optics 2015; 54(9): 2450-2460.

[39] Agarwal AK, Gupta T, Shukla PC, Dhar A. Particulate emissions from biodiesel fuelled CI engines. Energy Conversion and Management 2015; 94: 311-330.

[40] Elamin AA, Ezeldin M, Masaad AM, Suleman NM. Effect of magnetic field on some physical characteristics and cetane number of diesel fuel. American Journal of Applied Chemistry 2015; 3(6): 212-216.

[41] Singh A. Measurement of fuel flow behaviour of propane diffusion flame by dimensionless numbers under magnetic field application. International Journal of Combined Research and Development 2015; 4: 585-586.

[42] Wu W, Qu J, Zhang K, Chen W. Experimental studies of magnetic effect on methane laminar combustion characteristics. Combustion Science and Technology 2016.

[43] Barmina I, Zake M. Effects of magnetic field on swirling flame dynamics. Engineering for rural development, Jelgava 2016.

[44] Barmina I, Zake M. Magnetic field control of combustion dynamics. Latvian Journal of Physics and Technical Sciences 2017; 53(4): 36-46.

[45] Barmina I, Zake M, Strautins U, Marinaki U. Effects of gradient magnetic field on swirling flame dynamics. Engineering For Rural Development Jelgava 2017; 24.

[46] Morsi K. Combustion synthesis and the electric field: A review. International Journal of Self-Propagating High-Temperature Synthesis 2017; 26(3): 199–209.

[47] Boben RR, RamnathV, Lyons KM. Effect of moderate-strength magnetic field on local temperature in diffusion flames. Aeronautics and Aerospace Open Access Journal 2018; 2(4): 250–257.

[48] Agarwal S, Shakher C. Effect of magnetic field on temperature profile and flame flow characteristics of micro flame using talbot interferometer. Optic - International Journal for Light and Electron Optics 2018; 168: 817–826.

[49] Di Renzo M, Urzay J, De Palma P, De Tullio MD, Pascazio G. The effects of incident electric fields on counterflow diffusion flames. Combustion and Flame 2018; 193: 177–191.

[50] Ramnath V, Lyons KM. The potential of simple, low-cost permanent magnets for flame manipulation in flow fields. Aeronautics and Aerospace Open Access Journal 2018; 2(1).

[51] Marouf HH, Elsemary IM, Abdel Rahim AA, Abd Rabo MF. Effect of electromagnetic field on combustion of candle flame. Engineering Research Journal 2019; 1(39): 18–22.

[52] Perdana D, Adiwidodo S, Choifin M, Winarko WA. The effect of magnetic field variations in a mixture of coconut oil and jatropha on flame stability and characteristics on the premixed combustion. EUREKA: Physics and Engineering 2021; (5): 13–22.

[53] Perdana D. The experimental of impact of additional magnetic fields and nitrogen pressure on olive oil droplet combustion. Indonesian Journal of Applied Research (IJAR) 2023; 4(1): 1–10.

[54] Perdana D, Adiwidodo S, Winarko WA. The role of perforated plate and orientation of the magnetic fields on coconut oil premixed combustion. Energy 2022; 67(2): 77–84.

[55] Perdana D, Yuliati L, Hamidi N, Wardana ING. The role of magnetic field orientation in vegetable oil premixed combustion. Journal of Combustion 2020; 2020: 11.

[56] Perdana D, Setiyawan DG, Choifin M. Experimental study on flame characteristics of premixed combustion of kapok oil with various magnetic field. Orientations 2020; 8(1). Sjme Kinematika Juni 2023.

[57] Zharfa M, Karimi N. Intensification of MILD combustion of methane and hydrogen blend by the application of a magnetic field- a numerical study. Acta Astronautica 2021; 184: 259–268.

[58] Zhang Z, Wei Z. Experiment and simulation of the effects of non-uniform magnetic field on the regression rate of PMMA. Combustion and Flame 2021; 223: 337–348.

[59] Xie Y, Wei Z, Zhou, T, Zhen H, Liu Z, Huang Z. Combustion characteristics of small laminar flames in an upward decreasing magnetic field. Energies 2021; 14: 1969.

[60] Gao JC, Yang XG, Hu ST, Hong ZJ, Et Al. Effect of external magnetic field on acetylene explosion reaction. Explos. Shock Waves 2022; 42(07): 150-160.

[61] Zhou S, Gao J, Luo Z, Hu S, Wang L, Wang T. Role of ferromagnetic metal velvet and DC magnetic field on the explosion of a C_3H_8/air mixture-effect on reaction mechanism. Energy 2021; 239(21): 122218.

