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Effect of Adding Ultrafine Bubble to Diesel and Biodiesel Fuel on Two-Wheel Tractors' Diesel Engine Performance

Sam Herodian

Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Technology, IPB University
Raya Dramaga Street, Babakan, Dramaga Sub-district, Bogor Regency, West Java, Indonesia

Corresponding author: s_herodian@apps.ipb.ac.id

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ABSTRACT - Diesel engines are widely utilized in various sectors due to their high torque and power, enabling efficient handling of heavy loads. The type of fuel used in a diesel engine significantly influences its performance. Numerous advancements in fuel refinement have been achieved through diverse methods. Therefore, this research aimed to test and analyze the effectiveness of Ultra Fine Bubble (UFB) combustion improvements in various diesel fuels. UFB is a method of adding nano-sized oxygen to fuel to enhance engine performance. The method used is a performance test on a hand tractor axle dynamometer with B0 (diesel), B35 (biodiesel–diesel blends 35%), and biodiesel fuel. The addition of UFB results in variations in characteristic values, including the cetane number, fog point, lubricity, density, viscosity, and flash point. The power output of B0 fuel increased by 3.46% with the addition of UFB, while B35 showed a 7.45% increase, and biodiesel experienced a 1.6% improvement. The increase in power that occurs in B35 and biodiesel is also followed by a decrease in the specific fuel consumption (SFC) value, while in B0 fuel, the addition of UFB increased SFC.

Keywords: biodiesel, diesel engine, diesel fuel, ultrafine bubble.

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INTRODUCTION

A diesel engine is a type of internal combustion engine in which fuel is ignited by gas at a high temperature due to compression (Saputra & Sunaryo 2019). This engine uses compression ignition, where fuel is injected into the pressurized combustion chamber by an injector (Rizky et al. 2020). One of the key advantages of this engine is its fuel efficiency, which makes it highly effective in accelerating various agricultural activities (Fadly & Pakan 2021). Diesel engines produce mechanical power through hot compression for combustion (Chakiim et al. 2023). Another notable advantage is the ability to handle heavy loads with optimal efficiency. According to (Ammar et al. 2023), the most important factor in diesel engine performance is the quality of the fuel used. Good fuel quality will produce good engine performance and overcome the impact of environmental pollution (Utomo & Anis 2021). Conversely, fuels with high carbon dioxide content negatively affect combustion stability (Ainuddin & Suryadilada 2021).

Biodiesel fuel is one of the renewable, environmentally friendly substitute energy sources for petroleum (Rahmandhika et al. 2024). It has a higher cetane number than conventional diesel, making it particularly effective in enhancing automatic starting performance in diesel engines (Wibowo et al. 2016). However, one of the disadvantages of diesel engines is the thickness of the smoke and the emissions produced (Nisa & Warju 2019). (Prahmana et al. 2020) mixed diesel fuel with citronella oil and 1% clove oil significantly reduced diesel engine fuel consumption by 18.3%. The raw materials for citronella oil and clove oil are relatively difficult to find in large quantities. (Arina et al. 2022) reported that adding Sorbitan Monooleate to biodiesel derived from palm oil and reducing the cloud point by 1.6^{o}C and cold filter plugging point by 2^{o}C enhances its usability in colder conditions. (Harsono & Siregar 2015) produced biodiesel from coconut oil production waste (*cocos nucifera*) with laboratory test results showing that a 70% diesel and 30% biodiesel mixture achieved a maximum power output of 5.37 horsepower (HP) at 2200 rpm, and a power efficiency of 97.64%. Emission test results also show that the mixture of diesel fuel and biodiesel from coconut oil production waste has a reduced carbon monoxide (CO) and hydrocarbon (HC) content. 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). While EGR technology offers performance benefits, it still generates considerable NOx emissions during application.

Several other efforts related to reducing the amount of production emissions are carried out continuously, one of which is with the help of Ultra Fine Bubble (UFB) technology. One of the unique features of UFB is its remarkable stability in water, allowing it to remain suspended for extended periods. UFB is commonly applied in various everyday processes, such as washing agricultural products and enhancing water quality (Yasuda 2023). (Wu et al. 2019) reported that nanobubbles can increase the oxygen concentration in water with a very small size for a long time remaining in the water. Nanobubble applications are currently widely used in water, and can also help reduce contaminants in water and improve water quality (Fuadi et al. 2020). (Sharif et al. 2019) also mixed nanobubbles into gasoline fuel, which resulted in increased combustion in gasoline engines if the bubbles were injected into gasoline fuel. The addition of oxygen to fuel using UFB has the potential to increase the effectiveness of combustion in diesel engines because the oxygen content makes the combustion reaction perfect. Therefore, it is necessary to test the addition of UFB to various diesel and biodiesel fuels to examine the performance produced by diesel engines.

