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Experimental Study of the Effect of Magnetization on Bioethanol Injectors on Spray Characteristics for Applications in the SINJAI-150 Engine

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Abstract

In general, the hydrocarbon molecules in the fuel perform vibrational activity towards the core and attract each other, forming clustering molecules. Induction of a magnetic field in the fuel flow can change the hydrocarbon molecules so that their arrangement becomes more regular (de-clustering). The induction of the magnetic field in this research utilized a coil that was fed by an output current from the SINJAI-150 engine alternator. Magnetic field placement was placed before Bioethanol E100 fuel entered the injector. Observation of the magnetization of the fuel was carried out molecularly with the FTIR (Fourier Transform-Infra Red Spectroscopy) test and observing the characteristics of the fuel spray at the injector output. The results obtained were an increase in the fuel transmittance of Bioethanol E100 up to 41.31% for C-H compounds, 48.8% for C-O compounds, and 114% for O-H compounds compared to standard conditions. In the spray characteristics, there was an increase in the spray angle up to 2 and a decrease in the Sauter Mean Diameter (SMD) to 1.312 mm, due to a decrease in the value of the fuel properties in the form of surface tension, viscosity, and density up to 2.6%, 10.28% and 10.15% from the standard state without magnetization. As a result of decreasing the density value, the mass flow rate of the fuel decreases to 10.28% from the standard conditions at 2,000 rpm.

Keywords: Bioethanol E100, FTIR, injector spray characteristics, magnetic induction

1. Introduction

Ingeneral, the hydrocarbon molecules in the fuel compound will carry out vibrational activities (vibrations) towards the core. In addition, hydrocarbon compounds will tend to attract between molecules to form molecules that are clustered (clustering). The clustering of this fuel causes the hydrocarbon molecules not to be completely oxidized when they react with oxygen. In the Spark Ignition Engine (SIE), the combustion of a certain amount of fuel that has been mixed with air is initiated by a spark from the spark plug. In this process, there is a fast chemical reaction between hydrogen and carbon in the fuel and oxygen contained in the fuel and air mixture. As a result of the clustering effect, it is estimated that there is still unburned fuel and turned into UHC (unburned hydrocarbon) and carbon monoxide.It is necessary to improve the atomization process to reduce emission levels and increase combustion efficiency. One way to improve the fuel atomization process is to apply a magnetic field to the fuel stream.

Hamdani & Sudarmanta [1] has conducted research on giving magnetic fields to fuel on engine performance. Hamdani & Sudarmanta's research was carried out on gasoline by varying the magnitude of the magnetic field according to variations in voltage and resistance. In the FTIR test, it was found that there was an increase in the transmittance of infrared rays in fuel spectroscopy due to the application of a magnetic field. In the engine test, due to magnetization, there was a decrease in the value of the Air Fuel Ratio. This causes an increase in the value of thermal combustion efficiency and shows an improvement in the quality of emissions. Subsequent research was carried out by Anang & Sudarmanta [2] by utilizing the alternator output voltage to generate magnetic field induction. From the research results, it was found that the maximum engine performance occurs at several variations of engine speed. The increase in infrared light transmittance in fuel spectroscopy occurred at 5,000 rpm rotation. At 3,500 rpm, there was the highest increase in torque, bmep, volumetric efficiency, thermal efficiency, and also decreased fuel consumption and emissions. While the maximum power increase occurs at 4500 rpm engine speed.

Research on the effect of magnetization on fuel properties has been carried out by Chalid et al. [3] and Faris et al. [4]. Research by Chalid was conducted on kerosene fuel by varying the value of magnetic field induction and magnetization time. From this research, it was found that the magnetization did not cause changes in the constituent

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compounds of the fuel. The induction value of the magnetic field and the duration of magnetization affect the decrease in the viscosity and polarity of kerosene fuels. Meanwhile, research conducted by Faris by giving a magnetic field to Iraqi gasoline. The results of this test cause a decrease in the value of the surface tension along with a given magnetic induction.

The fuel combustion process in the chamber is influenced by the atomization of the fuel with air. One way to improve atomization is to provide a declustering effect on the fuel molecule. The treatment used to cause the declustering effect is to apply a magnetic field to the fuel stream. The declustering effect on the fuel molecule can be seen in the fuel FTIR spectroscopy test. Whereas in the engine, one way to observe fuel atomization is to pay attention to the injectors' fuel spray. Based on this description, a test was done to observe the effect of magnetization on the mass flow rate of fuel, changes in infrared light transmittance on fuel spectroscopy, and spray characteristics on the injectors.

