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AN INVESTIGATION OF 30% PALM BIODIESEL BLEND FUEL (B30) UNDER INDONESIAN OPERATING CONDITIONS

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ABSTRACT

A study was conducted under Indonesian operating conditions to verify that utilising 30% palm methyl ester (B30) did not negatively impact vehicle performance, ensuring the smooth nationwide implementation of B30 in Indonesia. A comprehensive study involved a 50 000 km road test and periodic laboratory assessments to evaluate the long-term effect on vehicle performances, including engine power, fuel economy, and exhaust emissions. These investigations were conducted in compliance with UN-ECE R85, R101, and R83 regulations. As a comparison, 20% palm biodiesel blend fuel (B20) were also evaluated alongside B30. The results showed that both vehicles fuelled with B20 and B30 had no problem until a distance travelled of 50 000 km. The power B30 varied in average by 4.8 kW when compared to B20, while fuel economy was 0.2 km/L. B30 exhibited lower emissions of CO, HC, and PM in comparison to B20, with average reduction of 0.10 g/km, 0.01 g/km, and 0.02 g/km, respectively. However, there was an average increase of 0.11 g/km in NOx emissions when compared to B20. Furthermore, this study revealed that the fuel filter replacement interval for B30 and B20 remained within the range recommended by the manufacturer, with no issues observed regarding cold start-ability.

Keywords: engine performance, filter blocking, monoglycerides, palm biodiesel blend fuel, road test.

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INTRODUCTION

Indonesia requires to evaluate an alternative fuel due to its high reliance on fossil fuels. Biofuel from palm oil is a promising alternative fuel due to the abundant palm oil supply in Indonesia. Abdelgader *et al.* (2022) reported that biofuel is one of the potential fuels to be used as a substitute for fossil fuels. Furthermore, biofuel is also known as carbon neutral fuel, despite the fact that it has the potential to emit CO_2 during the production process (Kuncoro and Purwanto, 2020). Reksowardojo *et al.* (2020) reported a study on the implementation of 20% palm biodiesel blend with diesel fuel (B20) in light-duty vehicles. Their results revealed that vehicles running on B20 exhibited comparable durability to those using pure diesel fuel (B0). Moreover, as the mileage increased, these B20-fuelled vehicles demonstrated enhanced fuel economy, despite a slight 3% reduction in maximum power. Implementing biodiesel at a higher ratio, such as palm methyl ester with a blend ratio of 30% (B30) shows promise as a method to further decrease CO_2 and reduce dependence on fossil diesel duel.

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Various research has been conducted for the implementation of B30 to prevent problems in real-world applications. Paryanto *et al.* (2019a, 2019b) have reported that to increase the palm biodiesel ratio, the monoglyceride (MG) value must be a maximum of 0.6% to prevent a decrease in fuel filter mileage. Cardeño *et al.* (2020) made a similar report, recommending limiting MG content to a maximum value of 0.4% for applications in advanced engine technologies. Other studies have also been carried out to support the implementation of B30 which is related to the compatibility of materials in the fuel systems, influence in exhaust after treatment, degradation of lubricant, and the formation of deposits due to metal contaminant parameters in biodiesel (Hartono and Cahyono, 2020; Hidayat and Sugiarto, 2020; Iswantoro *et al.*, 2021; Liaquat *et al.*, 2013; Maharani *et al.*, 2022; Petiteaux and Monsallier, 2009; Sadashiva *et al.*, 2022). Reksowardojo *et al.* (2023) studied the effect of B30 in the performance and emissions of the advanced vehicle on Indonesia market. Utilisation of palm B30 could result in a slight increase in fuel economy and a decrease in power, while exhaust emissions could comply with EURO4 regulation limit. Other studies have also been carried out by Wu *et al.*, (2020) who have provided a comprehensive review regarding the use of biodiesel in engines by reviewing various parameters including performance, emissions, noise, vibration, and material compatibility. Another study conducted by several researchers on the application of biodiesel in various applications showed that the use of biodiesel in general could reduce emissions by optimising the engine parameters. Moreover, an optimisation of engine parameters could improve performance close to that of diesel fuel (Altarazi *et al.*, 2022; Doppalapudi *et al.*, 2023; Fernandes *et al.*, 2022; Ge *et al.*, 2020; Huang *et al.*, 2022; Pawar *et al.*, 2022; Singh *et al.*, 2021; Soudagar *et al.*, 2021).

