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Performance Testing of a Multicylinder Diesel Engine Using Antioxidant Bio-Oil Additives from *Moringa Oleifera* Leaf Pyrolysis

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Abstract

Crude oil reserves are steadily depleting. One viable alternative is the use of biodiesel fuel in diesel engines. However, a major drawback of biodiesel is its susceptibility to degradation due to low oxidative stability. Antioxidants are compounds that inhibit or slow down the oxidation process by preventing the formation of oxidants or reducing the propagation of free radicals. This study aims to investigate the effect of adding antioxidant additives derived from Moringa oleifera bio-oil, produced through pyrolysis, to B30 biodiesel fuel at concentrations of 0, 500, 1000, and 1500 ppm on the performance of a multicylinder diesel engine. A quantitative approach was employed using an experimental method, and data analysis was conducted using descriptive analysis. The results showed that fuel consumption decreased with the addition of Moringa oleifera antioxidants, with reductions of 5.31%, 6.66%, and 7.08% at 500 ppm, 1000 ppm, and 1500 ppm, respectively, at an engine speed of 2500 rpm. The highest torque was achieved with 1000 ppm of Moringa oleifera antioxidant at 2728 rpm, reaching 111.9 Nm (an increase of 4.48%), while the highest power output was also obtained at 1000 ppm, reaching 70.9 HP at 5100 rpm (an increase of 3.2%).

1. INTRODUCTION

The extremely high demand for petroleum has led to a significant depletion of oil reserves, as it contrasts sharply with the limited availability. According to the statement by Minister of Energy and Mineral Resources, Bahlil Lahadalia, in the ESDM press release (No: 491.Pers/04/SJI/2024), Indonesia's oil consumption in 2024 is reported to reach 1,600,000 barrels per day (Kementerian Energi dan Sumber Daya Mineral, 2024). In contrast, the country's oil lifting for the same year stands at only 600,000 barrels per day. Nearly 26–27% of total energy consumption is attributed to fuel used in the transportation sector (Imdadul et al., 2016). Diesel fuel is one of them; the increasing consumption of diesel has become an issue that must be anticipated. As a non-renewable fuel, if diesel consumption is not controlled, its availability will continue to decline and may be completely depleted by 2053 (Iskandar et al., 2020; Iskandar et al., 2024; Sentanuhady et al., 2021).

There are alternatives, one of which is the use of biodiesel in diesel engines. According to the Regulation of the Minister of Energy and Mineral Resources No. 12 of 2015, starting in January 2020, the use of biodiesel as a fuel blend must be at least 30%, known as Biosolar 30 (B30). In 2023, the sales of Biosolar reached approximately 37,567,411 kiloliters. The Indonesian government is making efforts to reduce dependence on fossil fuels, lower greenhouse gas emissions, and develop renewable energy sources.

Based on Regulation No: 1803 K/10/MEM/2018, the government designated business entities for petroleum fuels and biodiesel, as well as established rules for blending biodiesel with petroleum-based fuels. Potential feedstocks for biodiesel production include palm oil, soybean, sunflower, jatropha, sugarcane, avocado, and several other plant species (Devita et al., 2015). Coconut oil-based biodiesel has a calorific value close to that of diesel fuel and a lower flash point compared to diesel (Darmanto & Sigit, 2006). Biodiesel derived from palm oil has an acidity level of 0.24 mg-KOH per gram (Putri et al., 2015). The lower the acid number, the better the quality of the biodiesel, as it indicates a lower level of corrosiveness (Kartika & Pujiastuti, 2012).

One of the drawbacks of biodiesel is its susceptibility to degradation due to low oxidative stability. Biodiesel contains relatively high levels of corrosive compounds, making it necessary to add antioxidants to slow down the oxidation rate of the fuel (Suaniti et al., 2012).

Antioxidants are compounds that inhibit the formation of oxidants or reduce the propagation of free radicals. This is one of the main factors contributing to the decline in biodiesel fuel quality and negatively affects combustion performance (Das et al., 2021).

