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Effect of Magnetic Field on the Flame Characteristics of Droplet Combustion of Coconut and Palm Oil

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ABSTRACT

Experimental has been conducted on the effects of variations in the direction of the magnetic fields on flames characteristic of droplets combustion of coconut and palm oils. Two variations of the directions magnetic field N-N and S-N were used in this experiment by placing droplets of vegetable oils on the type K thermocouple between two permanent magnet rods. High-speed camera (120 frame per second) recorded the flames up to extinguished. The result showed that S-N magnetic fields affected on shorter burning time of coconut and palm oil, respectively 670 ms and 871 ms, with the highest temperature of 816.25 ^oC and 778 ^oC. The flame height produced by the S-N magnetic field in coconut oil is 34.36 mm shorter, ignitions delay time for all oils has faster than the N-N magnetic field. The strong magnetic field direction increases the oxygen concentrations and fuel molecules around the reaction zone, causing shorter combustion. This combustion produces different flame evolution, shape, height, temperature, and ignition delay times.

1. INTRODUCTION

Worldwide energy consumption has increased due to cultural changes and human population increase. Transportation is one of the primary energy consumers, mainly diesel engine, leading to the depletion of petroleum fuels. The energy crisis caused the energy exploration of alternative sources to sustain global energy demand (Ayeni et al., 2021). Several studies have identified biomass as an alternative, renewable, and environmentally friendly as solar cell, wind and hydro (Ighalo & Adeniyi, 2020; Fitriana & Febriana, 2021). Vegetable oil as biomass has much superior to petrol, has lower emissions and abundant availability. However, vegetable oils have the high density, surface tensions, flash points, and viscosity while having lower volatilities than diesel. Several problems were encountered in its direct use in the combustion chamber: clog filters and deposits on piston rings (San José Alonso et al., 2012). However, various solutions have been proposed to overcome this problem, including making vegetable oils and its derivatives; mixing with diesel fuel in different ratios; vegetable oil heating; mixing with additives; exhaust gas recirculated and combustion chamber modification (piston, nozzle, etc.). Several studies that have been carried out using biomass fuel found that preheating coconut oil is directly used as an alternate diesel and engine replacements are not required (Malik et al., 2017). Coconut oil is an alternate diesel fuel because its fatty acids have lengthy carbon chains comparable to diesel fuel (Nanlohy et al., 2018). Four-stroke diesel engine, single-cylinder with various throttle settings using a blend of diesel and biodiesel from coconut oil (B5 and B15). The two biodiesels produce higher exhaust gas temperatures and reduced CO but slight increased NOx than to diesel (Liaquat et al., 2013). Research by Malik et al. (2017) has investigated the combustion performance of blend biodiesel coconut oil (B5, B15, and B25) with diesel fuel under three equivalence ratios (ϕ = 0.8, ϕ = 1.0, ϕ = 1.2). Results showed the biodiesel coconut oil blend burns at a lower temperature and produced fewer emissions than diesel for all equivalent ratios. In addition, increasing the content of coconut oil biodiesel mixture reduces the temperature of combustion chamber walls and concentration of emissions.

Many studies have used palm oil in diesel engines to evaluate engine performance and emissions. Preheating palm oil and mixed to diesel (PO20, PO30, and PO40). The result is 5.1% brake thermal efficiency (BTE) and 7.1% lower cylinder pressure, while 11.4% higher brake specific fuel consumption (BSFC) than diesel (Prabu et al., 2018). The oxygen molecules in vegetable oils reduce pollutants such as CO and HC while lower BSFC than diesel (Bari & Hossain, 2019). A mixture of 20% palm oil to diesel has been used in diesel engines to study combustion characteristics. It found that ignition delay decreased. At the same time, cylinder pressure and BTE increased with increasing compression ratio (Rosha et al., 2019). A mixture of various concentrations of diesel-crude palm oil (CPO) on diesel engines was found to have decreased that cylinder pressure and heat release rate (HRR). Furthermore, HC and NOx are decreasing, but CO and BSFC are increased than diesel (Ge et al., 2021). Other studies have investigated the emission to single-cylinder diesel engines of a blend of coconut and palm oil with diesel. CO and HC are reducing to a certain by 13.75 to 17.97%, while NOx emissions by 3.13 to 5.67% higher than diesel (Habibullah et al., 2014). Cottonseed, palm, and hemp oil biodiesel on diesel engines results in increased exhaust gas recirculation and CO emissions while NOx decreases (Shehata, 2013). Various palm oil biodiesel blended diesel with three different fuel flow rates at the nozzle (1.25, 1.5 and 1.75 gal/hour). All blends of palm oil biodiesel and fuel flow rates result in lower combustion wall temperatures, NOx and CO emissions than diesel (Ganjehkaviri et al., 2016).

