



TESTING CENTER FOR OIL AND GAS LEMIGAS

SCIENTIFIC CONTRIBUTIONS OIL AND GAS (SCOG)

Vol. 49. No. 3, September: 477 – 492 - <https://journal.lemigas.esdm.go.id>

ISSN: 2089-3361, e-ISSN: 2541-0520

Published by:

LEMIGAS

Comparative Analysis of B35–B40 Biodiesel Blends in Passenger Train Generator Sets: Performance, Emissions, and 1,200 h Endurance Tests

Riva Yudha Abriyant^{1,2,3*}, Naufal Rasendriya Azmi¹, Irawan Adhi Putra¹, Faqih Supriyadi¹, Yogi Pramudito¹, Dimaz Warahadi¹, Riesta Anggarani¹, Eki Dwi Wijanarko⁴, Cahyo Setyo Wibowo^{1,2} and Ahmad Syihan Auzani³

¹Fuel & Lubricant Laboratory, Department of Product Application Technology,
Balai Besar Pengujian Minyak dan Gas Bumi LEMIGAS,
Ciledug Raya Street, Lot 109, Cipulir, Kebayoran Lama, South Jakarta, 12230, Indonesia.

²Indonesian Association Bioenergy Experts (IKABI),
Jakarta, Indonesia.

³Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia,
Depok, 16424, West Java, Indonesia.

⁴Directorate General of Renewable Energy and Energy Conservation,
Ministry of Energy and Mineral Resources, Republic of Indonesia,
Pegangsaan Timur Street No. 1, Menteng, Central Jakarta 10320, Indonesia.

*Corresponding author: Riva Yudha Abriyant (riva.abriyant@esdm.go.id)

Riva Yudha Abriyant: <https://orcid.org/0009-0002-5777-6179>

Received: 17 April 2026; Revised: in revised form 07 August 2026; Accepted: 09 September 2026
Available: online 30 September 2026.

ABSTRACT - The transition from B35 to B40 biodiesel is a key step toward reducing dependence on fossil diesel in railway power systems. Still, its field performance in passenger-train generator sets remains insufficiently established. This study comprehensively evaluates the fuel-lubricant quality, engine performance, fuel consumption, NO_x emissions, component rating, and filter behavior of B40 biodiesel blends in an MTU 10V1600G20F passenger-train generator set. Initial tests compared B35 and B40 under various load conditions, followed by a 1,200 h dynamic endurance test with B40 under railway operating conditions. Initial test results showed that B40 had a higher cetane number than B35 but a lower heating value and higher water content, reflecting the expected trade-off of increasing FAME content. B40 delivered comparable power (-3.88%-1.78%) to B35 at higher loads, while fuel consumption remained similar (-2.91%-0.03%) under medium- and high-load operation. After 1,200 h, B40 maintained stable power output (0.33%-0.38%) and fuel consumption (0.75%-1.56%), with no progressive increase in NO_x emissions. All measured NO_x values remained below regulatory limits. Lubricant analysis, component rating, and filter monitoring showed no severe oil degradation, abnormal component damage, or visible filter blockage. These findings indicate that B40 is technically feasible for passenger train generator operation when supported by controlled fuel quality and routine maintenance.

Keywords: B40 biodiesel; B35–B40 blends; passenger train generator set; endurance test; NO_x emissions.

How to cite this article:

Riva Yudha Abriyant, Naufal Rasendriya Azmi, Irawan Adhi Putra, Faqih Supriyadi, Yogi Pramudito, Dimaz Warahadi, Riesta Anggarani, Eki Dwi Wijanarko, Cahyo Setyo Wibowo and Ahmad Syihan Auzani, 2026, Comparative Analysis of B35–B40 Biodiesel Blends in Passenger Train Generator Sets: Performance, Emissions, and 1,200 h Endurance Tests, Scientific Contributions Oil and Gas, 49 (3) pp. 477-492.



© 2026 The Author(s). Published by LEMIGAS under the Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA 4.0)

<https://doi.org/10.29017/scog.v49i3.2129> | 477

1. Introduction

Indonesia has rapidly advanced from low biodiesel blending levels to high-biodiesel-blend fuels, such as B35 and B40. B35 and B40 refer to diesel fuels containing 35 vol.% and 40 vol.% biodiesel, respectively, with the remainder being petroleum diesel. The biodiesel component primarily consists of Fatty Acid Methyl Ester (FAME), which is commonly produced from palm oil in Indonesia. Following the implementation of B20 and B30, the national program progressed to B35 and is currently transitioning toward B40 for wider transport use. This transition is driven by the need to reduce fossil diesel imports, strengthen the domestic palm-oil biodiesel industry, and lower greenhouse gas emissions from the transport sector (Reksowardojo et al., 2020, Reksowardojo et al., 2023; Wirawan et al., 2024). However, higher biodiesel use also shifts part of the challenge from fuel supply to fuel performance. For diesel-dependent industries, particularly those operating engines with long duty cycles, B40 must be evaluated not only as a compliant fuel blend but also as an operational fuel that sustains power output, fuel efficiency, and filtration reliability (Karabulut et al., 2024; Wojcieszuk et al., 2023).

Railway power systems are a relevant case for this assessment. Specifically, passenger train generator sets supply electrical power to onboard systems and must operate for long periods with stable output. Train generator engines experience repeated load changes, long running hours, daily refueling, and practical exposure to fuel storage and filtration systems. Therefore, B40 use in this sector requires evidence on power stability, fuel consumption, emissions, lubricant condition, engine component cleanliness, and filter behavior during extended operation. In addition, biodiesel has several advantages as a diesel blending component. Its oxygenated methyl ester structure can support more complete combustion and reduce some smoke-related emissions (Musthafa & Asokan 2023; Zhang et al., 2022). However, increasing the biodiesel fraction also changes the fuel properties. Biodiesel generally has a higher density, viscosity, and water affinity, and a lower calorific value than petroleum diesel (Barabas & Todoru 2011; Achmad et al., 2025). These characteristics can influence fuel injection, combustion behavior, fuel consumption, storage stability, and filterability. In high-blend applications such as B40, these issues become more relevant because small shifts in properties can affect engine reliability during continuous operation. Previous studies have reported that biodiesel blends can affect fuel filter clogging, injection-system cleanliness, water uptake, oxidation stability, and engine performance. Monoglycerides and water content are especially important because they can contribute to deposits or filter blockage in high-biodiesel blends (Chupka et al., 2011; Pichler et al., 2024). For this reason, improved B40 fuel quality, including controlled monoglyceride and water content, as well as oxidation stability, is needed before field implementation. In railway generator sets, this issue is practical because filter replacement, fuel pressure drop, or deposit accumulation can disturb operation and maintenance schedules.

