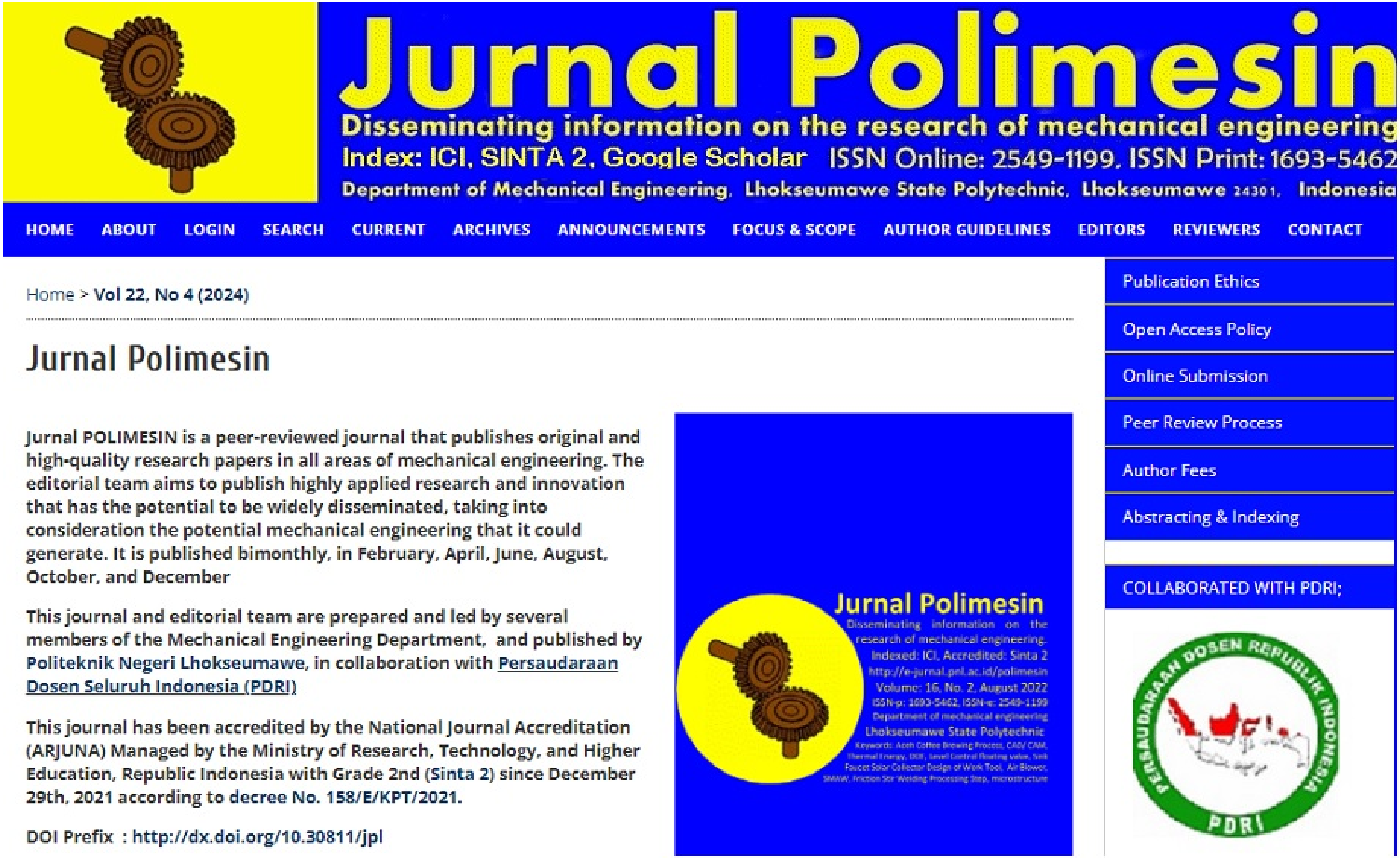

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Investigation of fuel properties and structural-functional group analysis in blending low and high boiling point fuels: the case of ethanol with fuel

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Abstract

For numerous decades, diesel fuel has served as the primary source of energy for diesel engines. For optimal performance, these engines are designed to withstand a high flammability threshold. Diesel fuel is therefore the preferable option for refueling military combat vehicles, particularly battle tanks. Concerns have been expressed regarding the use of diesel fuel due to its potential contribution to environmental pollution; emissions from combustion include NO_2, NO, CO, SO_2, and particulate matter. To reduce these emissions, diesel fuel must be blended with another substance. To reduce emissions, ethanol incorporation is a potential solution. A previous study demonstrated that combining fuels with high and low boiling points can enhance performance. Mixing ethanol, which has a low boiling point, with biodiesel/diesel fuel and fuel with a high boiling point can produce a superior fuel. Analyzing the characteristics of the fuels produced by merging ethanol with diesel fuel and biodiesel is crucial. This analysis aids in the comprehension of the fuel's physical properties prior to its use in a diesel engine. In this investigation, Indonesian diesel fuel and biodiesel standards are blended with ethanol at 10%, 25%, and 35% (volume) blending ratios. In addition to utilizing FTIR (Fourier Transform Infrared Spectroscopy) for analysis, the objective of this study is to determine the combustion properties of a blend of biodiesel, diesel fuel, and ethanol. Using the American Society of Testing Materials (ASTM) D method, fuel properties such as density, viscosity, cetane index, and distillations are analyzed. The results indicate that increasing the proportion of ethanol in diesel fuel and biodiesel reduces viscosity and density. By integrating ethanol, which has a lower density and viscosity than diesel fuel and biodiesel alone, the fuel properties can be improved. A perfect blend of ethanol, diesel fuel, and biodiesel can increase the quality of fuel, thereby enhancing diesel engine combustion.

Keywords: Ethanol, diesel fuel, biodiesel, FTIR, the boiling point

1 Introduction

Diesel fuel has been the primary source of energy for diesel engines for several decades, fueling transportation, industry, military combat, and other sectors. However, diesel engines can emit numerous pollutants, including CO2, NO2, CO, SO2, and particulates. To reduce these pollutants, numerous studies are actively investigating methods to improve the composition of diesel fuel by adding various substances. Water emulsion [1–3], biodiesel blending [4–6], petroleum [7–8], and ethanol are a few of the noteworthy methods being investigated. These cutting-edge techniques seek to reduce diesel engine pollution and promote more sustainable energy solutions.

Ethanol, which is classified as an alcohol, has a low boiling point of approximately 78°C [9], whereas biodiesel fuel has a boiling point range of 340°C to 375°C [10]. A notable study by Senda et al. [11] highlighted the advantages of merging fuels with different boiling points to improve fuel quality. The paucity of fuel with a low volatile value and a high boiling point, when combined with fuel with a high volatile value and a low boiling point, will result in an improvement in volatile and boiling point values, as depicted in Fig. 1. Consequently, fuel quality and properties will be enhanced..