2. Method

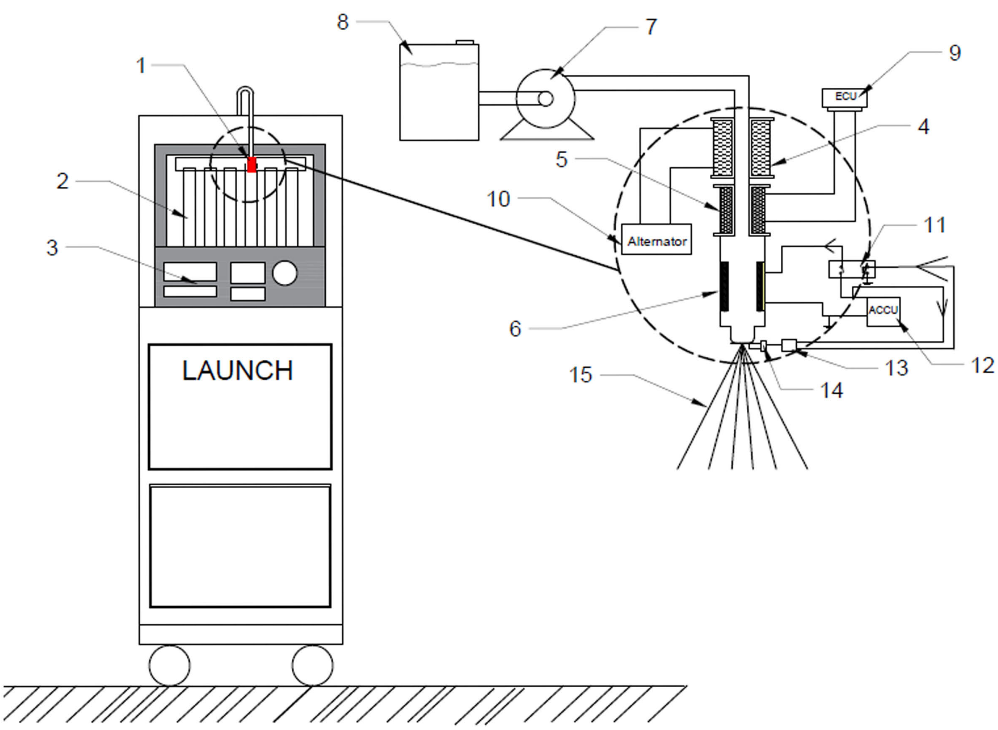
2.1. Experimental Set-up

Before testing the injector tester, the magnetic field induction magnitude was tested according to the alternator current output. The results of magnetic field testing can be seen in Table 1.

Table 1. Magnetic field test results.

Magnetic Field	Current (Ampere)	Magnetic Field (Gauss)
B1	1.1	250
B2	1.6	280
B3	2.4	310
B4	2.9	330

Installation of injector tester equipment for data collection of fuel flow rates can be seen in Figure 1.



Explanation :

1. Bioetanol E100 Injector
2. Measuring cup on Injector tester
3. Injector tester controller
4. Magnet
5. Injector solenoid
6. Injector heater
7. Fuel Pump
8. bioethanol E 100 fuel
9. ECU
10. Alternator (Power Supply)
11. Stop contact
12. Accu
13. Sensor
14. Termocouple
15. Fuel spray

Figure 1. Schematic of fuel flow rate testing installation using injector tester unit.

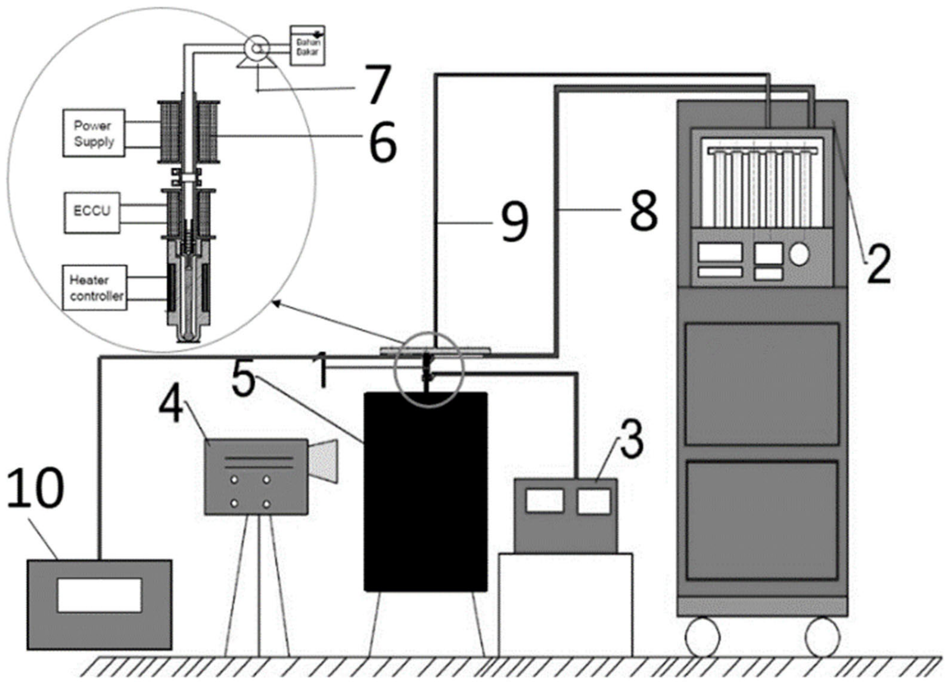
Induction of a magnetic field in the fuel was carried out before the fuel entered the injector. Magnetic field induction makes use of the electric current output from the alternator. At the time of testing, the alternator was replaced by a power supply whose current output matched the alternator output current. The electric current induced by the magnetic field was adjusted according to the current variation in the alternator output. In this test, the fuel was set at a temperature of 70°C. The source of fuel heating generation comes from accu.