[62] Govindasamy P, Dhandapani S. Performance and emissions achievements by magnetic energizer with a single cylinder two-stroke catalytic coated spark ignition engine 2007.

[63] Govindasamy P, Dhandapani S. Experimental investigation on the effect of magnetic flux to reduce emissions and improve combustion performance in a two-stroke, catalytic-coated, spark-ignition engine. International Journal of Automotive Technology 2007; 8(5): 533-542.

[64] Govindasamy P, Dhandapani S. Reduction of NO_X emission in bio diesel engine with exhaust gas recirculation and magnetic fuel conditioning. In GMSARN International Conference on Sustainable Development: Challenges and Opportunities for GMS 2007; 14.

[65] Fatih F, Saber G. Effect of fuel magnetism on engine performance and emissions. Australian Journal of Basic and Applied Sciences 2010; 4: 6354-6358.

[66] Faris AS, Al-Naseri SK, Jamal N, Isse R, Abed M, Fouad Z, Jasim H. Effects of magnetic field on fuel consumption and exhaust emissions in two-stroke engine. Energy Procedia 2012; 18: 327-338.

[67] Habbo ARA, A Khalil R, S Hammoodi H. Effect of magnetizing the fuel on the performance of an si engine. AL-Rafdain Engineering Journal (AREJ) 2011; 19(6): 84-90.

[68] Jain S, Deshmukh S. Experimental investigation of magnetic fuel conditioner in ic engine. IOSR Journal of Engineering, 2012; 2: 27-31.

[69] Siregar H, Nainggolan R. Electromagnetic fuel saver for enhancing the performance of the diesel engine. Global Journal of Researches in Engineering, Mechanical and Mechanics Engineering 2012; 12.

[70] Attar AR, Tipole P, Bhojwani V, Deshmukh S. Effect of magnetic field strength on hydrocarbon fuel viscosity and engine performance. International Journal of Mechanical Engineering and Computer Applications 2013; 1(7): 94-98.

[71] Garg R, Agarwal A. Fuel energizer: the magnetizer (a concept of liquid engineering). International Journal of Innovative Research & Development 2013; 2: 617-627.

[72] Vijayakumar P, Patro S, Pudi V. Experimental study of a novel magnetic fuel ionization method in four stroke diesel engines. International Journal of Mechanical Engineering and Robotics Research 2014; 3: 151-159.

[73] Abd-Allah GH. Using exhaust gas recirculation in internal combustion engines: A review. Energy Conversion and Management 2001; 43: 1027–1042.

[74] Patel PM, Rathod GP, Patel TM. Effect of magnetic field on performance and emission of single cylinder four stroke diesel engine. IOSR Journal of Engineering 2014; 4(5): 28-34.

[75] Sala A, Notti E. Preliminary tests of new magnetic device for fuel saving and emission reduction in fisheries. Third International Symposium on Fishing Vessel Energy Efficiency 2014; 1-5.

[76] Khedvan A, Gaikwad V. Review on effect of magnetic field on hydrocarbon refrigerant in vapour compression cycle. International Journal of Scientific Engineering and Technology Research 2015; 4: 1374-1378.

[77] Kacem SA, Ferdaouss L, Abrerrahim L, Mohammed B. Evaluation de l'impact de la pollution agricole sur la qualite des eaux souterraines de la nappe du gharb. European Scientific Journal 2016; 12(11).

[78] Gabiña G, Basurko OC, Notti E, Sala A, Aldekoa S, Clemente M, Uriondo Z. Energy efficiency in fishing: are magnetic devices useful for use in fishing vessels. Applied Thermal Engineering 2016; 94: 670-678.

[79] Gad MS. Assessment of biodiesel derived from waste cooking oil as an alternative fuel for diesel engines. International J. of Chem. Tech. Research 2016; 9(3): 140-146.

[80] Chen C, Lee W, Mwangi J, Wang L, Lu J. Impact of magnetic tube on pollutant emissions from the diesel engine. Aerosol and Air Quality Research 2017; 17: 1097-1104.