Due to the limitations of vegetable oils, some researchers use a magnetic field to increase combustion efficiency and reduce emissions. The properties of the fuel can be improved by adding magnets, such as aligning and directing the hydrocarbon atoms so that the fuel's atomization is better (Jain & Deshmukh, 2012). The fuel viscosity decreases significantly by applying a magnetic field of sufficient strength and suitable duration (Oommen & Kumar, 2019). Five magnetic fields of 3000 G each are applied to the fuel line in a two-wheeled four-stroke single-cylinder petrol engine. It was found that fuel savings increased to a maximum of 9.36%, CO and HC decreased an 12% and 72.84%, respectively (Tipole et al., 2022). A magnet tube is installed on the fuel inlet of the diesel generator at idle a constant rate of 1800 rpm, with a load of 50% and 25%, respectively. It found fuel consumption and BSFC reduced by an average of 15% and 3.5%, while BTE increased by around 3.5% (Chen et al., 2017).

From the explanation above, all researchers conducted performance and performance studies only on internal combustion engines. However, the behavior of the flame, which plays a vital role in combustion stability, is very rarely studied. A study of the effect of fuel on the combustion chamber is needed, especially for transportation engines. The research was conducted using the droplets combustion method, which was given an additional magnetic field to determine the flame behavior of various vegetable oils and the direction of a magnetic field.

2. MATERIALS AND METHODS

2.1. Materials

Coconut and palm oil as test fuels was obtained from commercial products, with different chemical and physical properties, respectively, have been shown in previous studies (Wahyudi et al., 2018; Hellier et al., 2015; Perdana et al., 2018) in Table 1 and Table 2.

Table 1. Fatty acid composition of various vegetable oils

Fatty Acid	Carbon Number	Vegetable Oils					
		Palm	Rapeseed	Coconut	Jatropha	Karanja	Castor
Lauric	C12:0	0.1–0.2	–	47.2	–	–	–
Myristic	C14:0	0.8–0.9	<0.1	18.5	0.15	–	–
Palmitic	C16:0	39.5–47	3.3–6	–	14.4–15.6	10.9	1.4–2.0
Palmitoleic	C16:1	<0.6	0–3.0	9.41	0.69	–	–
Stearic	C18:0	3–6	1.3–6	–	5.8–10.5	7.9	1.1–2.0
Oleic	C18:1	36–44	52–65	–	42–43	53.6	3.4–6.0
Linoleic	C18:2	6–12	18–25	3.1	30.9–35.4	21.3	4.0–4.8
Linolenic	C18:3	<0.5	8–11	8.2	0.2	2.1	<0.6
Ricinoleic	C18:1 (OH)	–	–	–	–	–	86–88

Table 2. Physical properties of various vegetable oils

Property	Vegetable Oils						
	Palm	Rapeseed	Coconut	Jatropha	Karanja	Castor	Diesel
Kinematic viscosity (mm^2/s)	39.6[a]	37[a]	29,35	24.5–53[b]	27–56[b]	29.7[a]	1.3–4.1
Calorific value (MJ/kg)	36.9	37.4–39.7	31.25	38–40	34–38.8	39.5	42–43.8
Cloud point (°C)	31	−3.9	25	8–16	13–15	−11.6	−15 to −5
Pour point (°C)	31	−31.7	15	−3 to 5	−3 to 6	−31.7	−33 to 15
Flash point (°C)	267–330	246–320	249	180–280	198–263	229	60–80
Density at 20°C (kg/m^3)	910	915	885.95	901–940[b]	870–928[b]	970	834–855

[a] Data at 38 °C.
[b] Data at 40 °C.

2.2. Experimental Apparatus

The research was carried out using the equipment shown schematically in Figure 1. Droplets of coconut and palm oil have suspended a junction of a type K thermocouple made from 13% Pt/Rh material at a diameter of 0.1 mm. Droplets were prepared manual use a syringe of conventional (1 mL) size fixed at a diameter of about 0.4 mm. These droplets are ignited by an electric heater coil with a diameter of 0.3 mm made of material Ni-Cr wire. A length of 30 mm has a resistance of 1.02, voltage of 6 V and current of 5 A. The temperature data collection begins when the electric heater is turned on and then recorded by the data logger Arduino UNO R3 Atmega 328 at a frequency 0.01 Hz connected to a laptop. While an image of a flame is recording used high-speed camera (120 fps) and carried out three times from start to flame until extinguished. The recording results are then processed using the Free Video to JPG Converter application with millisecond (ms) time measurement. Image J converts image files into several frames. Flame evolution, height and delay time were measured using the Corel Draw application. The experiment was repeated three times for each treatment combination, shown in Table 3 to 6.