The data collection for the fuel flow rate was carried out entirely in the Injector Tester Unit. Initially, the injector tester was set to uniform/spreadability mode. Then the heater on the injector was activated. The magnetic field was induced according to the variation of the current. Pulse width and injection pressure were set at 6ms and 3 bar. Furthermore, the fuel flow rate was adjusted by using a variation of rpm in accordance with the engine rotational speed to be observed, namely 2,000, 4,000, 6,000, and 8,000 rpm. The fuel injection time was set for 60 seconds.

Observations were made to collect fuel flow rate data, in the form of the volume of fuel injected and the time of injection. The volume of fuel can be observed through a measuring cup on the injector tester unit.

Figure 2 shows the installation of the injector tester equipment for observing the spray characteristics. The difference in the installation for testing the spray characteristics is the placement of the injectors outside the injector tester. The injector is placed in front of the blackboard so that the spray characteristic image can be captured perfectly by the camera.

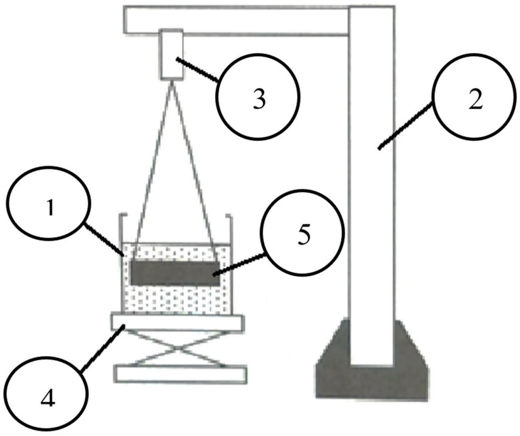
After that, the fuel samples were taken for FTIR testing and fuel properties testing. Properties testing was carried out in the form of viscosity testing, surface tension, and density due to the application of a magnetic field. Properties testing was carried out to determine the *SMD* value of the fuel due to magnetization. The data obtained from the properties test is the dynamic viscosity value for the viscosity test. The mass of the fuel at a certain volume for the density and the difference in forces with the circumference of the ring in the surface tension test. The surface tension test scheme can be seen in Figure 3.



Explanation :

1. Bioetanol E100 Injector
2. Injector tester
3. Accu
4. Camera
5. Black screen
6. Magnetic Field
7. Fuel Pump
8. ECU Connector Cable
9. Fuel flow hose
10. Power Supply

Figure 2. Schematic of the spray characteristic testing installation.



Explanation :

1. Test container
2. Steel rod
3. spring balance Newton scale
4. Jack
5. Aluminium ring

Figure 3. Schematic of the surface tension testing installation.

2.2. Data Processing

Table 2 is the data obtained from the results of testing properties and fuel flow rates. In the density test, data were obtained in the form of mass (m) and fuel volume (V). So that the magnitude of the density value is obtained by the following equation:

$$\rho = \frac{m}{V} \tag{1}$$

Table 2. Testing result data.

Magnetic field	m (gram)	V (mL)	t (s)	Vi (mL)	ΔF (mN)	μ (cP)
B0	29	42	60	23	7.5	0.35
B1	63	98	60	23	7.35	0.33
B2	62.4	98	60	23	7.3	0.33
B3	64.2	102	60	23	7.3	0.32
B4	60.8	98	60	23	7.3	0.315

In the surface tension test, data were obtained in the form of the difference in force on the ring when it touches the fuel surface and when the ring is completely inside the fuel (ΔF). The sizes of the outer diameter of the ring (d_1) and the inner diameter of the ring (d_2) are known. So that the surface tension value is obtained by the following equation:

$$\sigma = \frac{\Delta F}{3.14(d_1 + d_2)} \tag{2}$$

The fuel flow rate test results obtained data in the form of fuel injection volume (Vi) and injection time (t). Once the fuel density value is known, the mass flow rate of the fuel out of the injector can be determined by the following equation:

$$\dot{m}_t = \rho \frac{Vi}{t} \tag{3}$$

The injector used in the test is a multihole injector, with 4 fuel outlet holes. So that the equation used to calculate the fuel flow rate at one hole, is:

$$\dot{m} = \frac{1}{4}\dot{m}_t \tag{4}$$

Based on the results of the calculation of the mass flow rate of the fuel, the speed at which the fuel leaves the injectors can be determined by the equation:

$$\dot{m} = \rho.A.v \tag{5}$$

After obtaining the velocity of fuel flow out of the injector, the Weber Number [5] calculation can be performed with the equation:

$$W_e = \frac{\rho.v^2.d}{\sigma} \tag{6}$$

To get the *SMD* value, it is necessary to calculate the Reynolds Number of the known fuel properties. The Reynolds Number [5] value is obtained by the equation:

$$R_e = \frac{\rho.v.do}{\mu} \tag{7}$$

In testing the characteristics of the injector spray, fuel was sprayed into the air at 1 atm room temperature. Assuming the air temperature was 27°C, the value of dynamic viscosity of air (μ_g) = 18.46 x 10^{-6} Pa.s and air density (ρ_g) = 1.1614 kg/m^3 was obtained. The value of SMD [6] can be calculated with the equation:

$$SMD = 4.12 d_{nozz} Re^{0.12} {W_e}^{-0.75} \left(\frac{\mu}{\mu_g}\right)^{0.54} \left(\frac{\rho}{\rho_g}\right)^{0.18} \tag{8}$$