METHODOLOGY

Production of UFB fuel

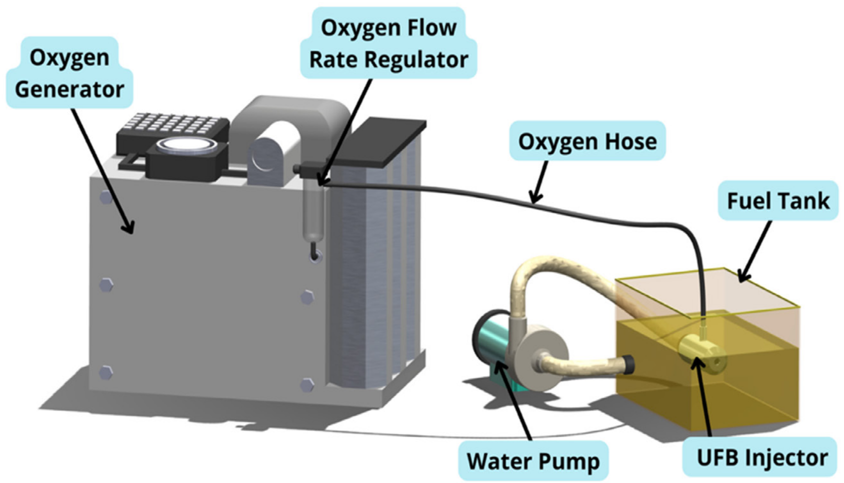


Figure 1
UFB generator diesel fuel

In this research, the fuels used were sourced from commercial suppliers. These included non-blended diesel (B0), a biodiesel-diesel mixture (B35) with a Fatty Acid Methyl Ester (FAME) percentage of 35%, and palm oil-based biodiesel, all obtained from suppliers in Indonesia. The method to produce fine bubbles involves injecting them into a liquid to enhance its oxygen content. This process is facilitated by an oxygen generator. Initially, the liquid is fed into a rotating pump, where centrifugal force is generated through the circulation of intake gas. This creates a gas vortex along the central axis. Then the gas is separated into fine bubbles at the outlet to form microbubbles. The greater the pressure on the nozzle, the smaller the bubble size. Fuel is subjected to UFB injection for 10 minutes with an oxygen discharge opening in the oxygen generator of 1 liter per minute (lpm). An illustration of the oxygen injection circuit into the fuel can be seen in Figure 1.

Analysis of fuel characteristic

Most of the compounds contained in diesel fuel are hydrocarbons. In addition, diesel fuel also contains small amounts of sulfur, nitrogen, and oxygen. Biodiesel is produced from the esterification or transesterification process of vegetable oils or animal fats in the form of fatty acid methyl esters (Fatty Acid Methyl Ester/FAME). The fuel was initially characterized based on its physical properties to observe any differences in these properties after the treatment with UFB. Parameters intended to characterize fuel and data collection methods are presented in Table 1.

Table I
Fuel characterization and test method

Parameter	Test method
Cetane Number	ASTM D613
Density	ASTM D445
Viscosity	ASTM D445
Sulfur Content	ASTM 4294
Flash Point	ASTM D93A
Fog Point	ASTM 5773
Pour Point	ASTM 5949
Lubricity	ASTM D6079
FAME	ASTM D8274

In this research, B0, B35, and biodiesel fuel were prepared under both standard and UFB conditions, with each test sample amounting to 8 liters. 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), each of which is stated on the test parameter tool. The testing was carried out at the Lemigas Application Building Characteristics Testing Laboratory, South Jakarta.

Emission testing

Performance testing was carried out using an instrument known as a hand tractor axle dynamometer. This instrument is a comprehensive measurement tool consisting of a two-wheeled hand tractor, a diesel engine, a fuel flowmeter, prony brake mechanism, compressor, water pump, and control panel. The specifications of the diesel engine used in the testing are presented in Table 2.

Table 2
Specification of diesel engine

Specification	Information
Model	Yanmar TF 85 MR-di no series DK7168
Number of Steps	4 Steps
Cylinders	1 Cylinder
Diameter x Step	85 mm x 87 mm
Continuous Power	5,5 kW / 7,5 DK
Maximum Power	6,2 kW / 8,5 DK
Cylinders Volume	0,493 Liter
Fuel Tank Capacity	10,5 Liter
Fuel	Diesel
Combustion System	Direct Injection

The first stage of this research involved preparing the two-wheeled tractor to be tested. A Yanmar TF85MR-di diesel engine was mounted on a Quick G1000 Boxer two-wheeled tractor. After the engine was mounted on the tractor, adjustments were made to ensure the engine and tractor were aligned and balanced. After the engine had been successfully seated, the fuel line to the engine was modified. Fuel distribution was redirected from an external fuel tank, requiring the removal of the hose connected to the engine's internal fuel tank and its replacement with a hose linked to the external tank. A proximity sensor was positioned on the wheel axle to measure rotation data on the wheel axle. An infrared sensor was positioned on the flywheel to measure engine rotation at the flywheel. After all sensors were properly installed, calibration was carried out. If differences were detected during calibration, the adjusted values were recorded and used as reference data. The setup for the performance test is presented in Figure 2.

The diesel engine is initially attached to a two-wheeled tractor, with a fuel flowmeter installed to measure fuel consumption, which is displayed on the control panel. The prony brake mechanism has an arm length of 41 cm, used to regulate the opening of the airflow rate produced by the compressor. This mechanism is connected to the tractor wheel axle and uses a disc on the braking canvas. The Prony brake is equipped with a loadcell force sensor which functions to measure the load. The load data is then multiplied by the arm length a constant distance from the shaft's center of rotation to the load cell to calculate the torque.

An infrared sensor is configured to target the flywheel, allowing it to measure the engine's rotational speed. This sensor detects binary signals (1 and 0) corresponding to the gear's peak and valley positions, which are then converted into shaft rotation value (rpm). The compressor is used during the prony brake mechanism to provide air pressure during the braking process under load. Meanwhile, the water pump ensures cooling water circulation for the loading mechanism, controlled pneumattically through a solenoid valve in the panel control room. The panel control room consists of a control panel, torque loading, as well as a fuel flowmeter display, engine speed display, and wheel axle rotation.