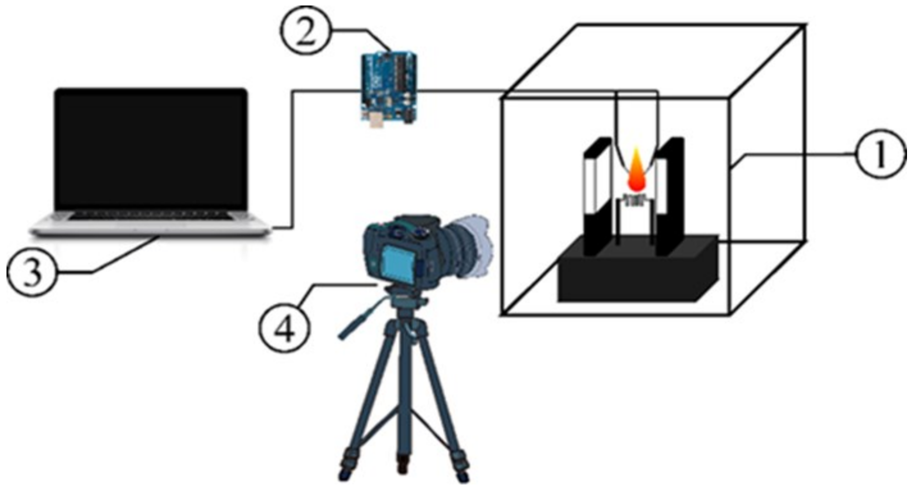

Figure 1. Research installation; 1. Combustion chamber, 2. Data logger, 3. Laptop, 4. High speed camera

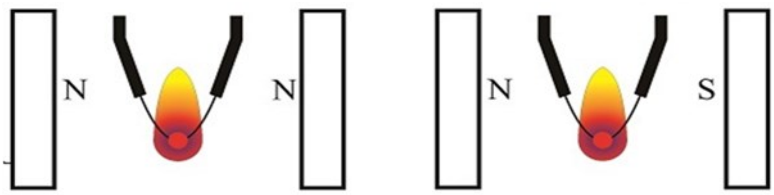

Figure 2. Variations in the direction of a magnetic field

2.3. Magnetic Field

11000 G magnetic field strength of a permanent bar magnet made of neodymium N45 material with dimensions of 40×25×10 mm. The two permanent magnet bars are spaced 20 mm using two different variations of the magnetic field poles, namely the North-North (N-N) and South-North (S-N) magnetic fields, showed in Figure 2.

2.4. Observation and Measurment

The experiment was carried out three times, and the data obtained were processed each time experiment. The average results are the final data for analyzing flame height, and temperature in Table 3 to 6.

Table 3. Effect of magnetic fields N-N and S-N on flame height using palm oil

Time (ms)	Palm Oil; Magnet N-N					Palm Oil; Magnet S-N				
	Test 1	Test 2	Test 3	Mean	SD	Test 1	Test 2	Test 3	Mean	SD
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
67	17.65	18.45	18.12	18.07	0.40	15.82	15.90	15.10	15.61	0.44
134	22.48	22.15	21.50	22.04	0.50	15.95	16.80	16.90	16.55	0.52
201	25.00	24.65	23.90	24.52	0.56	19.35	18.61	18.14	18.70	0.61
268	26.91	26.25	27.55	26.90	0.65	22.05	21.30	22.15	21.83	0.46
335	29.10	29.30	28.20	28.87	0.59	24.28	25.40	24.55	24.74	0.58
402	30.90	31.35	30.49	30.91	0.43	26.57	27.55	26.95	27.02	0.49
469	35.30	35.74	34.45	35.16	0.66	32.10	31.05	30.90	31.35	0.65
536	40.26	39.96	39.15	39.79	0.57	33.19	32.45	33.57	33.07	0.57
603	38.20	38.05	36.90	37.72	0.71	36.15	36.75	35.55	36.15	0.60
670	42.10	41.20	40.90	41.40	0.62	42.45	43.68	42.55	42.89	0.68
737	37.40	37.00	36.45	36.95	0.48	41.00	40.06	39.60	40.22	0.71
804	38.20	38.85	37.65	38.23	0.60	40.45	41.00	41.75	41.07	0.65
871	35.15	35.75	36.45	35.78	0.65	32.15	32.65	33.45	32.75	0.66
938	33.90	34.89	35.38	34.72	0.75	-	-	-	-	-
1005	31.98	32.35	31.25	31.86	0.56	-	-	-	-	-
1072	21.95	21.35	22.65	20.98	0.65	-	-	-	-	-

Table 4. Effect of magnetic fields N-N and S-N on flame height using coconut oil

Time (ms)	Coconut Oil; Magnet N-N					Coconut Oil; Magnet S-N				
	Test 1	Test 2	Test 3	Mean	SD	Test 1	Test 2	Test 3	Mean	SD
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
67	17.05	16.15	16.75	16.65	0.46	16.34	15.40	16.00	15.91	0.48
134	18.15	18.87	18.30	18.44	0.38	16.55	16.85	17.40	16.93	0.43
201	21.47	20.7	20.35	20.84	0.57	18.00	17.89	17.18	17.69	0.45
268	24.30	23.78	24.95	24.34	0.59	20.15	21.14	20.87	20.72	0.51
335	26.96	27.05	26.15	26.72	0.50	22.55	22.20	21.59	22.11	0.49
402	28.95	28.26	29.13	28.78	0.46	25.05	25.50	26.10	25.55	0.53
469	32.35	32.69	31.65	32.23	0.53	29.25	28.77	28.05	28.69	0.60
536	33.80	34.75	35.05	34.53	0.65	30.95	31.30	32.05	31.40	0.56
603	39.17	38.60	38.15	38.64	0.51	34.05	34.90	34.13	34.36	0.47
670	44.65	44.08	43.75	44.16	0.46	31.70	31.20	30.85	31.25	0.43
737	42.25	42.75	41.60	42.20	0.58	-	-	-	-	-
804	38.85	39.35	40.15	39.45	0.66	-	-	-	-	-

