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Physicochemical Properties of B-0 CN 51 Diesel Fuel with Ultrafine Bubbles

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ABSTRACT - Ultrafine bubbles are nano-sized and significantly smaller than regular bubbles considered efficient in gas exchange, leading to their reactivity in physical and chemical processes. The application of ultrafine bubbles includes medicine, agriculture, cleaning, and diesel engine fuels. Therefore, this research aimed to analyze the impact of ultrafine bubble additives injected into B-0 CN 51 diesel fuel to enhance fuel performance. The method focused on injecting oxygen additives at flow rates of 1, 3, and 5 liters/minute into 1.5 liters of fuel for treatment durations ranging from 10 to 60 minutes. The parameters observed include distillation, cetane number, density, flash point, and cloud point. The injection of oxygen at 1 liter/minute for 10 minutes had the highest values for viscosity at 2.65 mm^2/s, density at 813,7 kg/m^3, distillation at 341,2°C, cloud point at 7°C, and flash point at 67.4°C. Meanwhile, oxygen injection at 5 liters/minute for 60 minutes led to the lowest values for viscosity at 2.53 mm^2/s, density at 801.3 kg/m^3, distillation at 320.7°C, cloud point at 5.4°C, and flash point at 56.2°C. It was observed that the cetane number increased and the highest value of 63 was recorded at an oxygen injection rate of 5 liter per minute for 60 minutes while the lowest value of 56.5 was at 1 liter/minute for 10 minutes. The trend showed that ultrafine bubbles added value to B-0 CN 51 fuel by leading to the introduction of a new product with a promising cetane number and other parameters. The results showed that further development of ultrafine bubble technology could enhance the potential to become a game-changer in meeting the demand for environmentally friendly, efficient, and sustainable energy across different industrial sectors.

Keywords: ultrafine bubble, diesel fuel B-0 CN 51, cetane number, distillation.

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INTRODUCTION

Diesel is a type of fuel consisting of a mixture of hydrocarbons obtained from the distillation of crude oil. It has a higher viscosity and boiling point than gasoline, leading to more efficiency in combustion. Moreover, diesel engines operate by compressing air in the cylinder to a very high temperature and injecting diesel fuel to cause combustion. Diesel fuel originates from heavier fractions of crude oil, with longer hydrocarbon chains, and is richer in energy per liter than gasoline. Furthermore, several properties that determine quality have been studied to quantitatively correlate the property values of the fuel with the composition (Cookson et al. 1988).

In the modern technological era, there is a crucial need to enhance fuel efficiency in vehicles due to worsening environmental and energy issues. Therefore, the Indonesian government implemented a mandatory B30 biodiesel program in 2020 to ensure the country leads in the usage of biodiesel in the world (Farobie & Hartulistiyoso 2022). Another effort is the growing demand for fuel-efficient passenger diesel vehicles with lower emissions. Moreover, the addition of nano air bubbles to diesel fuel leads to energy conservation and reduce the environmental impact of diesel engines. This is necessary to promote the application of more environmentally friendly alternative and renewable energy sources in order to decrease dependence on fossil fuels and improve air quality. An example of an alternative energy source currently being researched and continuously developed for use in diesel engines is ultrafine bubble technology (Nakatake et al. 2013). This is possible because ultrafine bubbles are smaller than 1 nm in size and remain stable for an extended period, offering properties such as enhanced gas solubility and a larger bubble surface area (Raga et al. 2024).

Some additives are often added as catalysts to lower the activation energy required in the process of initiating combustion. This is necessary to increase the rate of chemical reaction and allow the fuel to reach optimal combustion conditions more efficiently. The process leads to more complete combustion by oxidizing more fuel molecules into CO_2 and H_2O, producing higher energy, and minimizing the formation of by-products such as CO, unburned hydrocarbons, and particulates. This shows that catalytic additives maximize the energy released from fuel while reducing waste and harmful emissions. Moreover, the inclusion of additives in diesel fuel can enhance fuel quality, reduce emissions, and improve engine efficiency (Gürü et al. 2002; Li et al. 2014; Rashedul et al. 2014).

Ultrafine bubbles can be developed and applied as a mixing agent to diesel fuel at specific concentrations (Küçükosman et al. 2022; Lv et al. 2022; Soudagar et al. 2018). However, several parameters associated with the combination of B-0 CN 51 diesel fuel and ultrafine bubble require further investigation to ensure conformity with the technology of current vehicles in the market.

The health, environmental impact, and material compatibility in fuel lines have been studied in addition to the safety aspects (Mofijur et al. 2013). It was observed that ultrafine bubbles and diesel fuel mixtures could lead to adverse effects due to the polarity and high moisture affinity, allowing the quick absorption of existing water. The water and its impurities can increase environmental aggressiveness due to acidic compounds and other ions, potentially causing corrosion to metal parts and damage to non-metal materials in vehicle fuel lines (Kannan et al. 2011). It was reported that the introduction of additive mixtures into diesel fuel successfully improved engine combustion efficiency and reduced fuel consumption in recent years (Hoang et al. 2022; Salahuddin 2014). Moreover, the addition of ultrafine bubbles to diesel fuel reduced fuel consumption and increased engine efficiency (Nakatake et al. 2013).