Previous studies show that biodiesel blends can improve some combustion and emission characteristics, but they also introduce clear operating trade-offs. Palani et al. (Palani et al., 2022) reported that diesel–biodiesel blends can shorten ignition delay and reduce CO, HC, and particulate emissions. Similar trends were observed by Fangyuan Zheng et al. (Zheng & Cho 2024), in which higher biodiesel content reduced CO, HC, and smoke. At the same time, NO_x and BSFC increased due to the lower calorific value and higher viscosity of biodiesel. Karabulut et al. (Karabulut et al., 2024) also showed that increasing the biodiesel fraction can raise specific fuel consumption and NO_x emissions, especially at higher loads and speeds, while reducing effective efficiency. With the transition from B35 to B40, filterability is central to this assessment because the filter is both the final protection for the injection system and the most sensitive location for deposit accumulation (Cardeno et al., 2020; Thangamani & Jeyaseelan 2024). Higher biodiesel blends are more prone to this issue because increased biodiesel content can raise viscosity, water affinity, and the concentration of saturated ester- or glyceride-derived species that may form wax-like or crystal-like precipitates, especially at lower temperatures or during prolonged circulation (Allif Fathurrahman et al., 2022; Gozan et al., 2022; Na-Ranong & Kitchaiya 2014). As deposits accumulate within the filter medium, the differential pressure across the filter increases, providing a direct indicator of flow restriction. Earlier work has shown that saturated monoglycerides, cold-soak precipitates, and fine contaminants can accelerate pressure build-up and shorten filter run time (Paryanto et al., 2019; Paryanto et al., 2022). For this reason, filterability analysis is essential for B35–B40 evaluation. In addition, Aaryan Chib et al. (Chib & Dugala 2024) demonstrated that higher biodiesel content can worsen fuel filter behavior, with B40

showing a greater tendency for filter blocking than B20. However, most available studies were carried out using laboratory engines, short-duration tests, or fuel-filter rigs. There is still limited evidence regarding how B35 and B40 behave in passenger-train generator sets during extended field operation, where power stability, fuel consumption, NO_x emissions, lubricant condition, component cleanliness, and filter response must be evaluated together.

Despite increasing interest in B40 implementation, there remains limited field-based evidence for passenger-train generator engines. Most biodiesel studies focus on vehicle engines, single-cylinder laboratory engines, or short-duration tests. Less attention has been given to railway generator sets operating over long endurance periods, where fuel performance, emission stability, lubricant condition, and component response can be evaluated together. This creates a gap between compliance with fuel specifications and operational confidence. Motivated by these, the current study addresses that gap by comparing B35 and B40 in an MTU 10V1600G20F passenger train generator set and by conducting a 1,200 h dynamic endurance test with B40. Fuel properties were first evaluated to confirm compliance with specifications and to explain the expected engine response. Performance tests were then conducted to compare power and fuel consumption between B35 and B40. During the endurance test, B40 performance, fuel consumption, NO_x emissions, lubricant condition, engine component condition, and Racor filter appearance were monitored at defined intervals.

2. Methodology

2.1 Fuel test sample preparation and characterization

The test fuels consisted of B0, B100, B35, and B40. B0 petroleum diesel and B100 palm-oil biodiesel were supplied by PT Pertamina Patra Niaga and the Indonesian Biofuel Producers Association (APROBI), respectively. B35 was prepared by blending 35 vol.% B100 with 65 vol.% B0, while B40 was prepared by blending 40 vol.% B100 with 60 vol.% B0. Blending was conducted using an in-line blending system at BBPMGB LEMIGAS and at the Lempuyangan fuel facility to obtain homogeneous fuel mixtures before testing. Fuel characterization was carried out to confirm compliance with specifications and to support the interpretation of the engine results. The measured parameters, which follow the ASTM standard method, included cetane number, density, kinematic viscosity, sulfur content, distillation temperature, flash point, pour point, water content, acid number, FAME content, calorific value, lubricity, oxidation stability, monoglyceride content, cold filter plugging point, filter blocking tendency, and cleanliness, depending on the fuel type. B40 fuel quality was also checked during storage and before use in the engine tank to identify possible changes between storage and operational handling.

2.2 Engine testing and 1,200 h dynamic endurance operation

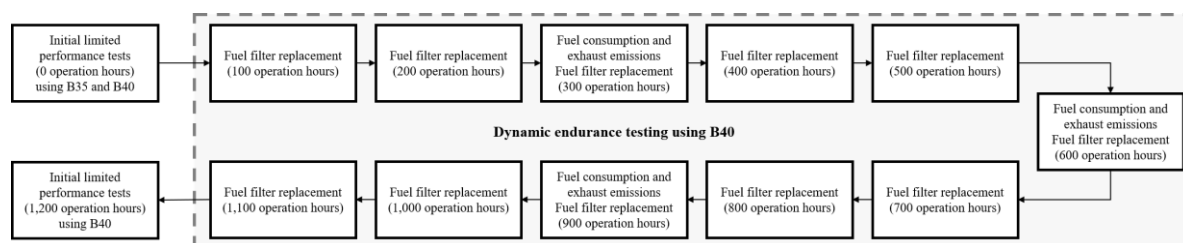


Figure 1.

Stages of engine testing and 1,200 h dynamic endurance operation.

Engine testing was conducted using an MTU 10V1600G20F passenger train diesel generator set. As shown in Figure 1, initial limited performance tests were performed using B35 and B40 to compare power output and fuel consumption under controlled load conditions. The engine was tested at several load levels, ranging from low to high load, using a self-load bank. Engine power and fuel consumption were recorded at each operating point after stable operation was reached. Dynamic endurance testing was then conducted using B40 for 1,200 h of generator-

set operation on the Bogowonto passenger train route between Pasar Senen Station in Jakarta and Lempuyangan Station in Yogyakarta. B40 was supplied daily to the generator-set fuel tank. During the endurance test, field fuel-quality checks were conducted after blending and before distribution to the engine tank. Fuel consumption and exhaust emissions were evaluated every 300 h. The fuel filters were replaced every 100 h, and fuel-pressure readings were taken before replacement to monitor possible filtration restriction.

2.3 Emission, lubricant, component, and filter evaluation

NO_x emissions were measured during the limited performance and endurance tests to evaluate the emission response of B40 relative to B35 and to assess emissions after extended operation. Emission results were compared with the applicable regulatory limit for railway diesel engines. Lubricant samples were collected at defined operating intervals and analyzed for viscosity, flash point, water content, total base number, total acid number, insoluble content, fuel dilution, and wear metals. These measurements were used to assess whether B40 operation affected lubricant degradation or wear-related indicators. Minor merit rating inspections were conducted before and after the 1,200 h B40 endurance test to examine the condition of key engine components, including the piston, cylinder liner, intake valve, exhaust valve, and injector. Visual inspection was used to identify deposits, wear, surface changes, or abnormal damage. Racor filters collected at 100 h intervals were visually inspected to monitor dirt accumulation, discoloration, and possible blockage. These observations were used as supporting evidence for fuel cleanliness, filterability, and short-term component compatibility during B40 operation.