Most studies reported that biodiesel quality and vehicle technology are two important factors that directly influence performance, emissions, and engine components lifetimes. In principle, alternative fuel should be compatible with engine technology and *vice versa* that comply with a standard (Le *et al.*, 2016). Furthermore, it is essential to consider the optimisation of various engine performance parameters, emissions, and prices when establishing the optimal biodiesel blending ratio (Yilmaz *et al.*, 2022). For these purposes, Indonesia government has made some improvements on biodiesel properties, including oxidation stability, MG content, water content, and total acid number for shifting from B20 to B30. As described in the previous paragraph, while there have been numerous laboratory-scale studies on B30, there is a noticeable lack of research that explores the nationwide implementation of B30. The objective of this study is to address the gaps in B30 research by examining enhanced biodiesel properties and assessing its performance for nationwide implementation under Indonesian operating conditions. Moreover, this study was conducted to ensure that the utilisation of B30 had no adverse effects on the performance parameters and engine components of diesel vehicles currently available in the Indonesia market. This paper presents the results of a 50 000 km vehicle road test conducted in Indonesia, evaluating its effects on power, fuel economy, emission, maintenance and low-temperature operation. This similar method was also employed when the Indonesian government planned to implement B20 to replace B10 in 2016 (Reksowardojo *et al.*, 2020).

MATERIALS AND METHODS

Test Vehicle Specifications

In this paper, the discussion will include samples of light-duty vehicles from two different brands. These two brands were based on the representation of the vehicle population and on the recommendation of the association of Indonesia automotive industries for evaluating B30 on common rail vehicle technology. Each pair consist of two vehicles fuelled by B20 and B30. In this case, B20 fuel was used as the reference fuel because it had been implemented in Indonesia since 2016 and was available as market fuel. The specifications of the test vehicle used for the study in this paper are shown in *Table 1*.

Test Fuels

In this road test, diesel fuel (B0) has a maximum sulphur content of 2000 ppm and a cetane number (CN) of 48. Palm methyl ester (B100) for blending fuel of B30 has an MG content of 0.55% and a maximum water content of 500 ppm, while B20 had an MG of 0.80% and a water content of 500 ppm. B20 was readily available in the market, produced by Indonesia State Owned Oil and Gas Corporation, PT. Pertamina. Meanwhile, B30 was a custom-blended fuel, with PT. Pertamina provided the diesel fuel (B0), while the pure palm methyl ester (B100) was supplied by the Indonesian Biofuel Producer Association (APROBI). The fuel properties of the B20 and B30 for the road test are shown in *Table 2*. B30 has the advantages of higher CN, lower sulphur, and particulate contaminants, and better lubricity compared with B20. However, the pour point and cold filter plugging point (CFPP) of B30 was higher than B20. Therefore, it is more likely to form precipitate at low temperature operation.

The test procedure for road and laboratory tests are shown in *Figure 1*. During the road test, all vehicles were examined for its performance,

TABLE 1. TESTED VEHICLE SPECIFICATIONS

Specification	Vehicle 1 (V1)	Vehicle 2 (V2)
Model	Mitsubishi-Pajero	Nisan-Terra
Engine type	DOHC	DOHC, Turbocharger with VGS
No. of cylinder	4	4
Displacement	2 500 cc	2 488 cc
Max. power	181 PS/3 500 rpm	190 PS/3 600 rpm
Max. torque	430 Nm/2 500 rpm	450 Nm / 2 000 rpm
Transmission	A/T	A/T
Additional information	Turbocharged Intercooler Common rail	Turbocharged Common rail