Oxygenated fuels such as ethanol, dimethyl carbonate, and dimethyl ether were selected to be mixed with diesel based on the fuel design concept. Subsequently, the effects of oxygen content and cetane number of the blended fuel on combustion and emissions in a diesel engine were evaluated in experiments conducted using a four-cylinder diesel engine. The results showed that an increase in the oxygen content of the blended fuel reduced the ignition delay and combustion duration under different operating conditions and improved thermal efficiency (Lü et al. 2005). Furthermore, ultrafine bubbles had significant potential as a mixture for diesel fuel and alternative fuels based on the physicochemical characteristics capable of influencing the performance enhancement of diesel combustion and warrant exploration. Previous research showed the benefits of microbubbles and nanobubbles in enhancing fuel performance. However, there is still insufficient understanding of the physicochemical properties of fuel that influence the relationship between the increase in cetane number and other parameters, such as viscosity, density, flash point, and spray temperature, due to the addition of ultrafine bubble additives. Therefore, this research aimed to investigate further the relationship between the improvement of physicochemical characteristics, including cetane number and other parameters, in the mixture of ultrafine bubbles and B-0 CN 51 diesel fuel.

METHODOLOGY

Material

The diesel fuel used, B-0 CN 51, was obtained from a major oil company in Indonesia. The physicochemical properties are presented in Table 1.

Experimental procedures

Oxygen was mixed into 1.5 liters of diesel fuel at the flow rates of 1 liter/minute, 3 liters/minute, and 5 liters/minute. Moreover, the injection durations were 10 minutes, 20 minutes, 30 minutes, and up to 60 minutes.

Experimental methods and instruments

The properties of diesel fuel were determined based on the maximum and minimum values outlined in Table 1. Moreover, the standard for B-0 CN 51 diesel fuel is regulated by the Ministry of Energy and Mineral Resources of Indonesia and the evaporation process is based on ASTM D86. This shows the standard can be used to determine the distillation curve through the experimental measurements of the vapor-liquid equilibrium distillation curve using a modified ASTM D86 setup (Ferris & Rothamer 2016). Moreover, the quantitative characteristics of the boiling range were determined in the batch distillation unit laboratory.

The Cetane Number was measured using the ASTM D613 standard test method for diesel injection engines. The method specifies that the repeatability for fuels with cetane numbers in the range of 44 to 56 is expected to be within 0.7 to 0.9 cetane units (American Society for Testing and Materials, 1988) (Van Gerpen 1996). Furthermore, density is another important parameter in relation to the design, energy content, as well as unit conversion in the process of buying and selling. The two reference methods for the experimental measurement of fuel density in the laboratory are ASTM D1298 and ASTM D4052 (Abdurrojaq et al. 2021).

Cloud point test was conducted successfully using automatic equipment based on optical detection and ASTM D5773 standard (Turcotte et al. 2000). Furthermore, the flash point method was applied to measure the temperature when the diesel fuel ignited based on ASTM D93 (Abdelkhalik et al. 2018).

The treatment was designed at varying oxygen flow rates, from 1 liter/minute to 5 liters/ minute, to explore the effect of the amount of oxygen mixed into B-0 CN 51 diesel fuel on the physicochemical properties. The focus was on the performance, including cetane number, viscosity, density, distillation, cloud point, and flash point temperature, with the expectation of improving fuel efficiency.

Table 1
Test data on the physicochemical properties of B-0 CN 51 diesel fuel with ultrafine bubble injection treatment

Test Parameters	Oxygen Volume (lpm)	The duration of oxygen injection (minute)						Analysis Method	Unit	Control	Min limits	Max limits
		10	20	30	40	50	60					
Cetane Numbers	1	56,5	56,9	57,7	58,9	60,1	61,3	ASTM D613		56	51	
	3	57	57,5	58,4	59,6	60,8	62					
	5	57,8	58,5	59,4	60,6	61,8	63					
Viscosity	1	2,65	2,63	2,61	2,59	2,57	2,55	ASTM D445	mm²/s	2,67	2	4.5
	3	2,62	2,61	2,6	2,58	2,56	2,54					
	5	2,61	2,6	2,59	2,57	2,55	2,53					
Density	1	813,7	812,1	811	809,7	808,7	807,9	ASTM D4052	kg/m³	815,8	815	860
	3	811,1	810,5	808,8	807,5	806,5	805,6					
	5	808,5	806,7	805,9	804,1	802,5	801,3					
Cloud point	1	7.0	6.8	6.7	6,5	6,3	6,1	ASTM 5773	^{0}C	7.4		18
	3	6.6	6.4	6.2	6	5,8	5,6					
	5	6.3	6.2	6.0	5,8	5,6	5,4					