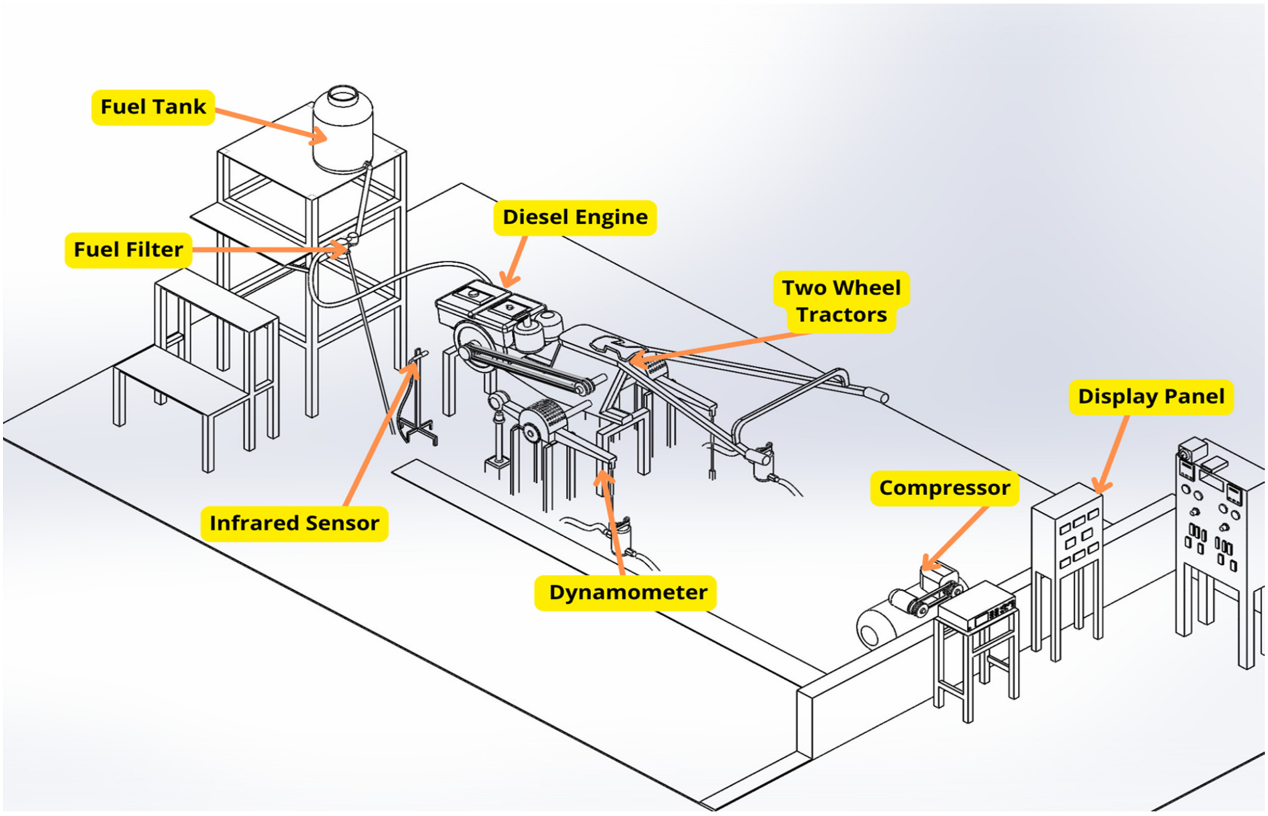


Figure 2
Performance test experimental setup

Data processing

Power

The power of a diesel engine refers to the energy generated by the engine that is utilized to perform work. In this case, the power is not measured directly at the engine's output but instead at the axle of the two-wheeled tractor driven by the diesel engine. The power calculation formula is:

$$bhp = \frac{\omega \times \tau}{1000} \tag{1}$$

$$bhp = \frac{2 \times \pi \times n \times \tau}{60 \times 1000} \tag{2}$$

Information:

ω = rotational speed of the wheel axle (rad/s)

τ = torque (Nm)

n = wheel axle rotation (rpm)

bhp = transmission power to the wheel axle (kW)

Specific fuel consumption

Specific fuel consumption (SFC) is the figure for the fuel used in the engine to produce the power or power used by the engine. SFC is calculated in units of time to indicate how good the fuel in the engine is for the resulting performance. The formulation of the SFC calculated is:

$$sfc = \frac{\dot{m}\text{bb}}{bhp} \tag{3}$$

$$sfc = \frac{fc \times \rho \times 3600}{bhp} \tag{4}$$

Information:

$\dot{m}bb$ = Fuel consumption rate (g/h)

ρ = fuel density (g/ml)

bhp = wheel axle power (kW) *SFC*

SFC = specific fuel consumption (ml/s)

RESULT AND DISCUSSION

Fuel characterization

UFB fuel injection was carried out for 10 minutes using an oxygen flow of 1 lpm. The fuel used in UFB injection research includes B0, B35, and biodiesel fuel. After the injection is carried out, the fuel is processed on the same day without special storage or special temperatures. The results of UFB injection into fuel regarding physical changes (color) of the fuel can be seen in Figure 3.

When observed directly, some fine bubbles remain in the fuel immediately after UFB injection. These visible bubbles rise to the surface, indicating they are microbubbles. The resulting nanobubbles will remain below the fuel whose shape cannot be seen directly because of their small size. It is not certain how long the residence time of nanobubbles in the fuel will last, but the results can be seen from the size of the nanobubbles formed. According to Gultom (2023), particles with a diameter of 528.9 nm contain 23% of the volume in the B30 UFB sample, and particles with a diameter of 568.1 nm contain 17% of the volume of the UFB biodiesel sample.

