Abstract: It has been known that magnetic exposure of fuel prior to combustion can improve effectiveness of combustion process. However, the main reason of the phenomenon is still unclear. In this paper, characteristics of fuel as exposed to electromagnetic field was measured experimentally and inter-related appropriately in order to have preliminary insight to the clarification of the phenomenon. Fuel characteristics being investigated were viscosity, vibration of the fuel molecules, dipole moment, and refractive index. These experiments were performed using various blend compositions between fossil diesel (petrodiesel) and biodiesel fuel i.e. B0, B10, B40, B70 and B100. The electromagnetic field was generated by a galvanum tube wounded with 9,000 wire coil. The fuel characteristics of both prior and post electromagnetic exposures were then measured with time variation of 0–1,800 s. The experimental results revealed that electromagnetic exposure of the fuel increased vibrational frequency of its molecules significantly, which in turn weakened the attracting energy and caused uniform arrangement of dipole moment of the molecules. The experimental data also revealed that the fuel characteristics did not alter significantly after it was exposed to the electromagnetic field for more than

PUBLIC STATEMENT INTEREST
Exposure of biodiesel to electromagnetic field yields in higher infrared absorption and lower viscosity. The higher infrared absorption indicates higher level of vibration of the function groups and resulted in lower viscosity of the fuel. This phenomena is regarded as the reason for more effective combustion reaction of the fuel. The influence of the magnetization was found to be temporary, which will be vanished after 20 minutes release from the electromagnetic field.
1,200 s. This information is considered to be useful for further research in order to resolutely clarify the phenomenon of efficient combustion process of fuel after exposure to magnetic field.

Subjects: Mechanical Engineering Design; Renewable Energy; Energy & Fuels

Keywords: electromagnetic field; biodiesel; infrared absorption; viscosity; vibration functional groups

1. Introduction

Energy is very important in supporting human’s activity since the earliest era of civilization. This dependency is getting more and more substantial, allowing humans to run the infrastructures on a much larger scale. The highest energy consumption is on fossil fuel, which is non-renewable and hence leading to its rapid declining supply. Several measures are therefore necessary, such as reducing fuel consumption, improving fuel quality and using alternative sources. Biodiesel has great potential as an alternative energy resource because it is considered as renewable fuel, which can be produced continuously (Bünger, Krahl, Schröder, Schmidt, & Götz, 2012; Maeda et al., 2008).

A number of studies have been conducted in regard to energy conservation by improving combustion efficiency. Mixing additives may be beneficial for that purpose, given that it could increase octane and cetane number, resulting in improving engine power and lowering fly ash emission (Ali, Abdullah, Mamat, & Adam, 2015; Fayyazbakhsh & Pirouzfor, 2016; Rahhal, Ghata, & Hourieh, 2009). Similarly, fuel magnetization can generate efficient combustion, in which permanent magnets applied on the fuel channel to the combustion chamber was reported for a reduction on fuel consumption (9–30%) and exhaust gas emissions such as hydrocarbon (HC) (5–32%) and carbon monoxide (CO) (5–34.3%) (Faris et al., 2012; Govindasamy & Dhandapani, 2007; Patel, Rathod, & Patel, 2014; Ugare, Dhoble, Lutade, & Mudafale, 2014). Each of these methods, however, has their own disadvantages. While most chemical additives contain metals which are harmful to humans, permanent magnets depletes over the application time.

An electromagnetic device has also been introduced to overcome the decrease in magnetic intensity of a permanent magnet. When applied on gasoline and diesel operated engines, the device was reported to reduce fuel consumption in the range of 12.8 to 30%, as well as reduce HC emission in the range of 44 to 58% and CO emission in the range of 35 to 80% (Chaware, 2015; Fatih & Saber, 2010; Patel et al., 2014).