Table 5. Effect of magnetic fields N-N and S-N on flame temperature using palm oil

Time (ms)	Palm Oil; Magnet N-N					Palm Oil; Magnet S-N				
	Test 1	Test 2	Test 3	Mean	SD	Test 1	Test 2	Test 3	Mean	SD
	(°C)	(°C)	(°C)	(°C)		(°C)	(°C)	(°C)	(°C)	
67	542.75	549.27	534.50	541.50	7.40	571.45	563.65	580.15	571.75	8.25
134	553.85	563.25	568.15	561.75	7.27	588.45	591.65	577.15	585.75	7.62
201	572.40	589.30	578.30	580.00	8.58	614.67	603.85	595.75	604.75	9.49
268	622.55	612.05	607.40	614.00	7.76	669.75	663.15	680.85	671.25	8.94
335	680.30	667.00	682.20	676.50	8.28	759.65	774.15	769.45	767.75	7.40
402	730.20	715.90	731.15	725.75	8.54	804.15	811.10	792.25	802.5	9.53
469	736.95	751.25	742.30	743.50	7.23	809.20	814.10	825.45	816.25	8.34
536	764.25	751.50	749.70	755.15	7.93	805.15	812.80	795.55	804.50	8.64
603	760.15	753.35	769.50	761.00	8.11	777.85	796.95	788.45	787.75	9.57
670	771.05	758.05	760.65	763.25	6.88	780.65	768.15	763.45	770.75	8.89
737	720.20	734.60	723.95	726.25	7.47	740.55	756.35	749.35	748.75	7.92
804	695.95	684.95	698.85	693.25	7.33	709.25	727.85	716.15	718.75	9.40
871	647.10	661.70	654.70	654.50	7.30	685.00	676.15	693.85	685.00	8.85
938	623.00	607.35	613.15	614.50	7.91	-	-	-	-	-
1005	566.45	577.25	582.82	575.50	8.32	-	-	-	-	-
1072	541.00	546.05	531.45	539.50	7.41	-	-	-	-	-

Table 5. Effect of magnetic fields N-N and S-N on flame temperature using coconut oil

Time (ms)	Coconut Oil; Magnet N-N					Coconut Oil; Magnet S-N				
	Test 1	Test 2	Test 3	Mean	SD	Test 1	Test 2	Test 3	Mean	SD
	(°C)	(°C)	(°C)	(°C)		(°C)	(°C)	(°C)	(°C)	
67	524.25	534.15	520.35	526.25	7.11	553.75	560.55	545.45	553.25	7.56
134	547.75	555.50	538.50	547.25	8.51	570.40	563.75	578.10	570.75	7.18
201	555.80	566.25	571.45	564.50	7.97	591.45	599.55	583.50	591.50	8.03
268	589.30	593.10	577.10	586.50	8.36	640.10	656.65	649.50	648.75	8.30
335	646.00	662.75	654.75	654.50	8.38	727.20	742.55	732.25	734.00	7.82
402	709.95	699.80	717.25	709.00	8.76	787.45	775.15	771.40	778.00	8.40
469	722.45	737.60	726.95	729.00	7.78	760.15	755.00	770.85	762.00	8.09
536	727.45	740.60	730.95	733.00	6.81	735.50	752.35	747.15	745.00	8.63
603	708.85	698.75	714.15	707.25	7.82	719.20	734.10	723.95	725.75	7.61
670	680.25	667.00	682.25	676.50	8.29	699.35	715.00	705.15	706.50	7.91
737	541.45	552.25	538.30	644.00	7.32	-	-	-	-	-
804	620.45	605.20	611.10	612.25	7.69	-	-	-	-	-

3. RESULTS AND DISCUSSION

3.1. Flame Evolution and Shape

Figure 3 and 4 shows the flame evolution and shape of a coconut and palm oil with various magnetic field directions. Figures 3a and 4a show that the N-N magnetic field of direction produces an asymmetry the bottom of a flame than S-N magnetic field. On the other hand, the N-N magnetic field of direction produces burning with long-duration coconut oil and palm of 804 ms and 1072 ms, respectively. Highest unsaturated fatty acids in palm oil than in coconut oil (Table 1). Vegetable oil burns at three stages, namely a burning stage of unsaturated fatty acids, saturated and glycerol. Flame's length of time burns due to the high composition of unsaturated fatty acid. This condition occurs because most oleic and linoleic acid carbon atoms burn first. After all, their flash point is lower than other fatty acids (Perdana et al., 2018). The S-N magnetic field of direction significantly influences the flame's evolution and shape, showed in Figure 3b and 4b.