The fuel used in the research consisted of B0, B35, and CPO biodiesel fuel. The fuel characteristic data taken consisted of 13 parameters, following the ASTM method for each parameter. The results of the characteristic tests carried out are presented in the following Table 3:

The cetane number

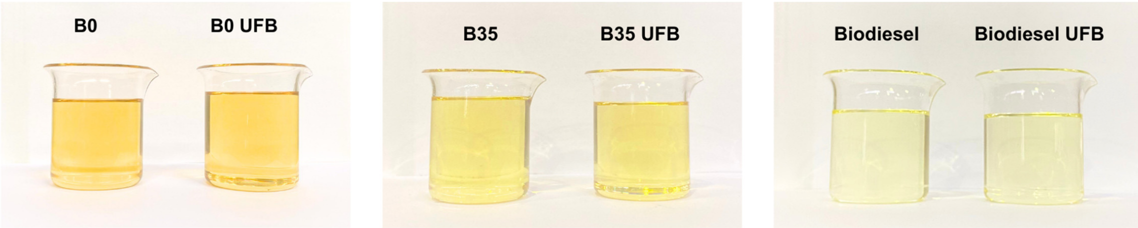
The cetane number is a key parameter indicating the ignition delay of fuel. Subsequently, fuel with a higher cetane number exhibits shorter ignition delay times, contributing to smoother engine operation (Fahmi and Idris 2024). Theoretically, biodiesel fuel has the highest cetane number compared to B0 and B335 fuel. Similarly, when fuel is injected with UFB, the results show an increase in the cetane number of each fuel. The fuel with the highest cetane number is biodiesel-UFB with a value of 59.8, while the lowest is B0 fuel with a value of 56.

Density and viscosity

The density and viscosity of B0 fuel increases after being treated with UFB, while biodiesel fuel remains the same after being treated with UFB. B35 fuel has a density of 840 kg/m^3 and after UFB treatment it increases to 833.4 kg/m^3. In contrast to its density, the viscosity of B35 fuel decreased by 1.2 mm^2/s after being treated with UFB.

Flash point

A flash point is an indicator of fuel at the lowest temperature that can burn when there is an ignition source. According to Ong'era et al. (2024), a flash point that is too low creates a risk of self-ignition and triggers fire accidents. In the tests carried out, biodiesel fuel had the highest flash point compared to B0 and B35 fuel. The application of UFB to fuel also increases the flash point of the third fuel, while the fog point decreases when given UFB treatment.



(a) (b) (c)

Figure 3
The color of (a) B0 fuel, (b) B35 fuel, (c) Biodiesel fuel before and after UFB treatment

Table 3
Characterization of fuel

Parameter	Unit	Fuel Type					
		B0	B0 – UFB	B35	B35 – UFB	Biodiesel	Biodiesel– UFB
The cetane Number	-	56	57,5	57,2	58,7	59,5	59,8
Density	kg/m^3	810	813	840	833,4	856,5	856,6
Viscosity	mm^2/s	2,67	2,72	3,2	3,08	4,4	4,4
Sulfur Content	%	0,007	0,006	0,005	0,003	0,004	0,003
Flash Point	ºC	57	60,4	65	69,4	136	152,3
Fog Point	ºC	7,4	3,6	8	5,5	12,9	12,9
Lubricity	micron	350	327,2	373,5	261,6	238,2	237,4
Oxidation Stability	minute	186,9	145,3	193,4	167,7	77,33	74,30
FAME	% v/v	0,36	-	35,15	35,74	96,6	96,6

Lubricity

Lubricity represents the ability of the fuel to lubricate rubbing parts. In diesel engines, the combustion chamber which has an injection pump does not have a lubrication system, thereby the fuel lubrication functions to lubricate it (Anwar 2015). In the three fuels tested, the addition of UFB can reduce the lubricity value of the fuel. B35 fuel had the most significant change in lubricity, namely decreasing by 29% when the fuel was treated with UFB. Reducing the lubricity value of UFB fuel will increase the lubricity properties of the fuel, thereby the fuel becomes better in terms of lubrication.

Performance result

Performance of B0

Based on analysis of B0 performance tests, it was found that the average power value produced by B0–UFB fueled engines was 3.46% higher than B0 fueled engines. B0–UFB fueled engines have an average power of 4.47 kW and B0 fueled engines have an average power of 4,32 kW. The torque produced by the engines using B0 and B0 UFB fuels is identical, with the average torque value for both fuels being 6899.2 Nfm. This is appropriate because UFB in fuel also increases the cetane number of the fuel. B0 has a cetane number of 56 while B0–UFB has a higher cetane number of 57.5. In addition, the flash point of B0 fuel treated with UFB also increased by 3.4^{o}C, while the fog point decreased. Meanwhile, SFC is represented in units of g/kW-h. The B0–UFB fuel engine obtained a higher SFC value compared to the B0 fuel engine. B0 fueled engines have an average SFC value of 328.9 g/kW-h while B0–UFB fueled engines have an average SFC value of 361,5 g/kW-h with a percentage difference between the two SFC values of 9,8%. The result of the performance test shown in a graphic can be seen in Figure 4.