[81] Attar AR, Tipole P, Bhojwani V, Deshmukh S. Effect of magnetic field strength on hydrocarbon fuel viscosity and engine performance. International Journal of Mechanical Engineering and Computer Applications 2013; 1(7): 94-98.
[82] Kurji HJ, Imran MS. Magnetic field effect on compression ignition engine performance. ARPN Journal of Engineering and Applied Sciences 2018; 13(12): 3943-3949.
[83] Sahoo RR, Jain A. Experimental analysis of nanofuel additives with magnetic fuel conditioning for diesel engine performance and emissions. Fuel 2019; 236: 365-372.
[84] Niaki SOD, Khatamnejad H, Khalilarya S, Jafarmadar S, Mirsalim M, Gharehghani A. Experimental investigation on the effect of natural gas premixed ratio on combustion and emissions in an idi engine. Journal of Thermal Analysis and Calorimetry 2019; 138(6): 3977-3986.
[85] Oommen LP, Narayanappa KG. Assimilative capacity approach for air pollution control in automotive engines through magnetic field-assisted combustion of hydrocarbons. Environ Sci Pollut Res 2021; 28: 63661–63671.
[86] Oommen LP, Narayanappa KG, Vijayalakshmi SK. Experimental analysis of synergetic effect of part-cooled exhaust gas recirculation on magnetic field-assisted combustion of liquefied petroleum gas. Arab J Sci Eng 2020; 45: 9187–9196.
[87] Oommen LP, Kumar GN. Influence of magneto-combustion on regulated emissions of an automotive engine under variable speed operation. Int. J. Vehicle Structures & Systems 2020; 12(1): 109-112.
[88] Oommen LP, Kumar GN. Analysis of cyclic variations and combustion behavior of liquid phase hydrocarbons under uniform axial and radial magnetic fields. In: Edwin Geo, V., Aloui, F. (eds) Energy and Exergy for Sustainable and Clean Environment 2023; 2. Green Energy and Technology. Springer, Singapore.
[89] Oommen LP, Kumar GN. Experimental analysis of conjoint effect of semi-cooled exhaust recirculation on combustion of liquid phase hydrocarbons under uniform magnetic fields. Arab J Sci Eng 2022; 47: 16049–16057.
[90] Pawar NR, Hudgikar SRK. Performance enhancement of multi-cylinder four stroke SI engine under the effect of magnetic field. In; (eds) Techno-Societal Springer Cham 2021;
[91] Brunekreef B, Holgate ST. Air pollution and health. Lancet 2002; 360(9341): 1233-1242.
[92] Mazaheri M, Johnson GR, Morawska L. An inventory of particle and gaseous emissions from large aircraft thrust engine operations at an airport. Atmos Environ 2011; 45(20): 3500–3507.
[93] Masiol M, Harrison RM. Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. Atmos Environ 2014; 95: 409–455.

[94] Sugara IR, Ilminnafik N, Junus S, Kustanto MN, Hermawan Y. Experimental study on the effect of magnetic fields on combustion characteristics of biodiesel from nyamplung (calophyllum ınophyllum). Automotive Experiences 2023; 6(1): 122-132.
[95] Mohamad Nor AF, Wan Mahmood WMF, Md Jedi MA. Magnetic field ability to treat hydrocarbon fuel in ınternal combustion engine. Jurnal Kejuruteraan 2023; 35(1): 105-115.
[96] Santos LO, Silva PGP, Costa SS, Machado TB. Magnetic field application to ıncrease yield of microalgal biomass in biofuel production. International Journal of Environmental Science and Development 2020.
[97] Andrianto DT, Kustanto MN, Hermawan Y, Ilminnafik N, Junus S. Characterization of premixed flames with ethanol fuel affected by magnetic field ınduction. International Journal of Emerging Trends in Engineering Research 2023; 11(2): 47–50.
[98] Nufus TH, Ulfiana A, Hidayati N, Nuriskasari I, Ridwan E, Kusumastuti SL, Permana S, Susanto I. Magnetization of bioethanol-gasoline fuel blends for development combustion energy and reducing exhaust gas emissions . Eastern-European Journal of Enterprise Technologies 2022; 3(6): 32–40.
[99] Nurkoyim M, Ilminnafik N, Junus S, Kustanto MN, Hermawan Y. Experimental study on the effect of magnetic fields on combustion characteristics of biodiesel from nyamplung (calophyllum ınophyllum). Automotive Experiences 2023; 6(1).
[100] Gonzalez DF. Magnetic field effects on diffusion flames. LSU Master's Theses 2008; 2936.
[101] Komuravelli N. Study of the effects of magnetic field on the properties of combustion synthesized iron oxide nanoparticles. Master's Thesis, LSU, 2005; 2812.
[102] Elias D. Influence of magnetic fields on the evaporation and combustion of a single droplet. Master's Thesis, LSU, 2014; 365.