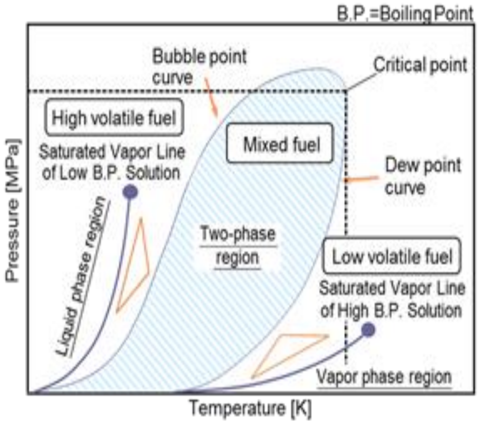

Fig. 1. Pressure and Temperature for Multi-Component Fuel [11]

Numerous studies have concentrated on the blending of ethanol with diesel and biodiesel. Sandalchi et al. [12] conducted a study on the performance and emissions of diesel engines with a 15 percent diesel fuel and 30 percent ethanol blend. A mixture of 85% diesel fuel and 15% ethanol was observed to separate 30 hours after combining, whereas a blend of 30% ethanol separated within 5 minutes. The results indicated that the NOx emissions produced by diesel fuel blended with 30% ethanol were lower than those produced by diesel fuel alone. However, the CO emissions were greater when 30% ethanol was blended with other fuels. Moreover, Kim et al. [13] investigated the low-speed combustion of ethanol blended with diesel fuel. In this study, the diesel engine was rotated at 750 revolutions per minute, and the maximum combustion pressure was approximately 4.1% higher than with pure diesel fuel, while the maximum heat release rate increased by 13.5%. This increase became more considerable as the ethanol blending ratio increased. Alptekin [14] investigated the effect of a 15% ethanol-diesel mixture on engine velocities of 1,500, 2,000, and 2,500 rpm under loads of 3,3,5,6,6,8 bar. The results indicated that emissions and BSFC increased as the ratio of ethanol to diesel increased. In addition, Huang et al. [15] studied ethanol combining, which can reduce NOx emissions. The decrease in NOx is due to evaporation and a reduction in the LHV of the ethanol in the mixture following injection in the cylinder. Tutak et al. [16] reported that the addition of 5.5 g/kWh of ethanol to diesel fuel containing 30% ethanol would increase NOx emissions. Di et al. [17] examined the effect of a mixture of ethanol and diesel and biodiesel at concentrations of 2, 4, 6, and 8% ethanol by volume. The results demonstrated that an increase in ethanol percentage resulted in increased thermal efficiency, decreased HC and CO emissions, and increased NOx emissions. In addition, Wahyu et al. [18] analyzed diesel fuel mixed with ethanol and methanol. The results revealed that combining ethanol and methanol decreased the fuel's boiling point, specific gravity, viscosity, and ignition temperature. Yasin et al. [19] studied the addition of ethanol and methanol to palm oil-based biodiesel. The results indicated that viscosity and specific gravity decreased, while the flash point and cetane number increased. Therefore, this blended fuel was suitable for use in diesel motors.

In this investigation, low-boiling-point fuels (diesel fuel and biodiesel) were blended with high-boiling-point fuel (ethanol). The purpose of this study is to collect exhaustive data on fuel properties and employ FTIR analysis. Data properties of fuels can be used to aid in the practice or simulation analysis of the combustion performance of the fuel in diesel engines.

2 Research methods

2.1 Fuel

In this investigation, diesel fuel and biodiesel were derived from commercial Indonesian petroleum oil. Biodiesel was derived from 30% blended between palm oil biodiesel and 70% diesel fuel. The blended fuels contain 10%, 25%, and 35% (by volume) of ethanol blended with diesel fuel and biodiesel. 10% ethanol and 90% diesel fuel is designated as 10DFE, 25% ethanol and 75% diesel fuel is designated as 25DFE, and 35% ethanol and 65% diesel fuel is designated as 35DFE. In addition, the designations for biodiesel are as follows: 10% ethanol and 90% biodiesel is 10BDE, 15% ethanol and 85% biodiesel is 15BDE, and 35% ethanol and 65% biodiesel is 35BDE. Petrolab Services analyzed the fuel properties, and a Thermo Scientific Nicolet iS10 was used to analyze the Fourier transform infrared spectrometry (FTIR).

2.2 Methods

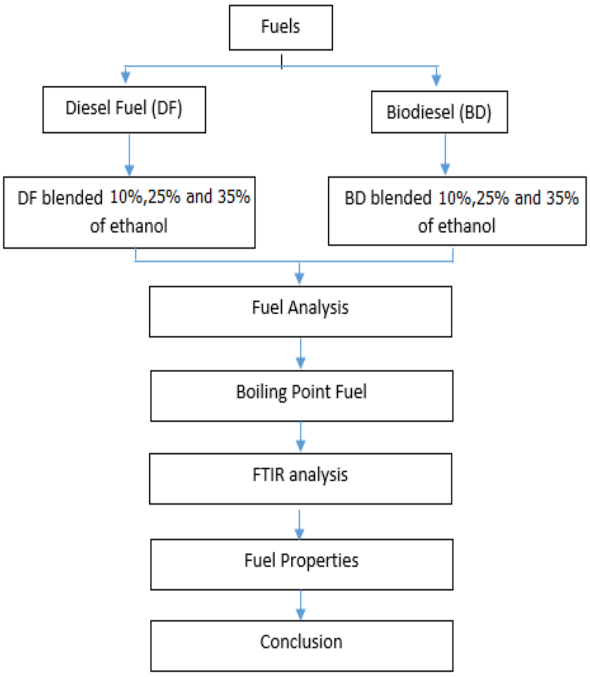

Fig. 2. Study in fuel analysis

Fig. 2 illustrates the analytical approach employed in this study for fuel analysis. First of all, fuels are prepared (diesel fuel and biodiesel). The fuels, namely diesel fuel, and biodiesel, were initially prepared. Subsequently, ethanol was blended with the fuels in proportions of 10%, 25%, and 35% (% volume). The blended fuels were subjected to analysis, including examination of boiling points, FTIR analysis, and assessment of fuel properties such as caloric value, density, and viscosity. ASTM D445-19a and ASTM D1298-12b methods were used to calculate the viscosity the density, respectively. The distillation and cetane index were determined using ASTM D68-17 and ASTM D4737-10 methods. Lastly, the conclusion is made from all data given to analyze the good fuel characteristics.

3 Results and Discussion

3.1 Boiling Point

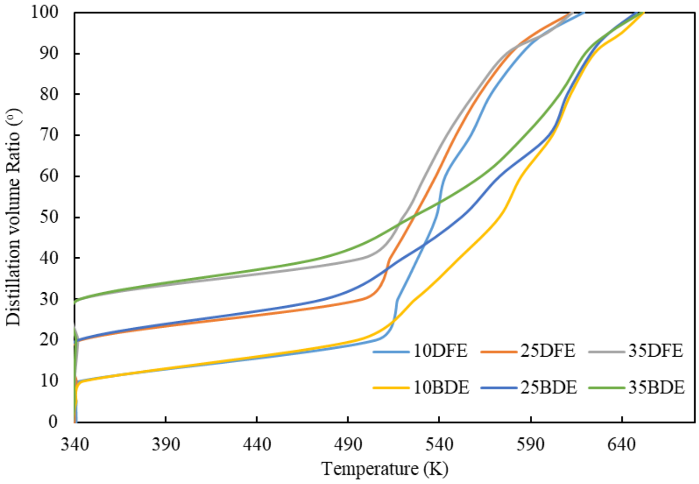

Fig. 3. Distillation from all fuel tested

Fig. 3 shows the distillation results for all fuels tested. It is evident from Fig. 2 that blending diesel fuel and biodiesel with ethanol at different proportions (10%, 25%, and 35%) yields varying distillation volumes at different temperatures. The distillation volume ratio for fuels blended with 35% ethanol is higher than that of fuels blended with 25% and 10% ethanol. However, fuels blended with 10% ethanol exhibit lower distillation volume ratios compared to 25% and 35%. Therefore, this curve can be explained that 35DFE and 35BDE have good atomization spray than other fuels because the volatility is low making it easy to atomize the fuel. This can be explained by several works of literature that mention that higher volatility in fuel makes it difficult for fuel to atomize [20,21].