There are two types of antioxidants: natural and synthetic. Synthetic antioxidants include BHA, BHT, PPDA, geraniol, pyrogallol, TBHQ, DTBP, and others. Natural antioxidants, on the other hand, can be derived from plants such as mangosteen peel, soursop leaves, moringa leaves, and various others (Mohammed et al., 2023). Moringa oleifera can be used as a raw material for producing natural antioxidants for biodiesel fuel, using methods such as pyrolysis and distillation.

The pyrolysis process of Moringa oleifera produces bio-char, bio-oil, and gas, with the bio-oil being a potential source of natural antioxidants (Anis et al., 2021). GC-MS analysis of bio-oil derived from pine wood pyrolysis reveals the presence of phenolic antioxidant compounds, which are capable of increasing the oxidative stability of biodiesel by up to 175% (García et al., 2017).

The addition of synthetic antioxidant additives to biodiesel can affect its viscosity, density, and calorific value (Rizwanul Fattah et al., 2014). Fuels with high viscosity can be difficult to ignite, resulting in incomplete combustion (Maulana et al., 2023). The reduction in diesel fuel's density and viscosity can improve fuel atomization and promote a more homogeneous air–fuel mixture, thereby enhancing diesel engine performance in terms of torque and power, as well as reducing fuel consumption (Tirtoatmodjo & Willyanto, 2000).

2. RESEARCH METHODS

This study employs a quantitative research approach through experimental methods. This research began with the production of antioxidants from Moringa oleifera using the pyrolysis method. A 1:1 ratio of activated carbon to moringa leaf extract was subjected to pyrolysis at a temperature of 500°C. The antioxidant compounds were then filtered from the combustion residue using filter paper. The resulting antioxidants were added and mixed into B30 biodiesel fuel using a hand mixer for 10 minutes, with concentrations of 500, 1000, and 1500 ppm.

Subsequently, tests were conducted to measure fuel consumption, torque, and power. Fuel consumption testing was carried out by measuring the amount of fuel used by the diesel engine over a specific period. Vehicle performance testing was performed using a dynamometer.

The parameters used in this study include the following independent variable: the addition of antioxidants to B30 biodiesel at concentrations of 500, 1000, and 1500 ppm (equivalent to 0.5, 1, and 1.5 milliliters). Dependent variables: fuel consumption, torque, and power output.

Controlled variables: the raw material for antioxidant production (moringa leaves), engine temperature during testing (maintained at 70–80°C), the engine type (Isuzu Panther 2500 cc), standard injection timing, and standard engine compression ratio.

After obtaining the test data, the next step was data analysis. The data were analyzed using a descriptive analysis method, which involved calculating the average values from the results of the fuel consumption and engine performance tests. The findings were presented in the form of tables and graphs and described using concise and easy-to-understand language.

3. RESULTS AND DISCUSSION

The fuel consumption test of the diesel engine (kg/h) for each mixture of antioxidant-added B30 biodiesel was conducted that can be seen in Table 1.

Table 1. Fuel Consumption Test Results

Engine rotation (rpm)	Kg/ h			
	0 ppm	500 ppm	1000 ppm	1500 ppm
750	0,612	0.620	0.569	0.561
1500	1.020	1.020	1.003	0.960
2500	1.921	1.819	1.793	1.785

