

Analysis of Ultra Fine Bubble Addition on Biodiesel Fuel to Reduce Emission of Two Wheel Tractors Diesel Engine

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ABSTRACT

Diesel engines are known as high efficiency engines and are used in public transportation and agricultural sector. The exhaust gas produced by diesel engines is dangerous for human health. Ultra Fine Bubble (UFB) technology which is currently being developed is an emission reduction alternative that can enrich oxygen in fuel and has the potential to reduce emissions. This research was carried out to apply UFB technology to a variety of fuels and compare the emission results. This research method is data collection based on experimental tests. The types of fuel used in this research are biodiesel and biodiesel-diesel mixture. The research procedure starts from instrument preparation, fuel inflation which produces UFB fuel, fuel characteristics, instrument performance testing and data processing. The characteristic testing method follows the American Standard Testing and Materials (ASTM) and performance testing follows the ISO/IEC 17025:2017 standard. The research results show that fuel treated with ultra-fine bubbles can reduce exhaust emissions compared to fuel without UFB. CO content decreased by 608 parts per million (ppm) in the biodiesel-diesel blend and 306 ppm in biodiesel with UFB. The exhaust gas temperature becomes stable when the fuel contains bubbles and reduces NO and NO_x content in emissions.

1. INTRODUCTION

Diesel engines are driven by energy which is used to help humans to carry heavy loads optimally in work such as in public transportation, private vehicles, and in the agricultural sector such as tractors (Hakim *et al.*, 2020). According to Chalid *et al.* (2021), the use of engines in transportation and industry tends to use vehicles with diesel engines compared to petrol engines. Diesel engines are known as very efficient engines, but there is still the problem of air pollution from residual exhaust gas. The air pollution caused can be in the form of soot and toxic gasses such as carbon monoxide (CO), nitrogen oxide (NO) which is usually called NO_x. Emissions arise because carbon dioxide (CO₂) lacks oxygen at temperatures >1500 K, causing the formation of emission particles. The increasing use of diesel engines for daily needs causes an increase in diesel fuel consumption and leads to an increase in exhaust emissions.

One of the technologies to reduce emissions is exhaust gas recirculation (EGR), which is a method of reducing exhaust emissions while increasing fuel efficiency by circulating the exhaust gas flow back into the engine. The use of EGR can be applied to high temperature diesel engines and has a positive impact on reducing NO_x levels (Wagino *et*

et al., 2020). The exhaust gas recirculation (EGR) system is the use of exhaust gas that re-enters the engine to absorb heat in the combustion chamber and improve performance (Siregar *et al.*, 2024). EGR is widely used as a technology to improve diesel engine performance. The use of EGR still produces quite a lot of NO_x emissions in its application. According to Septiyanto *et al.* (2017), the use of EGR can increase smoke opacity levels in soot emissions. Apart from that, there is a method of mixing low purity methanol (LPM) with biodiesel fuel. Effendi & Syaiful (2019) shows a decrease in brake power values for variations in the fuel mixture of biodiesel, LPM and japothe compared to using 100% biodiesel. This is quite good for reducing diesel engine exhaust emissions, but variations in the fuel mixture are difficult to find commercially and cannot be used as daily fuel in diesel engines. Prahmana *et al.* (2020) mixing diesel fuel with citronella oil and 1% clove oil significantly reduced diesel engine fuel consumption by 18.3%. However, the raw materials for citronella oil and clove oil are relatively difficult to find in large quantities, which has hampered the application of this technology.

Ultra fine bubble (UFB) technology is a process of bubbling a liquid with a diameter of less than 1 μm which contains invisible fine bubbles (Maia *et al.*, 2021; Yamamoto *et al.*, 2022). One way to earn a fine bubble is to inject oxygen bubbles into the liquid in order to increase oxygen. The machine used in injecting bubbles is an oxygen generator (Paradhiba *et al.*, 2021). Initially the liquid is fed into the rotating pump, there is a centrifugal force caused by circulating gas intake (Marui, 2013). The gas is separated into fine bubbles in the outlet to form microbubbles and nanobubbles. In pure oxygen bubbles can last up to several days, while in air bubbles can last less than 1 hour in liquid (Ushikubo *et al.*, 2010). Sharif *et al.* (2019) also mixed gas oil with nanobubbles for 10 minutes and found a distribution of particles in the range of 100 to 200 nm. The results shown are that engine combustion when fuel is injected increases compared to regular fuel. According to Alam *et al.* (2021), oxygen nanobubbles in water can be stable for up to 10 months with an average bubble size of 70.6 nm. Nanobubbles can be stable because of the mechanical balance between pressure Laplace due to surface tension of the liquid and repulsive pressure due to the electric charge on the bubble.

According to Oh *et al.* (2015), nanobubble hydrogen in gasoline fuel can be stable over a period of 121 days with a diameter of less than 100 nm. This was also validated by Zeta potential measurements which showed that the surface hydrogen nanobubbles were negatively charged without significant change for 121 days. Erny *et al.* (2018) shows there is better development in engine performance when using mixed fuel micro bubbles. This is due to the ability of the micro bubble to supply excess oxygen in the fuel for a long time and dissolve it in the fuel so that it can improve engine performance. UFB added to fuel produces UFB fuel which has the potential to optimize the combustion process and have an impact on reducing exhaust emissions. Therefore, it is necessary to carry out scientific testing regarding the addition of UFB to fuel on diesel engine exhaust emissions.

2. MATERIALS AND METHODS

The research carried out consisted of two different tests, namely characteristic testing and engine performance testing which focused on exhaust emissions produced in the performance test. The testing stage started with instrument preparation including the fuel and test equipment used. Then, UFB fuel was made for each fuel sample. Then, characteristic testing and engine performance testing were carried out which focus on the exhaust emissions produced. The materials used in this research were biodiesel-diesel blends fuel obtained from commercial fuel suppliers and biodiesel fuel obtained from the Standard Testing Center for Industrial and Refreshment Plant Instruments. The tools used in this research presented in Table 1.

