The Effects Magnetic Field on Droplet Combustion of Avocado Seed Biodiesel

Berliana Rizki Suganda[1], *Andi* Sanata[1*], *Yuni* Hermawan[1], *Nasrul* Ilminnafik[1], and *Danang* Yudistiro[1]

[1]Department of Mechanical Engineering, University of Jember, 68121, Jember, Indonesia

Abstract. The physical and chemical properties of the fuel will affect the combustion characteristics. Avocado seed oil (ASO) was chosen to be used as biodiesel fuel because it is non-edible sources. ASO biodiesel from the transeserification process is considered to have met SNI and can be used as diesel engine fuel. A breakthrough is needed to optimise the combustion results of a single droplet, namely by applying a permanent magnet that can focus on the oxidation reaction of the fuel. The droplet is hung on the end of a thermocouple, placed in the centre between the permanent magnets. Four magnetic field orientations were applied: N-S, S-N, N-N, and S-S. Flame temperature was measured with a K-type thermocouple and the combustion test process was recorded using a DSLR camera. The combustion parameters observed include flame visualisation, ignition delay time, burning time, flame temperature, and flame height. This study was conducted by analysing the behaviour of magnetic field orientation on the combustion of a single droplet of avocado seed biodiesel. The combustion characteristics produced by the attractive magnetic field are more optimal than the repulsive magnetic field. Oxygen and hydrogen reactions are more reactive under attractive magnetic field conditions. Oxygen is paramagnetic so that its molecules can be attracted by the magnetic field and the combustion results are stoichiometric. By optimising single droplet combustion, it will result in more efficient combustion and increase the speed of the combustion reaction. This development is a first step in the analysis of fuel magnetisation in micro-scale combustion before it is applied to diesel engine combustion with potential applications for energy efficiency.

1 Introduction

Improving energy efficiency is a major challenge in the field of fuels and their combustion. Fuels have an impact on the environment [1]. Biofuels such as biodiesel hold great promise in terms of sustainability as they can be produced from plants or biomass [2]. Biodiesel as an environmentally sustainable alternative fuel is the focus of research due to its renewable nature and lower emission potential compared to fossil fuels [3]. High emissions resulting from incomplete combustion process in the combustion chamber [4]. However, the combustion performance of biodiesel is often hampered by its physical and chemical

---

[*] Corresponding author: sanata@unej.ac.id

characteristics, such as high viscosity and lower flash point than fossil diesel fuel [5]. This requires innovation to find solutions to improve the combustion efficiency of biodiesel, including biodiesel from avocado seed oil, which has great potential but has not been widely studied [6].

Previous research has explored ways to improve biodiesel combustion efficiency in the application of fuel atomization technology. Studies show that magnetic fields can affect the orientation of fuel and oxygen molecules and lead to an increase in the combustion reaction rate [7]. The biodiesel droplet combustion test can represent the droplets formed in spray combustion. Some types of biodiesels, depending on their physical properties, can improve heat distribution and accelerate combustion reactions [8]. Previous studies have mostly focused on vegetable oils or biodiesel from common vegetable sources such as palm oil, while avocado seed oil (ASO) from non-edible sources has potential as a biodiesel feedstock and has not been widely explored. The free fatty acid (FFA) content in ASO is 0.87% which allows the oil to go straight through the transesterification process without esterification, as the FFA content is <2% [9].

Magnetic fields have the advantage of improving combustion quality from the influence the role of oxygen [10]. The effect of the magnetic field can also affect the paramagnetic molecules of the fuel, causing changes in the physicochemical properties of the fuel for the better [11]. The greater the magnetic field intensity, the more stable the combustion efficiency will be. At a magnetic intensity of 4000 gauss, it can reduce fuel consumption by 2.3% [12]. In general, biodiesel has a higher viscosity, density, and lower calorific value than diesel. High viscosity often weakens the combustion performance of the fuel [13]. One approach that has attracted attention is the application of magnetic fields in the combustion process [14]. However, variations in the direction of the magnetic field also need to be considered because they can affect the resultant strength of the magnetic field intensity [15].

The research was conducted through experimental method using a biodiesel avocado seed oil and droplet combustion setup equipped with a variable magnetic field system. The method was applied with magnetic field direction control (N-S, S-N, S-S, and N-N), combustion parameter measurement, and comprehensive data analysis to identify the significant impact of the magnetic field treatment. This study analyses the effect of magnetic field direction on biodiesel droplet combustion parameters, such as flame visualisation, ignition delay time, burning time, flame temperature, and flame height.