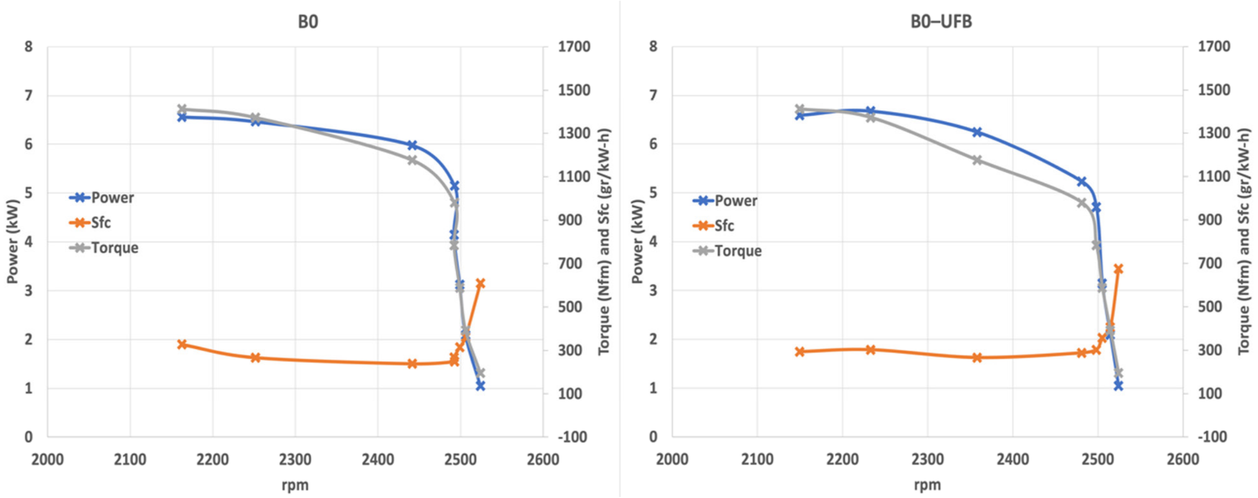


Figure 4
Performance of (a) B0, and (b) B0–UFB

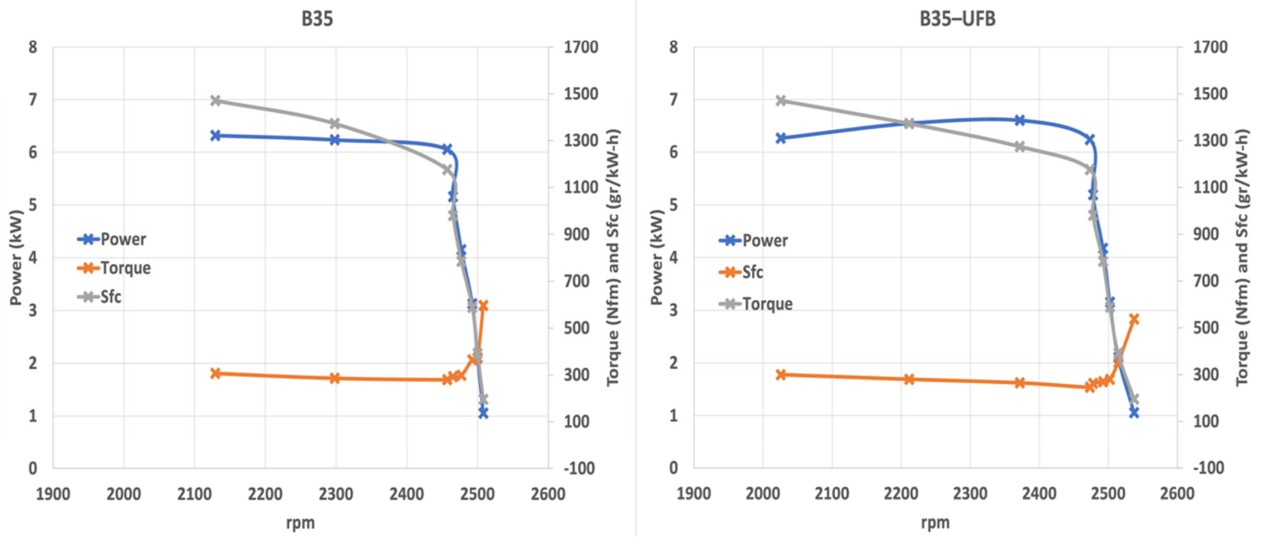


Figure 5
Performance of (a) B35, (b) B35–UFB

Performance of B35

Biodiesel-diesel blend fuel is a mixture of 35% biodiesel and diesel. This fuel represents an effort to reduce the use of non-renewable energy, specifically diesel fuel, by replacing it with a blend containing 35% biodiesel. B35 fuel is expected to enhance performance and reduce emissions in its application. The results of performance tests presented in Figure 5. B35 performance showed that the average power value produced by B35–UFB fueled engines was 7.45% higher than B35 fueled engines. The B35–UFB-fueled engine has an average power of 4.59 kW, while the B0 fueled engine has an average power of 4.27 kW. The following results are appropriate because UFB in fuel also increases cetane number of the fuel. B35 has a cetane number of 57.2 while B35–UFB has a higher cetane number of 58.7. In addition, the flash point of B35 fuel treated with UFB also increased by 4.4^{o}C, and the fog point of B35–UFB fuel decreased. The SFC value is represented in units of g/kW-h. The B35–UFB fueled engine obtained a lower sfc value compared to the B35-fueled engine. B35-fueled engines have an average SFC value of 349.3 g/kW-h while B0–UFB fueled engines have an average SFC value of 310.2 g/kW-h with a percentage difference between the two SFC values of 11. 2%.