3. Result and discussion

3.1 Fuel quality and lubricant test results

Fuel characterization was first conducted to establish the quality baseline prior to engine testing. The results show that increasing biodiesel content from B0 to B35 and B40 improved ignition quality, as reflected by the cetane number increase from 49.4 (B0) to 54.7 (B35) and 55.2 (B40), as shown in Table 1. This behavior is consistent with the higher cetane improver nature of palm-based biodiesel compared with petroleum diesel. The biodiesel sample showed the highest cetane number of 60.2, confirming its strong contribution to ignition quality in the blended fuels. The main trade-off of increasing the biodiesel fraction was seen in fuel energy and storage-related properties. The higher heating value decreased from 45.76 MJ kg⁻¹ for B0 to 44.03 MJ kg⁻¹ for B35 and 43.58 MJ kg⁻¹ for B40. This reduction is important because a lower heating value can increase fuel demand when the engine must deliver the same electrical output. As the biodiesel content increased from 35.4 vol.% in B35 to 39.8 vol.% in B40, the water content and acid number increased accordingly. Furthermore, water content increased from 130 mg kg⁻¹ (B0) to 250 mg kg⁻¹ (B35) and 260 mg kg⁻¹ (B40), while acid number increased from 0.06 to 0.21 and 0.12 mg KOH g⁻¹, respectively.

Other properties also show how B35 and B40 differ in practical fuel-system behavior. For instance, the density remained within a narrow range for B35 and B40, while viscosity increased. This higher viscosity in B40 can influence injection and atomization, especially during repeated operation in train generator sets. Sulfur content decreased from 1200 ppm in B0 to 200 ppm in B35 and 600 ppm in B40, reflecting dilution by low-sulfur biodiesel and supporting lower sulfur-related emission potential. Meanwhile, the biodiesel used in blending had 98.77 wt.% methyl ester content and 0.32 wt.% monoglycerides. The low monoglyceride value is important because monoglycerides are commonly linked to precipitate formation and filter clogging in high-biodiesel blends.

Lubricant analysis was used to support the engine-performance results by checking whether the 1,200 h B40 operation affected oil condition. Table 2 shows the new and used lubricant characteristics. The kinematic viscosity at 100 °C remained stable between 12.72 and 12.13 cSt over 1,200 h. This variation indicates that viscosity did not show a continuous thickening trend during operation. Flash point remained high, between 228 and 238 °C, compared with 242 °C for the new oil, suggesting that severe fuel dilution or volatile contamination was not evident. Fuel dilution also decreased from 2.76% at 300 h to 1.40% at 1,200 h, supporting the view that unburned fuel accumulation in the lubricant was not progressive under the tested condition. In addition, the acid–base

balance also showed acceptable behavior during the test period. This indicates that the lubricant still retained a large part of its alkalinity reserve after extended B40 operation. Pentane insoluble and toluene insoluble values remained low, with maximum values of 0.0211 g and 0.0102 g, respectively, at 1,200 h. This suggests that sludge-forming or carbonaceous insoluble material was still limited. The water-content values also remained within a narrow range. Meanwhile, wear-metal results further suggest that B40 operation did not cause abnormal wear during the 1,200 h test. Additive-related elements such as Ca, Mg, and Zn were still detected throughout operation, showing that the lubricant additive system remained present after extended use.

Table 1.
Physicochemical properties of diesel fuel (B0), B35, B40, and biodiesel (B100)
used in the passenger train generator-set evaluation.

Properties	Fuel samples				Testing methods
	Diesel fuel (B0)	B35	B40	Biodiesel (B100)	
Cetane number	49.4	54.7	55.2	60.2	ASTM D613
Density at 15 °C (kg/m ³)	858.0	856.4	856.9	876.1	ASTM D4052
Kinematic viscosity at 40 °C (cSt)	3.850	3.382	3.849	4.439	ASTM D445
Sulfur content (ppm)	1200	200	600	-	ASTM D4294
Distillation at 90° (°C)	340.5	341.5	341.2	344.6	ASTM D86/1160
Water content (mg/kg)	130	250	260	270	ASTM D6304
Acid number (mg KOH/g)	0.06	0.21	0.12	0.20	ASTM D664
FAME content (%v/v)	0	35.4	39.8	-	ASTM D 8274
Higher heating value (MJ/kg)	45.76	44.03	43.58	40.64	ASTM D240
Monoglycerides (%w/w)	-	-	-	0.32	ASTM D6584
Methyl ester content (%w/w)	-	-	-	98.77	EN 14103

Table 2.
New and used lubricant characteristics of the passenger train generator engine during 1,200 h operation with B40.

No	Parameter	Unit	Limits	Train generator lubricant				
				New oil	300 hours	600 hours	900 hours	1.200 hours
1	Kinematic viscosity at 100°C	cSt	-1	10.48	12,72	13,07	13,12	12,92
2	Flash point	°C	<190	232	230	228	268	228
3	Water content	ppm	>0,2	-	131	112	66.5	66.4
4	Total base number	mgKOH/g	<60%	12.10	11,45	11,81	12,10	10,70
5	Total acid number	mgKOH/g	>New oil + 1,5	-	0,123	0,083	0,140	1,617
6	Pentane insoluble	gr		-	0,0154	0,0147	0,0107	0,1932
7	Toluene insoluble	gr		-	0,0082	0,0072	0,0049	0,0163
8	Fuel dilution	%		-	2,76	2,15	1,70	1,40
9	Metal content	Ca	% mass	0.177	0,229	0,228	0,235	0,224
		Mg	% mass	0.053	0,054	0,051	0,0018	0,053
		Zn	% mass	1.54	0,149	0,157	0,1338	0,158
		Fe	ppm	-	5,3	6,8	8	7,5
		Cr	ppm	-	4,9	4,2	3,6	3,8
		Cu	ppm	-	1,4	1,2	1,4	1
		Al	ppm	-	4,1	3,5	1,2	1,2

3.2 Power and fuel consumption analysis

The power and fuel-consumption results in Table 2 to 5 indicate that B40 can maintain the functional performance required for passenger-train generator operation, despite its lower calorific value compared with B35. As expected, power output increased with load for both fuels. At 5% load, the difference between B35 and B40 was negligible, with 21 kW for B35 and 22 kW for B40. Between 25% and 55% load, B35 produced slightly higher power than B40, with differences of about 2–4 kW, corresponding to -3.88% to -1.78% for B40. This small reduction is consistent with the lower energy content of B40. However, at higher loads of 65% and 75%, B40 matched or slightly exceeded B35, with differences of 0.38% and 0.33%, respectively. This indicates that the lower heating value of B40 did not translate into a clear power limitation under the higher-load conditions more relevant to generator-set operation.

This load-dependent response has an important practical meaning. Passenger train generator sets are expected to supply stable electrical power during long operation, and their performance at medium-to-high loads is more critical than at very low load. The fact that B40 approached or matched B35 at high load suggests that the engine could compensate for the fuel-property difference through its normal combustion and load-control response. Therefore, the performance impact of increasing the biodiesel fraction from B35 to B40 was not uniform across the load range. It was more visible at intermediate loads, but became less important at high loads. This finding supports the use of load-resolved analysis when evaluating higher biodiesel blends, rather than relying solely on a single average power value.