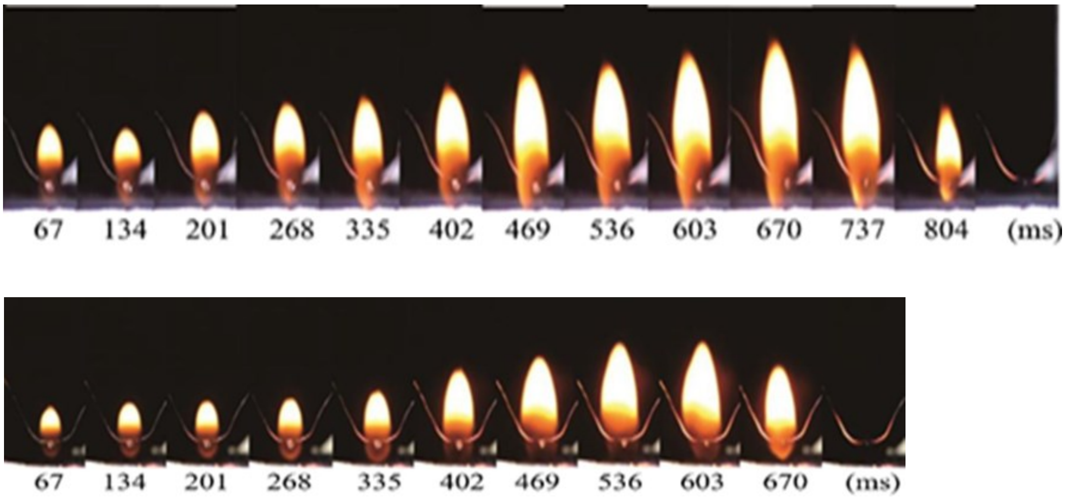

Figure 3. Flame evolution and shape of coconut oil with two directions: (Top) N-N magnetic field; (bottom) S-N magnetic field

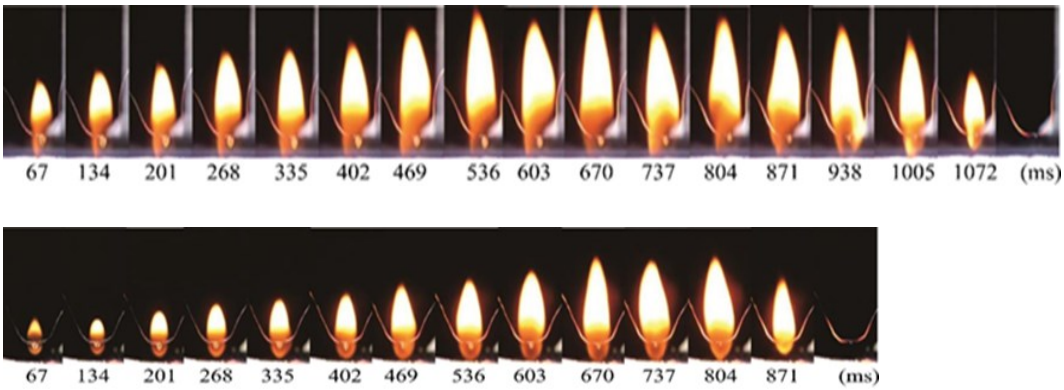

Figure 4. Flame evolution and shape of palm oil with two directions: (Top) N-N magnetic field; (bottom) S-N magnetic field

The direction of S-N magnetic field results in a shorter burning duration of coconut oil and palm of 670 ms and 871 ms than N-N 804 ms and 1072 ms, respectively. The directions of S-N magnetic field affect a shape of the resulting flame, which is widened and symmetrical than N-N magnetic field, as shown in Figure 3a and 4b. The asymmetry in the shape of the flame is caused because the magnetic field that forms the H_2O molecule is broken so that each molecule is pulled out of the combustion reaction zone. The shape of the flame in a micro-explosion is spherical due to the release of bubbles containing fuel vapour at a higher pressure. When it explodes, the fuel vapours in the bubbles do not have enough time to disperse and rapidly react. Therefore, the flame becomes spherical or widened (Perdana et al., 2022).

3.2. Flame Height

The difference in height a flame on droplets combustion of coconut and palm oil in the various directions of a magnetic fields are shown in Figure 5. The highest flame was 44.16 mm in coconut oil with an N-N magnetic field of direction at 670 ms and then went down until it was extinguished, while the lowest was 34.36 mm at 603 ms with an S-N magnetic field. The change in the height of flame in coconut oil with the direction of the N-N and S-N magnetic fields is relatively stable. It can be observed at 67 ms to 603 ms and 670 ms. The trend increases and then decreases after reaching the maximum height. However, it differs from palm oil where the flame height is unstable. After reaching the maximum height, the size of the flame decreases, then increases and decreases until it is extinguished.