Performance of biodiesel

Biodiesel fuel produced from crude palm oil (CPO) has a performance test and the result is presented in Figure 6. Performance test with the average power value produced by biodiesel–UFB fueled engines was 1.6% higher than biodiesel fueled engines. Biodiesel–UFB fueled engines have an average power of 4.73 kW and biodiesel-fueled engines have an average power of 4.66 kW. The power produced by UFB fuel increases according to the increase in the UFB cetane number in the fuel. Biodiesel has a cetane number of 59.5 while biodiesel–UFB has a higher cetane number of 59.8. Additionally, the flash point of biodiesel fuel treated with UFB also increased by 16.3°C, and the fog point of biodiesel–UFB fuel decreased. The SFC value is represented in units of g/kW-h. In biodiesel-fueled engines, UFB obtains a lower SFC value compared to biodiesel-fueled engines. Biodiesel-fueled engines have an average SFC value of 367.1 g/kW-h while biodiesel–UFB–fueled engines have an average SFC value of 348.2 g/kW-h with a percentage difference between the two SFC values of 5. 2%. The increase in power observed in biodiesel fuel after UFB treatment is also reflected by a decrease in SFC. Meanwhile, there are also differences in the characteristic values of biodiesel fuel when treated with UFB. The increase in power that occurs is not too high with 1.6% resulting in a decrease in SFC of 5.2%.

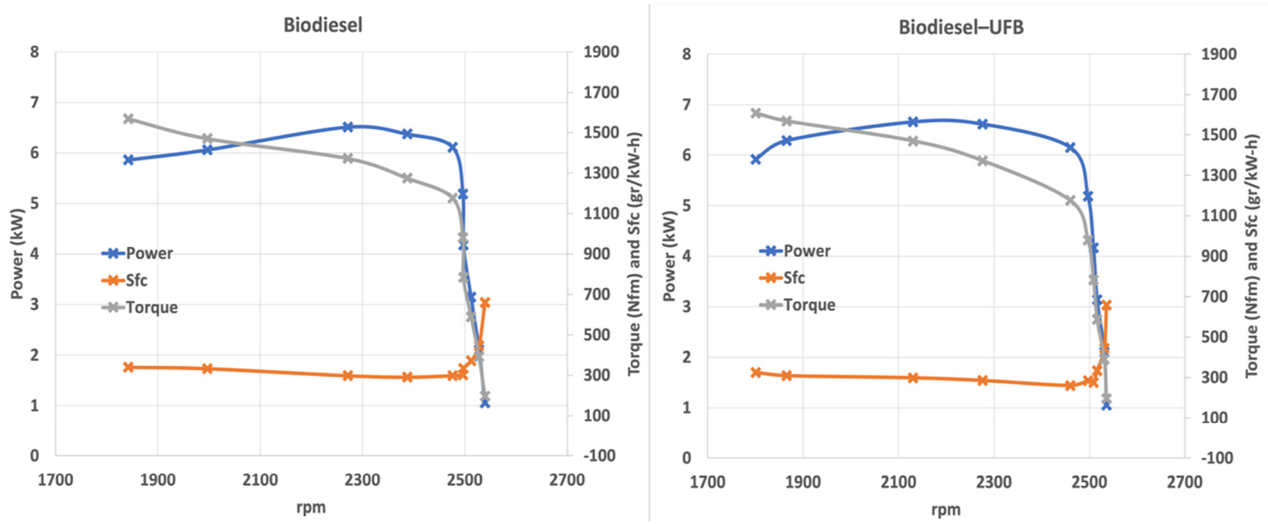


Figure 6
Performance of (a) Biodiesel, (b) Biodiesel–UFB

Average of power

Three diesel fuels tested showed an increase in the average power produced when the fuel was treated with UFB. The average power data produced by the three fuels is presented in Figure 7.

Under normal treatment, the fuel with the lowest average power is B35, with a value of 4.27 kW, while the highest average power is observed in biodiesel fuel, at 4.66 kW. After administering UFB, the lowest average power is recorded for B0 fuel at 4.47 kW, while the highest average power remains in biodiesel fuel, reaching 4.73 kW. The highest average power increase after UFB treatment was observed in B35 fuel, with an increase of 7.45%. This was followed by B0 fuel, which saw an increase of 3.46%, and biodiesel fuel, which increased by 1.6%. Biodiesel fuel has the smallest increase in average power because biodiesel without UFB also has the highest average power. Therefore, the best UFB can be given to B35 fuel which can increase the highest average power percentage after being given UFB.

Average of specific fuel consumption

The three diesel fuels tested show a decrease in the average SFC produced when the fuel was treated with UFB on B35 and biodiesel fuels. Meanwhile, there was an increase in SFC for B0 fuel when the fuel was treated with UFB. The average SFC data produced by the three fuels is presented in

Figure 8.

The fuel with the lowest average SFC in normal treatment is B0 fuel, namely 328.9 g/kW-h, while the highest average SFC is in biodiesel fuel, namely 367.1 g/kW-h. After administration of UFB, the fuel with the lowest average SFC is B35 fuel, namely 310.2 g/kW-h and the fuel with the highest average SFC is B0 fuel, 361.5 g/kW. -h. The highest average decrease in SFC after UFB treatment was observed in B35 fuel, which decreased by 11.2%. This was followed by biodiesel fuel, which decreased by 5.2%, while B0 fuel experienced an increase of 9.8%.