2 Methods and materials

Avocado seed oil is obtained through the process of pressing avocado seeds using a hydraulic press. The pure oil is then processed through the refining stages, as shown in **Fig. 1**. The degumming process is carried out on raw avocado seed oil reacted with 0.5% phosphoric acid for 30 minutes at 90 °C to remove phospholipids (gums) which are complex compounds that cause the oil to become cloudy and affect the stability and quality of the product [16]. Test the FFA content and ensure the value is <2% before proceeding to the transesterification stage, which is to convert crude oil into methyl ester [17]. The transesterification process, which reacted the ester oil with methoxide liquid (methanol and KOH) for 60 minutes at 60°C. The transesterification product was precipitated for ±12 hours and obtained methyl ester and glycerol. The methyl ester was then washed with distilled water at 50°C for 15 minutes to remove the remaining impurities and impurities such as base catalyst and glycerol that remained after the transesterification process. The methyl ester is heated again at 100°C (boiling point of water) to reduce the remaining water content from the washing process. The final biodiesel needs to be tested for physical and chemical properties including density, viscosity, flash point, calorific value, and GC-MS (Gas Chromatography-Mass

Spectrometry) test to analyse the dominant molecular compounds in ASO biodiesel and fuel characteristics that affect droplet combustion results.

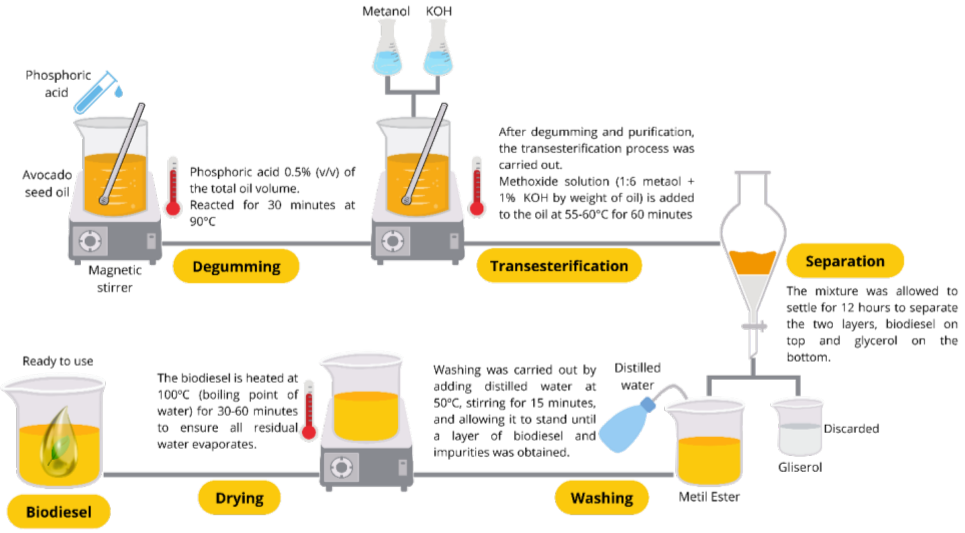


Fig. 1. Biodiesel production process

The fuel droplet combustion test experimental apparatus is shown schematically in **Fig. 2.** The ASO biodiesel droplet combustion test was conducted in a closed chamber with dimensions of 20×15×15 cm to reduce external environmental interference. A variation of magnetic field direction of repulsive; north-north (N-N), south-south (S-S), and attractive; north-south (N-S), south-north (S-N) is used to test the different combustion characteristics as presented in **Fig. 3**.

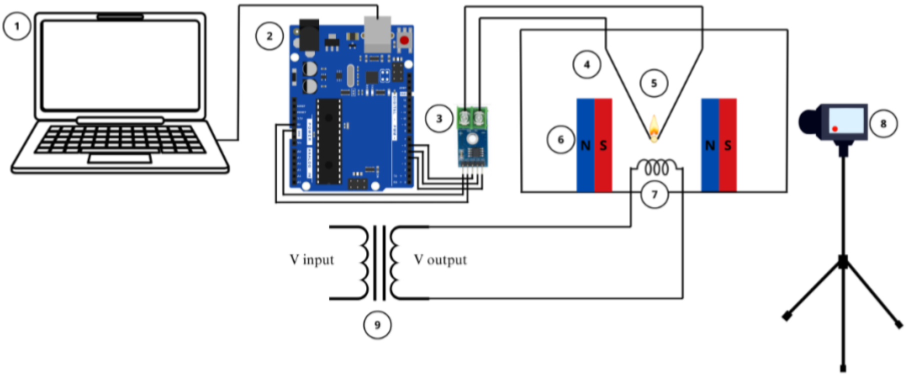


Fig. 2. Droplet combustion test scheme; (1) laptop, (2) arduino uno, (3) max6675 modul, (4) thermocouple k-type, (5) droplet biodiesel, (6) permanent magnet n52, (7) heating element, (8) camera, (9) transformer.