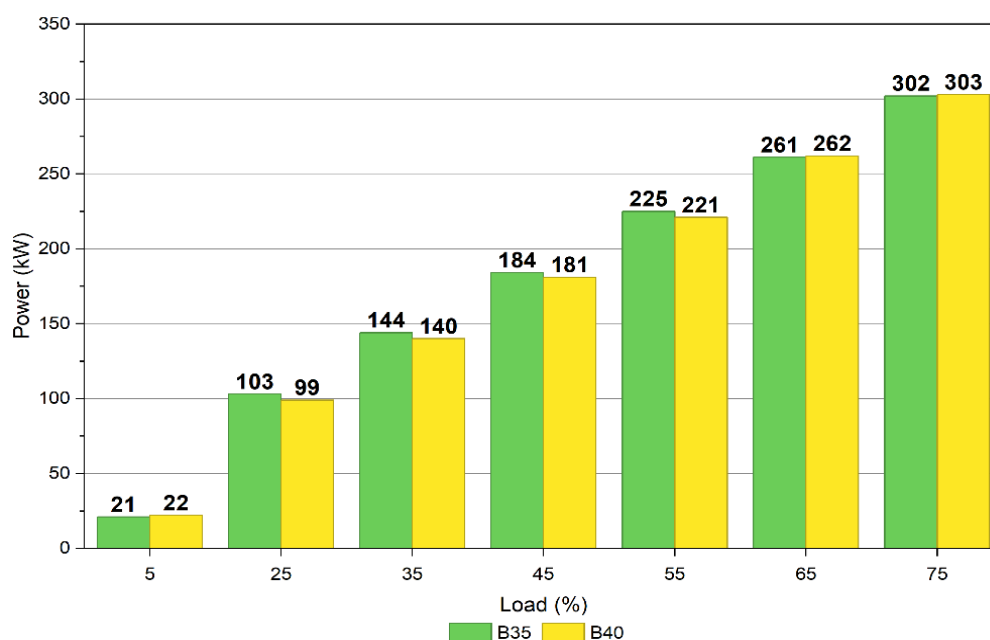


Figure 2.

Power output comparison between B35 and B40 under initial operating conditions at different load levels.

Fuel consumption showed a similar pattern in Figure 4. At 5% load, B40 consumed 2.38% more fuel than B35, which is reasonable because the higher biodiesel fraction lowers the energy content per unit fuel. However, at loads of 25% and above, the difference between B35 and B40 became small, ranging from -2.91% to -0.03% . This suggests that, under practical operating loads, B40 did not cause a meaningful fuel-consumption penalty compared with B35. For railway operations, this is an important result because small differences in consumption can become economically significant over long service periods. Nevertheless, the data indicate that the fuel-use behavior of B40 remained broadly comparable to B35 during medium- and high-load operation. The 1,200 h endurance comparison further strengthens this interpretation. Power output with B40 remained nearly unchanged

after extended operation, with differences generally within ± 1 kW or about 0–1% across the tested load points. As shown in Figure 5, fuel consumption also remained stable after 1,200 h, with only small changes of 0.75–1.56% at 25–75% load, while the 5% load point even showed lower consumption after endurance operation. These results suggest that prolonged B40 use did not produce measurable performance loss or progressive fuel-consumption deterioration under the tested conditions.

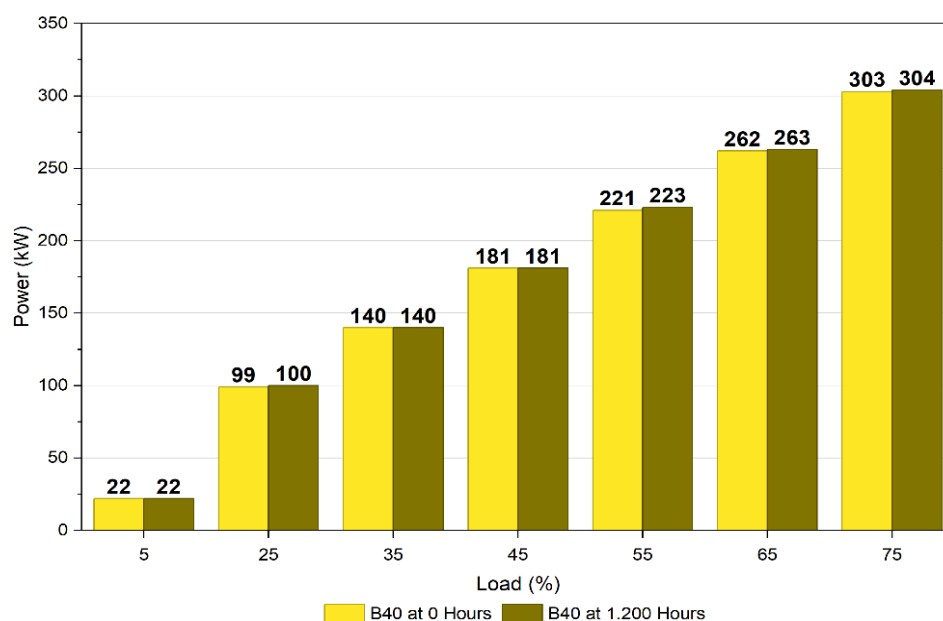


Figure 3.
Power output of B40 before and after 1,200 h of generator-set operation.

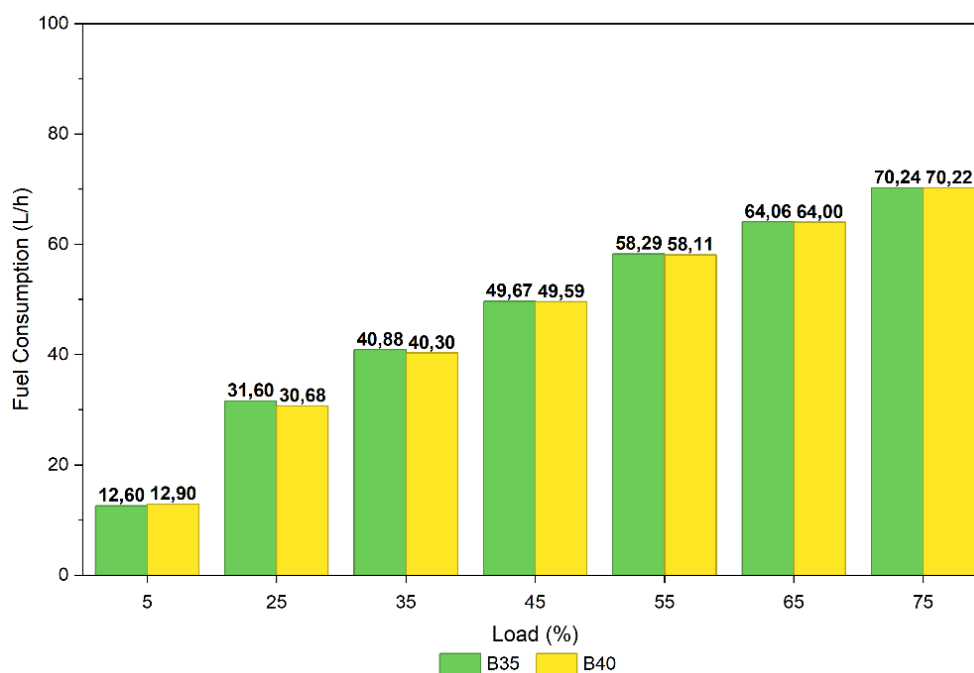


Figure 4.
Fuel-consumption comparison between B35 and B40 at the initial operating condition.