2.1. Ultra Fine Bubble Addition to Fuel

The first stage was made sample UFB fuel from B35 and biodiesel fuel. The output connected to hose from the oxygen generator to the top nozzle UFB injection to place the oxygen in the generator into the UFB injection. The capacity of the UFB processing fuel tank is 2 liters. The next step is to pour 2 liters of fuel into the processing fuel tank by conditioning it so that there is no air remaining in the fuel flow through the hose. Water pump and oxygen generator are turned on simultaneously by pressing the switch on the socket and starting to count the injection time bubble for 10 minutes through a stopwatch. Set the flow rate regulator in the oxygen generator to 1 L/min. The choice

Table 1. Tools for characterization and emission test

Equipment	Function
High Frequency Reciprocating Rig (HFRR)	Lubricity measurement
SetaCheck Biodiesel	FAME measurement
Anton Paar SVM 3001	Viscosity and Density measurement
CFR XCP	Cetane number measurement
M690 BR Instrument	Vacuum distillation measurement
OptiDist PAC Herzog	Atmospheric distillation measurement
Clarus Perkin Elmer Gas Chromatograph	FAME Purity Biodiesel measurement
Hand Tractor Axle Dynamometer	Performance test
Gas Analyzer	Emission measurement

of using an oxygen flow rate of 1 L/min follows a study by Alfath (2023), namely that the use of an oxygen flow rate of 1 L/min on various types of commercial diesel fuel has the best performance increase compared to 3 L/min and 5 L/min. The process of addition ultra fine bubbles to the diesel fuel can be seen in Figure 1.

2.2. Analysis of Fuel Characteristic

The materials used in this research were biodiesel Fatty Acid Methyl Esters (FAME) obtained from palm oil and biodiesel-diesel blends FAME obtained from the gas station which is currently regulated in Indonesia on FAME percentation 35% (B35). All of the fuels being characterized for critical parameters as presented on Table 2. In this research, B35 and biodiesel fuel was prepared under normal and UFB conditions with 5 liters each test sample. Testing of fuel characteristics under normal conditions and adding bubbles is carried out following several parameters needed to support the emission measurement results. The fuel characteristic testing method follows the American Standard Testing and Material (ASTM) and European Standard (EN), each of which is stated on the test parameter tool. Distillation test have two different methods were carried out on the fuel because there were differences in the water content of each fuel. In FAME testing, two different methods are also carried out due to the type of fuel used and the limitations of measuring instruments in measuring FAME levels. Characteristics testing was carried out at the Lemigas Application Building Characteristics Testing Laboratory, South Jakarta.

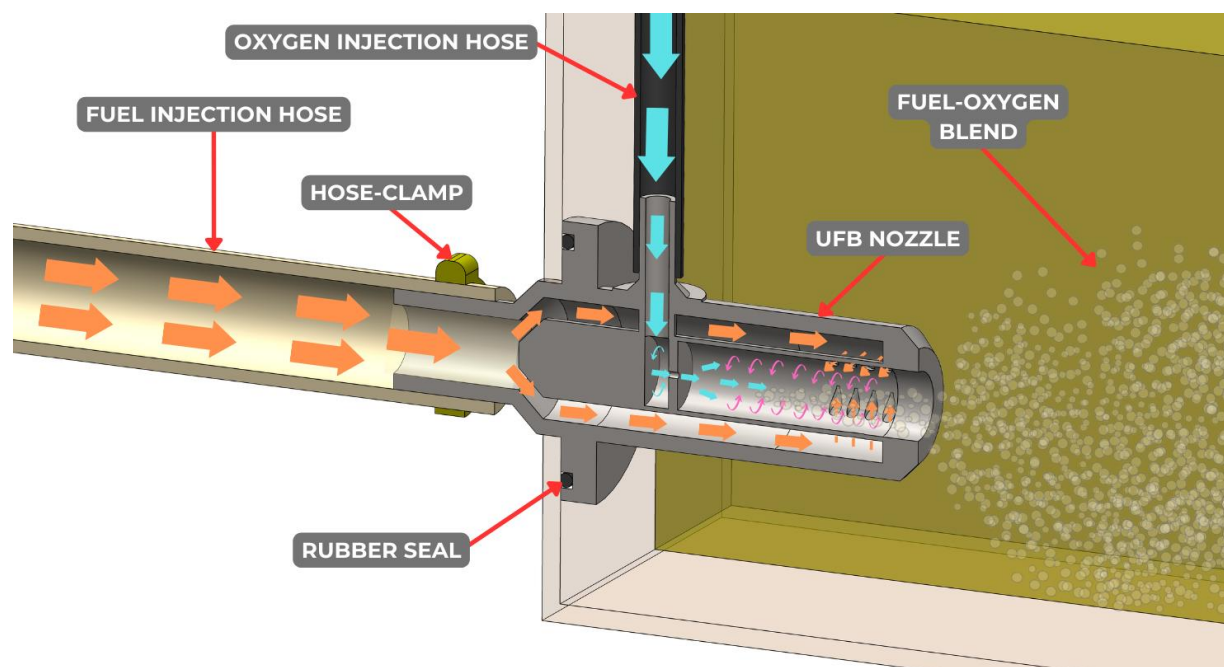


Figure 1. Schematic UFB injection to diesel fuel

Table 2. Fuel characterization and test method

No	Parameter	Test method
1	Lubricity	American Standard Testing and Materials (ASTM) D6079
2	FAME (percentage in diesel blend)	ASTM D8274
3	Viscosity and Density	ASTM D445
4	Cetane Number	ASTM D613
5	Vacuum Distillation	ASTM D86
6	Sulfur Content	ASTM D4294
7	Atmospheric Distillation	ASTM D1160
8	FAME Purity for Biodiesel	European Standard (EN) 14110

Table 3. Specification of diesel engine

No	Parameter	Test method
1	Model	Yanmar TF 85 MR-di no series DK7168
2	Number of Steps	4 Steps
3	Cylinders	1 Cylinder
4	Diameter x Step	85 mm x 87 mm
5	Continuous Power	5.5 kW / 7.5 DK
6	Maximum Power	6.2 kW / 8.5 DK
7	Cylinders Volume	0.493 Liter
8	Fuel Tank Capacity	10.5 Liter

2.3. Emission Testing

Emission testing is carried out at the Two-Wheel Tractor Laboratory, Center for Standard Testing of Agricultural Mechanization Instruments contained in an instrument device called hand tractor axle dynamometer. Engine diesel paired to a hand tractor, then there is a mechanism prony brake with dynamometer which is used to produce braking from the engine to get maximum power. The specification of diesel engine used in this research shown at Table 3. An illustration of the experimental setup and hand tractor axle dynamometer can be seen in Figure 2. The prony brake mechanism has an arm length of 41 cm, functions to regulate the opening of the air flow rate produced by the compressor. The prony brake mechanism is connected to the tractor wheel axle and uses a disc on the braking canvas. Prony brakes are equipped with a loadcell force sensor which functions to measure the load. The load data obtained will be multiplied by an arm that is a constant distance from the center of rotation of the shaft to the load cell to obtain torque data.