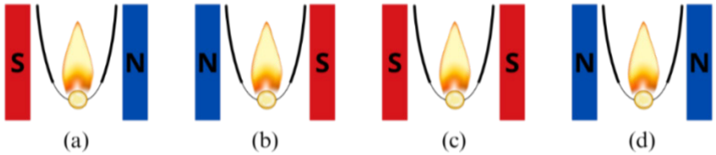


Fig. 3. Variation of magnetic field direction; (a) S-N, (b) N-S, (c) S-S, (d), N-N

The heat energy in the heating element is generated from the electrical energy of the transformer. The heating element is 0.4 mm from nickel-chromium (Ni-Cr) material wire. Biodiesel droplet and placed at the tip of a K-type thermocouple Pt/Rh13% diameter 0.1 mm. The flame temperature is measured from when the heating element is switched on until the flame is extinguished. The MAX6675 module receives the analog signal from the thermocouple and is recorded by the Arduino UNO as a data logger connected to a laptop. Biodiesel droplet were placed at 1 cm between neodymium permanent magnets and 5 mm above the heating element. The N52 magnet has dimensions of 50×25×10 mm with different flux intensities for each magnetic field direction variation, that are N-S (1124.7 Gs), S-N (1008.2 Gs), S-S (549.6 Gs, and N-N (541.8 Gs). During the combustion test, the flame was recorded with a 24-megapixel Nikon D3200 camera. The data tested in this study include flame visualization, flame temperature, burning rate, and ignition delay time. The data obtained included 3 repetitions for each magnetic field configuration to ensure adequate statistical representation.

3 Results and discussion

3.1 The Test Result of Avocado Seed Oil Biodiesel

The avocado seed oil biodiesel has physical properties as shown in **Table 1**. The FFA content of ASO was found to be 0.55%, and can be directly transesterified. SNI 7182:2015 is used as a reference for biodiesel quality standards. ASO biodiesel has physical properties that meet the quality standards of SNI 7182: 2015, with a density of 887.4 kg/m^3, viscosity of 5.32 cSt, flash point of 234°C, and calorific value of 9021 cal/g. From the chemical properties tested, there is a fatty acid composition of methyl esters produced from avocado seed oil biodiesel. This is proven by the GC-MS test, an analytical method used to identify and measure chemical compounds in a sample, as shown in **Table 2**. Biodiesel produced from ASO is dominated by saturated fatty acid composition, namely lauric acid (46.65%), myristic acid (16.13%), caprylic acid (9.77%), capric acid (7.40%), palmitic acid (6.53%), and unsaturated fatty acid oleic acid (7%). From the data generated, the highest fatty acid in ASO biodiesel is dodecanoic acid methyl ester or lauric acid.

Table 1. Physical properties of biodiesel avocado seed oil

Parameter	SNI	Test Value	Units	Test Method
Density at 40 °C	850-890	887.4	kg/m3	ASTM D 1298
Viscosity at 40 °C	2.3-6.0	5.32	cSt	ASTM D 445-97
Flash Point	Min.100	234	°C	ASTM D 92
Calorific Value	-	9021	cal/g	Bomb calorimetry

Table 2. Chemical properties of biodiesel avocado seed oil

Methyl Ester	Molecular Formula	Content (%)
Caprylic Acid	$C_9H_{18}O_2$	9.77
Capric Acid	$C_{11}H_{22}O_2$	7.40
Lauric Acid	$C_{13}H_{26}O_2$	46.65
Myristic Acid	$C_{15}H_{30}O_2$	16.13
Palmitic Acid	$C_{17}H_{34}O_2$	6.53
Oleic Acid	$C_{19}H_{36}O_2$	7.02

This fatty acid composition affects the density and viscosity of biodiesel so that it can achieve the SNI standard. Lauric acid has a relatively short carbon chain, making it susceptible to oxidation. Meanwhile, oleic acid as a long-chain unsaturated fatty acid is more resistant to oxidation than lauric acid [18]. Viscosity increases with the length of the carbon chain due to the increase in the number of interactions between its molecules [19].

3.2 Flame Visualization

Fig. 4. shows the flame visualization of the biodiesel droplet combustion test results processed using ImageJ software. The flame images were created with a time interval of 150 ms per frame. The combustion condition takes place by diffusion as oxygen moves into the droplets naturally [20]. The flame resulting from this diffusion combustion is yellow [21].