While the effect of magnetic exposure in reducing the fuel consumption has been proven, the explanation on the phenomenon is still unclear. Many researchers claim that the magnetic exposure can cause ionization in the fuel (Chaware, 2015; Okoronkwo, Nwachukwu, Ngozi, & Igbokwe, 2010; Singh & Solanki, 2015). Others claim the de-clustering effect and the reduction in size of a fuel’s molecule constellation as shown in Figure 1 (Attar, Tipole, Bhojwani, & Desmukh, 2013; Jain & Deshmukh, 2012; Jundale, 2015). Accordingly, thorough study on the magnetic exposure on the fuel and logical explanation to the phenomenon is indispensably required. The clear explanation to the phenomenon will contribute to the development of the combustion technology that will significantly increase the effectiveness of combustion process.
In this paper, the characteristics of biodiesel blends under electromagnetic exposure were experimentally measured and analyzed. Several parameters, which is considered to be important for clarification of the phenomenon, such as viscosity, molecular vibration of the fuel, magnetic moment, refractive index, and fuel spray characteristics, were experimentally investigated both prior and post exposure to electromagnetic field. Furthermore, the alteration of fuel characteristics due to the electromagnetic exposure was comprehensively discussed. The characteristics to be obtain in this experiment are expectedly can be useful to the clarification of the effect of magnetic exposure to combustion efficiency which has been experimentally proven by many researcher as explained above.

2. Materials and method
Schematic diagram of the experiment is given in Figure 2. The detail of the experimental materials and method is given in the following sub-sections.

2.1. Generation of electromagnetic field
Electromagnetic field was generated by using a galvanum tube with diameter of 15 mm and length of 100 mm wounded with 0.20 mm diameter of copper wire. The tube was wounded with 9,000 wire coils, and 12 volts DC voltage were used to generate the electromagneticity. The intensity of the electromagnetic field was then measured by using Digital Teslameter Model MG-801, following equation of Biot Savart’s law as shown in Equation (1).

\[ B = \frac{\mu_0 \mu N i}{L} \]  

(1)

Here \( \mu \) is material permeability (Gauss cm/amp), \( \mu_0 \) is vacuum permeability (Gauss cm/amp), \( L \) is length of galvanum tube (cm), \( B \) is magnetic field (Tesla), \( N \) is coil number inductor, and \( i \) is DC electric current (amp).

2.2. Sample collection and preparation
Fuel samples consisting of biodiesel and petrodiesel were collected from Watt Co. Ltd and Pertamina Co. Ltd, respectively. The biodiesel was blended with petrodiesel in proportions of 0% (B0), 10% (B10), 40% (B40), 70% (B70), and 100% (B100). Biodiesel used for the blend was checked in laboratory to confirm its conformity to Indonesian National Standard (INS) as shown in Table 1. A 45 ml sample of each blend was placed in the galvanum tube. The samples were exposed to the electromagnetic field in time variable of 0, 10, 20, 30, 60, 180, 600, 1,200 and 1,800 s at room temperature.
2.3. Fuel characteristics

2.3.1. Viscosity
Fuel sample viscosities of B0, B10, B40, B70, and B100 were measured by using a modified Oswald viscometer equipped with magnetic ball and censoring coils connected to sound data detector as shown in Figure 3. Time of magnetic ball in fluid \( t_b \) was calculated as soon as the ball passed the first coil and the second coil with the distance between these coils was 107 mm. The device was calibrated by using distillate water in order to obtain time accuracy of 1 μs. The fuel viscosity measurement was conducted with 5 replications and used the average value for discussion in order to abate the data uncertainty caused from the measurement. The viscosity was calculated by using Equation (2).

\[
\eta = \frac{2r^2 t_b g (\rho_b - \rho_f)}{9L} \tag{2}
\]

Here \( r \) is radius of magnetic ball (0.961 mm), \( g \) is acceleration of gravity (9.8 m/s\(^2\)), \( \rho_b \) is density of the ball (310,467 kg/m\(^3\)), and \( \rho_f \) is density of the fuel. The \( \rho_f \) was measured separately as shown in Table 2.

2.3.2. Vibration of the fuel molecules
Molecular interactions of fuel samples were investigated by analyzing their infrared spectra. The Infra-red spectra were obtained using Fourier Transform Infrared (FTIR) spectroscopy (IR Prestige-21,
Shimadzu Co. Ltd). The FTIR spectroscopy is equipped with L-alanine-doped triglycerine sulfate (DLATGS) detector. The equipment was set at 4 cm\(^{-1}\) resolution, 20 scans accumulation, and absorbance (%A) measurement mode with wave number ranging from 4,000 to 400 cm\(^{-1}\) in order to determine the functional groups which were formed in the fuel. Samples of 1 μL were mixed with 0.5 g KBr. The FTIR measurements were carried out at room temperature.