TABLE 2. TESTED FUEL PROPERTIES

Parameter	Unit	B20	B30	Method
Cetane number	-	51.9	53.2	ASTM D613
Cetane index	-	48.3	50.2	ASTM D4737
Sulphur	%	0.143	0.136	ASTM D4292
Distillation T90 °C	°C	347	335	ASTM D86
Flash point	°C	68	77	ASTM D93
Pour point	°C	9	12	ASTM D5949
Carbon residue	%	Nil	Nil	ASTM D4530
Copper strip corrosion	merit	1A	1A	ASTM D130
Ash content	%	0	0	ASTM D482
Sediment content	%	Nil	Nil	ASTM D473
Strong acid number (SAN)	mg KOH/gr	0	0	ASTM D664
FAME content	%v	20.6	30.5	ASTM D7371
Lubricity (HFRR wear scar dia.)	micron	198	174	ASTM D6079
Appearance	-	bright and clear	bright and clear	-
ASTM color	No. ASTM	2.5	2.8	ASTM D1500
Oxidation stability (Rancimat)	Hours	>48	>48	EN 15751
CFPP	°C	12	16	ASTM D6371
Particulate sontaminant	Code Rating	4.21	3.32	ASTM D5425

fuel economy, emissions, and filter blocking test as shown in *Figure 1*.

Route of road test was determined so that it can represent the conditions of daily operation with road type and condition in main island of Indonesia. The general route for road test includes 10.6% flat terrain, 49.9% climbing and downhill roads, and 39.5% highway. The total distance for a one-day route was an average of 570 km.

The power of the vehicle was tested on a chassis dynamometer with the adopted UN-ECE R85, which measures the maximum power of the vehicle on wheels. The power absorption and speed of the chassis dynamometer are 150 kW and 200 km/hr, respectively. Fuel economy was calculated using the carbon balance method from measured exhaust gases as shown in Equation 1. Hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NOx) were measured using an emission analyser with specific sensors. Hydrocarbon was detected with heated flame ionisation detector (HFID), while CO and CO_2 were assessed through non-dispersive infrared (NDIR) sensors. Additionally, NOx was analysed with chemiluminescence detector (CLD). A carbon balance calculation is conducted using a Equation 1 in R101 as follows:

$$FE = \frac{100 \times D}{(0.115 \times ((0.866 \times mHC) + (0.429 \times mCO) + (0.273 \times mCO_2)))} \quad (1)$$

Where, FE is the fuel consumption in km/liter, D is the density of the fuel, and mHC, mCO, and mCO_2 are measured emission quantities of hydrocarbon, carbon monoxide, and carbon dioxide in g/km, respectively.