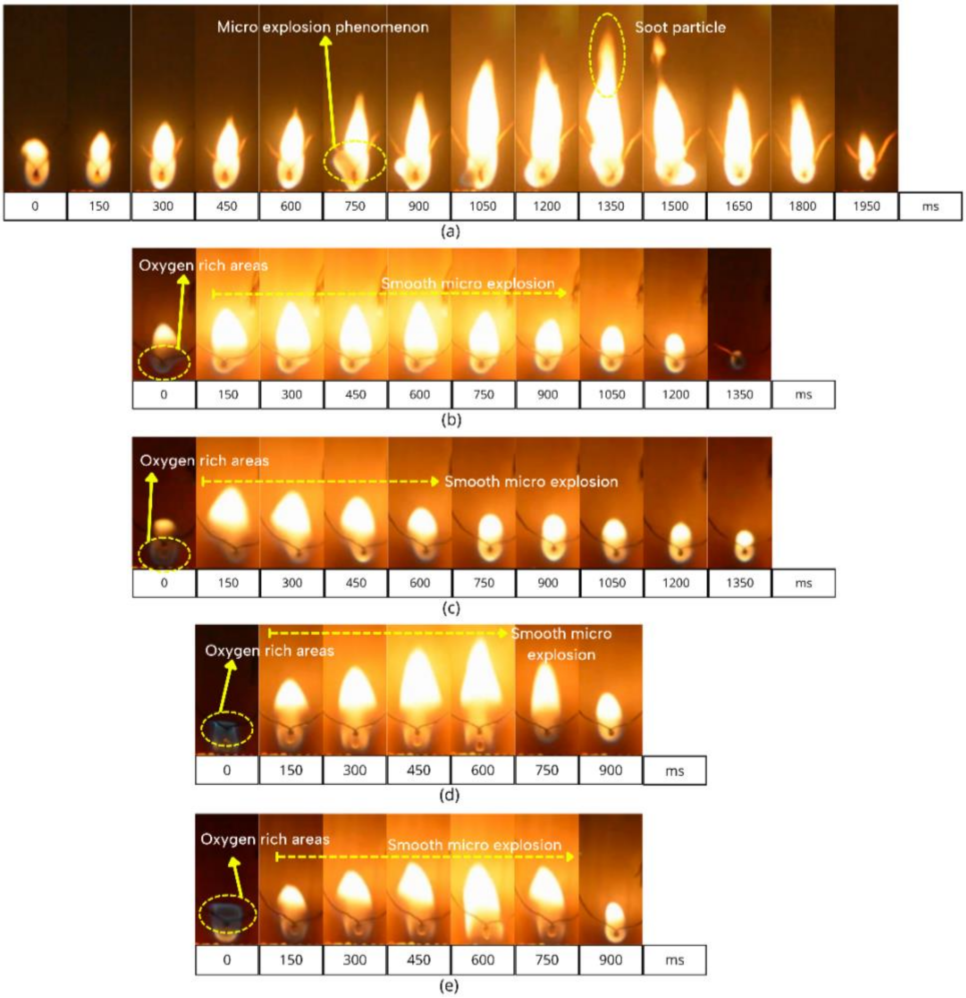


Fig. 4. Flame visualization droplet biodiesel; (a) WM, (b) N-S, (c) S-N (d) S-S, (e), N-N

At the beginning of droplet combustion, the magnetic field effect produces a blue flame at the bottom. This is considered to increase combustion efficiency. The blue colour in the flame is formed due to a flammable mixture with a composition close to stoichiometry, where the fuel burns completely with sufficient oxygen, producing the main products in the form of carbon dioxide (CO_2) and water vapour (H_2O) without the formation of soot or unburned particles [22]. The paramagnetic oxygen molecule is affected by the direction of the magnetic flux [23], as shown in **Fig. 5**. The more focused oxygen produces the dominant CH radical in the blue spectrum [24]. Whereas WM (Without Magnet) combustion tends to radiate orange light around the flame indicating incomplete combustion [25]. The brighter light intensity around the droplet is due to the formation of soot particles that appear at the tip of the flame forming a larger flame size and preventing the formation of a blue flame. The soot particles are caused by the combustion of unsaturated compounds with long carbon chains. The difference in oxygen reaction in droplet combustion with attractive and repulsive magnetic fields lies in the distribution and concentration of oxygen around the fuel droplet. In an attractive magnetic field, the magnetic flux lines are more focused, thus increasing the oxygen concentration and accelerating the fuel oxidation reaction, resulting in more efficient combustion [10], [26]. Whereas in a repulsive magnetic field, the magnetic flux lines spread outwards and cause oxygen to be more widely distributed around the droplet. Although oxygen is still affected by the paramagnetic properties of the magnet, the concentration in the combustion zone is not as high as in the attractive magnetic field.