### 2.3.3. Magnetic moment
Vibrating Sample Magnetometer (VSM) instrument (Oxford VSMI.2H) was used to measure the magnetic properties of the fuel samples as a function of magnetic field. The VSM had amplitudes of 1–1.5 mm. The fuel sample with volume of 10 μL was placed in the coiled tube.

### 2.3.4. Refractive index
The refractive index was then measured by using Atago 3T refractometer model RX-5000α-plus, which needs 3 μL of the fuel sample at room temperature. The instrument was capable for measuring refractive index at the range between 1.327 and 1.585. The measurement was conducted with 5 replications to take into account the possible data uncertainty.

### 2.3.5. Fuel spray characteristics
Spray characteristic of B10 fuel was firstly investigated in order to assure the effect of electromagnetic exposure of the fuels. It can be realized by using nozzle injector tester with testing pressure of 14.7 MPa. The spray characteristic was then captured by using high resolution camera.

## 3. Results and discussion

### 3.1. Effects of electromagnetic exposure on fuel spray performance
Figure 4 shows spray performance of biofuel (B10) out of the injector after 0, 30, 60, 180, 600, 1,200, and 1,800 s of electromagnetic exposure. It appears that exposure of the fuel to electromagnetic...
field (b, c, d, e, f, g) have wider spray characteristics as compared to un-magnetized one (a). Technically, wider spray of fuel give advantages to combustion process (Avinash & Vipul, 2012; Casey et al., 2013), since the local viscosity is lower, as it is also confirmed by the measured viscosity. Again, wider spray of the fuel could increase its contact surface with oxygen, and hence improve the combustion process.

### 3.2. Effects on kinematic viscosity

Figure 5 shows the viscosity of various fuel blends exposed to electromagnetic fields at time intervals. Even though the biodiesel used in the experiment met the INS, its viscosity was higher than...
It is important to state the higher viscosity of biodiesel than petrodiesel, as it is also reported by other researchers (Borges, Díaz, Gavin, & Brito, 2011; Chavarria-hernandez & Pacheco-catalán, 2014; Gülüm & Bilgin, 2016; Kafui, Sunnu, & Parbey, 2015), since viscosity is closely related to combustion process. The electromagnetic exposure was proven to lower kinematic viscosity of the fuel samples (Marques et al., 1997; Rosensweig, Kaiser, & Miskolczy, 1969; Tung, Vinh, Phong, Long, & Hung, 2003), and there by exposing the biodiesel blend to electromagnetic field will be advantageous for improving its combustion process. Furthermore, longer exposure time to electromagnetic field resulted in lower viscosity, but not significant anymore after 1,200 s of the exposure time. It is also noted that viscosity value is not only determined by the tensile strength of molecules but also by the state of molecular orientation at liquid (fuel sample) – solid (magnetic ball) interface (Nakano, 2003; Sengupta, Herminghaus, & Bahr, 2014; Tung et al., 2003). It can be expected that the effect of magnetic exposure to the viscosity can be continued for longer exposure time by changing distribution of the molecular orientation at the interface.

### 3.3. Effects of electromagnetic exposure on fuel molecule interactions

Figure 6 shows the intensity of infrared absorption of petrodiesel and biodiesel fuels from FTIR observation at various wave numbers. Each peak in the graph shows the existence of functional groups. The figure showed that petrodiesel and biodiesel can be distinguished by peak existence at wave numbers 1,743 and 1,176 cm\(^{-1}\) in biodiesel absorbance curve, which represent C=O and C–O bonds (Berman, Meiri, Linder, & Wiesman, 2016; Ferrão et al., 2011; Furlan, Wetzel, Johnson, Wedin, & Och, 2012).

Figure 7 shows FTIR observation of B0, B10, B40, B70, and B100 fuels at varied exposure time to various wave number of electromagnetic field. It can be seen that spectrum of each fuel have identical shape and peak positions regardless the exposure time. This means that the electromagnetic exposure time did not alter molecular structure of those fuels, which also proved that ionization might not occur. Furthermore, by comparing all of the fuel spectra after electromagnetic exposure to the original fuel spectra, the increment of the absorption intensity for each functional group was observed. Table 3 is the summary of the comparison by taking the difference in absorption intensity at wavenumber 2,924 cm\(^{-1}\). The table revealed that extension of exposure time yielded in increasing intensity of infrared absorption, as it is also reported by Calabrò and Magazù (2015) for lower electromagnetic intensity and longer exposure time. The absorption intensity can be correlated to molecular vibration of functional groups. Longer time of electromagnetic exposure causes more number of molecules to vibrate. This phenomenon was consistent with all functional groups existing in the fuel samples, and thereby consistent with all fuel samples regardless of the fuel's structure.