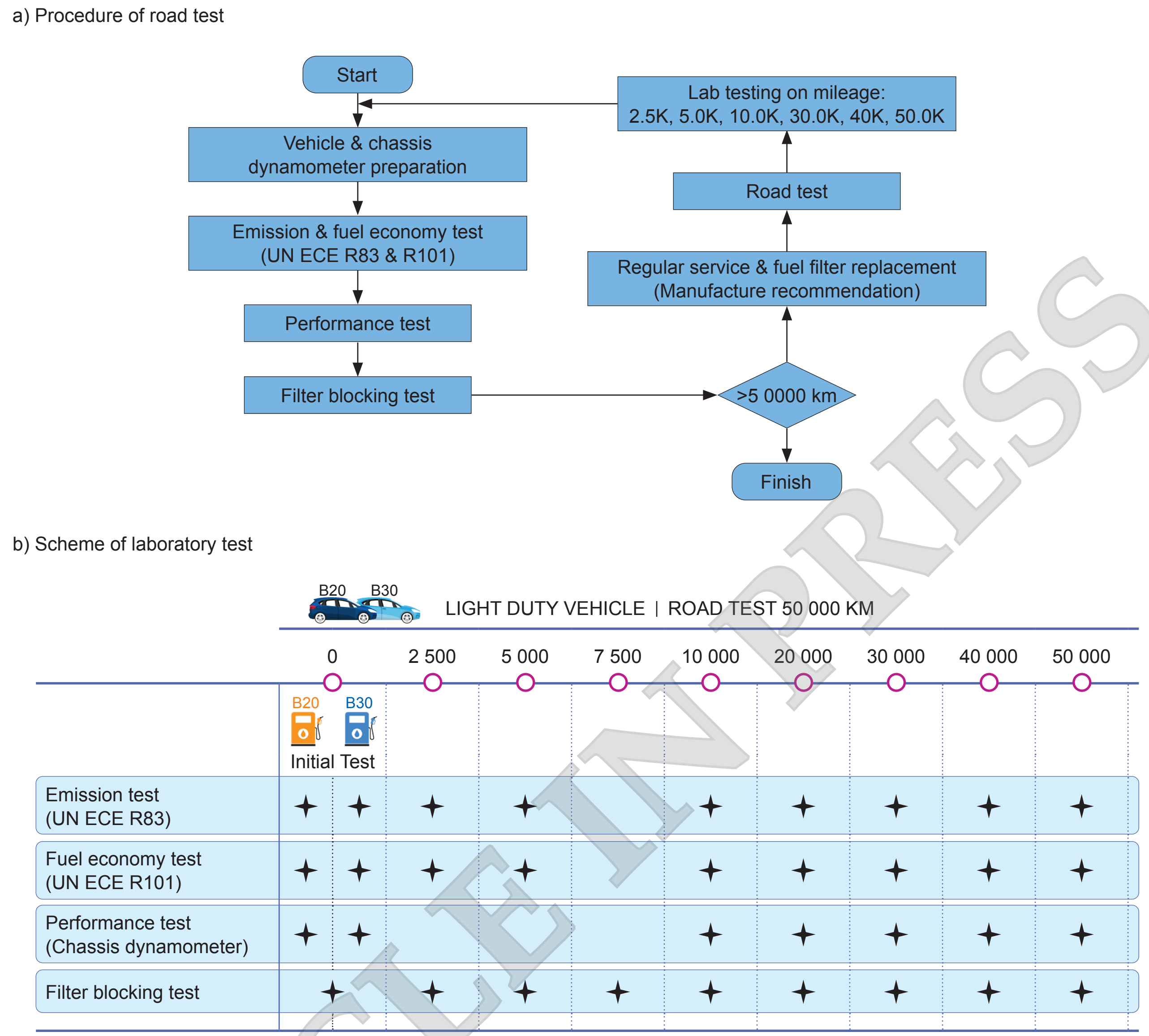

Figure 1. Procedure of road and laboratory test.

In this study, measurement of exhaust gas emission referred to the standard of United Nation Economic Commission for Europe (UN-ECE) R83-04 and was conducted at the laboratory of the National Research and Innovation Agency of Indonesia (BRIN). In addition, an evaluation of fuel filter mileage was also conducted to find out how much influence B30 has on the occurrence of blockages in the fuel filter in the vehicle. This test was done by checking the pressure difference that occurred in the fuel line before and after the fuel filter.

RESULTS AND DISCUSSION

An examination of uncertainty has been conducted to assess the precision of measurements. This analysis was based on the widely recognised reference standard, Joint Committee for Guide Metrology (JCGM) 100:2008, which is commonly used for evaluating uncertainty in testing and calibration laboratories. The measurement of uncertainty was determined by considering a sum of influential parameters outlined in the testing standard. Among these parameters, the measurement data and equipment calibration play a substantial role in combined uncertainty, surpassing the impact of other factors. In quantifying the uncertainty, a confidence level of 95% is applied along with a coverage factor of 2.

Cross-test Before Road Test

A cross-test was conducted for all vehicles prior to the road test (0 km). This aims to determine the effect of the use of fuel B20 and B30 on the initial condition of the vehicle. The vehicle had been set up in accordance with the recommendations of the manufacturers for fuel properties in Indonesia, namely B20. The cross-test at 0 km was conducted by means of a vehicle that uses B20 fuel on the road to perform a performance test using B30 fuel and *vice versa*, B30-fueled vehicles during road tests were tested using B20 fuel.