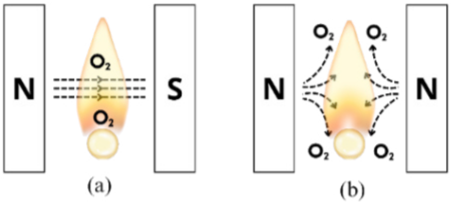


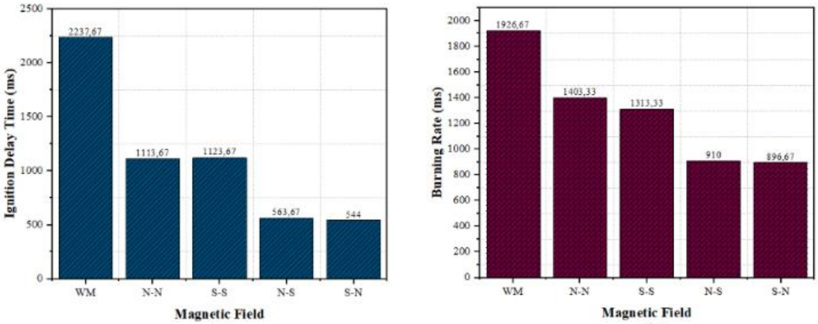
Fig. 5. Scheme of oxygen distribution; (a) attractive, (b) repulsive

The shape of WM flame combustion occurs micro-explosion, characterized by the presence of bubble bulges at frames of 750 ms to 1500 ms. In magnetic field effect combustion, the flame tends to be round because the micro explosion is smoother [10]. The micro explosion phenomenon is thought to accelerate the combustion process [27]. These micro explosions occur due to the combination of saturated and unsaturated fatty acids in ASO biodiesel, creating an uneven pattern of evaporation and oxygen supply [28],[21]. Lauric acid has a boiling point of 225 °C [29], while oleic acid with a higher boiling point of 360 °C [26] evaporates more slowly, which can lead to the accumulation of internal pressure and volatility out of the droplets that then trigger micro explosions. The smooth micro explosion that occurs in magnetic field effect combustion is due to the more even distribution of oxygen to the droplet surface.

The role of the magnetic field is to accelerate the fuel fragmentation process so that it burns faster [30]. The resulting flame is shorter in duration but more stable. Physicochemical phenomena occur due to the effect of magnetic fields in combustion, namely the hydrogen molecules in the fuel change from para to ortho. This phenomenon affects the dynamics of combustion because changes in the spin orientation of molecules play a role in chemical reactivity. Para-hydrogen molecules have antiparallel core spin orientation which is considered less reactive compared to ortho-hydrogen with parallel spins that have higher energy [31]. Magnetic fields can also reduce fuel viscosity and surface tension [32]. The decreased fuel viscosity makes the molecules become more tenuous and more free to move so that the combustion process that occurs in the droplet becomes faster and more evenly distributed. In this case, more energy from the fuel is converted into heat energy, reducing soot formation and incomplete emissions. The increased amount of energy released allows for more efficient use of fuel and can reduce fuel consumption.

3.3 Ignition Delay Time and Burning Time

Ignition delay time and burning time of ASO biodiesel droplet combustion are shown in **Fig. 6.** Ignition delay time with magnetic field effect is faster at 563.67 ms (N-S), 544 ms (S-N), 1123.67 ms (S-S), and 1113.67 ms (N-N), while that of WM is 2237.67 ms. Meanwhile, the burning time in the variation of magnetic field influence is also faster, namely 910 ms (N-S), 896.67 ms (S-N), 1313.33 ms (S-S), 1403.33 ms (N-N), and in WM 1926.67 ms is much longer. Ignition delay time is directly proportional to burning time. The burning rate describes the rate of mass reduction of fuel droplets over time [33]. The droplets vaporize and enter the reaction zone, where they react with O_2 to produce heat energy that drives further vaporization. The oxygen distribution of WM combustion is slower and less efficient [34]. The addition of a magnetic field can accelerate the evaporation rate, as the magnetic field effect increases the reactivity of oxygen. Oxygen molecules are drawn closer to the reaction zone and the focused magnetic flux accelerates the supply of oxygen to the droplet surface and causes the collision of fuel particles with O_2 to be greater so that the fuel molecular bonds become weak. When the molecular bonds are weakened, the distance between the molecules widens making it easier for O_2 to enter which results in a faster reaction between the fuel and O_2. The higher O_2 concentration around the droplet increases the intensity of the combustion reaction [35]. The combustion reaction becomes more efficient because the initial reaction becomes faster and the burning rate becomes shorter.