Table 1
Test data on the physicochemical properties of B-0 CN 51 diesel fuel with ultrafine bubble injection treatment (continued)

Test Parameters	Oxygen Volume (lpm)	The duration of oxygen injection (minute)						Analysis Method	Unit	Control	Min limits	Max limits
Flash point	1	67,4	65,5	64,3	63,5	62,6	61,5	ASTM D93A	^0C	67.8	55	
	3	64,7	63,2	62,2	61,3	60	58,5					
	5	60,9	59,8	58,8	58	57,1	56,2					
Distillation	1	341,2	338,7	334,2	332	329,9	327,8	ASTM D86	^0C	344.6		370
	3	337,4	334,4	331,1	328,7	326,2	324,5					
	5	334	330,7	327	324,9	322,8	320,7					

RESULTS AND DISCUSSION

Base fuel properties for B-0 CN 51

The data presented in Table 1 shows the physicochemical properties of B-0 CN 51 fuel treated with ultrafine bubbles.

Distillation

The distillation of pure B-0 CN 51 diesel fuel injected with oxygen was conducted by verifying the components based on the boiling points after the addition of oxygen as shown in Figs. 1, 2, and 3. It was observed that oxygen injection enhanced the reactivity of the fuel, leading to the reduction of the distillation temperature and an increase in the evaporation of more volatile components.

Oxygen aided the breaking down of fuel molecules more efficiently and allowed components with lower boiling points to separate at lesser temperatures compared to fuel without oxygen injection, as presented in Figure 4. The reduced temperature during the distillation process can lead to cleaner fuel production.

The distillation temperature of ultrafine bubble-treated B-0 CN 51 diesel fuel shows a tendency to decrease at different oxygen injection volumes of 1, 3, and 5 liters/minute and durations of 10, 20, and 30 minutes. The lowest distillation temperature recorded was 327°C at 5 liters/minute and 30 minutes while the highest was 341.2°C with the control temperature at 344.6°C. According to the energy and mineral resources standard in Indonesia, the maximum temperature limit is 370°C. The results showed that ultrafine bubbles had a positive impact on the performance of B-0 CN 51 fuel.

The injection of ultrafine bubbles into fuel for an extended period led to the tendency of the distillation process to occur at lower temperatures. This was due to the changes in the fuel composition because ultrafine bubbles enhanced the mixing and dissolution of several components. The process caused the production of a more homogeneous fuel mixture with lighter and more volatile components, thereby lowering the distillation temperature.

The reduction in the size of ultrafine bubbles assisted in breaking down larger or heavier molecules into smaller, more volatile ones, which was necessary to ensure an easier evaporation process as well as the occurrence of distillation at lower temperatures. Moreover, the enhancement of the mixing and the dispersion of ultrafine bubbles improved the blending of components within the fuel. The situation influenced components that typically required higher distillation temperatures to evaporate at lower points.

Previous research examined the effects of mixing oxygen with gasoline to improve fuel properties, specifically observing how distillation temperatures affected the performance of gasoline engines (Babazadeh Shayan et al. 2012). Furthermore, the impact of fuel evaporation temperature and the characterization of increased cetane numbers on the volatility of diesel fuel was explored by observing the effects of distillation conducted with oxygen additives (Burger et al. 2014). The oxygenated additives in diesel fuel were also compared in previous research using the curve method. Another research assessed the properties of diesel fuel mixtures with oxygen additives (Lovestead & Bruno 2011). The improvement of flow properties in diesel fuel was further examined using Sorbitan Monooleate. It was reported that the additive did not directly affect the boiling point of fuel. Meanwhile, the presence enhanced heat distribution within the liquid, leading to an increase in distillation efficiency and reduction of the boiling point (Arina & Nasikin 2022).