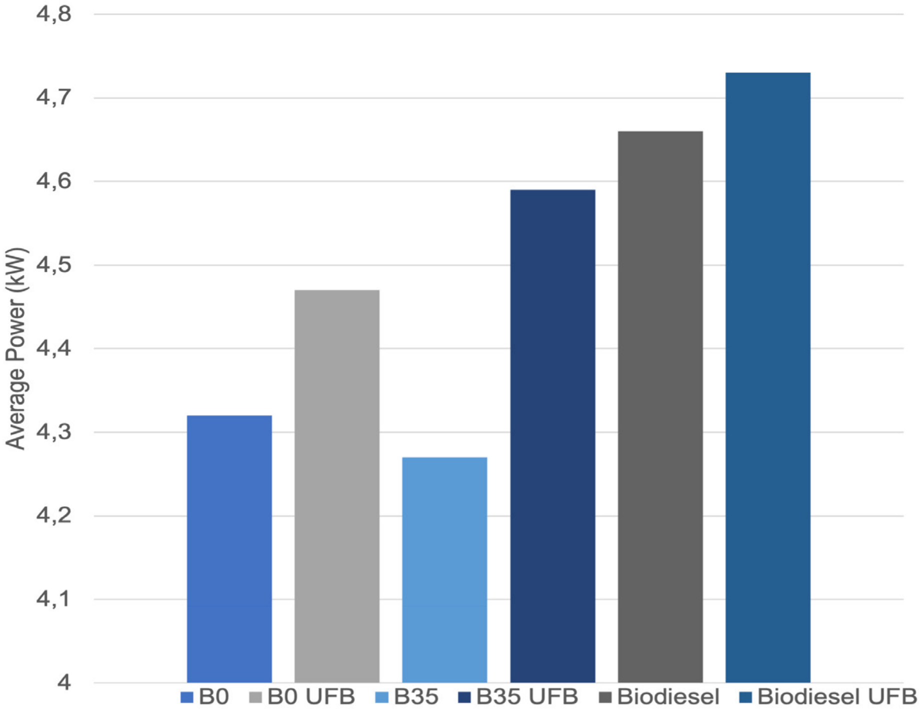


Figure 7
Average Power of B0, B35 and Biodiesel

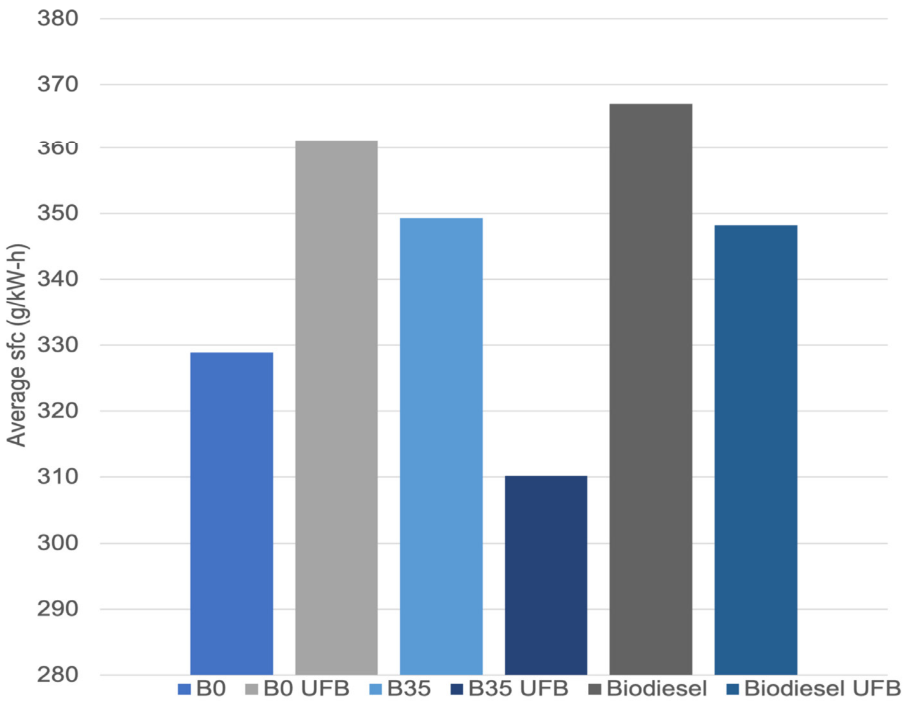


Figure 8
Average SFC of B0, B35 and Biodiesel

Therefore, the best administration of UFB can be carried out on B35 fuel which can reduce the highest average SFC percentage after administration of UFB.

CONCLUSION

In conclusion, UFB affected changes in cetane number, density and viscosity, flash point, fog point, lubricity, and oxidation stability of the fuel. The increase in the cetane number and flash point positively influenced the performance produced by the diesel engine. UFB increased power on B0 fuel by 3.46%, on b35 by 7.45%, and on biodiesel by 1.6%. Meanwhile, SFC for B35 fuel decreased by 11.2% and biodiesel fuel decreased by 5.2% after being treated with UFB. The best fuel to receive UFB treatment was B35, as it achieved the highest power increase of 7.45%, and the greatest reduction in SFC, with a decrease of 11.2%.

GLOSSARY OF TERMS

Symbol	Definition	Unit
UFB	Ultrafine bubble	
B0	Diesel Fuel (contains 0% biodiesel)	
B35	Biodiesel-Diesel blends (contains 35% biodiesel)	
SFC	specific fuel consumption	ml/s
P	power	kW
FAME	Fatty acid methyl esters	
ASTM	American Standard Testing Machine	
lpm	Liter per minute	

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REFERENCES

Ammar, M.D.N., Supriyadi, S. & Hermana, R., 2023, Uji Performa Mesin Diesel Isuzu C 190 Dengan Menggunakan Bahan Bakar Pertamina Dex. In *Proceeding Science and Engineering National Seminar* (Vol. 8, No. 1, pp. 320-327).

Anwar, C., 2015, Pengaruh pencampuran minyak sawit dan minyak solar sebagai pengganti minyak solar terhadap kinerja mesin. *Lembaran publikasi minyak dan gas bumi*, *49*(2), 119-130.

Ainuddin, Suryadilaga, M.A., 2021, Oil and Gas in the Dynamics of Time and Development. *Scientific Contributions Oil and Gas, 42* (2), 153-159.