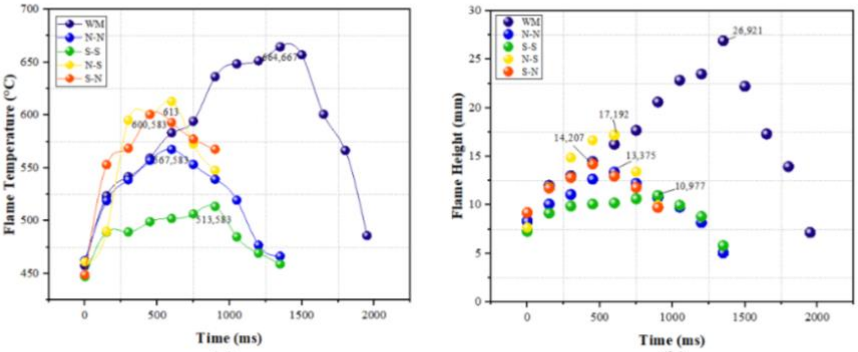
(a) (b)

Fig. 6. (a) Ignition delay time; (b) Burning rate

3.4 Flame Height and Flame Temperature

Fig. 7. shows the flame height and flame temperature graphs of the combustion of ASO biodiesel droplets 2. The highest flame height at WM at 6.921 mm, and the variations in magnetic field direction produced lower flame intensities of 13.375 mm (N-N), 10.977 mm (S-S), 17.192 mm (N-S), 14.207 mm (S-N). The flame height is directly proportional to the flame temperature, at 664.667 °C (WM), 567.583 °C (N-N), 513.583 °C (S-S), 613 °C (N-S), and 600.583 °C (S-N). The amount of energy in the combustion process is related to the calorific value and combustion speed which will affect the flame temperature results [26]. The higher the heat release rate, the higher the combustion temperature. This is consistent with the viscosity condition of ASO biodiesel before being exposed to the magnetic field. Combustion requires more energy to reach the optimum temperature, resulting in a higher combustion temperature and an elongated flame shape with soot production.

The N-S and S-N conditions have greater magnetic intensity so that the flame temperature is higher than the N-N and S-S conditions. Combustion reaction energy is released more efficiently and produces higher flame temperatures. The high hydrogen spin velocity will have an impact on the intermolecular collision reactions that occur so that the temperature produced by the flame is also maximized. The repulsive magnetic condition shows a shorter flame because the oxygen molecules are pushed away from the droplet which causes a less efficient oxygen supply in the reaction zone. As a result, the intensity of combustion is lower.



(a) (b)

Fig. 7. (a) Flame temperature; (b) Flame height

4 Conclusions and suggestions

Experimental studies of ASO biodiesel droplet combustion showed different characteristics with the application of no magnetic field, attractive magnetic field, and repulsive magnetic field. Without magnetic field, combustion resulted in longer flame duration, higher flame height and micro explosions due to different boiling points of different fuel components and uneven oxygen distribution. Combustion with a magnetic field result in smooth micro explosions and a more stable flame towards stoichiometry. The strong magnetic flux increases the oxygen concentration around the droplets, accelerates the oxidation reaction, and creates a blue flame thus showing the best performance in producing stable, efficient combustion. While the repulsive field provides an increase in efficiency but not as strong as the attractive field. This research contributes to the field of renewable energy studies and alternative fuel combustion by introducing the effect of magnetic fields on the combustion characteristics of biodiesel droplets. This technology has the potential to be applied in energy systems such as diesel engines to improve fuel efficiency. With reduced ignition delay time and better flame stability, magnetic fields can reduce soot formation. The application of this technology also supports energy sustainability by optimizing the use of biofuels in an efficient, greener and cleaner way.

Acknowledgment-The authors would like to dedicate my special and deep gratitude to the Mechanical Engineering Department and Faculty of Engineering, University of Jember.