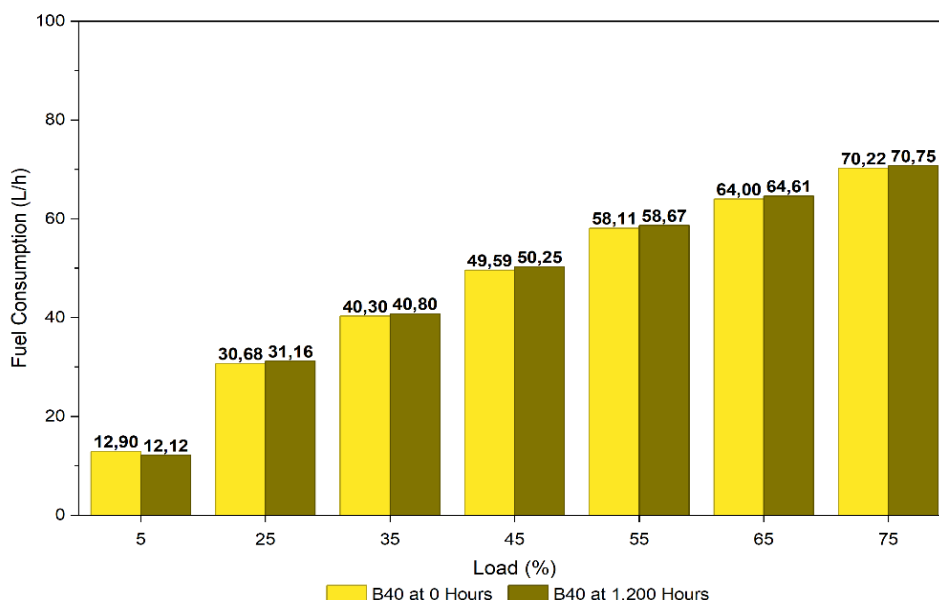


Figure5.

B40 fuel consumption before and after 1,200 h of generator-set operation NOx emission

The NO_x results provide an important check on the emissions implications of switching from B35 to B40 in passenger-train generator operation. As shown in Figure 6, NO_x emissions increased with engine load for both fuels, as expected, because higher load typically increases combustion temperature and promotes thermal NO_x formation. At the initial operating condition, B40 produced slightly higher NO_x than B35 at several medium- to high-load points. The difference ranged from -1.06% to 4.58%, indicating that the increase from B35 to B40 had only a modest effect on NO_x under the tested conditions. The slightly higher NO_x tendency of B40 can be linked to the higher FAME fraction in the blend. FAME contains oxygen in its molecular structure, which can support more complete combustion, but may also increase local oxygen availability and combustion temperature in some operating regions. This condition can favor NO_x formation, especially at higher load. However, this explanation should be treated carefully because this study did not measure in-cylinder pressure, heat-release rate, or local combustion temperature.

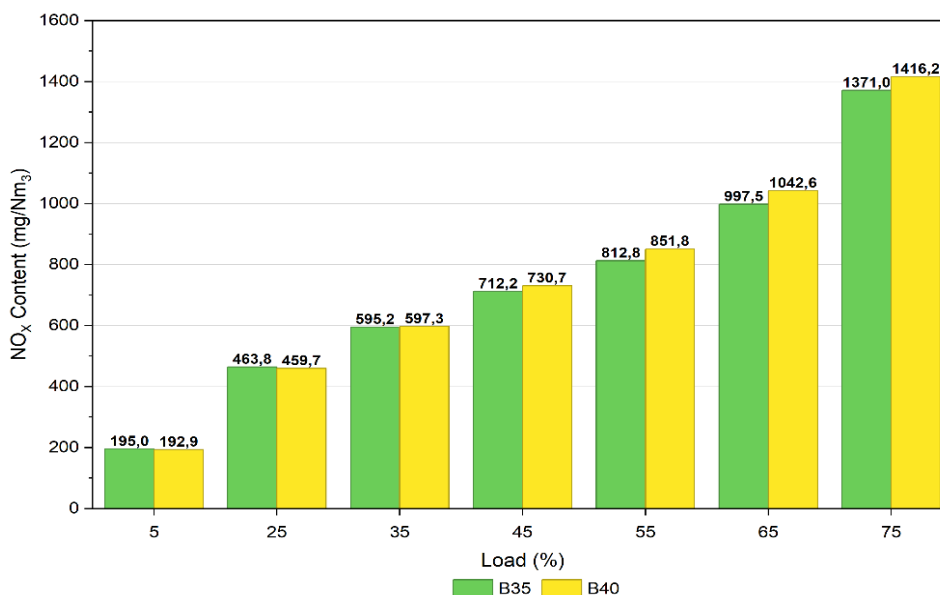


Figure 6.

Comparison of NO_x Emissions at 0 Hour Using B35 and B40

The endurance results further show that NO_x emissions did not deteriorate after 1,200 h of B40 operation (Figure 7). At 25–75% load, the difference between the initial and final B40 measurements remained small, ranging from –3.75% to 2.02%. At 5% load, NO_x decreased from 192.93 to 143.67 mg Nm⁻³, corresponding to a 34.29% reduction. This low-load decrease should not be overinterpreted as a permanent improvement mechanism, because NO_x at low load can be sensitive to combustion stability, measurement conditions, and engine operating variation. Nevertheless, the broader trend indicates that extended B40 use did not result in a progressive increase in NO_x during the 1,200 h test.

From an operational perspective, the most relevant point is that NO_x emissions from both B35 and B40 remained well below the regulatory limit of 1,850 mg Nm⁻³. This supports the suitability of B40 for passenger-train generator use from an NO_x-compliance perspective, while also showing that the B35-to-B40 transition does not impose a severe NO_x penalty under the tested duty condition.