Arina, H., Nasikin, M., 2022, Enhancement of Flow Properties Biodiesel Using Sorbitan Monooleate. *Scientific Contributions Oil and Gas, 45* (3), 143-152.

Chakiim, L., Supriyadi, S. & Hermana, R., 2023, Uji Performa Mesin Diesel Isuzu C190 Menggunakan Campuran Bahan Bakar Biodiesel Minyak Jelantah 30% Dengan Pertamina Dex 70%. In *Proceeding Science and Engineering National Seminar* (Vol. 8, No. 1, pp. 356-363).

Fadly ER, Pakan Y., 2021, Analisis variasi putaran terhadap torsi dan daya pada motor diesel satu silinder. Jurnal Voering. 6(1): 33-38. doi: 10.32531/jvoe.v6i1.378.

Fahmi, M.C. & Idris, M., 2024, Studi Eksperimental Angka Setana Diproduksi dari Minyak Goreng Bekas. *IRA Jurnal Teknik Mesin dan Aplikasinya (IRAJTMA)*, *3*(1), 101-107.

Fuadi, A., Sami, M. & Usman, U., 2020, Teknologi tepat guna budidaya ikan lele dalam kolam terpal metode bioflok dilengkapi aerasi buble oksigen. *Jurnal Vokasi*, *4*(1), 39–45.

Gultom YC., 2023, Analisis berbagai jenis bahan bakar ber-ufb terhadap kinerja mesin diesel pada traktor roda dua. [Skripsi]. Bogor: Institut Pertanian Bogor.

Harsono, S. S. & Siregar, K., 2015, Peningkatan kinerja mesin diesel dengan produksi biodiesel Dari kelapa (coconut nufera) dan unjuk kinerjanya berbasis transesterifikasi dengan sistim injeksi langsung. *Rona Teknik Pertanian*, *8*(2), 62-75.

Nisa IF, Warju, 2019, Pengaruh variasi bentuk exhaust manifold pada diesel particulate trap berbahan dasar kuningan dan wire mesh stainless steel terhadap performa mesin diesel 4 langkah. Jurnal Teknik Mesin Unesa. 7(3): 65-72.

Ong'era, C., Gathitu, B., Murunga, S., Kuloba, P. & Gathirwa, J., 2024, Evaluation of flash point and calorific value of nanostructured rapeseed oil biodiesel as an automotive fuel. *Journal of Agriculture, Science, and Technology*, *23*(1), 115-124.

Prahmana, R., Alfian, D., Supriyadi, D., Silitonga, D. & Muhyi, A., 2020, Pengaruh Komposisi Campuran Minyak Sereh Wangi dan Minyak Cengkeh terhadap Unjuk Kerja Mesin Diesel. *Journal Of Science And Applicative Technology, 4*(2), 82-85. doi:10.35472/jsat.v4i2.244.

Rahmandhika, A., Hasanah, N., Viandi, R. A. & Soegiharto, A.F.H., 2024, Pengaruh Campuran Minyak Jarak Pagar dengan Dexlite Terhadap Performa Mesin Diesel. *Quantum Teknika: Jurnal Teknik Mesin Terapan*, *5*(2), 49-54.

Rizky, A., Paryono & Nauri IM., 2020, Pengaruh penggunaan biosolar dan pertamina dex terhadap daya mesin dan emisi gas buang pada mesin diesel 4N15 common rail. *Jurnal Teknik otomotif Kajian Ilmuan dan Pengajaran*. 4(1): 9- 16.

Saputra, R. & Sunaryo, MF., 2019, Analisis kinerja mesin penggerak traktor pertanian model HST KHS 18 JTDB hasil perakitan lokal di PT. X Bina Teknika, *15*(2), 127-135. doi: 10.54378/bt.v15i2.1272.

Sharif PM, Hairuddin AA, As'arry A, Rezali KAM, Noor MM, Norhafana M. & Shareef SM., 2019, Nano Gas *Bubble*s Dissolve In Gasoline Fuel And Its Influence On Mesin Combustion Performance. *IOP Conference Series: Materials Science and Mesinering*, 1(2019), 3–5.

Siregar, S.P., Joni, J. & Ranteallo, O.T., 2024, Pemakaian Sistem Venturi Scrubber–EGR (Exhaust Gas Recirculation) Terhadap Performa Mesin Diesel Satu Silinder. *G-Tech: Jurnal Teknologi Terapan*, *8*(2), 964-974.

Utomo, O.H.A. & Anis, S., 2021, Pengaruh penambahan octane booster dan minyak atsiri dalam biosolar terhadap performa mesin diesel. *Sainteknol: Jurnal Sains dan Teknologi*, *19*(2), 36-45.

Wibowo, C.S., Anggarani, R., Hermawan, N. & Aisyah, L., 2016, Pengaruh kondisi penyimpanan terhadap stabilitas oksidasi bahan bakar jenis biodiesel (b-100), biosolar (b-20) dan minyak solar murni (b-0)(effect of storage conditions on oxidation stability of biodiesel (b-100), biosolar (b-20) and diesel fuel (b-0)). *Lembaran publikasi minyak dan gas bumi*, *50*(3).

Wu, Y., Lin, H., Yin, W., Shao, S., Lu, S. & Hu, Y., 2019, Water quality and *micro*bial community changes in an urban river after *micro- bubble* technology in situ treatment. *Journal Water (Switzerland), 11*(1), 1–14. doi: 10.3390/w11010066

Yasuda K., 2023, Characteristics of ultrafine bubbles (bulk nanobubbles) and their application to particle-related technology. *KONA Powder and Particle Journal*. 41(11): 183-196.