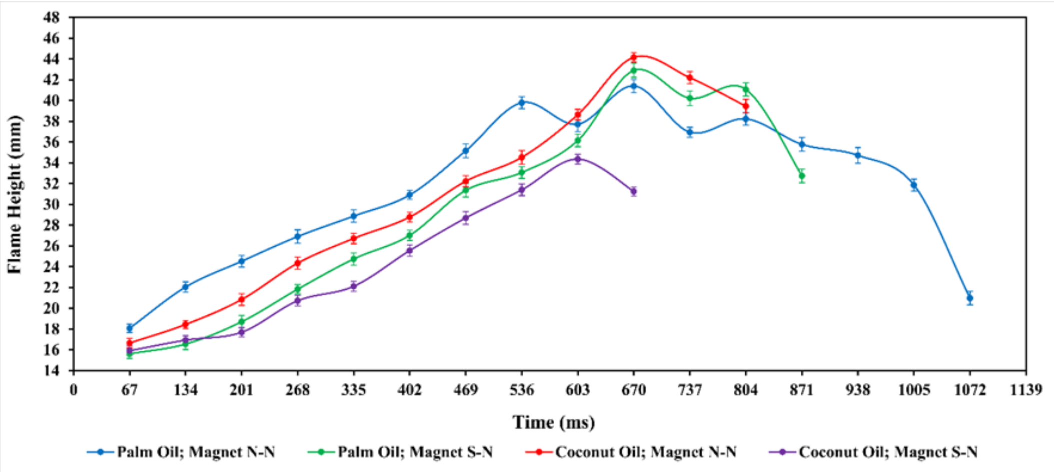

Figure 5. Flame height of coconut and palm oil with two directions of a magnetic field

Palm oil produces on highest flame on direction of S-N magnetic field of 42.89 mm and the N-N magnetic field of 41.4 ms at 670 ms. This height difference is possible: first, there is a difference in saturated and unsaturated fatty acids. Higher the unsaturated fatty acids, the fastest evaporation occurs. So that the combustion process is more immediate after diffusing into the air, causing a shorter flame height. Secondly, the direction of a magnetic field affects combustion to be more complete. The S-N magnetic field attracts O_2 from the surrounding air, accelerating the combustion reaction process with fuel.

3.3. Flame Temperature

Variations in the temperature of the droplet combustion of coconut and palm oil with various magnetic field directions are shown in Figure 6. All vegetable oils show that the resulting temperature increases after reaching the maximum temperature and decreases until the flame is extinguished. The droplet combustion of each vegetable oil produces the highest temperature at different times. Palm oil with on direction of an S-N magnetic field produces the highest temperatures of 816.25 ^{o}C at 469 ms, followed by coconut oil S-N, palm oil N-N and coconut oil N-N, 778 ^{o}C at 402 ms, 763.25 ^{o}C at

670 ms and 733 ^{o}C at 536 ms, respectively. The factors that affect the flame temperature of vegetable oil include, first, the short length of a carbon chain and number of double bonds (Table 1). The temperature was affected by a calorific value of fuels, combustion rates, flash points and heat losses to radiation (Zhu et al., 2020). Palm oil produces the highest temperature than coconut oil because calorific value of palm oils more elevated to coconut oil (see Table 2). The higher the calorific value, the greater the resulting temperatures. Maximum temperatures occur toward the end of combustion, as droplets are entirely burned. Direction of S-N magnetic field on droplets combustion of coconut and palm oil experiences a drastic temperature increase, inversely proportional to the N-N magnetic field. This shows that direction of a magnetic field affects higher flame temperature in droplets combustion. The smaller on intensity of a magnetic field, lower at resulting temperature. Lower intensity magnetic field binds poor O_2, results in the incomplete combustion reaction .

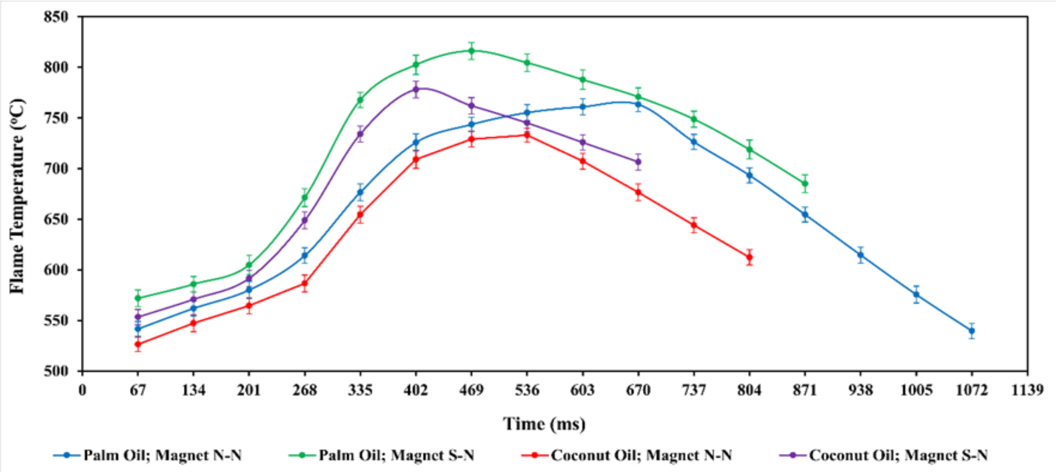

Figure 6. Flame temperature of coconut and palm oil with two directions of a magnetic field