3. Result and Discussion

3.1. Effect of Magnetic Fields on FTIR Testing Graphs

Figure 4 shows the FTIR test results of Bioethanol E100 fuel subjected to a magnetic field. The test was carried out by comparing the FTIR results of bioethanol fuel E100 without magnetization (B0) with fuel given a magnetic field of 250 Gauss (B1), 280 Gauss (B2), 310 Gauss (B3), and 330 Gauss (B4). The test was carried out at the same fuel flow rate according to the SINJAI 150 cc engine rpm. Figure 5 is the result of FTIR testing with variations in the flow rate of fuel through the magnetic field according to engine speed.

From the test results, it can be seen that the application of a magnetic field does not affect the structure of the bioethanol E100 constituent compounds. The application of a magnetic field only affects the transmittance value. The greater the magnetic field value applied to the fuel, the greater the change in% transmittance. Also, it is known that the lower the fuel flow rate passing through the magnetic field, the greater the change in transmittance. Changes in the fuel's absorption value indicate de-clustering of the compounds in Bioethanol due to magnetization, which changes the polarity of the functional groups of the compounds. This change allows a change in the intensity of the functional group vibration transmission. The increase in polarity of a molecule is made possible by the change in the distance of the electrons in the atom or molecule's bond area due to the orientation of the molecule or the polar bond during magnetization. This change leads to an increase in the bond's dipole moment. This has a strong relationship with the de-clustering phenomenon because an increase in the bond's dipole moment allows repulsion between hydrocarbon molecules. Finally, the molecular distribution increases, and the refractive index of Bioethanol is higher than before magnetization

Further observations were made on the fuel constituent compound Bioethanol E100. The fuel constituents of Bioethanol E100 are in the form of C-H, O-H, and C-O bonds. C-H compounds can be detected by the presence of a peak at a wavelength of 2,978.16 cm^{-1}. O-H compounds can be detected with peaks at 3,433.4 cm^{-1} wavelength. And the C-O compound can be detected with a peak at a wavelength of 1,074.38 cm^{-1}.

Figure 6 shows the percentage increase in transmittance due to magnetization with variations in the magnetic field's magnitude and the flow rate of fuel through the magnetic field. From this graph, it can be seen that with the same magnetic field variations at different rpm, the change in the absorption value tends to decrease along with the higher the rpm value. In the magnetic field B1 (250 Gauss), the percentage value of the increase in the value of C-H Alkane absorption decreases with the increase in the rate of fuel flow through the magnetic field. At 8,000 rpm, the increase in the absorption value percentage was only around 8.34%, while at the low rotation of 2,000 rpm, the increase in fuel transmittance reached 13.65%. This is due to the difference in the time the fuel hits the magnetic field. The longer the magnetization time, the higher the increase in transmittance. In the C-H Alkane Bioethanol E100 fuel compound, applying a magnetic field of 330 Gauss can increase the transmittance of the compound by up to 48% from standard conditions.

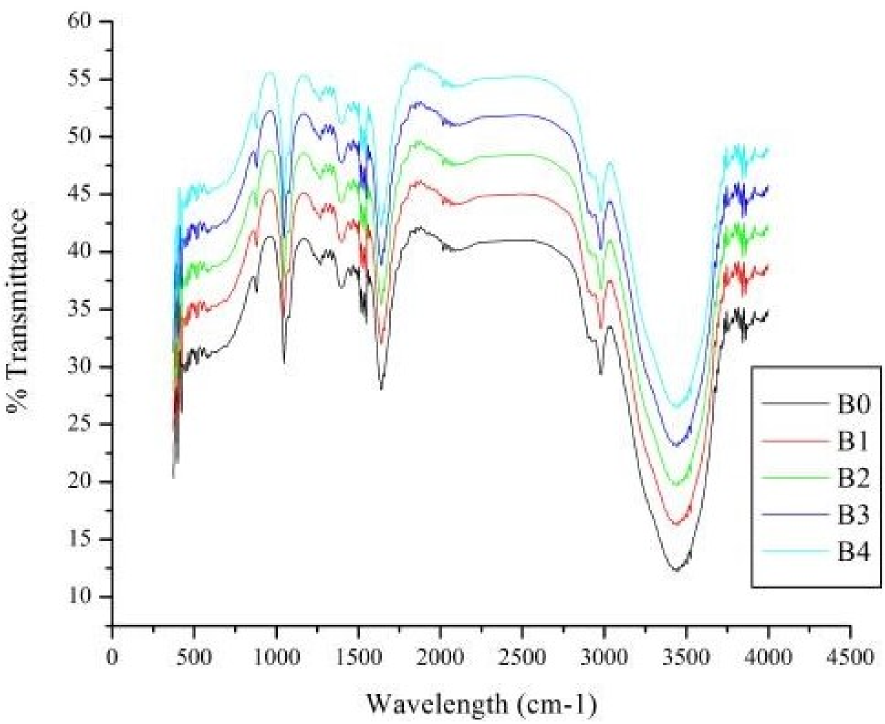


Figure 4. Effect of variations in the magnitude of the magnetic field on the FTIR test results.