The results of the cross-test of measured power for all test vehicles are shown in *Figure 2*. V is the type of vehicle and the following number indicates the brand or type of the test vehicle. B20 fuel is indicated by the number 20 and B30 by 30. For example, the V1-20 is a type/brand number one vehicle with B20 fuel. In this study, measurement uncertainties for power and fuel economy (FE) have been determined, with values of 3.3 kW and 0.24 km/L, respectively. These values are represented as error bars in the *Figure 2*.

Figure 2 shows that utilisation of B30 fuel increased the power of V1-20 and V2-20 compared to B20, while V1-30 and V2-30 showed the opposite trend. Theoretically, the use of biodiesel will reduce the calorific value, resulting in a decrease in power. In the UN-ECE R85 performance test regulation, it is stated that the maximum power tolerance produced at rated power is 2%. Therefore, it can be assumed that the utilisation of B20 and B30 does not lead to a significant difference in the maximum power of the vehicle, which can be considered due to their different vehicle settings. *Figure 2* also showed that V1-20 and V1-30 had similar power characteristics at the initial condition of 0 km, while V2-30 had a slightly higher power maximum compared with V2-20.

Road Test Results 50 000 km

The effect of using B30 on vehicles during the 50 000 km road test was evaluated through various parameters such as power, fuel consumption, exhaust emissions, component degradation, cold start ability, fuel storage stability, and others. However, this paper only discussed an effect of B30 on power, fuel consumption, emissions, fuel filter mileage, and cold start ability.

An Evaluation of Power During Road Tests

Power evaluation by using R85 test method was conducted at 10 000 km interval, with the exception in the initial range of 0 to 10 000 km, during which evaluations were also conducted at 2500 and 5000 km. All vehicles were tested after they had passed periodic maintenance services. Here, the service intervals for V1 and V2 were at every 10 000 km mileage. *Figure 3* shows the results of power measurements for two vehicles using B20 fuel and two vehicles using B30 fuel at km 0 to 50 000 km. V1 and V2 vehicles show a trend of increasing power for each distance travelled for both B20 and B30 fuel. For the V1-20, the maximum power increase could reach a maximum of 4.0% at km to 30 000 km while the V1-30 could reach a maximum increase of 2.0% at 20 000 km and 40 000 km. For V2, the increase is higher than V1, where the V2-20 reaches a maximum increase of 5.1% at 30 000 km and V2-30 with a maximum increase of 9.7% at 40 000 km. *Figure 3* shows that the use of B20 and B30 fuel does not have