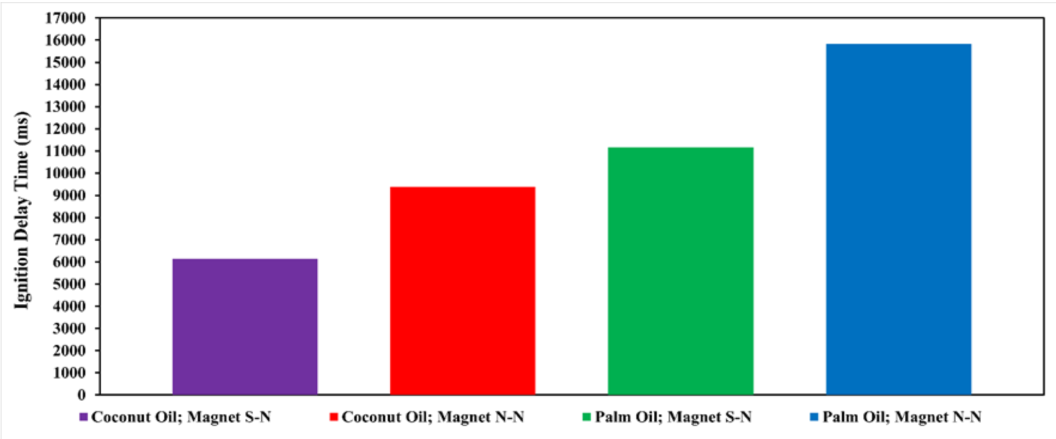

Figure 7. Ignition delay time of coconut and palm oil with two directions of a magnetic field

3.4. Ignition Delay Time

Figure 7 shows the direction of magnetic field affects ignition delay time in coconut and palm oil. The direction of the N-N magnetic field in palm oil produces longest ignition delay time of around 15839.5 ms, followed by the S-N magnetic field of 11176 ms.

Coconut oil with on direction of S-N magnetic field, produces the fastest ignition delay time of 6129.5 ms than palm oil. The short ignition delay time is due to the viscosity playing an important role in combustion. Fuel with low viscosity causes a shorter ignition delay time.

Lower viscosity of coconut oil (Table 2) accelerates the combustion reaction because unsaturated fatty acids have a low flash point. The magnetic field causes the spin electrons to be more reactive towards their nuclei in the vegetable oil molecules, thus accelerating the reaction of the fuel with oxygen.

4. CONCLUSIONS

The results of this study are magnetic field improves combustion quality by increasing the collisions between molecules to become stronger. The direction of magnetic field S -N makes electron spin more energetic, making it easier to attract oxygen and fuel molecules to the reaction zone, causing faster burning. The combustion has produced the highest temperature and short ignition delay time. In addition, the chemical and physical properties of vegetable oils affect combustion characteristics, such as fatty acid composition, flash point, calorific value and density. However, this study has shortcomings regarding the various vegetable oil and magnetic field intensity. This is probable, given the loss in plantation land influences Indonesia's vegetable oil output, which is on the decline. This analysis can also not forecast how volumetric, thermal and fuel consumption efficiency on internal combustion engine. Further research is needed to apply various vegetable oil fuels and magnetic field intensities to internal combustion engines.

REFERENCES

Ayeni, A.O., Agboola, O., Daramola, M.O., Grabner, B., Oni, B.A., Babatunde, D.E., & Evwodere, J. (2021). Kinetic study of activation and deactivation of adsorbed cellulase during enzymatic conversion of alkaline peroxide oxidation-pretreated corn cob to sugar. *Korean Journal of Chemical Engineering*, *38*(1), 81–89. https://doi.org/10.1007/s11814-020-0667-2

Bari, S., & Hossain, S.N. (2019). Performance and emission analysis of a diesel engine running on palm oil diesel (POD). *Energy Procedia*, *160*, 92–99. https://doi.org/10.1016/j.egypro.2019.02.123

Chen, C.Y., Lee, W.J., Mwangi, J.K., Wang, L.C., & Lu, J.H. (2017). Impact of magnetic tube on pollutant emissions from the diesel engine. *Aerosol and Air Quality Research*, *17*(4), 1097–1104. https://doi.org/10.4209/aaqr.2016.11.0478.

Fitriana, W., & Febrina, W. (2021). Analisis potensi briket bio-arang sebagai sumber energi terbarukan. *Jurnal Teknik Pertanian Lampung, 10*(2): 147–154. http://dx.doi.org/10.23960/jtep-l.v10.i2.147-154

Ganjehkaviri, A., Mohd Jaafar, M.N., Hosseini, S.E., & Musthafa, A.B. (2016). Performance evaluation of palm oil-based biodiesel combustion in an oil burner. *Energies*, *9*(2). https://doi.org/10.3390/en9020097

Ge, J.C., Yoon, S.K., & Song, J.H. (2021). Comparative evaluation on combustion and emission characteristics of a diesel engine fueled with crude palm oil blends. *Applied Sciences*, *11*(23). https://doi.org/10.3390/app112311502

Habibullah, M., Masjuki, H.H., Kalam, M.A., Rizwanul Fattah, I.M., Ashraful, A.M., & Mobarak, H.M. (2014). Biodiesel production and performance evaluation of coconut, palm and their combined blend with diesel in a single-cylinder diesel engine. *Energy Conversion and Management*, *87*, 250–257. https://doi.org/10.1016/j.enconman.2014.07.006

Hellier, P., Ladommatos, N., & Yusaf, T. (2015). The influence of straight vegetable oil fatty acid composition on compression ignition combustion and emissions. *Fuel*, *143*, 131–143. https://doi.org/10.1016/j.fuel.2014.11.021

Ighalo, J.O., & Adeniyi, A.G. (2020). Factor effects and interactions in steam reforming of biomass bio-oil. *Chemical Papers*, *74*(5), 1459–1470. https://doi.org/10.1007/s11696-019-00996-3

Jain, S., & Deshmukh, S. (2012). Experimental investigation of magnetic fuel conditioner (MFC) in I.C. engine. *IOSR Journal of Engineering, 2*(7), 27–31.