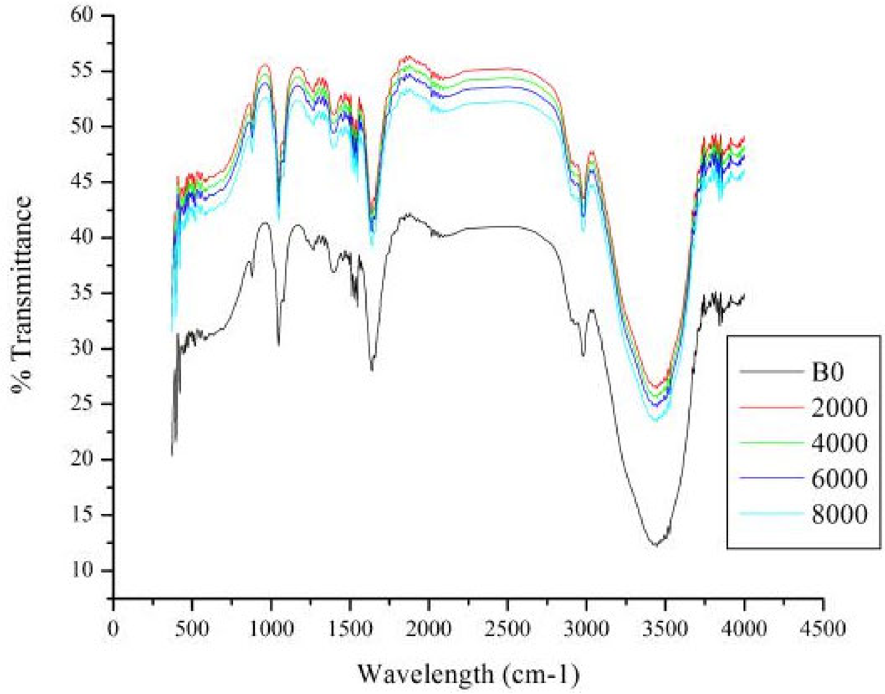
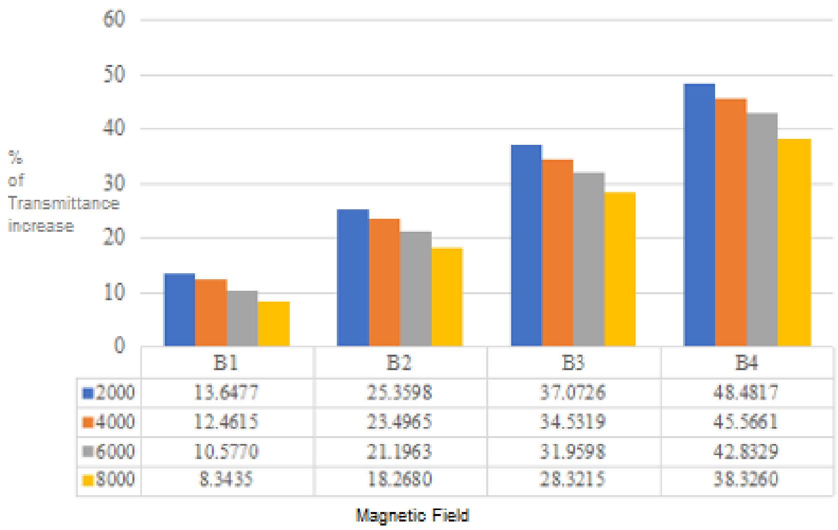


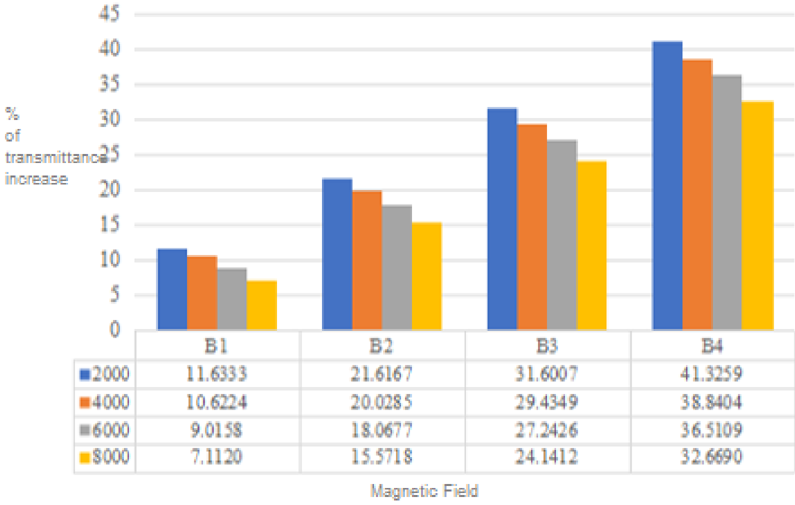
Figure 5. Effect of the flow rate of fuel through a magnetic field on the results of the FTIR test.