The infrared setting used is by shooting infrared at the fly wheel to measure the amount of engine rotation. The rotation of the wheel axle is measured using a proximity sensor directed at the gear to determine the signals 1 and 0 according to the position of the gear at the peak and valley of the gear. This value is then converted into a shaft rotation value (rpm). The compressor is used in the prony brake mechanism to provide air pressure during the braking process under load conditions. The water pump functions to provide cooling water circulation to the loading mechanism with a pneumatic mechanism via a solenoid valve in the panel control room. Furthermore, the engine which is connected to the exhaust pipe is connected to a 1 meter long muffler extender to accommodate the gas analyzer to measure the exhaust gas emissions.

The step for measuring exhaust gas emission levels begins with preparations for making a muffler extender so that the gas analyzer probe can measure exhaust gas emissions properly. This is in accordance with SNI 09-7118.2-2005 (BSN, 2005) to insert the sampling probe into the exhaust pipe to a depth of 30 cm and if it is less than 30 cm then an additional pipe is installed in the exhaust pipe. The next step is to prepare the gas analyzer by checking the battery, filter and instrument readings. The specifications of the gas analyzer measuring instrument used in this research are presented in Table 4. The gas analyzer probe was placed on the exhaust extender in the exhaust section of the engine test stand. During the performance test, the exhaust gas emissions recorded by the measuring instrument are recorded and appear on the gas analyzer display. During testing, the filter on the analyzing gas is also checked periodically to avoid the buildup of dirt on the analyzing gas filter.

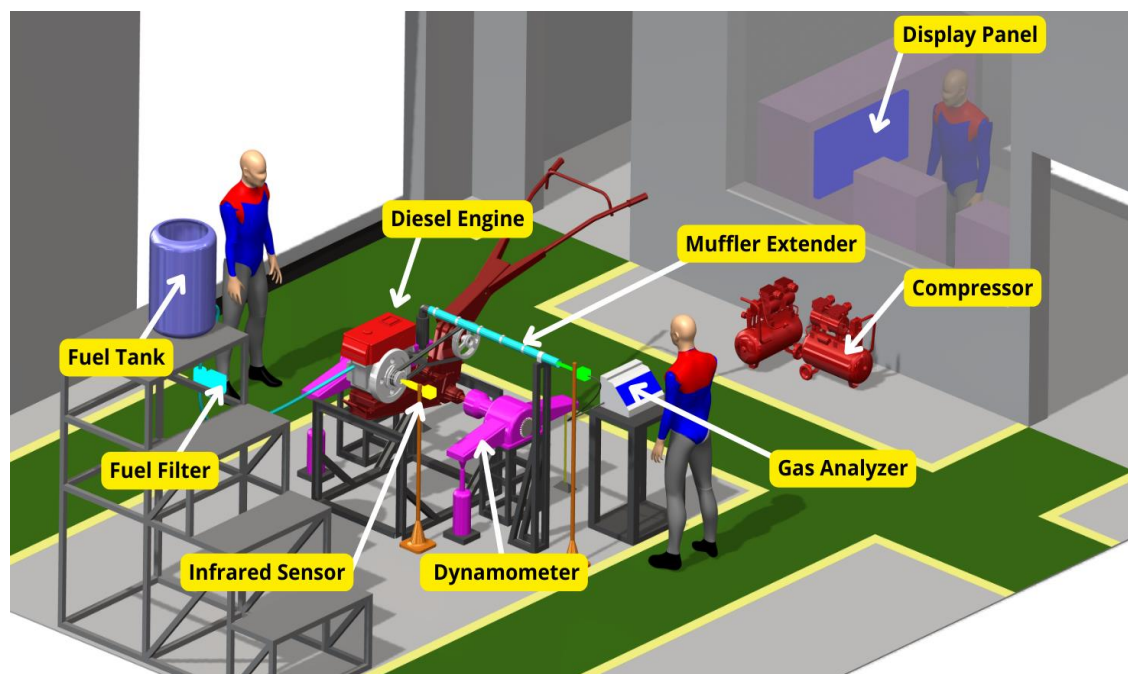


Figure 2. Experimental setup for emission testing

Table 4. Specification of gas analyzer

Parameter	Sensor	Range	Resolution	Accuracy
O ₂	Electrochemical	0 – 25%	0,1%	± 0,2 % vol
CO	Electrochemical	0 – 8000 ppm	1 ppm	± 10 ppm (0 – 200 ppm) ± 5% rdg (201 – 2000 ppm) ±10% rdg (201 – 8000 ppm)
CO ₂	Calculated	0 – 99,9%	0,1%	--
NO	Electrochemical	0 – 5000 ppm	1 ppm	± 5 ppm (0 – 100 ppm) ± 5% rdg (101 – 5000 ppm)
NO _x	Calculated	0 – 5000 ppm	1 ppm	--
SO ₂	Electrochemical	0 – 5000 ppm	1 ppm	± 5 ppm (0 – 100 ppm) ± 5% rdg (101 – 5000 ppm)
C _x H _y	Pellistor	0 – 5%	0,01%	± 5% full scale

3. RESULT AND DISCUSSION

3.1. Fuel Characterization

The results of testing the characteristics of B35 fuel and biodiesel show significant changes in the cetane number and lubricity values after being treated with UFB, which can be seen in Table 5. With the UFB treatment, it can be seen in Table 4 that UFB has a significant influence on:

- Combustion properties are improved, which is represented by the cetane number. Before being treated, the B35 sample had a cetane number of 58.3, and after being treated, UFB had a cetane number of 59.9. Meanwhile, before UFB treatment, the biodiesel sample had a cetane number of 69.9 and after being treated with UFB it had a cetane number of 72.4. This is in accordance with research by Lü *et al.* (2005) which increases the cetane number in ethanol-diesel mixture fuel, resulting in better combustion and reducing CO, HC and NO_x emissions compared to without increasing the cetane number. Song *et al.* (2018) also carried out tests on oxygen-enhanced fuel using a mixture of rapeseed methyl ester (RME) which resulted in an increase in the n-cetane of the fuel and reduced opacity emissions.