3.2 Fuel Properties

Viscosity

The viscosity of ethanol blended with diesel fuel and biodiesel is depicted in Fig. 4. As depicted in Fig. 3, the addition of ethanol to diesel fuel and biodiesel reduces viscosity. The Fig.'s arrows indicated the vertical value from the right and left. Ethanol-blended biodiesel (10DDE, 15BDE, and 53 BDE) can enhance viscosity and increase volatility compared to pure biodiesel. In comparison to 10BDE, 35BDE exhibits a 2.6% reduction in viscosity. Comparatively, 35DFE obtains a 4.5% reduction in viscosity compared to 10DFE..

Viscosity is the most important characteristic of fuel as it affects fuel injection components, specifically at low temperatures due to fuel flowability. Higher viscosity can make it difficult for fuel to atomize and makes incomplete combustion in the engine. By incorporating ethanol, viscosity is decreased due to ethanol's higher boiling point and lower viscosity relative to diesel fuel and biodiesel. Therefore, the addition of ethanol can improve the viscosity and can make it superior in the atomization in the fuel-injected cylinder in the diesel engine [23]. This result aligns with other investigations [23-25].

Density

The density characteristics of a mélange of diesel fuel, biodiesel fuel, and ethanol are depicted in Fig. 5. Fig.s 4 and 5 demonstrate that the density and viscosity characteristics have the same trend. In particular, the density of 35BDE is 1.44 percent lower than that of 10BDE, while the density of 35DFE is 0.24 percent lower than that of 10DFE. A greater proportion of ethanol can reduce the fuel's density. This lower density can influence fuel injection within the cylinder and improve atomization dispersion during fuel injection, consistent with the findings of previous studies [23-26].

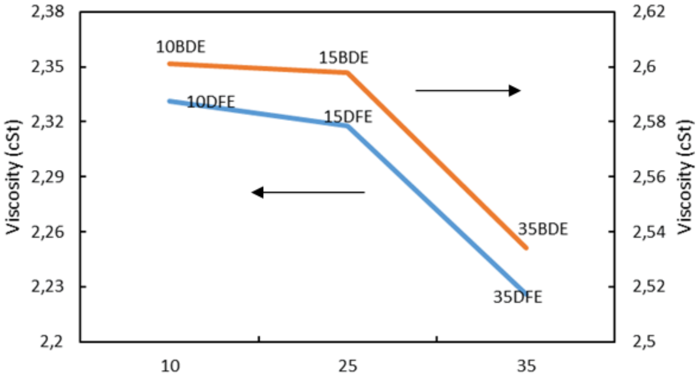

Fig. 4. Viscosity from all fuel tested

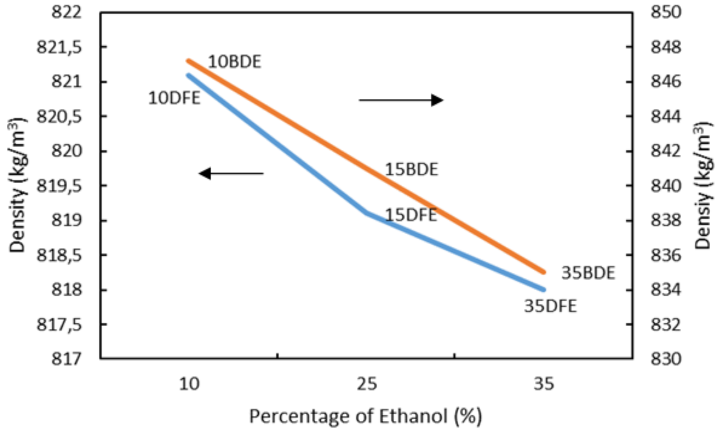

Fig. 5. Density from all fuel tested

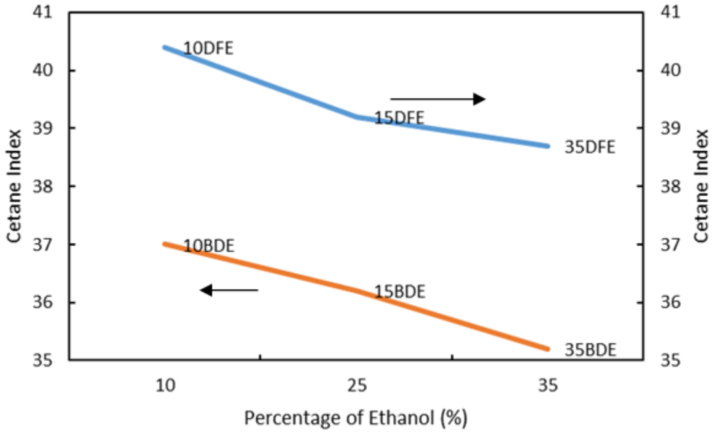

Fig. 6. Cetane Index from all fuel tested

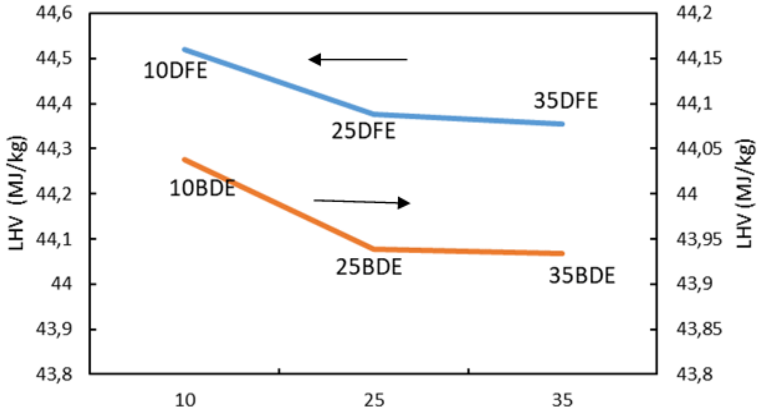

Fig. 7. LHV from all fuel tested

Cetane Index

Fig. 6 illustrates the Cetane Index for all tested fuels. The Cetane Index can be used to measure the performance quality of the fuel in a diesel engine. When ethanol is added to gasoline, the Cetane Index can decrease. Due to ethanol's higher boiling point than diesel and biodiesel, a micro-explosion will occur when diesel and biodiesel are blended with ethanol. This phenomenon is advantageous because it enhances combustion and decreases emissions [27]. These results confirm previous research on the properties of ethanol and fuels [27]. This research concurs with previous research on the properties of ethanol and fuels [27].

Low Heating Value (LHV)

Fig. 7 depicts the LHV for all tested fuels. Low Heating Value (LHV) [28] is a measurement of the heat energy availability produced by combustion. As shown in Fig. 7, biodiesel blends with ethanol have a lower LHV than diesel fuel blends with ethanol. This result is a result of the oxygen content of biodiesel and ethanol. One of the benefits of oxygen content in fuel is that it reduces diesel engine emissions [29]. Consequently, oxygen content in the fuel enhances diesel engine combustion. These conclusions are consistent with those of other researchers [30-31]. In addition, these results are consistent with previous research [25, 32, 33] indicating that the addition of ethanol can reduce LHV and impact fuel economy in engines. Therefore, the addition of ethanol improves combustion and reduces emissions.