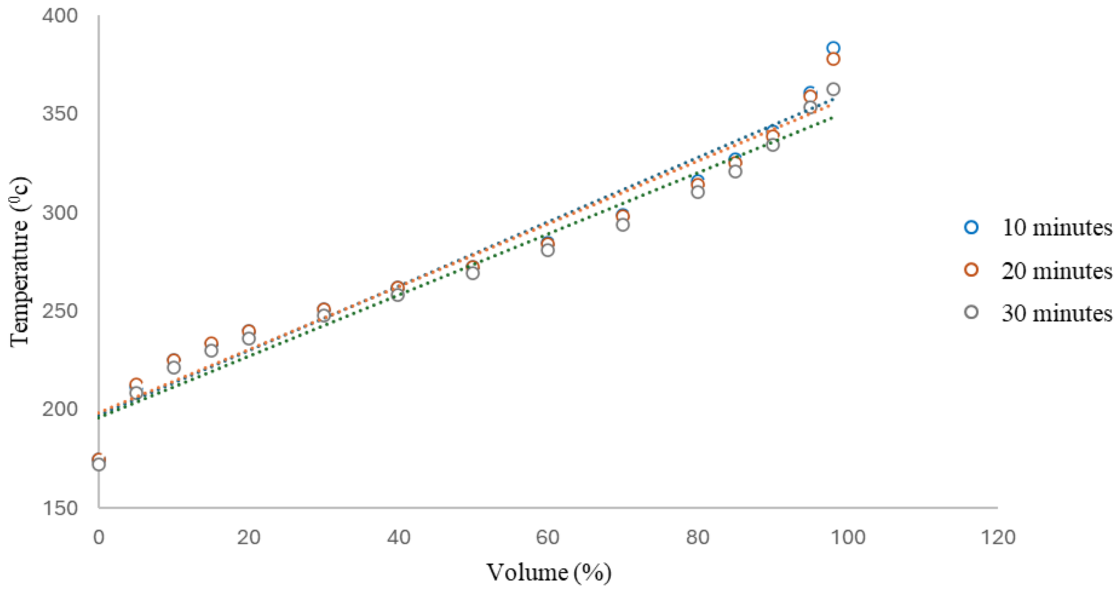

Figure 1
Distillation of oxygen injection at 1 liter/minute

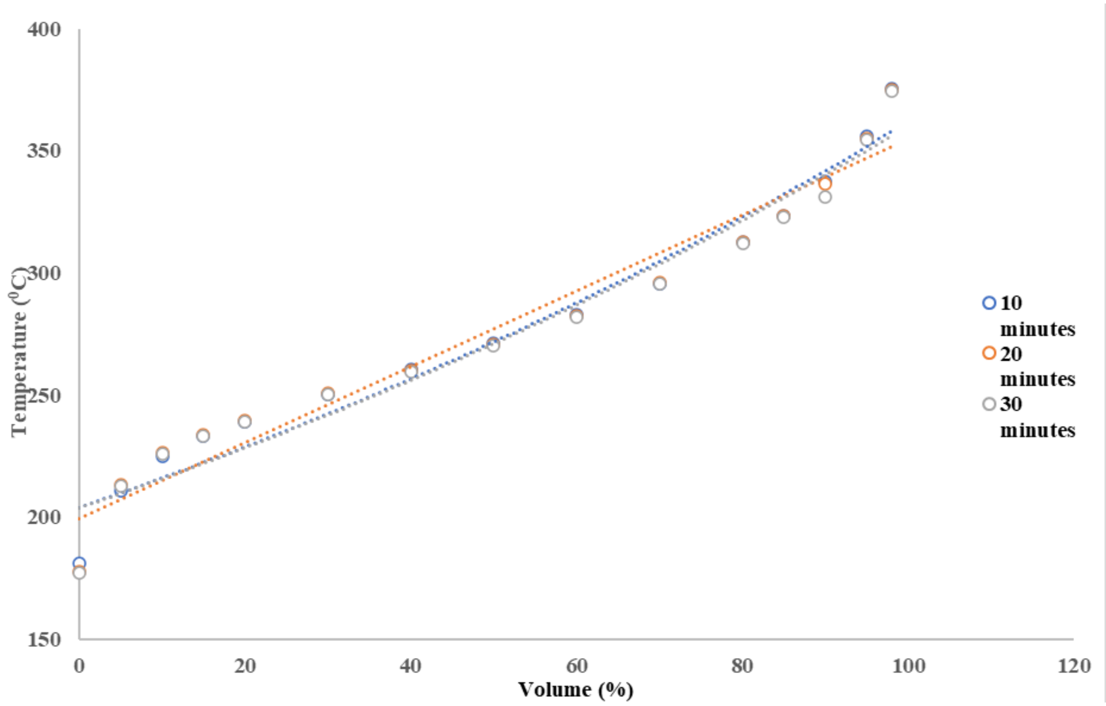

Figure 2
Distillation of oxygen injection at 3 liters/minute

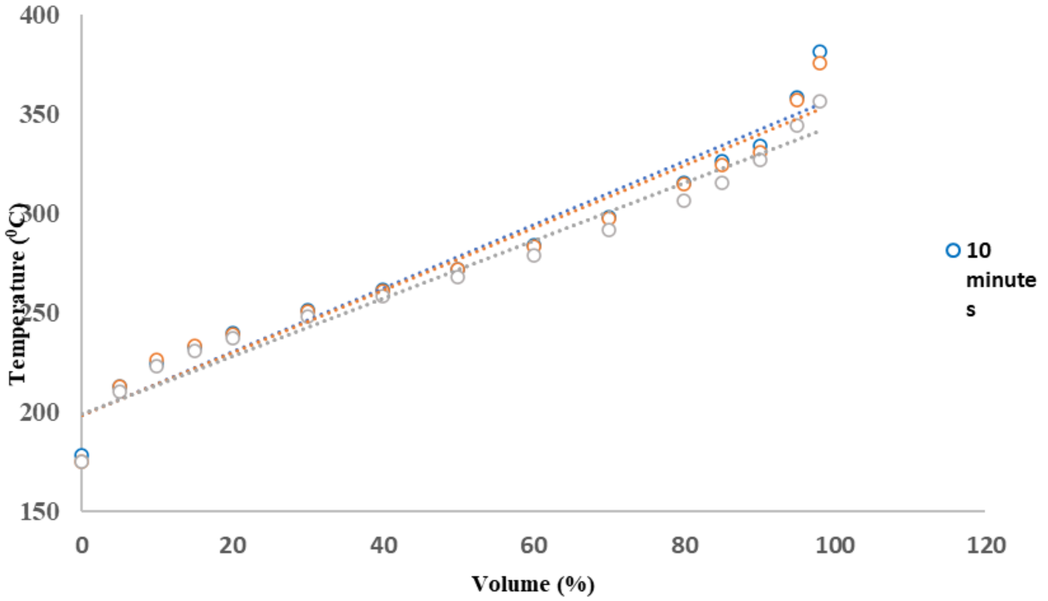

Figure 3
Distillation of oxygen injection at 5 liters/minute

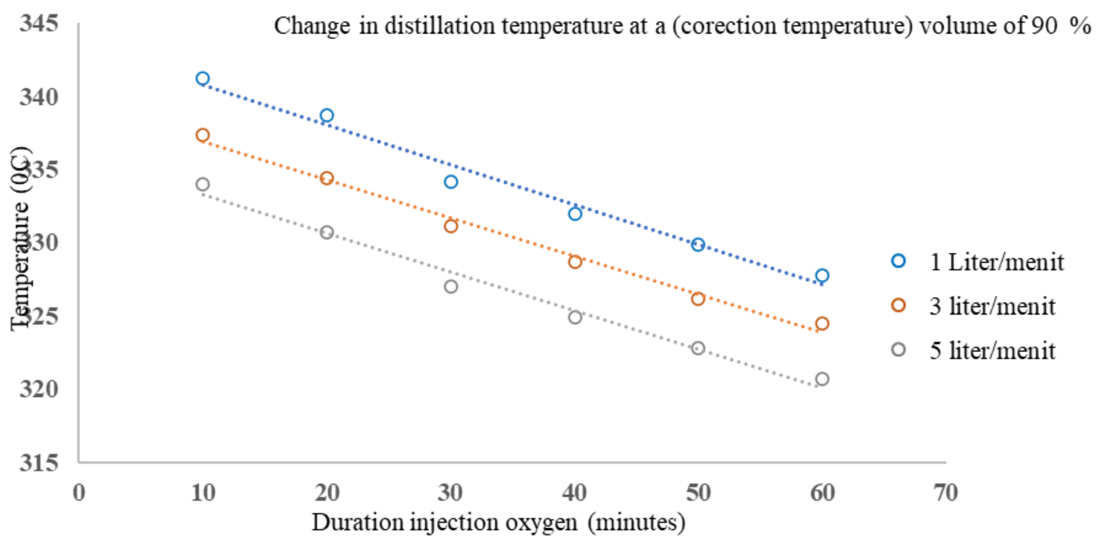

Figure 4
Change in distillation correction temperature volume by 90%

Cetane number

The effect of ultrafine bubble content on the B-0 CN 51 diesel fuel mixture is presented in Figure 5. It was observed that the cetane number increased with higher oxygen injection volumes and longer injection times. The highest value recorded was 59.4 at 5 liters/minute and 30 minutes while the lowest was 56.5 at 1 liter/minute and 10 minutes. A higher cetane number is an indication of reduced fuel consumption due to more efficient combustion which allows the engine to use less fuel in producing the same power, thereby improving fuel economy. Moreover, enhanced combustion efficiency shows that the fuel ignites more quickly when injected into the combustion chamber. The results showed improved engine performance results from higher cetane number fuels, especially at low temperatures. This ensures the diesel engines are more accessible to start and run more smoothly, leading to the reduction in vibration, noise, and risk of knocking.