Table 5. Fuel characterization

No	Parameter	Fuel			
		B35	B35 UFB	Biodiesel	Biodiesel UFB
1	Density ($\text{g/cm}^3 \times 10^{-3}$)	840 ± 0.0	832 ± 0.1	864 ± 0.1	865 ± 0.1
2	Cetane Number	58.3 ± 0.82	59.9 ± 0.45	69.9 ± 0.17	72.4 ± 0.53
3	Distillation (T_{90}) ($^{\circ}\text{C}$)	341.8 ± 0.87	341 ± 0.70	356.5 ± 0.85	353.8 ± 0.46
4	Lubricity (micron)	266 ± 0.20	253.5 ± 0.10	359 ± 0.17	344.5 ± 0.10
5	Viscosity (mm^2/s)	3.2 ± 0.006	3.22 ± 0.005	5.41 ± 0.000	5.52 ± 0.031
6	FAME Content (% v/v)	35.2 ± 0.085	35.7 ± 0.035	88 ± 0.000	88.3 ± 0.136
7	Sulfur Content (% $\times 10^{-1}$)	0.50 ± 0.20	0.30 ± 0.00	0.05 ± 0.01	0.02 ± 0.01

- b. Improves lubrication properties, before being given UFB the lubrication value of B35 fuel is 266 microns and after being given UFB is 253.5 microns. Meanwhile, biodiesel fuel has a lubrication value of 359 microns and if processed with UFB it drops to 344.5 microns. The lubricating properties of biodiesel fuel can reduce engine wear and can be considered as an additional lubricant to diesel fuel (Hazrat *et al.*, 2015).

Characteristics for others parameters does not have a significant influence when gives UFB. The density and viscosity of B35 fuel and biodiesel did not show significant changes when given UFB treatment. This is because the addition of ultra-fine bubbles to the fuel in the form of nanobubbles does not change the density and viscosity characteristics of the fuel.

The distillation of T_{90} also does not have a noticeable change in B35 fuel, while in biodiesel fuel there is quite a noticeable decrease in the distillation temperature. The FAME test and sulfur content in the fuel also did not experience significant changes after being given UFB treatment. This is because the addition of ultra fine bubbles in the form of nanobubbles does not change the structure of the fuel further, and needs to be investigated in more depth for changes in the chemical elements that make up the fuel.

3.2. Emission Result

Exhaust gas emissions are gases formed from the combustion residue that occurs in internal combustion engines. Combustion occurs during the energy stroke to push/move the piston through gas expansion. Meanwhile, exhaust emissions resulting from the diesel engine combustion process are influenced whether or not the combustion process occurs perfectly. Exhaust gas emissions contain a number of dangerous chemical elements that can pollute the air. Such as exhaust gas emission compounds in diesel engines, namely Nitrogen Oxide (NO_x), Carbon Monoxide (CO), Hydrocarbons (HC), Carbon Dioxide (CO_2), and others (Persulesy *et al.*, 2022). These compounds are toxic and can cause human health problems. Meanwhile, the exhaust gas emitted from the exhaust can be seen clearly visually, indicating an incomplete combustion process. The tests carried out focused on obtaining exhaust gas emissions produced with 7 compound parameters used to analyze the addition of ultra fine bubbles to the exhaust gas emissions produced, including unreacted O_2 , CO, CO_2 , SO_2 , C_xH_y , NO and NO_x . The research results obtained from emissions testing are presented in the following section.

3.2.1. Unreacted of O_2

Figure 3 shows the increase in oxygen (O_2) levels in the emissions produced when the fuel is given bubble treatment. At 2500 rpm or without loading, the O_2 produced tends to be higher because there is no loading so the diesel engine can still burn perfectly. When loading starts to occur at 2400 rpm to 1900 rpm, the O_2 produced decreases along with the higher load given to the engine which causes more incomplete combustion and results in lower rpm as well. B35 fuel shows the highest O_2 content is found in B35 UFB at 2545 rpm with an O_2 value of 18.4%, while the lowest O_2 content is found in B35 at 2129 rpm with an O_2 value of 8.6%. Biodiesel fuel shows the highest O_2 content is found in biodiesel UFB at 2555 rpm with an O_2 value of 18.4%, while the lowest O_2 content is found in biodiesel at 1996 rpm with an O_2 value of 8.6%. The combustion process in the engine requires sufficient oxygen so that the fuel can burn completely and produce good exhaust emissions (Dwinanda *et al.*, 2023). This corresponds to the additional function of UFB in fuel, namely it can increase O_2 levels in the fuel.

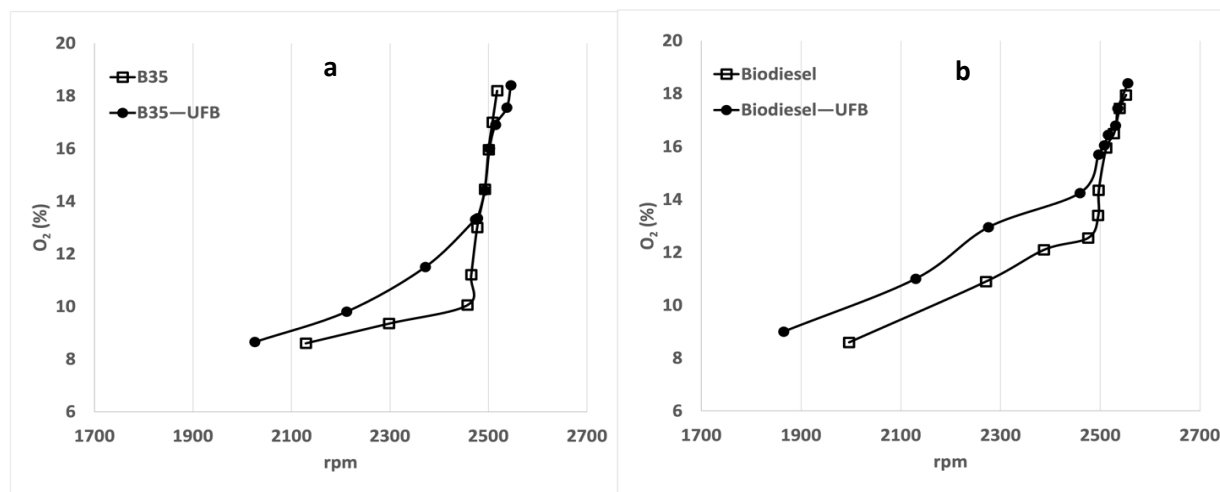


Figure 3. The effect of rpm on O₂ emissions in: (a) B35 fuel, (b) Biodiesel fuel

B35 fuel has the highest O₂ value of 18.2% at 2517 rpm and the lowest O₂ of 8.6% at 2129 rpm. B35-UFB fuel has the highest O₂ value of 18.4% at 2545 rpm and the lowest O₂ of 8.65% at 2025.5 rpm. The average O₂ content in B35 fuel is 12.4%, while the average O₂ content in B35-UFB is 13.75%. The increase in O₂ emissions obtained when B35 fuel was given UFB injection was 11.2% compared to B35 fuel. Biodiesel fuel has the highest O₂ value of 17.9% at 2551 rpm and the lowest O₂ of 8.6% at 1996 rpm. Biodiesel-UFB fuel has the highest O₂ value of 18.4% at 2555 rpm and the lowest O₂ of 9% at 1865 rpm. The average O₂ content in biodiesel fuel is 13.4%, while the average O₂ content in biodiesel-UFB is 14.2%. The increase in O₂ emissions obtained when biodiesel injected with UFB was 6.2% compared to biodiesel. UFB injection on B35 fuel and biodiesel can increase the O₂ emissions, due to the injection of O₂ in the form of UFB into the fuel