3.3 FTIR

Fourier Transfer Infrared (FTIR) analysis plays a vital role in examining molecular vibrations from the sample [34,35]. The Infrared (IR) radiation in the FTIR can detect transmission energy from molecules by atomic vibration in the sample [36]. In this study, FTIR is used to analyze the wave number and transmission energy in the fuels. This can be explained with samples that have long or short chains, cetane numbers in the fuels, and high or few bonds in the molecule.

FTIR Blending Diesel and Ethanol

Table 1. Functional Group from Diesel Fuel blends Ethanol

No	Wavenumber (cm^{-1})			Functional Group/ Assignment	Lit.
	Literature	Experiment			
		25DFE	35DFE		
1	3400-3200	3322.45	3318.88	O-H Stretch Alcohol Stretch Hydrogen Bounding	[37] [38] [39]
2	2935-2915	2922.34	2922.31	C-H methylene	[37]
3	1485-1445	1459.14	1459.30	C-H bending, medium	[37]
4	1410-1310	1377.42	1377.42	S=O stretch, sulfonate OH Bend, a tertiary alcohol	[37]
5	1090-1020	1023.24	1023.30	C-N stretching	[37]
6	800-700	722.24	721.99	C-Cl Stretch	[37]

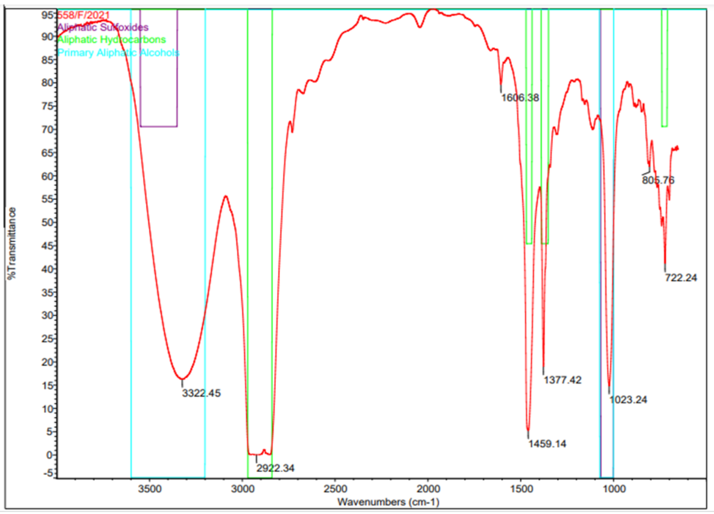

Fig. 8. FTIR 25DFE

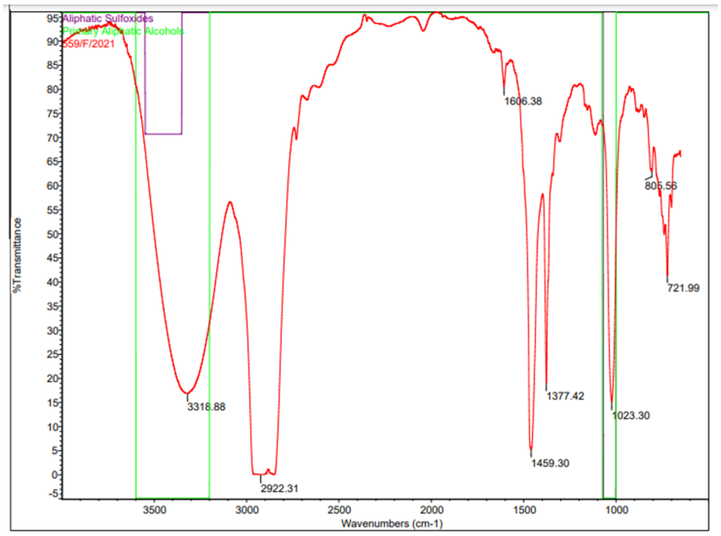

Fig. 9. FTIR 35DFE

Table 1 shows the functional group found in diesel fuel blends containing ethanol, while Fig.s 8 and 9 display the FTIR results from diesel fuel blends with ethanol. As shown in Fig.s 8 and 9, the results from the functional group analysis of 25DFE and 35DFE reveal six distinct peaks. The O-H stretch alcohol can be identified from wave numbers 3322.35 cm^{-1} (25DFE) and 3318.88 cm^{-1} (35DFE). C-H methylene is indicated in 2922.34 cm^{-1} (25DFE) and 2922.31 cm^{-1} (35DFE). C-H bending is in 1459.14 cm^{-1}(25DFE) and 1459.30 cm^{-1} (35DFE), S=O stretch sulfonate is in 1377.4cm^{-1} (25DFE and 35DFE), C-N stretching is in 1023.24 cm^{-1} (25DFE) and 1023.24 cm^{-1} (35DFE), and C-Cl Stretching is in 722.24 cm^{-1} (25DFE) and 721.99 cm^{-1} (35DFE).

The FTIR analysis depicted in Fig.s 8 and 9 reveals the presence of the S=O stretch in both 25DFE and 35DFE blends. This indicates that the blends contain diesel fuel, inherently contains sulfur, as reflected in the FTIR spectra. Additionally, the wave numbers 722.24 cm^{-1} (25DFE) and 721.99 cm^{-1} (35DFE) correspond to long-chain carbons present in the fuel [40,41]. The transmittance measurements provide insights into the abundance of high and few bonds in the fuels, with high transmittance indicating longer chains and low transmittance indicating shorter chains.

FTIR Blending Biodiesel and Ethanol

Table 2. Functional Group from Biodiesel blends Ethanol

No.	Wavenumber (cm^{-1})			Functional Group/ Assignment	Lit.
	Literature	Experiment			
		25BDE	35BDE		
1	3400-3200	3354.05	3343.55	O-H stretch alcohol Stretch hydrogen Bounding	[37] [38] [39]
2	2935-2915	2920.30	2919.34	C-H methylene	[37]
3	1725-1750	1744.54	1744.55	C=O ester	[37], [42] [43]
4	1485-1445	1458.73	1458.55	C-H bend, medium	[37]
5	1410-1310	1377.19	1377.18	S=O stretch, sulfonate OH Bend, a tertiary alcohol	[37]
6	1270-1230	1246.96	1246.71	-O stretch, aromatic ethers	[37]
7	1190-1130	1170.31	1170.33	C-N stretch, secondary amino	[37]
8	1090-1020	1031.36	1032.34	C-N stretch	[36]
9	800-700	722.05	722.06	C-Cl Stretch	[36]

FTIR analyses were conducted on 25BDE and 35BDE, as illustrated in Fig.s 10 and 11. Fig.s 10 and 11 show that biodiesel blends with ethanol exhibit a high concentration of long-chain carbon compounds, as evidenced by the presence of nine peaks corresponding to various functional groups in the FTIR spectra. These long-chain carbon compounds arise due to the blending of ethanol with biodiesel. The nine peaks are O-H stretching alcohol, C-H methylene, C=O ester, C-H bending, S=O stretching, -O stretching (ethers), C-N stretching (secondary amino), C-N stretching and C-Cl stretching. In comparison, the peaks observed in the FTIR spectra of biodiesel blends with ethanol are more prominent than those observed in diesel fuel blends with ethanol. This disparity can be elucidated by referring to Table 2, which outlines the composition of biodiesel, indicating the presence of C=O esters resulting from FAME.