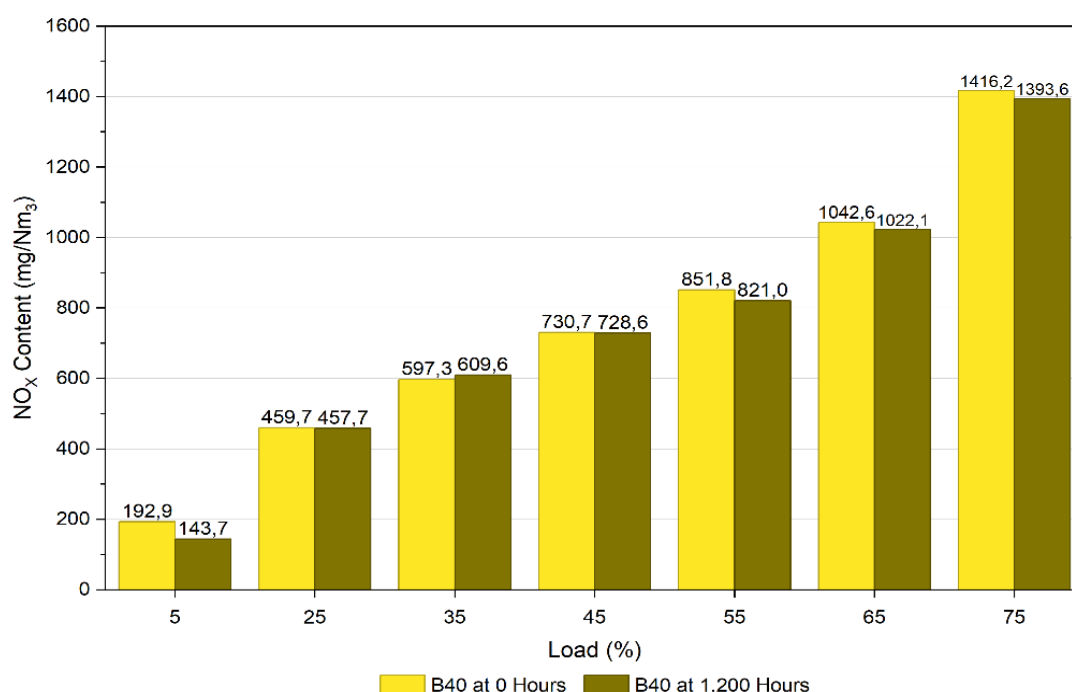


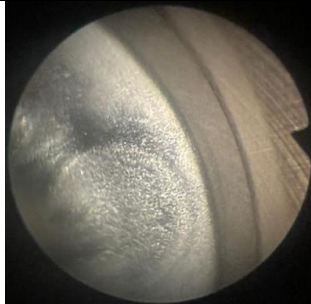
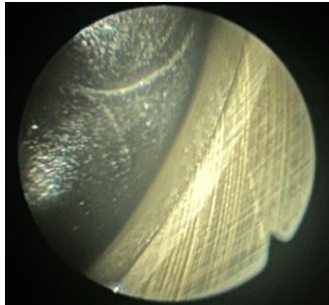
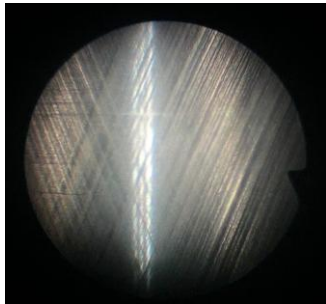
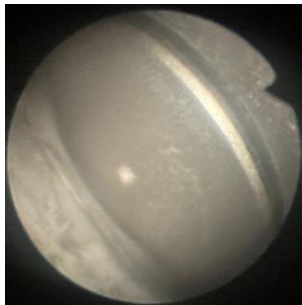
Figure 7.
NO_x emissions of B40 at the initial and after 1,200 operating conditions.

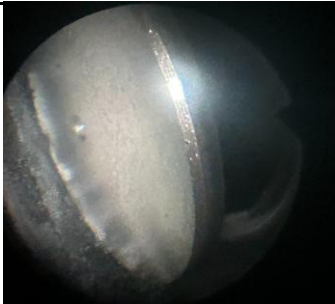
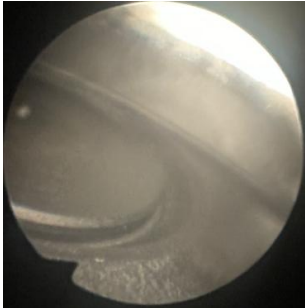
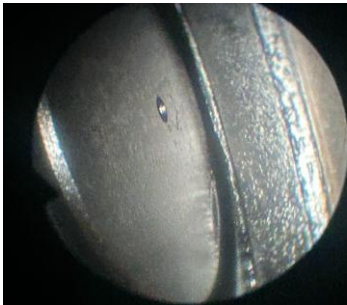
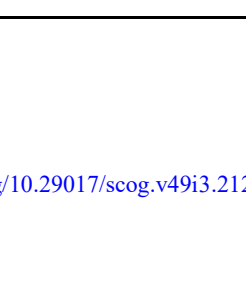
3.3 Component condition and fuel-filter response after 1,200 h B40 operation

The component inspection and filter monitoring results provide an important reliability check for B40 operation beyond power, fuel consumption, and NO_x emissions. Table 3 shows that, after 1,200 h of generator-set operation, the minor merit rating inspection did not show severe wear, abnormal deposits, or functional damage on the main inspected components, including the piston, cylinder liner, intake valve, exhaust valve, and injector. At the initial condition, these components were in normal operating condition, and after the endurance test, they remained within acceptable visual and functional condition based on endoscopic inspection. This result is relevant because one of the main concerns with higher biodiesel blends is not only immediate engine performance, but the possibility of deposit formation, injector fouling, or combustion-chamber contamination during longer operation.

The absence of visible severe degradation suggests that B40 did not cause abnormal component deterioration during the 1,200 h test period. This supports the earlier performance results, where power output and fuel consumption remained stable after extended operation. However, the interpretation should remain cautious. A 1,200 h endurance test provides useful operational evidence, but it does not represent full engine lifetime durability.

Table 3.
Minor merit rating inspection of engine components before and after 1,200 h B40 operation.

No.	Component	Operating hours	Results
1.	Piston	0 Hours	
		1.200 Hours	
2.	Cylinder liner	0 Hours	
		1.200 Hours	
3.	Intake valve	0 Hours	

No.	Component	Operating hours	Results
4.	Exhaust valve	1.200 Hours	
		0 Hours	
	Injector	1.200 Hours	
		0 Hours	
5.	Injector	1.200 Hours	
		0 Hours	

The Racor filter observations also support the operational stability of B40 under the tested railway service conditions, as shown in Figure 8. Filters were replaced and visually inspected every 100 h from 100 to 1,200 h of operation. The filter media showed normal color change and light particulate accumulation, but no severe blockage, heavy deposit build-up, or clear loss of filtration function was observed. This finding is important because high-FAME blends can be more sensitive to water, monoglycerides, insoluble materials, and cold-flow-related deposits, which may increase filter restriction in practical fuel systems. In this case, the controlled B40 fuel quality, including acceptable monoglyceride and water content, together with the 100 h replacement interval and upstream water filtration, likely helped maintain normal filter condition. Overall, the component and filter results strengthen the operational case for the use of B40 in passenger train generator sets. The fuel not only maintained power, fuel consumption, and NO_x compliance, but also showed no visible severe component deterioration or filtration problem during the 1,200 h field operation.