3.2.2. Emission of CO

Carbon monoxide (CO) is produced by incomplete combustion of the hydrocarbon in the fuel as in Equation (1):



Figure 4 shows the decrease in CO levels in the emissions produced when the fuel given bubble treatment. At 2500 rpm or no load, the CO produced is initially low because there is no load, so the diesel engine burns perfectly. When loading begins to occur at 2400 rpm to 1900 rpm, the CO produced becomes higher as the load given to the engine increases, causing combustion to become more imperfect. At 2298 rpm B35 fuel produces CO emissions of 4405 ppm while at 2211 rpm B35 UFB fuel produces CO emissions of 3445 ppm. The decrease in rpm of B35 fuel at 2129 rpm produces CO of 6307 ppm, on the other hand B35 UFB fuel at 2025 rpm produces CO of 4915 ppm. CO emissions can be formed from incomplete combustion of carbon and the decomposition of CO₂ into CO and O₂ at high temperature (Lawang *et al.*, 2019). The carbon content in the fuel reacts with the oxygen content in the UFB treatment so that the combustion is more perfect and produces less CO in the exhaust gas emissions.

B35 fuel has the highest CO value of 6307 ppm at 2129 rpm and the lowest CO value of 283 ppm at 2517 rpm. B35-UFB fuel has the highest CO value of 4915 ppm at 2025.5 rpm and the lowest CO value of 177 ppm at 2545 rpm. The average CO content in B35 fuel is 2023.8 ppm while the average CO content in B35-UFB is 1424.7 ppm. Biodiesel fuel has the highest CO value of 3980 ppm at 1996 rpm and the lowest CO value of 250 ppm at 2551 rpm. Biodiesel-UFB fuel has the highest CO value of 3560 ppm at 1865 rpm and the lowest CO value of 237.5 ppm at 2555 rpm. The average CO content in biodiesel fuel is 1408.8 ppm while the average CO content in biodiesel-UFB is 1102.4 ppm. B35 fuel reduces CO content 608 ppm with UFB, while biodiesel fuel reduces CO 306 ppm with UFB. This states that UFB injection carried out on B35 fuel and biodiesel can improve the combustion that occurs in the engine thereby reducing the CO exhaust emissions produced.

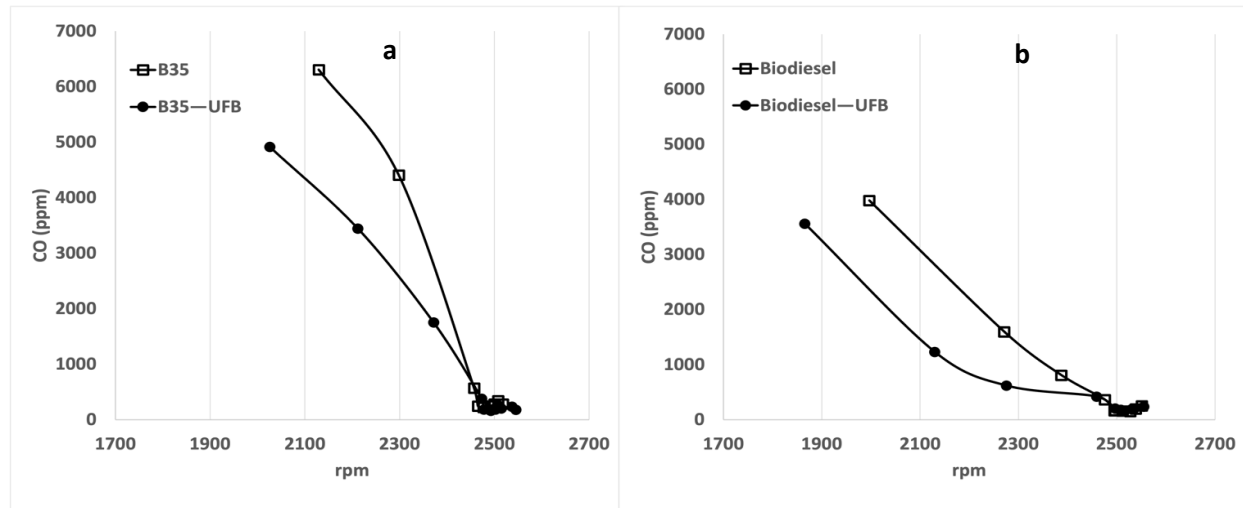


Figure 4. The effect of rpm on CO emissions in: (a) B35 fuel, (b) Biodiesel fuel

3.2.3. Emission of CO₂

Carbon Dioxide (CO₂) emissions formed from burning carbon with oxygen which produces a product in the form of CO₂. The reaction resulting from complete combustion of carbon in fuel with oxygen is:

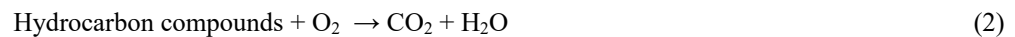
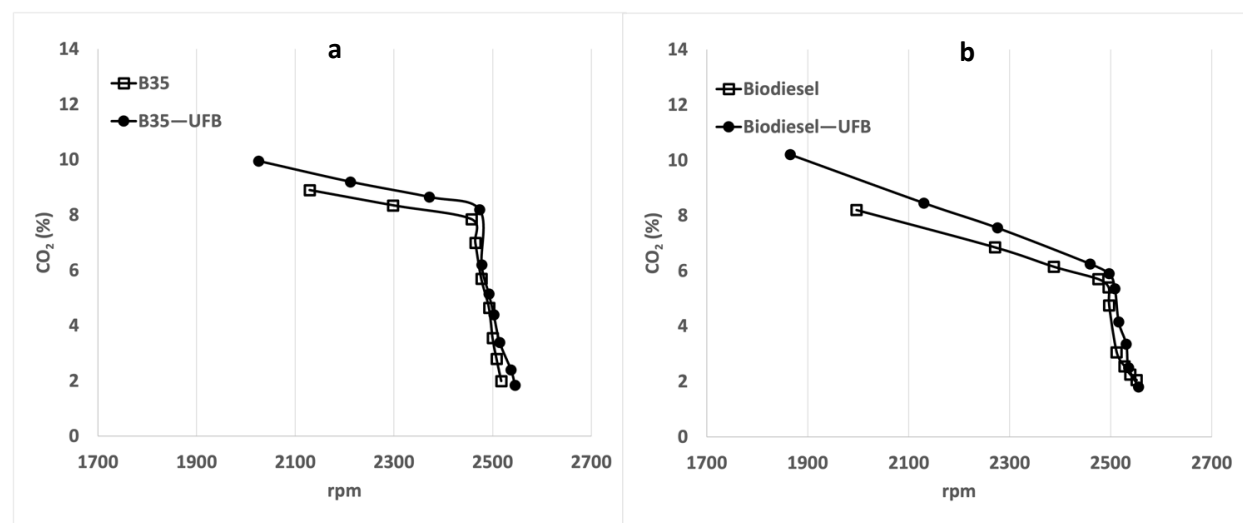