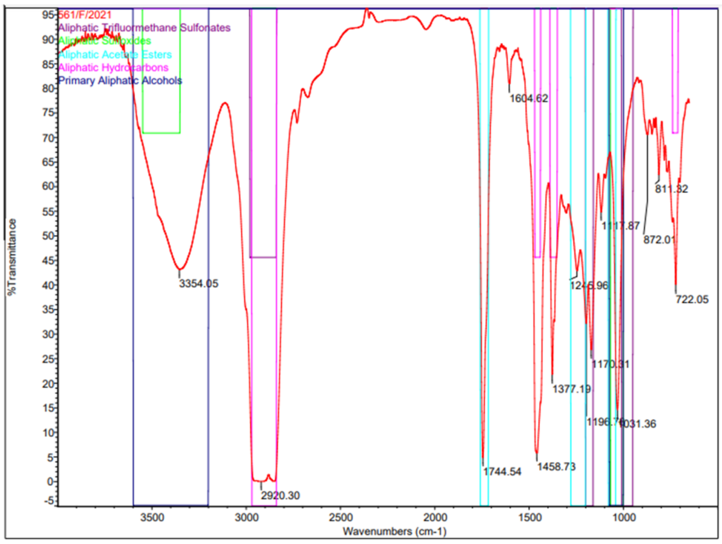

Fig. 10. FTIR 25BDE

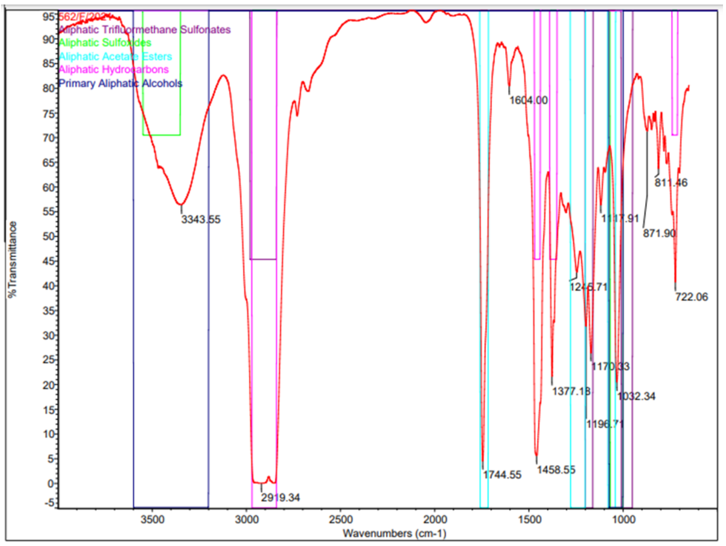

Fig. 11. FTIR 35BDE

Furthermore, 25BDE and 35BDE contain -O stretching aromatic ethers, which suggests the utilization of additives in these blends to enhance combustion efficiency and reduce emissions within the engine. The long-chain carbon with hydrogen attached to these fuels also contains C=O ester because it is blended with biodiesel.

4 Conclusions

The addition of ethanol to diesel fuel and biodiesel significantly alters the properties of the fuels. Compared to pure diesel fuel and biodiesel, the viscosity, density, lower heating value (LHV), and cetane index are lesser when ethanol is blended with these fuels. The results indicate that the distillation volume ratio is reduced when 10% ethanol is blended with diesel fuel and biodiesel compared to 25% and 35% ethanol blends. Notably, mixtures such as 35DFE and 35BDE have minimal volatility, which enables enhanced fuel atomization, combustion, and emission reduction. In addition, the FTIR analysis reveals intriguing findings. The presence of C=O ester from FAME and secondary amino groups in blends such as 25BDE and 35BDE indicates the presence of biodiesel-derived fuel. Additionally, biodiesel's ether content can improve engine combustion and reduce emissions.

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Investigation of fuel properties and structural-functional group analysis in blending low and high boiling point fuels: the case of ethanol with fuel

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Investigation of fuel properties and structural-functional group analysis in blending low and high boiling point fuels: the case of ethanol with fuel

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Abstract

For numerous decades, diesel fuel has served as the primary source of energy for diesel engines. For optimal performance, these engines are designed to withstand a high flammability threshold. Diesel fuel is therefore the preferable option for refueling military combat vehicles, particularly battle tanks. Concerns have been expressed regarding the use of diesel fuel due to its potential contribution to environmental pollution; emissions from combustion include NO_2, NO, CO, SO_2, and particulate matter. To reduce these emissions, diesel fuel must be blended with another substance. To reduce emissions, ethanol incorporation is a potential solution. A previous study demonstrated that combining fuels with high and low boiling points can enhance performance. Mixing ethanol, which has a low boiling point, with biodiesel/diesel fuel and fuel with a high boiling point can produce a superior fuel. Analyzing the characteristics of the fuels produced by merging ethanol with diesel fuel and biodiesel is crucial. This analysis aids in the comprehension of the fuel's physical properties prior to its use in a diesel engine. In this investigation, Indonesian diesel fuel and biodiesel standards are blended with ethanol at 10%, 25%, and 35% (volume) blending ratios. In addition to utilizing FTIR (Fourier Transform Infrared Spectroscopy) for analysis, the objective of this study is to determine the combustion properties of a blend of biodiesel, diesel fuel, and ethanol. Using the American Society of Testing Materials (ASTM) D method, fuel properties such as density, viscosity, cetane index, and distillations are analyzed. The results indicate that increasing the proportion of ethanol in diesel fuel and biodiesel reduces viscosity and density. By integrating ethanol, which has a lower density and viscosity than diesel fuel and biodiesel alone, the fuel properties can be improved. A perfect blend of ethanol, diesel fuel, and biodiesel can increase the quality of fuel, thereby enhancing diesel engine combustion.

Keywords: Ethanol, diesel fuel, biodiesel, FTIR, the boiling point

1 Introduction

Diesel fuel has been the primary source of energy for diesel engines for several decades, fueling transportation, industry, military combat, and other sectors. However, diesel engines can emit numerous pollutants, including CO2, NO2, CO, SO2, and particulates. To reduce these pollutants, numerous studies are actively investigating methods to improve the composition of diesel fuel by adding various substances. Water emulsion [1–3], biodiesel blending [4–6], petroleum [7–8], and ethanol are a few of the noteworthy methods being investigated. These cutting-edge techniques seek to reduce diesel engine pollution and promote more sustainable energy solutions.

Ethanol, which is classified as an alcohol, has a low boiling point of approximately 78°C [9], whereas biodiesel fuel has a boiling point range of 340°C to 375°C [10]. A notable study by Senda et al. [11] highlighted the advantages of merging fuels with different boiling points to improve fuel quality. The paucity of fuel with a low volatile value and a high boiling point, when combined with fuel with a high volatile value and a low boiling point, will result in an improvement in volatile and boiling point values, as depicted in Fig. 1. Consequently, fuel quality and properties will be enhanced..