A higher cetane number can reduce the risk of engine knocking or premature fuel explosion which can damage engine components. This observation is in line with the trend identified in the previous research entitled “Effect of nano air-bubbles mixed into gas oil on common-rail diesel engine” and “nano gas bubbles dissolve in gasoline fuel and its influence on engine combustion performance” (Gürü et al. 2002; Sharif et al. 2019). The same trend was also reported in others that observed the effects of additives on the cetane number of diesel fuel (Aisyah et al. 2016).

Density

Figure 6 shows that the density of the fuel mixture has a linear relationship with the oxygen injection volume concentration. This was observed from the fact that the injection of more oxygen led to a reduction in the density of the B-0 CN 51 ultrafine bubble fuel mixture. The lowest value was found to be 805.9 kg/m³ at 5 liters/minute and 30 minutes while the highest was 813.7 kg/m³ at 1 liter/minute and 10 minutes. This showed that the direct injection of oxygen into the fuel tended to lower the density due to the effect on the fuel composition. The trend was because ultrafine bubbles could influence the distribution and solubility of components in the fuel by breaking down or altering heavier components into lighter or more dispersed forms, potentially resulting in a lower density due to the formation of gas bubbles. Moreover, the injection of the tiny bubbles can create trapped gas within the fuel, reducing the overall density.