References

1. M. A. Abdelkareem, K. Elsaid, T. Wilberforce, M. Kamil, E. T. Sayed, and A. Olabi, “Environmental aspects of fuel cells: A review,” *Science of The Total Environment*, vol. 752, p. 141803, 2021.
2. M. Setiyo and B. Waluyo, “Evolusi Sistem Bahan Bakar LPG: Tinjauan Literatur,” *Jurnal Rekayasa Mesin*, vol. 10, no. 2, pp. 199–207, 2019.
3. O. Ogunkunle and N. A. Ahmed, “Overview of biodiesel combustion in mitigating the adverse impacts of engine emissions on the sustainable human–environment scenario,” *Sustainability*, vol. 13, no. 10, p. 5465, 2021.
4. B. C. Purnomo, N. Widodo, S. Munahar, M. Setiyo, and B. Waluyo, “Karakteristik Emisi Gas Buang Kendaraan Berbahan Bakar LPG untuk Mesin Bensin Single Piston,” *URECOL*, pp. 7–12, 2017.

5. Y. S. M. Altarazi, J. Yu, E. Gires, M. F. A. Ghafir, J. Lucas, and T. Yusaf, "Effects of biofuel on engines performance and emission characteristics: A review," *Energy*, vol. 238, p. 121910, 2022.
6. B. Rodríguez-Martínez, A. Romaní, G. Eibes, G. Garrote, B. Gullón, and P. G. Del Rio, "Potential and prospects for utilization of avocado by-products in integrated biorefineries," *Bioresour Technol*, vol. 364, p. 128034, 2022.
7. G. Jiancun *et al.*, "Effects of magnetic fields on combustion and explosion," *Chemistry and Technology of Fuels and Oils*, vol. 58, no. 2, pp. 379–390, 2022.
8. P. X. Pham, N. V. T. Pham, T. V Pham, V. H. Nguyen, and K. T. Nguyen, "Ignition delays of biodiesel-diesel blends: Investigations into the role of physical and chemical processes," *Fuel*, vol. 303, p. 121251, 2021.
9. R. E. Rachmanita and A. Safitri, "Pemanfaatan Minyak Biji Alpukat (Persea americana Mill) sebagai Bahan Baku Pembuatan Biodiesel dengan Pemurnian Water Washing," *Jurnal Ilmiah Sains*, pp. 88–99, 2020.
10. W. A. Winarko, N. Ilminnafik, M. N. Kustanto, and D. Perdana, "Pengaruh Orientasi Medan Magnet Terhadap Karakteristik Nyala Api Pembakaran Droplet Calophyllum Inophyllum," *JURNAL KETEKNIKAN PERTANIAN*, vol. 10, no. 3, pp. 215–225, 2022.
11. A. Chandravanshi, S. Pandey, and R. K. Malviya, "Effect of Magnetization of Biodiesel on Its Chemical Properties and Performance and Emission Parameters of Diesel Engine.," *Journal of Engineering Research (2307-1877)*, vol. 9, 2021.
12. Y. Darvishi, S. R. Hassan-Beygi, J. Massah, M. Gancarz, A. Bieszczad, and H. Karami, "Determining the Influence of a Magnetic Field on the Vibration and Fuel Consumption of a Heavy Diesel Engine," *Sustainability*, vol. 15, no. 5, p. 4088, 2023.
13. N. Hamidi and J. Nugroho, "Single droplet combustion characteristics of petroleum diesel-philippine tung biodiesel blends," *Trends in Sciences*, vol. 18, no. 24, p. 1409, 2021.
14. O. Öztürk and M. Taştan, "A review of magnetic field assisted combustion," *International Journal of Energy Studies*, vol. 9, no. 1, pp. 175–198, 2024.
15. A. Pardo, M. Gómez-Florit, S. Barbosa, P. Taboada, R. M. A. Domingues, and M. E. Gomes, "Magnetic nanocomposite hydrogels for tissue engineering: design concepts and remote actuation strategies to control cell fate," *ACS Nano*, vol. 15, no. 1, pp. 175–209, 2021.
16. M. A. F. M. Gaber, P. Juliano, M. P. Mansour, and F. J. Tujillo, "Entrained Oil Loss Reduction and Gum Yield Enhancement by Megasonic-Assisted Degumming," *Food Engineering Reviews*, vol. 13, pp. 148–160, 2021.
17. A. Kolakoti, B. Prasadarao, K. Satyanarayana, M. Setiyo, H. Köten, and M. Raghu, "Elemental, thermal and physicochemical investigation of novel biodiesel from wodyetia bifurcata and its properties optimization using artificial neural network (ANN)," *Automotive Experiences*, vol. 5, no. 1, pp. 3–15, 2022.
18. S. Mehrabi-Kalajahi, M. A. Varfolomeev, K. G. Sadikov, A. N. Mikhailova, and D. A. Feoktistov, "The impact of the initiators on heavy oil oxidation in porous media during in situ combustion for in situ upgrading process," *Energy & Fuels*, vol. 38, no. 5, pp. 4134–4141, 2024.
19. I. A. Ibadurrohman, N. Hamidi, and L. Yuliati, "Pengaruh panjang rantai karbon dan derajat ketidakjenuhan terhadap karakteristik pembakaran droplet asam lemak tunggal," *Jurnal Rekayasa Mesin*, vol. 12, no. 2, pp. 331–347, 2021.