Liaquat, A.M., Masjuki, H.H., Kalam, M.A., Fattah, I.M.R., Hazrat, M.A., Varman, M., Mofijur, M., & Shahabuddin, M. (2013). Effect of coconut biodiesel blended fuels on engine performance and emission characteristics. *Procedia Engineering*, *56*, 583–590. https://doi.org/10.1016/j.proeng.2013.03.163

Malik, M.S.A., Mohamad Shaiful, A.I., Mohd Ismail, M.S., Mohd Jaafar, M.N., & Sahar, A.M. (2017). Combustion and emission characteristics of coconut-based biodiesel in a liquid fuel burner. *Energies*, *10*(4), 458. https://doi.org/10.3390/en10040458

Nanlohy, H.Y., Wardana, I.N.G., Hamidi, N., Yuliati, L., & Ueda, T. (2018). The effect of Rh3+ catalyst on the combustion characteristics of crude vegetable oil droplets. *Fuel*, *220*, 220–232. https://doi.org/10.1016/j.fuel.2018.02.001

Oommen, L.P., & Kumar, G.N. (2019). A study on the effect of magnetic field on the properties and combustion of hydrocarbon fuels. *International Journal of Mechanical and Production Engineering Research and Development*, *9*(3), 89–98.

Perdana, D., Hatta, M., Rosidin, M.K., & Hanifudin, M. (2022). The influence of various preheating and direction of magnetic field on combustion characteristics of palm oil droplets for boiler combustion in power generation system. *Eastern-European Journal of Enterprise Technologies*, *6*(8 (120)), 73–83. https://doi.org/10.15587/1729-4061.2022.267282

Perdana, D., Wardana, I.N.G., Yuliati, L., & Hamidi, N. (2018). The role of fatty acid structure in various pure vegetable oils on flame characteristics and stability behavior for industrial furnace. *Eastern-European Journal of Enterprise Technologies*, *5*(8–95), 65–75. https://doi.org/10.15587/1729-4061.2018.144243

Perdana, D., Yuliati, L., Hamidi, N., & Wardana, I.N.G. (2020). The Role of Magnetic Field Orientation in Vegetable Oil Premixed Combustion. *Journal of Combustion*, *2020*. https://doi.org/10.1155/2020/2145353.

Prabu, S.S., Asokan, M.A., Prathiba, S., Ahmed, S., & Puthean, G. (2018). Effect of additives on performance, combustion and emission behavior of preheated palm oil/diesel blends in DI diesel engine. *Renewable Energy*, ***122***, 196–205. https://doi.org/10.1016/j.renene.2018.01.068

Rosha, P., Mohapatra, S.K., Mahla, S.K., Cho, H.M., Chauhan, B.S., & Dhir, A. (2019). Effect of compression ratio on combustion, performance, and emission characteristics of compression ignition engine fueled with palm (B20) biodiesel blend. *Energy*, *178*, 676–684. https://doi.org/10.1016/j.energy.2019.04.185

San José Alonso, J.F., Romero-Ávila, C., San José Hernández, L.M., & Awf, A.K. (2012). Characterising biofuels and selecting the most appropriate burner for their combustion. *Fuel Processing Technology*, *103*, 39–44. https://doi.org/10.1016/j.fuproc.2011.07.023

Shehata, M.S. (2013). Emissions, performance and cylinder pressure of diesel engine fuelled by biodiesel fuel. *Fuel*, *112*, 513–522. https://doi.org/10.1016/j.fuel.2013.02.056

Tipole, P., Karthikeyan, A., Bhojwani, V., Deshmukh, S., Babar, H., & Tipole, B. (2022). Examining the impact of magnetic field on fuel economy and emission reduction in I.C. engines. *International Journal of Ambient Energy*, *43*(1), 678–684. https://doi.org/10.1080/01430750.2019.1667434

Wahyudi, Wardana, I.N.G., Widodo, A., & Wijayanti, W. (2018). Improving vegetable oil properties by transforming fatty acid chain length in jatropha oil and coconut oil blends. *Energies*, *11*(2). https://doi.org/10.3390/en11020394

Zhu, M., Setyawan, H.Y., Zhang, Z., & Zhang, D. (2020). Effect of n-butanol addition on the burning rate and soot characteristics during combustion of single droplets of diesel–biodiesel blends. *Fuel*, *265*. https://doi.org/10.1016/j.fuel.2020.117020