Figures 7 and 8 show the percentage increase in % transmittance due to magnetization with variations in the magnitude of the magnetic field and the flow rate of fuel through the magnetic field in the C-O and O-H compounds trendline, the percentage increase in transmittance due to the difference in the magnitude of the magnetic field and the rate of fuel flow through the magnetic field is the same as the C-H compound. There is a difference in the increase in the transmittance value. In the C-O compound of Bioethanol E100 fuel, applying a magnetic field of 330 Gauss can increase the transmittance of the compound up to 41.33% from standard conditions. Whereas in O-H compound, the percentage increase in transmittance reached up to 114.26% from standard conditions.



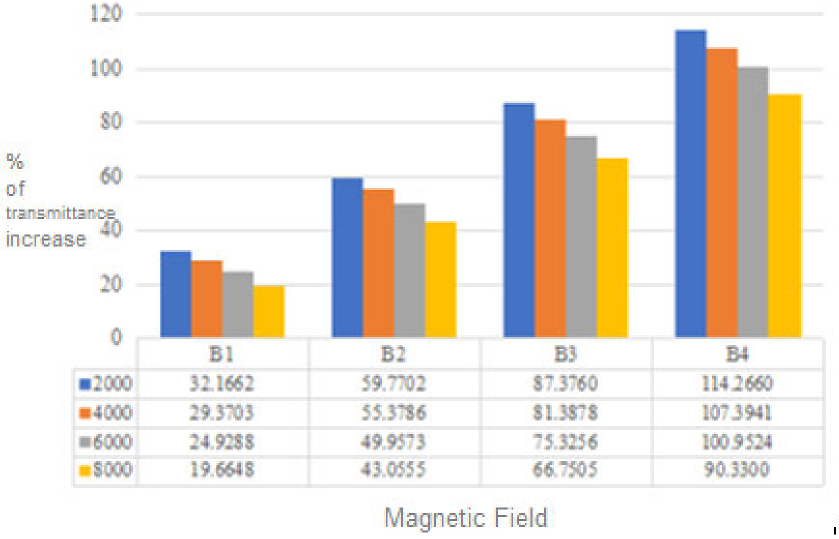
	B1	B2	B3	B4
2000	13.6477	25.3598	37.0726	48.4817
4000	12.4615	23.4965	34.5319	45.5661
6000	10.5770	21.1963	31.9598	42.8329
8000	8.3435	18.2680	28.3215	38.3260

Figure 6. Graph of the increase in% transmittance of C-H alkanes due to magnetization against standard conditions (without magnetization).



	B1	B2	B3	B4
2000	11.6333	21.6167	31.6007	41.3259
4000	10.6224	20.0285	29.4349	38.8404
6000	9.0158	18.0677	27.2426	36.5109
8000	7.1120	15.5718	24.1412	32.6690

Figure 7. Graph of the increase in the transmittance of the C-O compound due to magnetization against standard conditions (without magnetization).



	B1	B2	B3	B4
2000	32.1662	59.7702	87.3760	114.2660
4000	29.3703	55.3786	81.3878	107.3941
6000	24.9288	49.9573	75.3256	100.9524
8000	19.6648	43.0555	66.7505	90.3300

Figure 8. Graph of the increase in transmittance of O-H compounds due to magnetization against standard conditions (without magnetization).

3.2. Effect of Magnetic Fields on Fuel Properties

Based on the density test results, it appears that the fuel flow passing through the magnetic field has decreased the density value. This is shown in Figure 9, which tends to decrease with the application of a larger magnetic field. This is due to the de-clustering process in the Bioethanol E100 fuel molecule. So that the distance of hydrocarbon molecules stretches and causes an increase in the volume of fuel under conditions of constant fuel mass. Along with the increase in the magnetic field's magnitude applied to the fuel flow, the density value decreases. As a result of a decrease in the fuel density value, the mass flow rate of the fuel will decrease following the decreasing trendline in the density value. The value of the mass flow rate of fuel can be seen in Figure 10.

The results of viscosity and surface tension testing, applying a magnetic field to the fuel flow can reduce the viscosity and surface tension values. This can be seen in Figures 11 and 12. As a result of the declustering effect, there is an increase in molecular polarity during magnetization. This polarity change increases the repulsion between similar molecules and reduces the vibrations of the molecules towards the nucleus. This is what can reduce the viscosity of Bioethanol and surface tension.

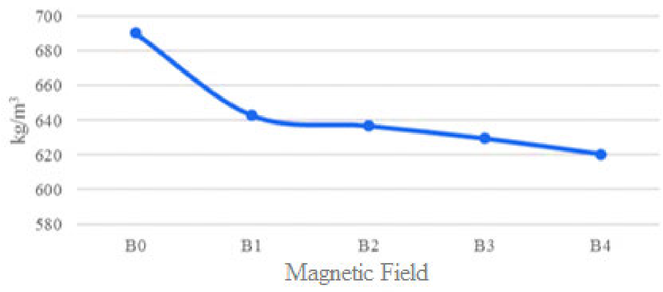


Figure 9. Effect of the magnitude of the magnetic field on the density value of E100 bioethanol fuel.