Figure 5 shows the increase in CO₂ levels in the emissions produced when the fuel is given bubble treatment. At the initial testing at high rpm, namely 2500 rpm without load, the CO₂ produced tends to be small because the engine can work optimally without load. Then as the load is applied, the rpm will decrease and cause an increase in CO₂ due to the need for more fuel. B35 fuel at 2457 rpm produces CO₂ of 7.85% while at 2473 rpm B35-UFB fuel produces CO₂ of 8.2%. Biodiesel fuel with 2271 rpm produces 6.85% CO₂, while biodiesel-UFB with 2276 rpm produces 7.55% CO₂. This is because the carbon content in the fuel reacts with the oxygen content in the UFB treatment so that combustion is more perfect and produces more CO₂ levels in exhaust gas emissions. [Kristiyadi et al. \(2022\)](#) stated that the amount of CO₂ emissions produced shows that more fuel is burned.

Figure 5. The effect of rpm on CO₂ emissions in: (a) B35 fuel, (b) Biodiesel fuel

B35 fuel has the highest CO₂ value of 8.9% at 2129 rpm and the lowest CO₂ value of 2% at 2157 rpm. B35–UFB fuel has the highest CO₂ value of 9.9% at 2025.5 rpm and the lowest CO₂ value of 1.9% at 2545 rpm. The average CO₂ content in B35 fuel is 5.64% while the average CO content in B35–UFB is 5.94%.

Biodiesel fuel has the highest CO₂ value of 8.2% at 1996 rpm and the lowest CO₂ value of 2% at 2551 rpm. biodiesel–UFB fuel has the highest CO₂ value of 10.2% at 1865 rpm and the lowest CO₂ value of 1.8% at 2555 rpm. The average CO₂ content in biodiesel fuel is 4.69%, while the average CO₂ content in biodiesel–UFB is 5.55%. This states that UFB injection carried out on B35 fuel and biodiesel can improve the combustion that occurs in the engine, thereby producing more CO₂ in exhaust emissions.

3.2.4. Emission of SO₂

Figure 6 show the sulfur content in B35 and biodiesel fuel does not have a significant difference. At the initial testing at high rpm, namely 2500 rpm without load, the SO₂ produced tended to be 0 or non-existent because the engine could burn the fuel completely, resulting in fewer emissions. Then as the load is applied, the rpm will decrease and cause an increase in SO₂ at low rpm which is due to the need for more fuel and the combustion that occurs becomes more imperfect. The SO₂ value produced by both fuels at 2500 rpm to 2300 rpm is almost close to 0 or 0. For example, for 2400 rpm biodiesel fuel, the SO₂ value in biodiesel is 0 ppm and in biodiesel-UFB it is 0 ppm. At 2300 rpm to 1900 rpm the SO₂ content in biodiesel fuel increases to 3.5 ppm while in biodiesel-UFB fuel it remains at 0 ppm. This is related to the sulfur content in the fuel, the sulfur characteristics of which are also measured when collecting characteristic data. SO₂ increases with decreasing rpm, but the results are still not considered significantly different. Meanwhile in the characteristic of fuel, B35 and B35 with UFB fuel do not have a significant difference in sulfur content, namely 0.05% for B35 with UFB and 0.03% for B35. Biodiesel fuel and biodiesel with UFB also do not have a significant difference in sulfur content, namely 0.005% for biodiesel with UFB and 0.002% for biodiesel. The sulfur contained in the fuel reacts with oxygen during combustion to produce sulfur dioxide (SO₂) products (Lawang *et al.*, 2019). The reactions that occur in the formation of SO₂ are:



Sulfur dioxide measured in normal fuel and UFB fuel showed a graph that did not have a significant difference, especially in biodiesel fuel in the emission measurements. SO₂ measurements are also considered to have the same results because the resulting reduction in emissions is not significantly different, this is indicated by stable emission results at 2500 rpm to 2300 rpm. In addition, the sulfur content in the fuel also did not have a decreasing impact when given UFB, thus supporting the SO₂ emission results which were not significantly different during testing.

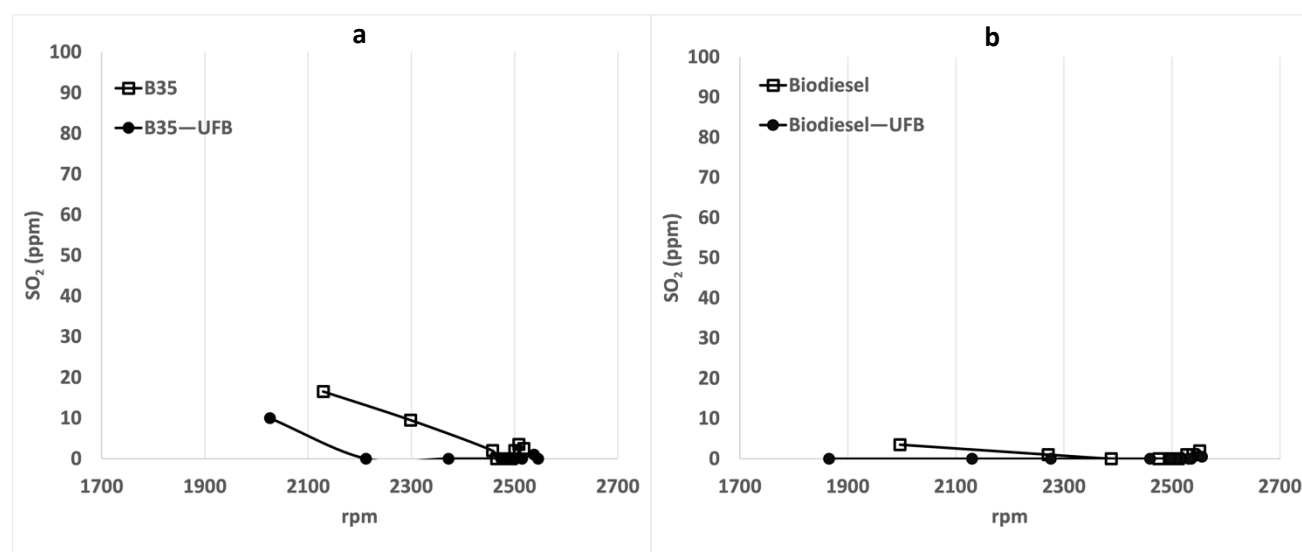


Figure 6. The effect of rpm on SO₂ emissions in: (a) B35 fuel, (b) Biodiesel fuel