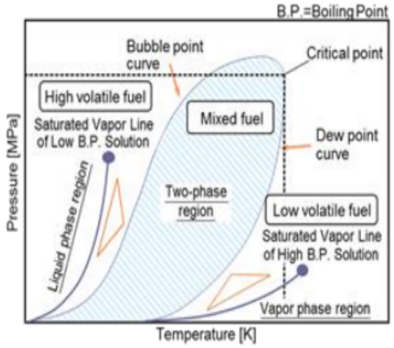

Fig. 1. Pressure and Temperature for Multi-Component Fuel [11]

Numerous studies have concentrated on the blending of ethanol with diesel and biodiesel. Sandalchi et al. [12] conducted a study on the performance and emissions of diesel engines with a 15 percent diesel fuel and 30 percent ethanol blend. A mixture of 85% diesel fuel and 15% ethanol was observed to separate 30 hours after combining, whereas a blend of 30% ethanol separated within 5 minutes. The results indicated that the NOx emissions produced by diesel fuel blended with 30% ethanol were lower than those produced by diesel fuel alone. However, the CO emissions were greater when 30% ethanol was blended with other fuels. Moreover, Kim et al. [13] investigated the low-speed combustion of ethanol blended with diesel fuel. In this study, the diesel engine was rotated at 750 revolutions per minute, and the maximum combustion pressure was approximately 4.1% higher than with pure diesel fuel, while the maximum heat release rate increased by 13.5%. This increase became more considerable as the ethanol blending ratio increased. Alptekin [14] investigated the effect of a 15% ethanol-diesel mixture on engine velocities of 1,500, 2,000, and 2,500 rpm under loads of 3,3,5,6,6,8 bar. The results indicated that emissions and BSFC increased as the ratio of ethanol to diesel increased. In addition, Huang et al. [15] studied ethanol combining, which can reduce NOx emissions. The decrease in NOx is due to evaporation and a reduction in the LHV of the ethanol in the mixture following injection in the cylinder. Tutak et al. [16] reported that the addition of 5.5 g/kWh of ethanol to diesel fuel containing 30% ethanol would increase NOx emissions. Di et al. [17] examined the effect of a mixture of ethanol and diesel and biodiesel at concentrations of 2, 4, 6, and 8% ethanol by volume. The results demonstrated that an increase in ethanol percentage resulted in increased thermal efficiency, decreased HC and CO emissions, and increased NOx emissions. In addition, Wahyu et al. [18] analyzed diesel fuel mixed with ethanol and methanol. The results revealed that combining ethanol and methanol decreased the fuel's boiling point, specific gravity, viscosity, and ignition temperature. Yasin et al. [19] studied the addition of ethanol and methanol to palm oil-based biodiesel. The results indicated that viscosity and specific gravity decreased, while the flash point and cetane number increased. Therefore, this blended fuel was suitable for use in diesel motors.

In this investigation, low-boiling-point fuels (diesel fuel and biodiesel) were blended with high-boiling-point fuel (ethanol). The purpose of this study is to collect exhaustive data on fuel properties and employ FTIR analysis. Data properties of fuels can be used to aid in the practice or simulation analysis of the combustion performance of the fuel in diesel engines.

2 Research methods

2.1 Fuel

In this investigation, diesel fuel and biodiesel were derived from commercial Indonesian petroleum oil. Biodiesel was derived from 30% blended between palm oil biodiesel and 70% diesel fuel. The blended fuels contain 10%, 25%, and 35% (by volume) of ethanol blended with diesel fuel and biodiesel. 10% ethanol and 90% diesel fuel is designated as 10DFE, 25% ethanol and 75% diesel fuel is designated as 25DFE, and 35% ethanol and 65% diesel fuel is designated as 35DFE. In addition, the designations for biodiesel are as follows: 10% ethanol and 90% biodiesel is 10BDE, 15% ethanol and 85% biodiesel is 15BDE, and 35% ethanol and 65% biodiesel is 35BDE. Petrolab Services analyzed the fuel properties, and a Thermo Scientific Nicolet iS10 was used to analyze the Fourier transform infrared spectrometry (FTIR).

2.2 Methods

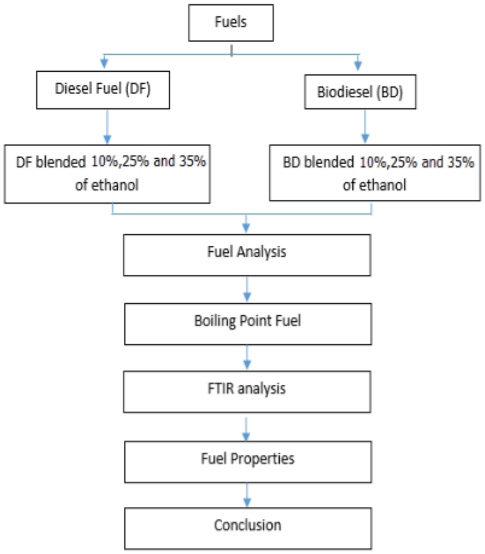

Fig. 2. Study in fuel analysis

Fig. 2 illustrates the analytical approach employed in this study for fuel analysis. First of all, fuels are prepared (diesel fuel and biodiesel). The fuels, namely diesel fuel, and biodiesel, were initially prepared. Subsequently, ethanol was blended with the fuels in proportions of 10%, 25%, and 35% (% volume). The blended fuels were subjected to analysis, including examination of boiling points, FTIR analysis, and assessment of fuel properties such as caloric value, density, and viscosity. ASTM D445-19a and ASTM D1298-12b methods were used to calculate the viscosity the density, respectively. The distillation and cetane index were determined using ASTM D68-17 and ASTM D4737-10 methods. Lastly, the conclusion is made from all data given to analyze the good fuel characteristics.

3 Results and Discussion

3.1 Boiling Point

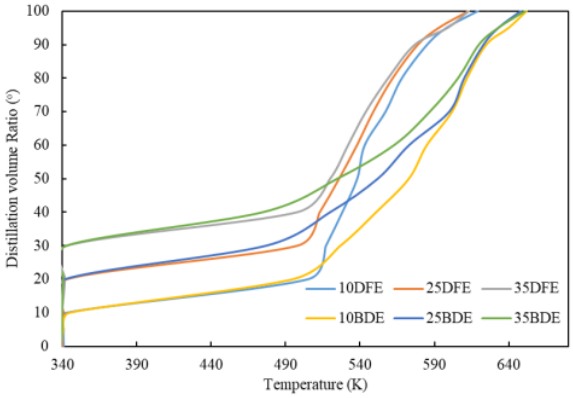

Fig. 3. Distillation from all fuel tested

Fig. 3 shows the distillation results for all fuels tested. It is evident from Fig. 2 that blending diesel fuel and biodiesel with ethanol at different proportions (10%, 25%, and 35%) yields varying distillation volumes at different temperatures. The distillation volume ratio for fuels blended with 35% ethanol is higher than that of fuels blended with 25% and 10% ethanol. However, fuels blended with 10% ethanol exhibit lower distillation volume ratios compared to 25% and 35%. Therefore, this curve can be explained that 35DFE and 35BDE have good atomization spray than other fuels because the volatility is low making it easy to atomize the fuel. This can be explained by several works of literature that mention that higher volatility in fuel makes it difficult for fuel to atomize [20,21].

3.2 Fuel Properties

Viscosity

The viscosity of ethanol blended with diesel fuel and biodiesel is depicted in Fig. 4. As depicted in Fig. 3, the addition of ethanol to diesel fuel and biodiesel reduces viscosity. The Fig.'s arrows indicated the vertical value from the right and left. Ethanol-blended biodiesel (10DDE, 15BDE, and 53 BDE) can enhance viscosity and increase volatility compared to pure biodiesel. In comparison to 10BDE, 35BDE exhibits a 2.6% reduction in viscosity. Comparatively, 35DFE obtains a 4.5% reduction in viscosity compared to 10DFE..