The vibrational increment of functional groups indicates that the polarization and transition of dipole moments of molecules occur due to the displacements of the fuel molecules and alteration of magnetic moment of those molecular interactions. Furthermore, molecular attracting energy of functional groups is determined by their vibrational frequency in which the higher frequency the lower the absolute value. This is the reason why the fuel viscosity, which is influenced by the molecular attracting energy (Faris et al., 2012), decrease after it is exposed to electromagnetic field. Higher absorption intensity, which indicates higher vibration frequency, yield in lower molecular

| Table 3. Comparison of infrared absorbance at wavenumber 2,924 cm\(^{-1}\) by various fuel samples before and after exposure to 1,500 Gauss electromagnetic field |
|-----------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Fuel   | Unexposed | 0 | 10 | 20 | 60 | 180 | 600 | 1,200 | 1,800 |
|--------|-----------|---|----|----|----|-----|-----|------|------|
| B0     | 0.596     | 0.596 | 0.603 | 0.631 | 0.662 | 0.721 | 0.807 | 0.967 | 0.967 |
| B10    | 0.621     | 0.621 | 0.642 | 0.664 | 0.781 | 0.781 | 0.823 | 0.956 | 0.956 |
| B40    | 0.512     | 0.512 | 0.603 | 0.631 | 0.652 | 0.723 | 0.821 | 0.976 | 0.976 |
| B70    | 0.603     | 0.603 | 0.632 | 0.697 | 0.752 | 0.756 | 0.814 | 0.957 | 0.957 |
| B100   | 0.567     | 0.567 | 0.603 | 0.657 | 0.695 | 0.734 | 0.817 | 0.953 | 0.953 |
affinity. This means less energy required to break the inter-atomic bonds. Therefore, the molecular affinity of the fuel molecules decreases after exposure to the electromagnetic field.

3.4. Effects on dipole moment
Petrodiesel, biodiesel and its blend are considered as paramagnetic material in which each molecule of the fuel has dipole moment influenced by electromagnetic field. Figure 8 shows the dipole moment obtained from VSM measurement. It can be seen that the electromagnetic exposure causes the increase of the dipole moment, regardless of the biodiesel blending proportion. It means that the fuel molecules arranges themselves according to the direction of electromagnetic field or, in other word, its dipole direction was arranged properly (Kuwako et al., 1997; Nittoh et al., 2012; Sheldon, Adjiman, & Cordiner, 2005). The main constituent molecule of the fuel sample is hydrocarbon (C–H) that has unpaired electron spin moments. When it is exposed to electromagnetic field, the induced magnetic moment becomes weak. A strong electromagnetic field exposing hydrocarbon
molecules causes intermolecular hydrocarbons to repel each other (de-clustering), which creates an optimal distance between molecules of hydrocarbons and oxygen. The polarized molecules are relatively more active and oriented in accordance with the direction of the electromagnetic field.

### 3.5. Effects on refractive index

In order to clarify that fuel molecules have been arranged uniformly following the electromagnetic field, the refractive index of each fuel sample under electromagnetic exposure was investigated. Theoretically, when fuel molecules arrange uniformly the value of refractive index will be high (Kaur & Pal, 2015; Nita, Geacai, Neagu, & Geacai, 2013; Zabala, Arzamendi, Reyero, & Gandía, 2014). Figure 9 shows the refractive index of biodiesel and its blend with petrodiesel measured by refractometer. It can be seen that longer exposure to electromagnetic fields yields higher refractive index. This result proves that uniform arrangement of the fuel molecules occurs after the fuel was exposed to electromagnetic field.
4. Conclusion

Exposure to electromagnetic fields on petrodiesel fuel, biodiesel, and its blends caused lower viscosity, wider spray characteristic, higher infrared absorption that cause higher vibrational frequency of the functional groups and weaker attracting energy, and higher refractive index values which indicated larger dipole moment. The result also revealed that the effect of electromagnetic field to the fuel was saturated when it was exposed longer than 1,200 s. These information are considered to be useful for further research in order to resolutely clarify the phenomenon of efficient combustion process of fuel after exposure to magnetic field.

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