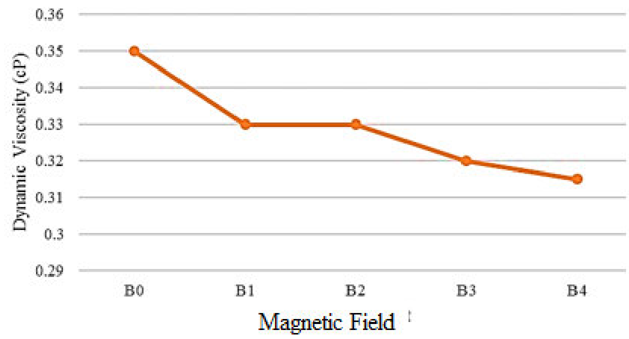


Figure 11. The influence of the magnitude of the magnetic field on the viscosity value of bioethanol fuel E100.

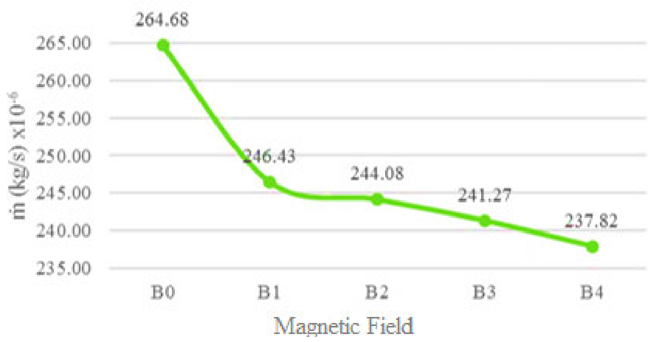


Figure 10. Effect of magnetic fields on changes in the mass flow rate of bioethanol E100 fuel.

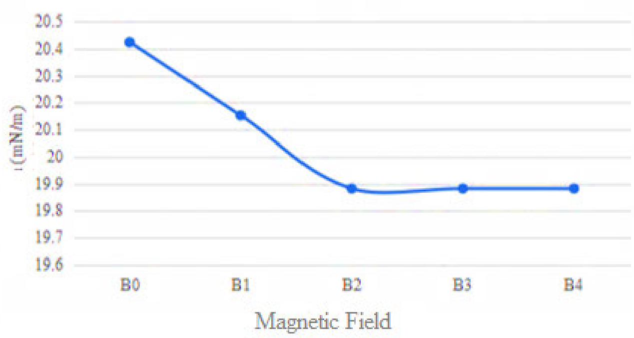


Figure 12. Effect of the magnitude of the magnetic field on the surface tension value of E100 bioethanol fuel.

3.3. Effect of Magnetic Fields on the Characteristics of the Injector Spray

When the fuel flow is subjected to a magnetic field, the Bioethanol E 100 fuel tends to experience a decrease in the density, viscosity, and surface tension values. This is what causes the *SMD* value to decrease along with the increase in the value of magnetic field induction. This can be seen in Figure 13. Based on Equation (8), the *SMD* value is influenced by the Reynolds and Weber numbers. The Reynolds and Weber numbers are influenced by the ratio of density values to surface tension and viscosity. Along with the application of magnetic field induction, bioethanol fuel experiences a decrease in the density value followed by a decrease in the value of surface tension and viscosity. This is what causes a decrease in the value of the *SMD*. A decrease in the *SMD* value can indicate an improvement in the atomization of the fuel when it is mixed with air. So that it can cause more complete combustion in applications in the combustion chamber.

In Figure 14, the visualization of fuel spray in different magnetization treatments is shown. In the absence of magnetization, it is seen that the fuel spray formed an angle of 26° with a penetration length of about 13 cm. After applying a magnetic field, figures 14 b, c, and d, the angle of the spray experienced an increase in angle to 27.3°. This increase in spray angle was not accompanied by a change in the length of penetration. And when a B4 magnetic field was applied, the spray angle increased to 28°. However, there was still no change in the length of penetration due to magnetic field.

The fuel property that affects the change in spray angle is the viscosity value. Applying a magnetic field to the fuel will reduce the viscosity value. This is what causes a wider distribution of the fuel output from the injectors and affects the size of the spray angle. However, this decrease does not coincide with the increase in the spray angle. This indicates a certain viscosity value so that it affects the change in spray angle. The *SMD* value also affects the spray angle of the injector output. From the results of the visualization, it can be seen that the increase in the spray angle is due to a change in the value of the fuel droplet size. Due to the smaller fuel droplet size, the fuel that is in direct contact with free air is volatile and reacts with the air, causing fog in the fuel spray.

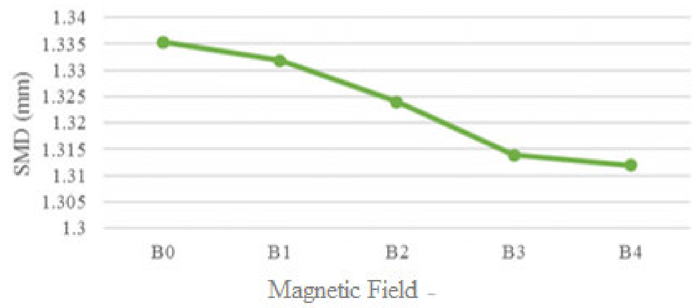


Figure 13. The influence of the magnitude of the magnetic field on changes in the SMD value.