Viscosity is the most important characteristic of fuel as it affects fuel injection components, specifically at low temperatures due to fuel flowability. Higher viscosity can make it difficult for fuel to atomize and makes incomplete combustion in the engine. By incorporating ethanol, viscosity is decreased due to ethanol's higher boiling point and lower viscosity relative to diesel fuel and biodiesel. Therefore, the addition of ethanol can improve the viscosity and can make it superior in the atomization in the fuel-injected cylinder in the diesel engine [23]. This result aligns with other investigations [23-25].

Density

The density characteristics of a mélange of diesel fuel, biodiesel fuel, and ethanol are depicted in Fig. 5. Fig.s 4 and 5 demonstrate that the density and viscosity characteristics have the same trend. In particular, the density of 35BDE is 1.44 percent lower than that of 10BDE, while the density of 35DFE is 0.24 percent lower than that of 10DFE. A greater proportion of ethanol can reduce the fuel's density. This lower density can influence fuel injection within the cylinder and improve atomization dispersion during fuel injection, consistent with the findings of previous studies [23-26].

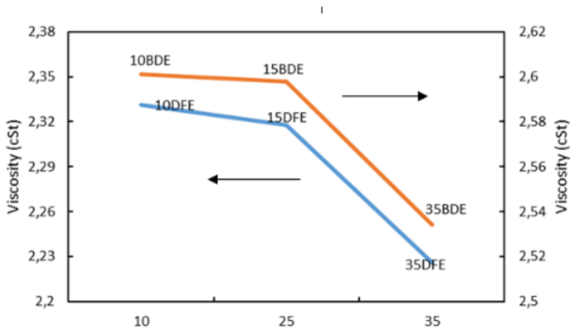

Fig. 4. Viscosity from all fuel tested

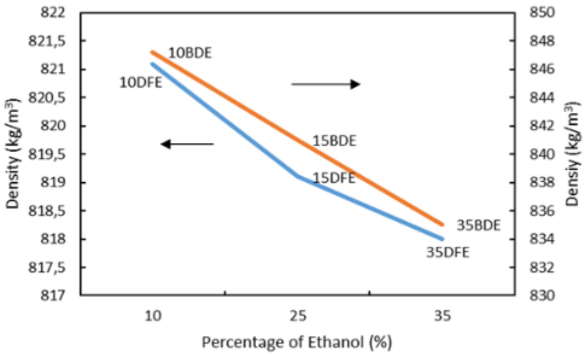

Fig. 5. Density from all fuel tested

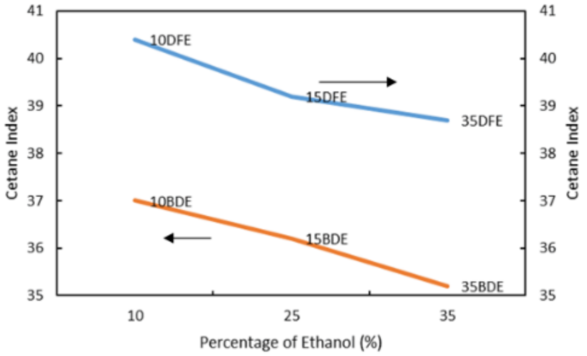

Fig. 6. Cetane Index from all fuel tested

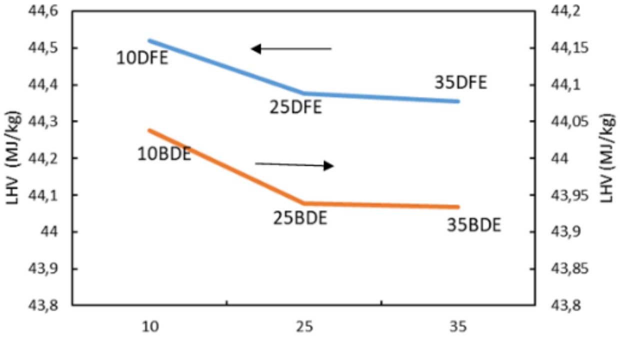

Fig. 7. LHV from all fuel tested

Cetane Index

Fig. 6 illustrates the Cetane Index for all tested fuels. The Cetane Index can be used to measure the performance quality of the fuel in a diesel engine. When ethanol is added to gasoline, the Cetane Index can decrease. Due to ethanol's higher boiling point than diesel and biodiesel, a micro-explosion will occur when diesel and biodiesel are blended with ethanol. This phenomenon is advantageous because it enhances combustion and decreases emissions [27]. These results confirm previous research on the properties of ethanol and fuels [27]. This research concurs with previous research on the properties of ethanol and fuels [27].

***Low Heating Value* (LHV)**

Fig. 7 depicts the LHV for all tested fuels. Low Heating Value (LHV) [28] is a measurement of the heat energy availability produced by combustion. As shown in Fig. 7, biodiesel blends with ethanol have a lower LHV than diesel fuel blends with ethanol. This result is a result of the oxygen content of biodiesel and ethanol. One of the benefits of oxygen content in fuel is that it reduces diesel engine emissions [29]. Consequently, oxygen content in the fuel enhances diesel engine combustion. These conclusions are consistent with those of other researchers [30-31]. In addition, these results are consistent with previous research [25, 32, 33] indicating that the addition of ethanol can reduce LHV and impact fuel economy in engines. Therefore, the addition of ethanol improves combustion and reduces emissions.

3.3 FTIR

Fourier Transfer Infrared (FTIR) analysis plays a vital role in examining molecular vibrations from the sample [34,35]. The Infrared (IR) radiation in the FTIR can detect transmission energy from molecules by atomic vibration in the sample [36]. In this study, FTIR is used to analyze the wave number and transmission energy in the fuels. This can be explained with samples that have long or short chains, cetane numbers in the fuels, and high or few bonds in the molecule.

FTIR Blending Diesel and Ethanol

Table 1. Functional Group from Diesel Fuel blends Ethanol

No	Wavenumber (cm^{-1})			Functional Group/ Assignment	Lit.
	Literature	Experiment			
		25DFE	35DFE		
1	3400-3200	3322.45	3318.88	O-H Stretch Alcohol Stretch Hydrogen Bounding	[37] [38] [39]
2	2935-2915	2922.34	2922.31	C-H methylene	[37]
3	1485-1445	1459.14	1459.30	C-H bending, medium	[37]
4	1410-1310	1377.42	1377.42	S=O stretch, sulfonate OH Bend, a tertiary alcohol	[37]
5	1090-1020	1023.24	1023.30	C-N stretching	[37]
6	800-700	722.24	721.99	C-Cl Stretch	[37]