3.2.5 Emission of C_xH_y

Figure 7 shows the weight fraction in the fuel is represented as the distillation temperature at 90%. C_xH_y value at 2500 rpm to 2400 rpm still ranges between 0 and 0.1% for both fuels. At 2500 rpm without load, the C_xH_y content is initially 0. This is because the combustion that occurs is still more perfect because there is no load placed on the engine. As the load is increased, the rpm will decrease and the resulting C_xH_y emissions will become greater, indicating that the combustion is not perfect. The increase in the C_xH_y content of B35 fuel is faster than that of biodiesel fuel, but the value tends to be stable. In the fuel characteristics that have been tested, there is a 90% decrease in distillation value in B35 fuel with UFB, namely 341°C compared to B35 fuel of 341.8°C. Biodiesel UFB fuel also has a 90% reduction in distillation value, namely 353.8°C compared to biodiesel fuel of 356.5°C. Biodiesel has a high C_xH_y value compared to B35 due to the higher 90% distillation temperature. Both fuels also had a decrease in C_xH_y values after UFB treatment which corresponded to a decrease in the 90% distillation value of UFB fuel. According to Sasmita et al. (2022) C_xH_y comes from unburned carbon due to insufficient combustion temperature which can produce HC emissions.

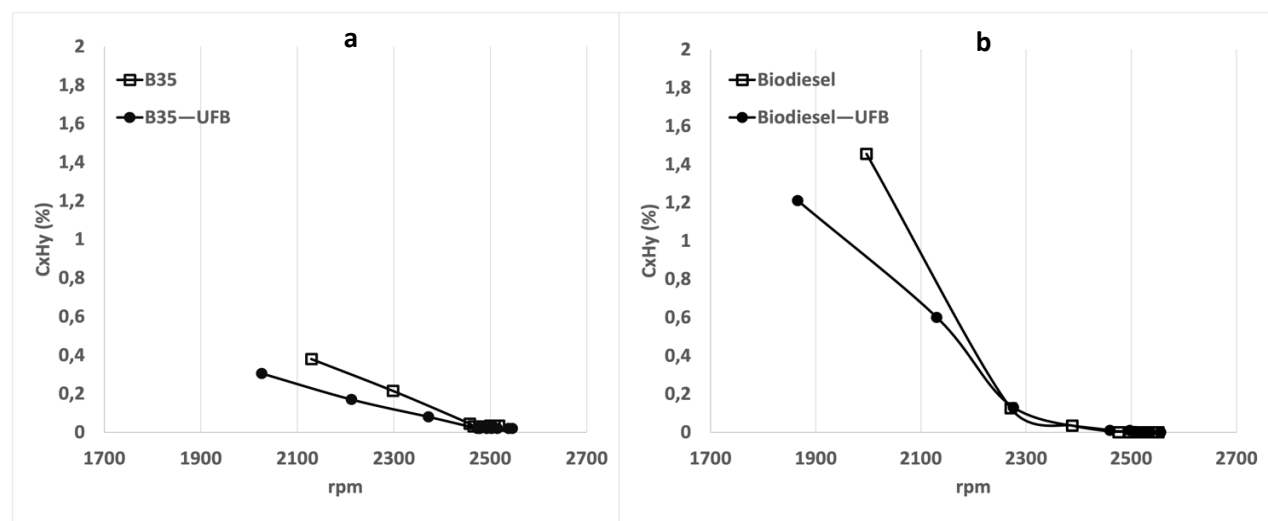
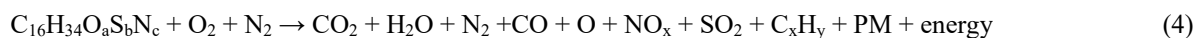


Figure 7. The effect of rpm on C_xH_y emissions in: (a) B35 fuel, (b) Biodiesel fuel

The incomplete fuel combustion reaction as presented in Equation (4) produce C_xH_y emissions where C₁₆H₃₄O_aS_bN_c is hydrocarbon compound on cetane, C_xH_y is unburn hydrocarbons, and PM is particulate molecules.



3.2.6. Emission of NO

Figure 8 shows the correlation between the engine exhaust temperature and the NO emissions produced. The nitrogen contained in the air mixes with the heat produced by emission gasses in the exhaust which results in the formation of NO and NO_x compounds. The higher the exhaust temperature in the engine, the higher the NO emissions produced. At the tests carried out starting from 2500 rpm without load, the NO emissions produced were very low. This is because the combustion is more complete and the engine does not overheat so the exhaust does not overheat and produces less NO. When the engine has been given gradual loading, the rpm will decrease and NO emissions will increase due to incomplete combustion. B35 at the lowest temperature of 140.2°C produces NO 79 ppm and at the highest temperature of 355.4°C produces NO 747 ppm. B35 UFB at a low temperature of 118°C produces NO 67.5 ppm and at the highest temperature of 302.9°C produces NO 487 ppm. Biodiesel at a low temperature of 129.1°C produces NO 78.5 ppm, while at the highest temperature of 342.6°C produces NO 601 ppm. Whereas, UFB biodiesel at the lowest temperature of 109.3°C produces NO 64 ppm, and at the highest temperature of 328.5°C produces NO of