The influence of ultrafine bubbles on the viscosity can further reduce the density, thereby ensuring the fuel is lighter and more fluid. The inclusion of ultrafine bubbles can also lead to fuel thinning which is capable of reducing the density. This result is consistent with previous research titled “The Effect of Increased Oxygen on Diesel Emissions through Fuel Manipulation and Gas Combustion Composition (Donahue & Foster 2000). The trend is also similar to previous research titled “Oxidizing Additives to Improve Performance and Emission Characteristics of Diesel Engines” (Abdelaal et al. 2013; Lin & Huang 2003). Moreover, other research investigated the compatibility of fuel system components in diesel engines with B-20 through immersion testing to observe weight changes in diesel fuel system materials (Anggarani et al. 2015).

Flash Point

The injection of large ultrafine bubbles into B-0 CN 51 diesel fuel for extended periods lowered the flash point as presented in Figure 7. The lowest flash point recorded was 58.8°C at 5 liters/minute and 30 minutes while the highest was 67.4°C at 1 liter/minute and 10 minutes. This showed that an increase in the volume of ultrafine bubbles in the fuel led to more flammability of the mixture. More ultrafine bubbles and longer exposure times allowed the fuel to become more reactive, leading to a lower flash point (Ramcke et al. 2018).

The flash point of the fuel was typically reduced when ultrafine bubbles were added for extended periods. This was due to the increased reactivity of the ultrafine bubbles which enhanced the amount of oxygen or sped up the oxidation process in the fuel, leading to more flammability at lower temperatures. Moreover, the formation of trapped gas can reduce the stability of fuel and lower the temperature required for combustion. Ultrafine bubble injection is also capable of influencing the thermal stability of fuel by increasing the susceptibility to decomposition or ignition at lower temperatures to reduce the flash point. This observation was in line with previous research conducted to determine the lower flammability limits of fuels with varying oxygen concentrations under high temperature and pressure conditions (Wang et al. 2022).