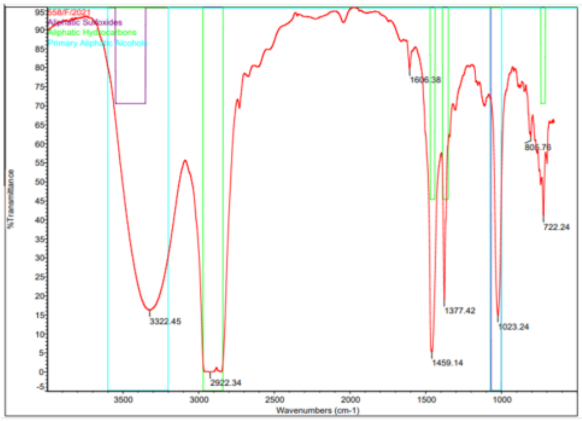

Fig. 8. FTIR 25DFE

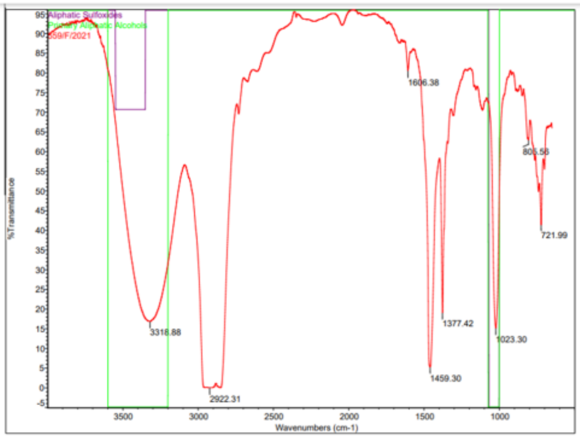

Fig. 9. FTIR 35DFE

Table 1 shows the functional group found in diesel fuel blends containing ethanol, while Fig.s 8 and 9 display the FTIR results from diesel fuel blends with ethanol. As shown in Fig.s 8 and 9, the results from the functional group analysis of 25DFE and 35DFE reveal six distinct peaks. The O-H stretch alcohol can be identified from wave numbers 3322.35 cm^{-1} (25DFE) and 3318.88 cm^{-1} (35DFE). C-H methylene is indicated in 2922.34 cm^{-1} (25DFE) and 2922.31 cm^{-1} (35DFE). C-H bending is in 1459.14 cm^{-1}(25DFE) and 1459.30 cm^{-1} (35DFE), S=O stretch sulfonate is in 1377.4cm^{-1} (25DFE and 35DFE), C-N stretching is in 1023.24 cm^{-1} (25DFE) and 1023.24 cm^{-1} (35DFE), and C-Cl Stretching is in 722.24 cm^{-1} (25DFE) and 721.99 cm^{-1} (35DFE).

The FTIR analysis depicted in Fig.s 8 and 9 reveals the presence of the S=O stretch in both 25DFE and 35DFE blends. This indicates that the blends contain diesel fuel, inherently contains sulfur, as reflected in the FTIR spectra. Additionally, the wave numbers 722.24 cm^{-1} (25DFE) and 721.99 cm^{-1} (35DFE) correspond to long-chain carbons present in the fuel [40,41]. The transmittance measurements provide insights into the abundance of high and few bonds in the fuels, with high transmittance indicating longer chains and low transmittance indicating shorter chains.

FTIR Blending Biodiesel and Ethanol

Table 2. Functional Group from Biodiesel blends Ethanol

No.	Wavenumber (cm^{-1})			Functional Group/ Assignment	Lit.
	Literature	Experiment			
		25BDE	35BDE		
1	3400-3200	3354.05	3343.55	O-H stretch alcohol Stretch hydrogen Bounding	[37] [38] [39]
2	2935-2915	2920.30	2919.34	C-H methylene	[37]
3	1725-1750	1744.54	1744.55	C=O ester	[37], [42] [43]
4	1485-1445	1458.73	1458.55	C-H bend, medium	[37]
5	1410-1310	1377.19	1377.18	S=O stretch, sulfonate OH Bend, a tertiary alcohol	[37]
6	1270-1230	1246.96	1246.71	-O stretch, aromatic ethers	[37]
7	1190-1130	1170.31	1170.33	C-N stretch, secondary amino	[37]
8	1090-1020	1031.36	1032.34	C-N stretch	[36]
9	800-700	722.05	722.06	C-Cl Stretch	[36]

FTIR analyses were conducted on 25BDE and 35BDE, as illustrated in Fig.s 10 and 11. Fig.s 10 and 11 show that biodiesel blends with ethanol exhibit a high concentration of long-chain carbon compounds, as evidenced by the presence of nine peaks corresponding to various functional groups in the FTIR spectra. These long-chain carbon compounds arise due to the blending of ethanol with biodiesel. The nine peaks are O-H stretching alcohol, C-H methylene, C=O ester, C-H bending, S=O stretching, -O stretching (ethers), C-N stretching (secondary amino), C-N stretching and C-Cl stretching. In comparison, the peaks observed in the FTIR spectra of biodiesel blends with ethanol are more prominent than those observed in diesel fuel blends with ethanol. This disparity can be elucidated by referring to Table 2, which outlines the composition of biodiesel, indicating the presence of C=O esters resulting from FAME.

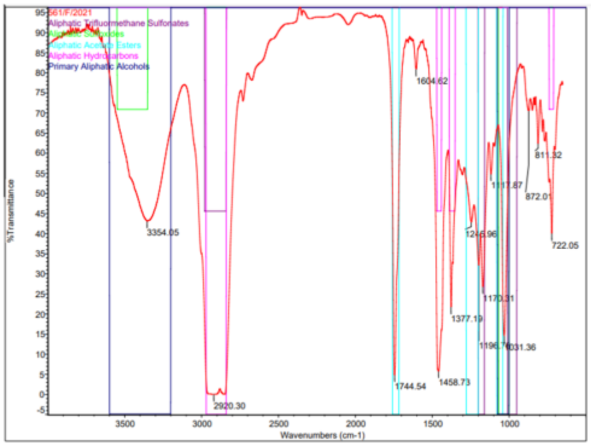

Fig. 10. FTIR 25BDE

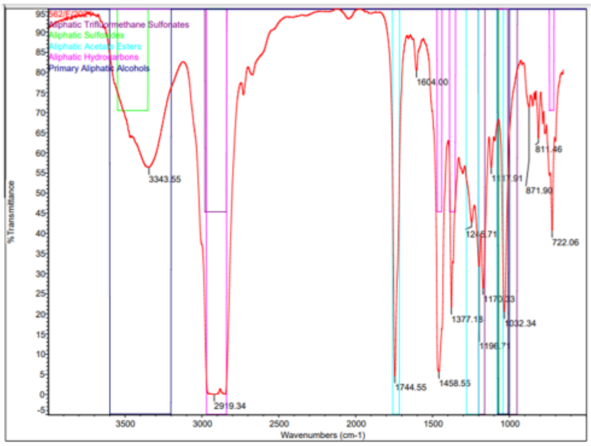

Fig. 11. FTIR 35BDE

Furthermore, 25BDE and 35BDE contain -O stretching aromatic ethers, which suggests the utilization of additives in these blends to enhance combustion efficiency and reduce emissions within the engine. The long-chain carbon with hydrogen attached to these fuels also contains C=O ester because it is blended with biodiesel.

4. Conclusions

The addition of ethanol to diesel fuel and biodiesel significantly alters the properties of the fuels. Compared to pure diesel fuel and biodiesel, the viscosity, density, lower heating value (LHV), and cetane index are lesser when ethanol is blended with these fuels. The results indicate that the distillation volume ratio is reduced when 10% ethanol is blended with diesel fuel and biodiesel compared to 25% and 35% ethanol blends. Notably, mixtures such as 35DFE and 35BDE have minimal volatility, which enables enhanced fuel atomization, combustion, and emission reduction. In addition, the FTIR analysis reveals intriguing findings. The presence of C=O ester from FAME and secondary amino groups in blends such as 25BDE and 35BDE indicates the presence of biodiesel-derived fuel. Additionally, biodiesel's ether content can improve engine combustion and reduce emissions.

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