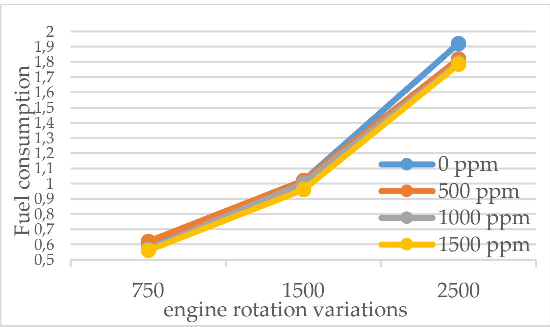

Figure 1. The Effect of Antioxidant Addition on Fuel Consumption

Based on Table 1 and Figure 2. these are shown that fuel consumption tends to increase as engine speed increases. However, the addition of natural antioxidants derived from moringa oleifera bio-oil at concentrations of 500, 1000, and 1500 ppm demonstrates a decreasing trend in fuel consumption compared to B30 biodiesel without antioxidant additives—especially at high engine speed (2500 rpm). Initially recorded at 1.921 kg/h, the addition of moringa oleifera antioxidants at 500, 1000, and 1500 ppm resulted in fuel consumption values of 1.819, 1.793, and 1.785 kg/h, respectively, corresponding to reductions of 5.31%, 6.66%, and 7.08%. The greatest reduction in fuel consumption occurred with the antioxidant addition at a concentration of 1500 ppm, which achieved a 7.08% decrease.

Based on the fuel consumption test data, it was shown that the greater the addition of moringa oleifera bio-oil antioxidant, the lower the fuel consumption. This occurs because the addition of moringa oleifera antioxidant additives to B30 biodiesel can alter the fuel's characteristics, particularly by reducing its viscosity due to the high oxygen content, which facilitates easier combustion. According to Tirtoatmodjo & Willyanto, (2000:127), in their research, the decrease in biodiesel viscosity can improve fuel atomization and result in a more homogeneous mixture of diesel fuel and air, thereby enhancing diesel engine performance in terms of torque and power, as well as reducing fuel consumption.

The results of the torque test on a multi-cylinder diesel engine using B30 biodiesel with the addition of Moringa oleifera antioxidants at concentrations of 500, 1000, and 1500 ppm can be seen in Table 2.

Table 2. Torque Test Results

Engine rotation (rpm)	Torque (Nm)			
	0 ppm	500 ppm	1000 ppm	1500 ppm
2200	53.1	62.4	59.9	60.0
2600	99.6	110.5	106.7	109.4
3000	105.3	107.7	108.2	106.2
3400	100.9	101.7	101.7	100.6
3800	97.2	98.0	97.8	96.9
4200	98.1	98.9	99.0	98.3
4600	99.4	100.4	100.6	99.8
5000	96.3	97.5	98.1	97.4
5400	86.1	87.8	88.7	87.9

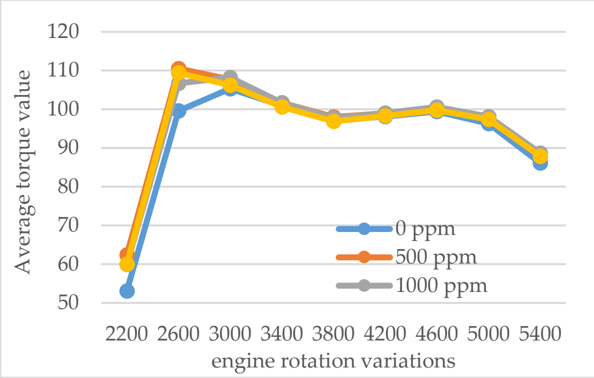

Figure 2. Torque Test Results

Figure 3 shows the effect of B30 biodiesel fuel with antioxidant additives on the average torque value. Among the tested concentrations, the addition of 500 ppm antioxidant resulted in the highest and most optimal torque compared to other antioxidant concentrations. The 500 ppm antioxidant addition led to an increase in torque of 3.46% compared to pure B30 biodiesel without antioxidant additives.