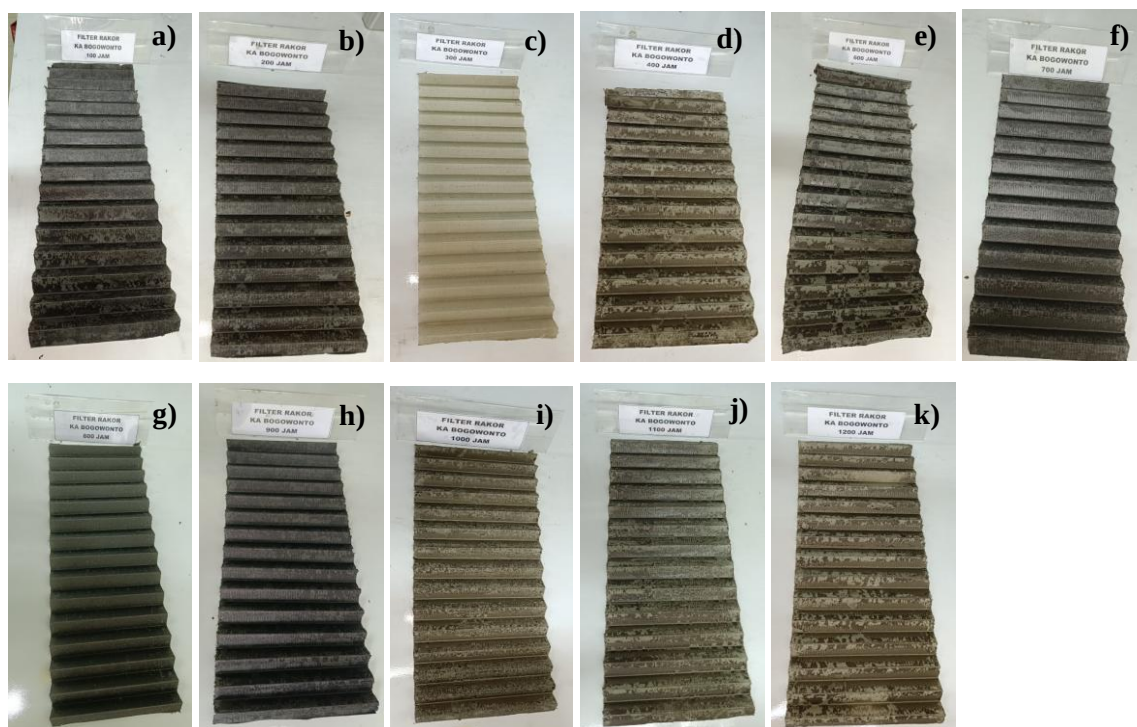


Figure 8.

Racor filter condition during 1,200 h B40 operation.

Filters were replaced and visually inspected at 100 h intervals to monitor discoloration, particle accumulation, and possible blockage, including a) 100, b) 200, c) 300, d) 400, e) 600, f) 700, g) 800, h) 900, i) 1,000, j) 1,100, and k) 1,200 Hours.

4. Conclusion

This study evaluated the technical readiness of B40 biodiesel for passenger-train MTU 10V1600G20F generator-set operation by comparing its initial performance with B35 and conducting a 1,200 h field endurance test under railway service conditions on the Yogyakarta–Jakarta route (~570 km). The results show that increasing the biodiesel fraction from B35 to B40 changed the fuel-property balance, particularly through lower heating value, higher water content, and higher viscosity. However, these property changes did not result in a severe performance penalty for the tested generator set. B40 produced power output comparable to B35 at higher loads, while fuel consumption remained broadly similar under medium- and high-load operation. After 1,200 h of B40 operation, power output and fuel consumption remained stable, indicating that extended operation did not result in measurable performance deterioration under the tested conditions. The emission results further support the operational suitability of B40. NO_x emissions increased with load for both B35 and B40, and B40 showed a slight NO_x increase at selected medium- to high-load points. Nevertheless, the difference between B35 and B40

remained modest, and all measured NO_x values were well below the applicable regulatory limit. More importantly, NO_x emissions did not increase progressively after 1,200 h of B40 operation. Lubricant properties did not show severe degradation, while wear-metal accumulation remained limited. Minor merit rating inspection of the piston, cylinder liner, valves, and injector did not reveal severe wear, abnormal deposits, or functional damage after 1,200 h. Filter monitoring every 300 hours also showed only normal discoloration and light particulate accumulation, without visible severe blockage. Overall, this work shows that B40 can be a technically feasible fuel for passenger train generator sets when supported by controlled fuel quality, appropriate filtration, and routine maintenance practice.

5. Acknowledgement

This study was funded by the Plantation Fund Management Agency (BPDP) Indonesia under the BPDP Sawit Grant No. PRJ-02/DPKS/2024. The authors would like to express their gratitude and highest appreciation to the Balai Besar Pengujian Minyak dan Gas Bumi LEMIGAS for supporting this study. The authors would also like to express their sincere gratitude and highest appreciation to the Directorate General of New, Renewable Energy and Energy Conservation Department, Ministry of Energy and Mineral Resources, BPDP, PERTAMINA, APROBI, BRIN, IKABI, PT Kereta Api Indonesia, and PT Isoelektra for their support in this project. This manuscript is original, has not been published previously, and is not under consideration for publication elsewhere. All authors have read and approved the final version of the manuscript and agree to its submission for publication.

6. Declarations

6.1 Author contributions

1. Riva Yudha Abriyant: Conceptualization, Writing - Review, Data curation. 2. Naufal Rasendriya Azmi: Writing - Original Draft, Writing - Review & Editing, Visualization, Software. 3. Irawan Adhi Putra: Writing - Original Draft, Writing - Review & Editing, Visualization, Software. 4. Faqih Supriyadi: Conceptualization, Investigation, Supervision. 5. Yogi Pramudito: Writing - Review, Investigation, Data curation. 6. Dimaz Warahadi: Resources, Formal analysis. 7. Riesta Anggarani: Conceptualization, Validation, Supervision. 8. Eki Dwi Wijanarko: Conceptualization, Investigation, Data curation. 9. Cahyo Setyo Wibowo: Conceptualization, Supervision. 10. Ahmad Syihan Auzani: Conceptualization, Supervision.

6.2 Funding statement

None.

6.3 Competing interest

None.

6.4 The use of AI-assisted technologies

None.