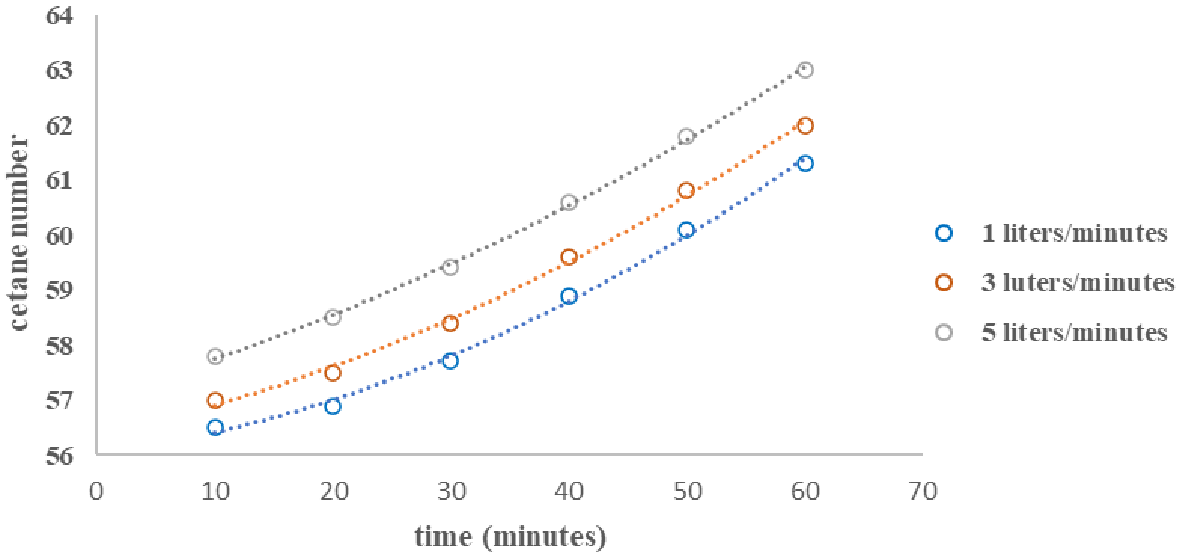

Figure 5
Cetane number of B-0 CN 51

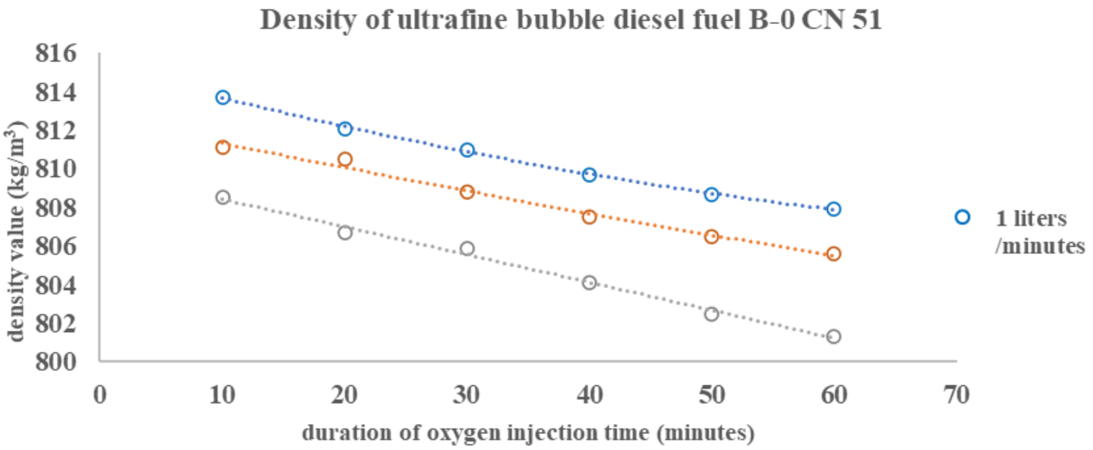

Figure 6
Density of B-0 CN 51

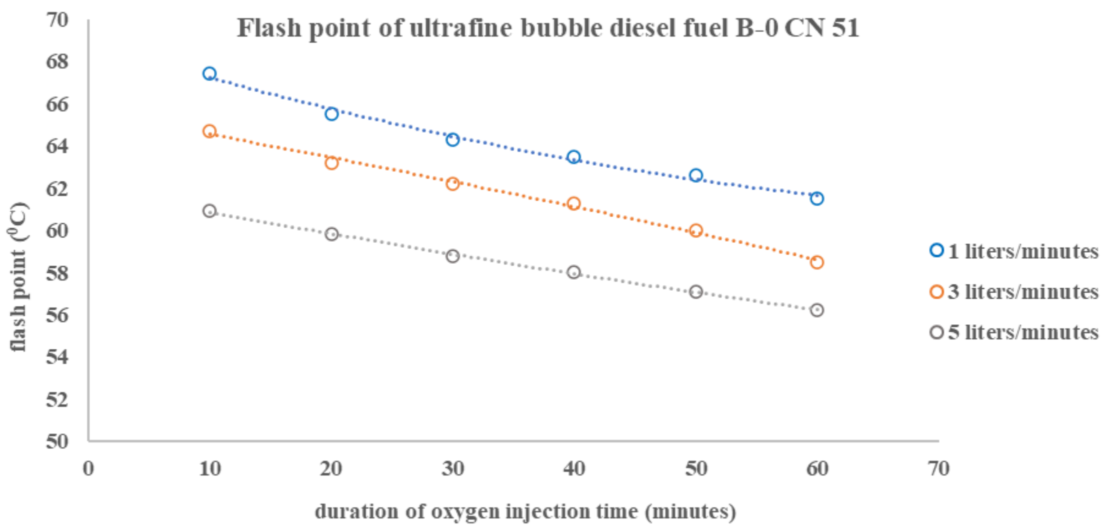

Figure 7
Flash point

Cloud point

Figure 8 shows that the cloud point value decreases as the oxygen injection volume increases and at a longer duration. The lowest value point was 6.0°C at 5 liters/minute and 30 minutes while the highest was 7.0°C at 1 liter/minute and 10 minutes. The reduced cloud point led to a decrease in the size of ultrafine bubbles and subsequently the crystals formed in the fuel at low temperatures. Moreover, smaller crystals are more difficult for the fuel to crystallize at higher temperatures, resulting in a lower cloud point.

The addition of ultrafine bubbles can enhance the ability of the fuel to dissolve its components. This increased solubility allows the components that often crystallize at higher temperatures to remain dissolved, resulting in a lower cloud point. The trend was associated with the even distribution of ultrafine bubbles which assisted in a more uniform distribution of fuel components and reduction in the formation of large crystals capable of increasing the cloud point. Furthermore, a lower cloud point is an indication that the fuel requires less heat for evaporation and the process leads to more efficiency. The observation was in line with the previous research on the impact of biodiesel fuel flow properties on engine performance (Dwivedi & Sharma 2014) and the influence of oxygenated fuels on the combustion process (Manin et al. 2014). The comparative analysis between the current and previous research is systematically presented in Table 2.

Laboratory tests showed that B-0 fuel with CN 51 experienced a reduction in viscosity, density, distillation temperature, and cloud point. This reduction had a positive impact on combustion efficiency, fuel spray patterns, and ignition within the engine with a further contribution to increased cetane number. However, the implementation of oxygen injection technology for this fuel from laboratory to industrial scale is faced with several challenges. Some of these include maintaining process efficiency, ensuring the stability of the fuel produced, and controlling reaction parameters at large-scale capacities, as well as the need to address potential increases in operational costs and infrastructure requirements to meet industrial safety and sustainability standards.