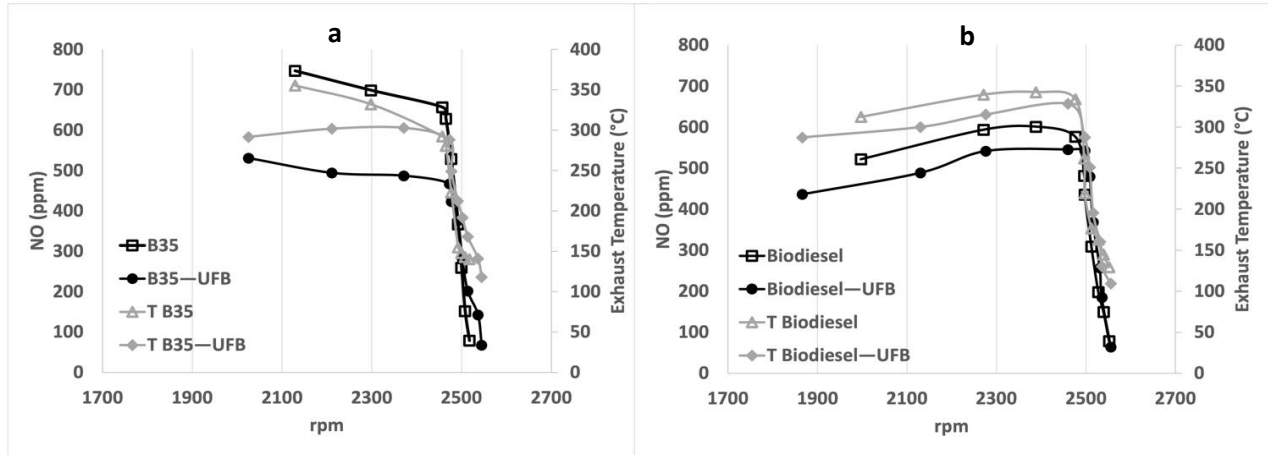


Figure 8. The effect of rpm and exhaust temperature on NO emissions in: (a) B35 fuel, (b) Biodiesel fuel

545.5 ppm. This is in accordance with [Persulesy et al. \(2022\)](#) which states that NO content is influenced by the air—fuel ratio and combustion time. The longer the combustion is carried out, engine exhaust temperature will increase, thus increasing the emission value.

Nitrogen molecules in the air during the combustion process react with excess oxygen, temperature, and the duration of the combustion gas at that temperature to produce NO content ([Lawang et al., 2019](#)). The NO and NO_x content is obtained from the nitrogen in the air reacting at high temperature in the exhaust, the reaction is as follows:

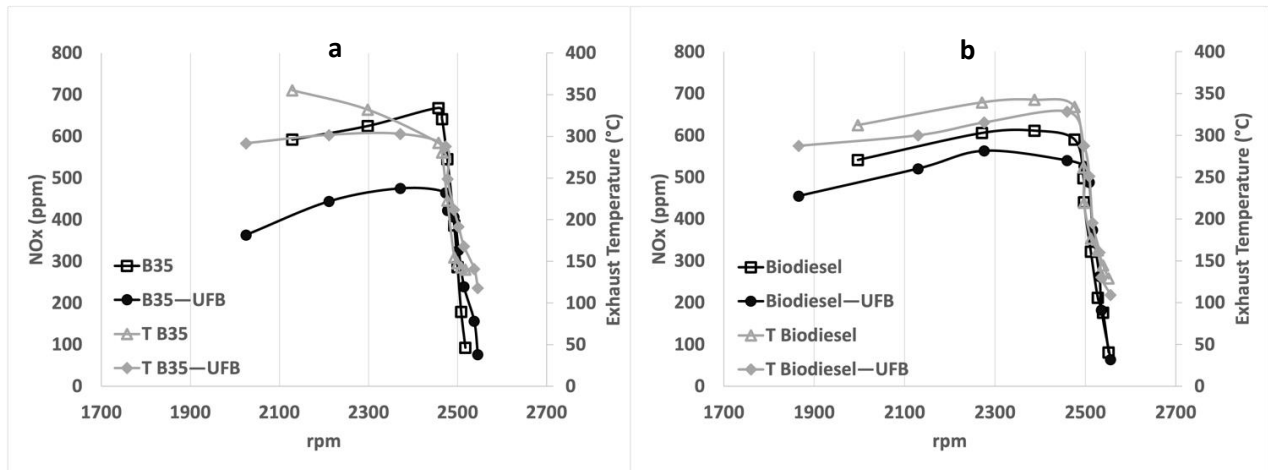


Figure 9. The effect of rpm and exhaust temperature on NO_x emissions in: (a) B35 fuel, (b) Biodiesel fuel

3.2.7. Emission of NO_x

Figure 9 shows the correlation between the engine exhaust temperature and the NO_x emissions produced. NO_x produces when the nitrogen contained in the air mixes with the heat produced by emission gasses in the exhaust with reaction as presented in Equations (5) to (8). The higher the exhaust temperature in the engine, the higher the NO_x

emissions produced. At the tests carried out starting from 2500 rpm without load, the NO_x emissions produced were very low. This is because the combustion is more complete and the engine does not overheat so the exhaust does not overheat and produces less NO_x. When the engine has been given gradual loading, the rpm will decrease and NO_x emissions will increase due to incomplete combustion. B35 at the lowest temperature of 140.2°C produces NO_x 92.5 ppm and at the highest temperature of 355.4°C produces NO_x 592.5 ppm. B35 UFB at a low temperature of 118°C produces NO_x 76.5 ppm and at the highest temperature of 302.9°C produces NO_x 444 ppm. Biodiesel at a low temperature of 129.1°C produces NO_x 81.5 ppm, while at the highest temperature of 342.6°C produces NO_x 611.5 ppm. Meanwhile, UFB biodiesel at the lowest temperature of 109.3°C produces NO_x 64 ppm, and at the highest temperature of 328.5°C produces NO_x 540 ppm. According to [Fayad *et al.* \(2022\)](#), NO_x emission concentrations will decrease if the temperature decreases during combustion. The nitrogen contained in the air mixes with the heat produced by emission gasses in the exhaust which results in the formation of NO and NO_x compounds. The higher exhaust temperature in the engine causes higher NO_x emissions to be produced.

4. CONCLUSION

The UFB treatment gives a significant change in cetane number and lubricity of B35 and biodiesel fuels. Otherwise, density, viscosity, distillation, FAME test and sulfur content of B35 and biodiesel fuels did not show any significant changes when given UFB. B35 and biodiesel fuel treated with UFB can significantly reduce the content of exhaust gas emissions compared to fuel without UFB. O₂ content increased by 11.2% in B35 and 6.2% in biodiesel, while CO content decreased by 608 ppm in B35 and 306 ppm in biodiesel after the fuel was given UFB. The rate of unburned hydrocarbons can decrease along with decrease in distillation value which is measured at T₉₀ as the C_xH_y parameter when the fuel is bubbled and the lowest C_xH_y value is found in B35 UFB fuel. The content of NO and NO_x is affected by the increase in engine exhaust temperature, the higher the exhaust temperature in the engine, the higher the value of NO and NO_x produced. Addition UFB on the fuel stabilizes the exhaust temperature so that it can lower the content of NO and NO_x emissions in diesel engines. The suggestion from this research is continue research on how long bubbles can last in fuel, storage of UFB fuel at various temperatures, and the effect of adding UFB to other types of fuel.

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