Table 3. Power Test Results

Engine rotation (rpm)	Power (HP)			
	0 ppm	500 ppm	1000 ppm	1500 ppm
2200	18.2	19.5	17.8	18.3
2600	38.3	40.9	39.5	40.5
3000	44.2	46.0	46.2	45.3
3400	47.8	49.2	49.2	48.7
3800	51.9	53.0	52.9	52.4
4200	56.1	59.2	59.2	58.8
4600	63.7	65.8	65.9	65.3
5000	67.8	69.4	69.9	69.3
5400	65.6	67.5	68.2	67.6

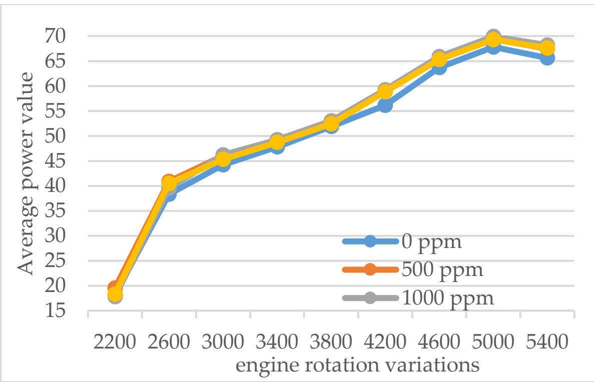

Figure 3. Power Test Results

Figure 3 shows the effect of B30 biodiesel fuel with antioxidant additives on the average power output. Among the tested concentrations, the addition of 500 ppm antioxidant resulted in the highest and most optimal power compared to other antioxidant concentrations. The 500 ppm antioxidant addition led to an increase in power output of 3.72% compared to pure B30 biodiesel without antioxidant additives.

Table 4. Maximum Torque Test Results

Variation of antioxidant addition (ppm)	Maximum torque value (Nm)	Engine rotation (rpm)
0	107,1	2755
500	111,6	2665
1000	111,9	2665
1500	111,1	2650

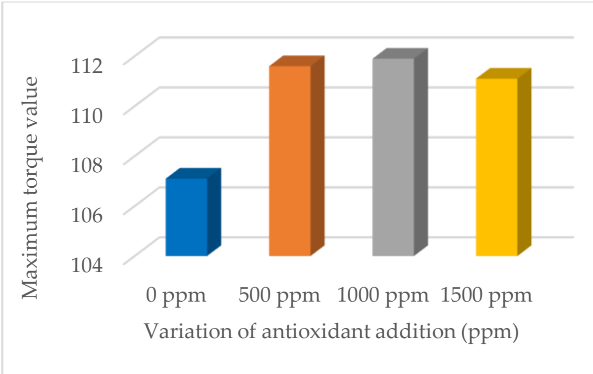

Figure 4. Effect of Antioxidant Addition on Maximum Torque Value

The highest torque value obtained from the engine performance test was recorded with the addition of 1000 ppm Moringa oleifera antioxidant to B30 biodiesel, reaching 111.9 Nm. In contrast, the lowest torque value was observed when using pure B30 biodiesel without antioxidant additives, which was 107.1 Nm. The increase in torque values due to the addition of Moringa oleifera antioxidants at concentrations of 500 ppm, 1000 ppm, and 1500 ppm was 4.2%, 4.48%, and 3.73%, respectively. These results indicate that the addition of Moringa oleifera-based antioxidant additives has a significant effect on increasing torque compared to pure B30 biodiesel.

The torque gains demonstrate that the use of Moringa oleifera antioxidants can enhance engine performance, particularly in terms of power output. The increase in torque associated with antioxidant concentration is likely due to changes in fuel viscosity caused by higher oxygen content, which facilitates easier and more complete combustion.

According to a study by Megawati et al., (2018), the addition of 5% v/v natural antioxidants derived from soursop leaves and mangosteen peels to B20 biodiesel was effective in reducing viscosity. Furthermore, Tirtoatmodjo & Willyanto, (2000) stated that reducing diesel fuel density and viscosity improves fuel atomization and produces a more homogeneous mixture with air, thereby enhancing engine power and reducing fuel consumption in diesel engines.