Table 2
Comparative analysis of research related to the application of ultrafine bubbles in fuel

Comparative	**This Research**	**(Babazadeh Shayan et al. 2012)**	**(Abdelaal et al. 2013)**	**(Nakatake et al. 2013)**	**(Sharif et al. 2019)**	**(Küçükosman et al. 2022)**
Fuel type	Fuel diesel.	gasoline	Fuel diesel.	Fuel diesel.	gasoline	Fuel diesel.
Metode	*nano oxygen*	*nano bubbles*	*nano bubbles*	*nano bubbles*	*nano bubbles*	*nano metal oxide*
Procedure	*Injection*	*Injection*	*Injection*	*Injection*	*Injection*	*Injection*
Advantages of the method used	Improve fuel efficiency	Improve fuel efficiency	Improve fuel efficiency	Improve fuel efficiency	Improve fuel efficiency and emissions	Improve fuel efficiency and emissions
	Improve combustion	Improve combustion	Improve combustion	Improve combustion	Improve combustion	Improve combustion
Weaknesses of the method used	The method used still requires maximum oxygen volume injection treatment to determine the stability of fuel oxidation.	The method used still requires maximum oxygen volume injection treatment to determine the stability of fuel oxidation.	The method used still requires maximum oxygen volume injection treatment to determine the stability of fuel oxidation.	The practicality and cost-effectiveness of the bubble mixing effect have yet to be clearly established for real-world applications.	The method used still requires maximum oxygen volume injection treatment to determine the stability of fuel oxidation.	Further research are needed to better understand how nanoparticle size and concentration affect combustion in isolated or aggregated states.

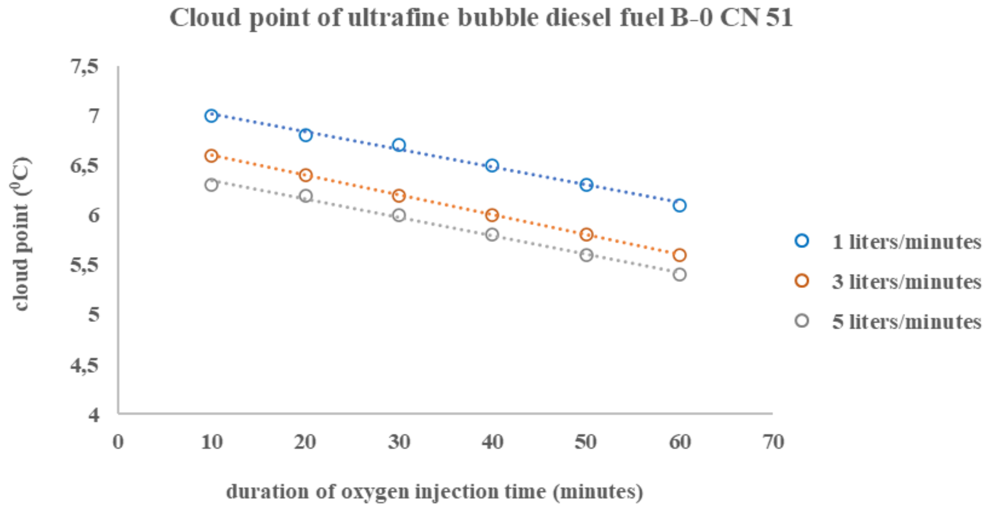

Figure 8
Cloud point

CONCLUSION

In conclusion, the experiment successfully determined the effect of ultrafine bubbles on the physicochemical properties of B-0 CN 51 diesel fuel. The results confirmed that an increase in the oxygen of diesel fuel could lead to more optimal combustion. This was because additional oxygen enhanced the combustion reaction, allowing the fuel to burn more completely. The process reduced residue and facilitated more efficient fuel evaporation, leading to a reduction in distillation temperature. Furthermore, oxygen injection altered the distillation characteristics of diesel fuel to ensure easier evaporation at lower temperatures and an improvement in combustion efficiency. It was observed that ultrafine bubbles reduced the distillation temperature by increasing oxygen injection volumes from 1 to 5 liters per minute and the treatment times from 10 to 30 minutes. The lowest evaporation point temperature was found to be 327°C at 5 liters/minute and 30 minutes while the highest was 341°C at 1 liter/minute and 10 minutes.

The addition of ultrafine bubbles to B-0 CN 51 fuel enhanced engine combustion performance. This was observed from the improvement of the cetane number and fuel longevity as well as the reduction in the flash and cloud points when the oxygen injection volume and the treatment time increased. Finally, the research showed that the use of ultrafine bubbles added value to B-0 CN 51 by producing a new diesel fuel product capable of reducing the volatility temperature to a lower point and enhancing fuel performance through the cetane number and other parameters.

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Symbol	Definition	Unit
UFB	Ultrafine bubble	
CN	Cetane number	
lpm	liters per minute	
B-0	biodiesel 0% (diesel fuel without biodiesel mixture)	
mm^2/s	millimeters per second	
kg/m^3	kilograms per cubic meter	
^{0}C	Celsius	
min	minimum	
max	maximum	
ASTM	American Society for Testing and Materials	
CO	Carbon Monoxide	
CO_2	Carbon Dioxide	
H_2O	Hidrogen Monoksida	

GLOSSARY OF TERMS

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