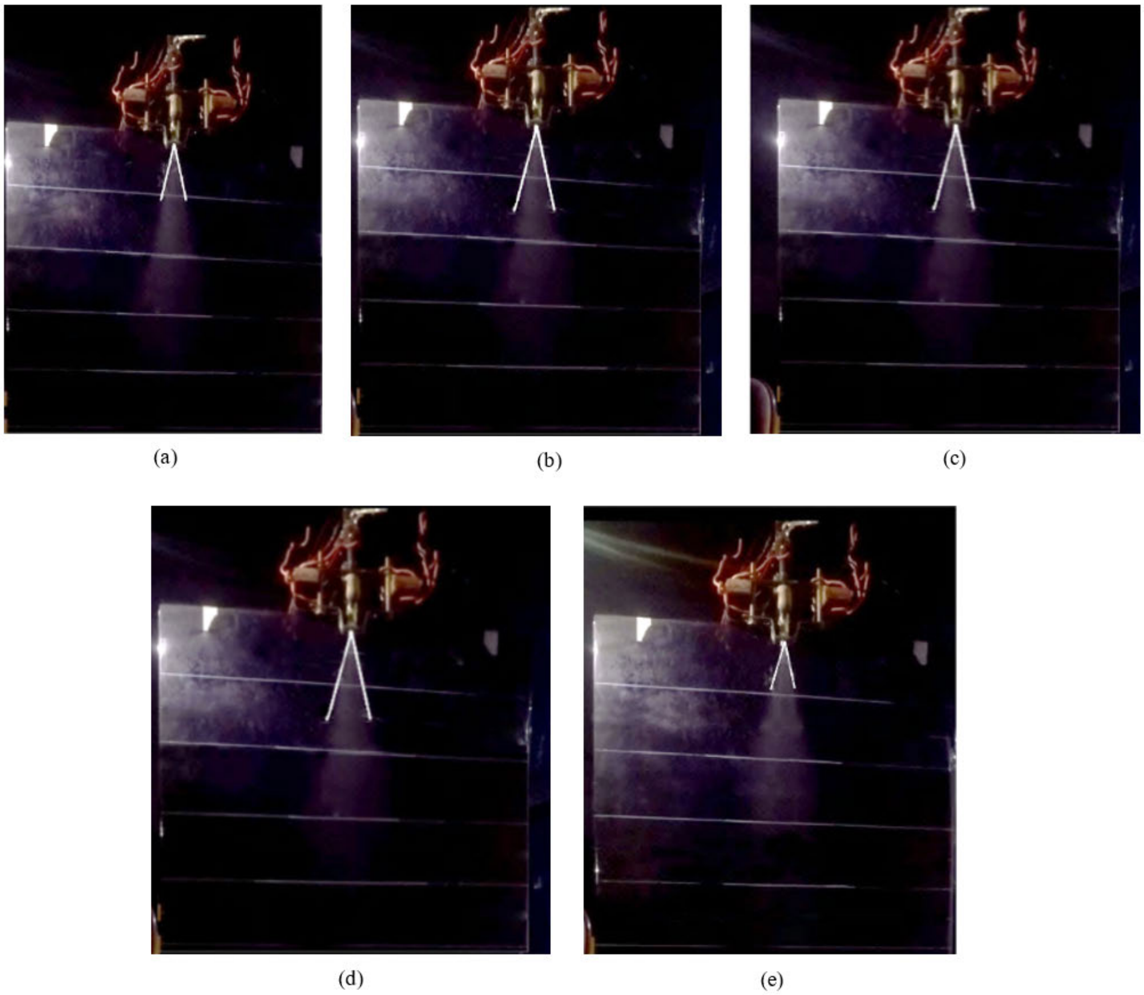


Figure 14. Visualization of fuel spray (a) without magnetization, (b) magnetization by B1, (c) magnetization by B2, (d) magnetization by B3, (e) magnetization by B4.

4. Conclusion

There is an increase in bioethanol fuel transmittance after being given a magnetic field flow that comes from the induction of the coil with the output electric current from the alternator. In the C-H compound, the percentage increase in transmittance value is up to 48.48% due to being magnetized by a magnetic field of 330 Gauss. And for the C-O compound, there was an increase in the transmittance value of up to 41.33%. While for O-H, it is 114% of the standard.

The rate at which the fuel flows through the magnetic field affects the increase in transmittance. The faster the fuel flow through the magnetic field, the smaller the increase in fuel transmittance. The difference in the percentage increase in the transmittance of the fuel compound due to the difference in fuel flow rate reached 8.6% at 2,000 rpm and 8,000 rpm.

The application of a magnetic field to bioethanol fuels affects the properties value of the fuel. Density, surface tension, and viscosity tend to decrease with the magnetic field's magnitude applied to the fuel. Due to the magnetization of 330 Gauss, the density values, surface tension, and viscosity decreased to 620.41 kg/m^3, 19.88 mN/m, and 0.315 cP. The application of a magnetic field to the fuel that passes through the injectors results in a decrease in the mass flow rate of the fuel along with a decrease in the density value due to magnetization.

Applying a magnetic field to the fuel in the injectors can reduce the SMD (Sauter Mean Diameter) value of the fuel spray to 1.312 mm. Applying a magnetic field of 250-310 Gauss to the fuel can increase the spray angle of the bioethanol fuel output from the injectors by up to 2°. However, applying magnetic field induction does not affect the length of the spray penetration.

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