Table 5. Maximum Power Test Results

Variation of antioxidant addition (ppm)	Maximum power value (HP)	Engine rotation (rpm)
0	68.7	5045
500	70	5040
1000	70.9	5100
1500	70	5075

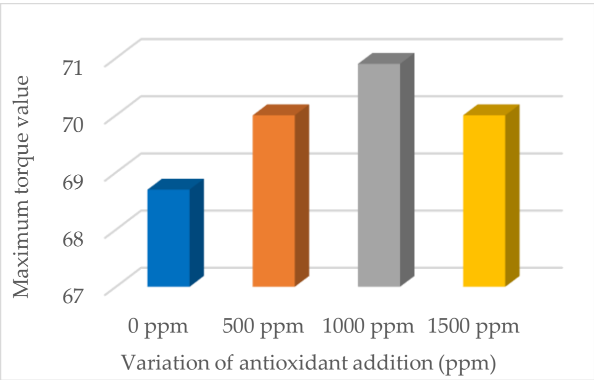

Figure 5. Effect of Antioxidant Addition on Maximum Power Value

The highest power output obtained from the engine performance tests was recorded with the addition of 1000 ppm Moringa oleifera antioxidant to B30 biodiesel, resulting in 70.9 HP. In contrast, the lowest power output was observed in the use of pure B30 biodiesel without any antioxidant additive, at 68.7 HP. The increase in power output due to the addition of Moringa oleifera antioxidants at concentrations of 500 ppm, 1000 ppm, and 1500 ppm was 1.9%, 3.2%, and 1.9%, respectively.

This indicates that the addition of Moringa oleifera-based antioxidant additives to B30 biodiesel significantly enhances engine performance, particularly in terms of power output, when compared to untreated B30 biodiesel. The highest power output was achieved with the 1000 ppm antioxidant concentration, suggesting that this level was the most effective in modifying the fuel's viscosity.

The observed performance improvements are likely due to the reduction in fuel viscosity caused by the antioxidant, which improves fuel pump efficiency and fuel atomization, thereby optimizing combustion and enhancing engine performance.

This finding is consistent with research by Rizwanul Fattah et al., (2014), who reported that the addition of 1000 ppm of synthetic antioxidants BHA and BHT to B20 biodiesel increased power output by 0.6% and 0.3%, respectively, compared to untreated B20. These enhancements were attributed to the reduced viscosity of the fuel, leading to more efficient combustion. Similarly, the use of Moringa oleifera as a natural antioxidant in B30 biodiesel demonstrates comparable potential in improving engine output and overall performance.

4. CONCLUSION

The addition of moringa oleifera antioxidant to B30 biodiesel has a positive impact on the fuel consumption of a multi-cylinder diesel engine. At an engine speed of 2500 rpm, the addition of 1500 ppm antioxidant resulted in a 7.08% reduction in fuel consumption. Moreover, the addition of Moringa oleifera antioxidant to B30 biodiesel positively affected engine performance, as indicated by an increase in both torque and power output. The highest torque was obtained with the addition of 1000 ppm antioxidant, reaching 111.9 Nm at 2665 rpm, or an increase of 4.48%. The highest power output was achieved at the same concentration, reaching 70.9 HP at 5100 rpm.

The authors recommend the use of Moringa oleifera bio-oil antioxidant additives at concentrations higher than 1500 ppm to explore the maximum potential improvement in torque and power output. Future research is also encouraged to include additional variables, such as the fuel characteristics of B30 biodiesel blends after the addition of Moringa oleifera bio-oil antioxidants. Furthermore, it is suggested that future studies consider using other types of fuels or antioxidants derived from alternative natural sources.

5. DECLARATION/STATEMENT

5.1. Acknowledgment

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5.2. Author Contribution

Jeri Juliyono wrote the article. Sonika Maulana was involved in the planning and supervision of the research. Rizqi Fitri Naryanto and Angga Septiyanto contributed to the design and implementation of the research, analysis of the results, and writing of the manuscript.

5.3. Conflict of Interest

We have no conflicts of interest to disclose.

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