7. Glossary of terms and symbols

Terms & Symbols	Definition	Unit
B0	Diesel fuels	
B35	Diesel fuels containing 35 vol.% biodiesel	
B40	Diesel fuels containing 40 vol.% biodiesel	
%	Percentage	
NO _x	Nitrogen oxide	
h	Hours	
CO	Carbon monoxide	
HC	Hydro carbon	
BSFC	Brake-Specific Fuel Consumption	
ASTM	American Society for Testing and Materials	
FAME	Fatty Acid Methyl Ester	
MJ	Mega Joule	
kg	Kilogram	
mg	Milligram	
KOH	Potassium Hydroxide	
ppm	Parts per million	
wt.%	Weight Percent	
cSt	Centistokes	
°C	Degrees Celsius	
%v/v	Percent volume by volume	
EN	Europäische Norm	
g	Grams	
Ca	Calcium	
Mg	Magnesium	
Zn	Zinc	
% mass	Mass percent	
kW	Kilowatt	
Nm	Newton-metre	

8. References

- Allif Fathurrahman, N., Nasikin, M., Yulizar, Y., & Khalil, M. (2022). Thermodynamic study on the prevention of B30 biodiesel wax crystallization by γ -Al₂O₃ nanoparticles and sorbitan monooleate. *Fuel*, 314, 123144. <https://doi.org/10.1016/j.fuel.2022.123144>
- Barabas, I., & Todoru, I.-A. (2011). Biodiesel Quality, Standards and Properties. *Biodiesel- Quality, Emissions and By-Products*. <https://doi.org/10.5772/25370>
- Cardeno, F., Lapuerta, M., Rios, L., & Agudelo, J. R. (2020). Reconsideration of regulated contamination limits to improve filterability of biodiesel and blends with diesel fuels. *Renewable Energy*, 159, 1243–1251. <https://doi.org/10.1016/j.renene.2020.06.079>
- Chib, A., & Dugala, N. S. (2024). Experimental investigations of the impact of third-generation biodiesel and its blends on diesel fuel filter. *World Journal of Engineering*, 23(1), 23–38. <https://doi.org/10.1108/WJE-07-2024-0407>
- Chupka, G. M., Yanowitz, J., Chiu, G., Alleman, T. L., & McCormick, R. L. (2011). Effect of saturated monoglyceride polymorphism on low-temperature performance of biodiesel. *Energy and Fuels*, 25(1), 398–405. <https://doi.org/10.1021/ef1013743>
- Gozan, M., Paryanto, I., Darmawan, M. A., Sahlan, M., Hermansyah, H., Rismana, E., Arbianto, A. D., Prakoso, T., Aroua, M. K., & Cognet, P. (2022). Prediction of B20 Storage Tank Precipitate Removal

- Based on Biodiesel Monoglyceride Content. *ChemEngineering*, 6(1). <https://doi.org/10.3390/chemengineering6010007>
- Karabulut, M., Sayın, C., & Erdoğan, S. (2024). Effects of an Exhaust System Equipped with a Thermoelectric Generator on Combustion, Performance, Emissions, and Energy Recovery in a Diesel Engine Using Biodiesel. *Energies*, 17(5). <https://doi.org/10.3390/en17051083>
- Kirana Fadilah Achmad, A., Fathurrahman, N. A., Kunarti, E. S., Wibowo, C. S., Khalil, M., & Al-Saadi, A. A. (2025). Optimizing cold-flow properties and oxidation stability of B40 biodiesel blend with turpentine oil and ethanol: Experimental and quantum chemical approach. *Fuel*, 381. <https://doi.org/10.1016/j.fuel.2024.133258>
- Musthafa, B., & Asokan, M. A. (2023). A Comparative Study of Fuel Filterability, Performance, and Emission Characteristics in CI Engine Fuelled with a Dual Biodiesel Mixture Blended with Conventional Diesel. *Solid Fuel Chemistry*, 57(1), S42–S52. <https://doi.org/10.3103/S0361521923070066>
- Na-Ranong, D., & Kitchaiya, P. (2014). Precipitation above cloud point in palm oil based biodiesel during production and storage. *Fuel*, 122, 287–293. <https://doi.org/10.1016/j.fuel.2014.01.003>
- Palani, Y., Devarajan, C., Manickam, D., & Thanikodi, S. (2022). Performance and emission characteristics of biodiesel-blend in diesel engine: A review. In *Environmental Engineering Research* (Vol. 27, Number 1). Korean Society of Environmental Engineers. <https://doi.org/10.4491/eer.2020.338>
- Paryanto, I., Budianta, I. A., Alifia, K. C. H., Hidayatullah, I. M., Darmawan, M. A., Judistira, Prakoso, T., Indarto, A., & Gozan, M. (2022). Modelling of Fuel Filter Clogging of B20 Fuel Based on the Precipitate Measurement and Filter Blocking Test. *ChemEngineering*, 6(6), 84. <https://doi.org/10.3390/chemengineering6060084>
- Paryanto, I., Prakoso, T., & Gozan, M. (2019). Determination of the upper limit of monoglyceride content in biodiesel for B30 implementation based on the measurement of the precipitate in a Biodiesel–Petrodiesel fuel blend (BXX). *Fuel*, 258(August), 116104. <https://doi.org/10.1016/j.fuel.2019.116104>
- Pichler, J., Frauscher, M., & Marchetti-Deschmann, M. (2024). Advanced Method for the Detection of Saturated Monoglycerides in Biodiesel Using GC-EI-MS/MS. *ACS Omega*, 9(22), 23476–23484. <https://doi.org/10.1021/acsomega.4c00513>
- Reksowardojo, I. K., Setiapraja, H., Fajar, R., Wibowo, E., & Kusdiana, D. (2020). An Investigation of Laboratory and Road Test of Common Rail Injection Vehicles Fueled with B20 Biodiesel. *Energies*, 13(November), 6118. <https://doi.org/10.3390/en13226118>
- Reksowardojo, I. K., Setiapraja, H., Mokhtar, Yubaidah, S., Mansur, D., & Putri, A. K. (2023). A Study on Utilization of High-Ratio Biodiesel and Pure Biodiesel in Advanced Vehicle Technologies. *Energies*, 16(2). <https://doi.org/10.3390/en16020718>
- Thangamani, S., & Jeyaseelan, T. (2024). An experimental study on fuel filterability and water separation efficiency with biodiesel fuels. *AIP Conference Proceedings*, 3031(1). <https://doi.org/10.1063/5.0195544>
- Wirawan, S. S., Solikhah, M. D., Setiapraja, H., & Sugiyono, A. (2024). Biodiesel implementation in Indonesia: Experiences and future perspectives. In *Renewable and Sustainable Energy Reviews* (Vol. 189). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2023.113911>
- Wojcieszky, M., Kroyan, Y., Kaario, O., & Larmi, M. (2023). Prediction of heavy-duty engine performance for renewable fuels based on fuel property characteristics. *Energy*, 285. <https://doi.org/10.1016/j.energy.2023.129494>
- Zhang, Y., Zhong, Y., Lu, S., Zhang, Z., & Tan, D. (2022). A Comprehensive Review of the Properties, Performance, Combustion, and Emissions of the Diesel Engine Fueled with Different Generations of Biodiesel. In *Processes* (Vol. 10, Number 6). MDPI. <https://doi.org/10.3390/pr10061178>

Zheng, F., & Cho, H. M. (2024). The Effect of Different Mixing Proportions and Different Operating Conditions of Biodiesel Blended Fuel on Emissions and Performance of Compression Ignition Engines. *Energies*, 17(2). <https://doi.org/10.3390/en17020344>