20. B. Chen, S. Shan, and J. Liu, “Evolution of solid-liquid coupling combustion characteristics of boron suspension fuel in O2/Ar atmosphere,” *Combust Flame*, vol. 237, p. 111869, 2022.
21. N. Hamidi, I. A. Ibadurrohman, L. Yuliati, W. Winarto, and D. B. Darmadi, “The Effect of Alcohol Compounds on Droplet Combustion Characteristics of Unsaturated Fatty Acid of Linoleic Acid,” *Trends in Sciences*, vol. 20, no. 7, p. 6720, 2023.
22. D. G. H. Adoe, P. Talo, J. C. A. Pah, A. Y. Tobe, and D. B. N. Riwu, “Karakteristik Pembakaran Premixed dari Campuran FAME (Fatty Acid Methyl Ester) dan Solar Murni,” *LONTAR Jurnal Teknik Mesin Undana*, vol. 9, no. 02, pp. 47–52, 2022.
23. H. Zadeh-Haghighi and C. Simon, “Magnetic field effects in biology from the perspective of the radical pair mechanism,” *J R Soc Interface*, vol. 19, no. 193, p. 20220325, 2022.
24. B. Feng, Z. Yang, and H. Liu, “Research on inhibition of flame retardants on flammability of R1234yf,” *International Journal of Refrigeration*, vol. 118, pp. 302–310, 2020.
25. K. Zhang *et al.*, “Research progress of modified and optimized AMn2O5 catalyst for efficient degradation of gaseous pollutants,” *J Mol Struct*, vol. 1289, p. 135828, 2023.
26. C. Pujiasmoro and A. Kadarohman, “Determination of Optimum Programmed Temperature for Fatty Acid Analysis of Chlorella Microalgae Extract Using GCMS Instrument,” *Unesa Journal of Chemistry*, vol. 12, no. 1, pp. 20–25, 2023.
27. K. Meng, L. Bao, Y. Shi, K. Han, Q. Lin, and C. Wang, “Experimental investigation on ignition, combustion and micro-explosion of RP-3, biodiesel and ethanol blended droplets,” *Appl Therm Eng*, vol. 178, p. 115649, 2020.
28. R. Küçükosman, A. A. Yontar, and K. Ocakoglu, “Nanoparticle additive fuels: Atomization, combustion and fuel characteristics,” *J Anal Appl Pyrolysis*, vol. 165, p. 105575, 2022.
29. M. Utami and A. Z. Kusumo, “Analisis Lemak dan Asam Lemak Jenuh pada Jagung Rebus di Balai Besar Penelitian dan Pengembangan Pascapanen Pertanian Bogor,” *Indonesian Journal of Chemical Research*, vol. 8, no. 2, 2023.
30. B. M. T. Pakpahan, H. Iskandar, and R. Manullang, “Pengaruh Kuat Medan Magnet pada Saluran Bahan Bakar terhadap Performansi Gasoline Engine High Technology,” *Mekanik*, vol. 5, no. 2, p. 329197, 2019.
31. Z. Hu, J. Li, and K. He, “Design and the flow characteristics analysis in an ortho-para hydrogen converter,” *Int J Hydrogen Energy*, vol. 82, pp. 1314–1323, 2024.
32. Z. Zhu, L. Hou, X. Zhang, J. Liu, X. Sun, and Y. Xiong, “Effect of magnetic field on the apparent viscosity of water-in-oil waxy crude oil emulsion,” *J Mol Liq*, vol. 400, p. 124575, 2024.
33. M. Zhu, H. Y. Setyawan, Z. Zhang, and D. Zhang, “Effect of n-butanol addition on the burning rate and soot characteristics during combustion of single droplets of diesel–biodiesel blends,” *Fuel*, vol. 265, p. 117020, 2020.
34. J. Hosseinpour and H. Mahdavy-Moghaddam, “Computational study of magnetic field effects on the nozzle of hydrogen micro flame,” *Combust Flame*, vol. 220, pp. 247–256, 2020.
35. J. Xu, S. Shi, J. Li, and J. Wang, “Effect of droplet spacing on micro-explosion and combustion characteristics of multi-component fuel droplet cluster,” *Fuel*, vol. 373, p. 132323, 2024.