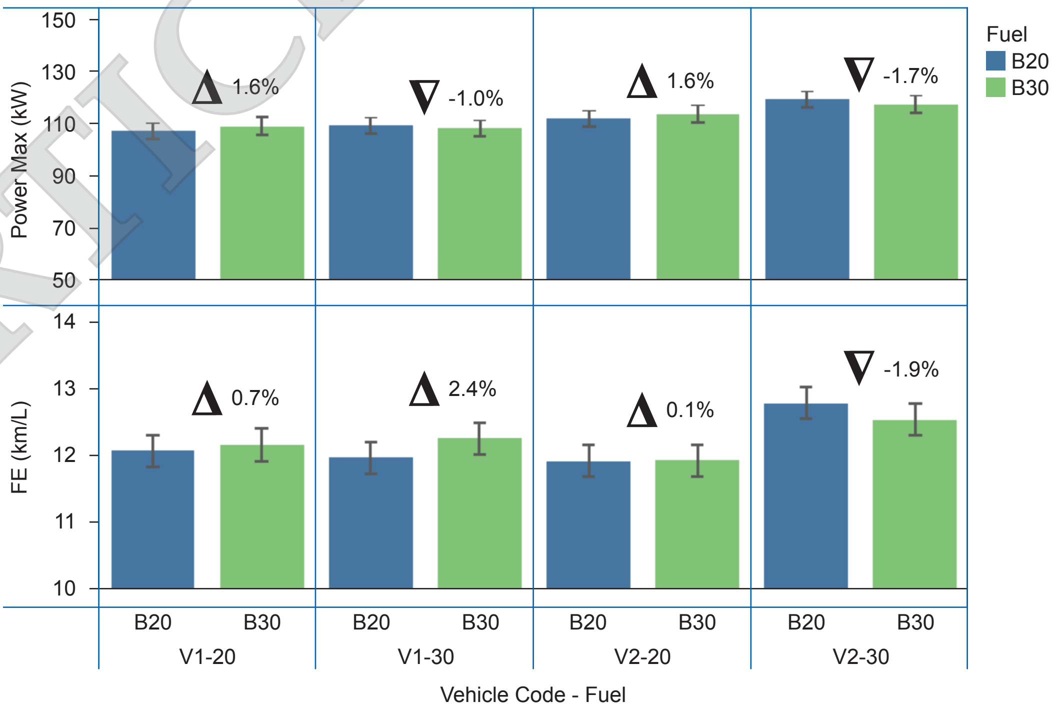

Figure 2. Cross test result before road test.

an impact on reducing power up to a mileage of 50 000 km with a maintenance pattern according to current standards for both V1 and V2 vehicles.

An evaluation for 50 000 km also revealed that V1 fueled with B20 has comparable averaged power with V1-30, while V2-30 has higher averaged power than V2-20. According to various studies, a higher biodiesel ratio will result in lower power output due to its lower heating value (Ogunkunle and Ahmed, 2020; Reksowardojo *et al.*, 2023). Reksowardojo *et al.* (2023) also reported that the reduction of lower heating value of biodiesel which resulted on lower power output could be suppressed by the higher thermal efficiency of biodiesel. While the percentage of reduction in power output differed according to the test method, operating conditions, and engine technology. However, the higher power result of V2-30 compared to V1-30 could be attributed to V2-30 having higher power output characteristics as elucidated in the subsection of cross test prior to the road test, rather than differences in fuel characteristics as shown in *Table 2*.

An Evaluation on Fuel Economy (FE) During Road Tests

Utilisation of high ratio biodiesel fuel would lead to a reduction in lower heating value and an increase in density and viscosity. Those characteristics could result on lower fuel economy of biodiesel (Reksowardojo *et al.*, 2023; Soudagar *et al.*, 2021; Wu *et al.*, 2020).

Figure 4 shows the results of the FE test for vehicles with B20 and B30 fuel by using UN-ECE R101 standard. The FE of V1 and V2 type vehicles has resulted in an improvement trend of FE for all mileage compared to the initial conditions for both B20 and B30. Here, the initial durability of the FE for V2-30 has decreased at 5000 km and 10 000 km distances. The results of the B30 test show the same trend as B20 for the V1 and V2 types. The V1-30 and V2-30 vehicle produced the optimum FE of 7.1% and 2.9%, respectively. The improvement in the FE value indicates that vehicle condition had more effect than calorific value of the fuel during the 50 000 km durability test. The test results also showed that V2 vehicles with B30 had slightly better FE values than B20. This characteristic was also reported by William *et al.*, (2021) who found that vehicle with B30 was not significantly different from those with B5. Further, a similar study conducted on a single cylinder diesel engine with common rail systems fueled with waste cooking oil methyl ester showed that deterioration of fuel economy could also be minimised with an optimisation on engine parameters, including pilot injection and nozzle opening pressure. The result was considered due to an improvement in the combustion process (Fernandes *et al.*, 2022). Therefore, the improved FE observed for V2-30 in comparison to V2-20 could be considered due to optimum engine setting for V2-30, which enhances the higher cetane number, thereby promoting more efficient combustion.

Emission Test Results.

Exhaust emissions were evaluated using the UN ECE R83-04 (EURO2 standard), which was implemented in Indonesia. Emission testing under UN ECE R83-04 is subjected to several factors

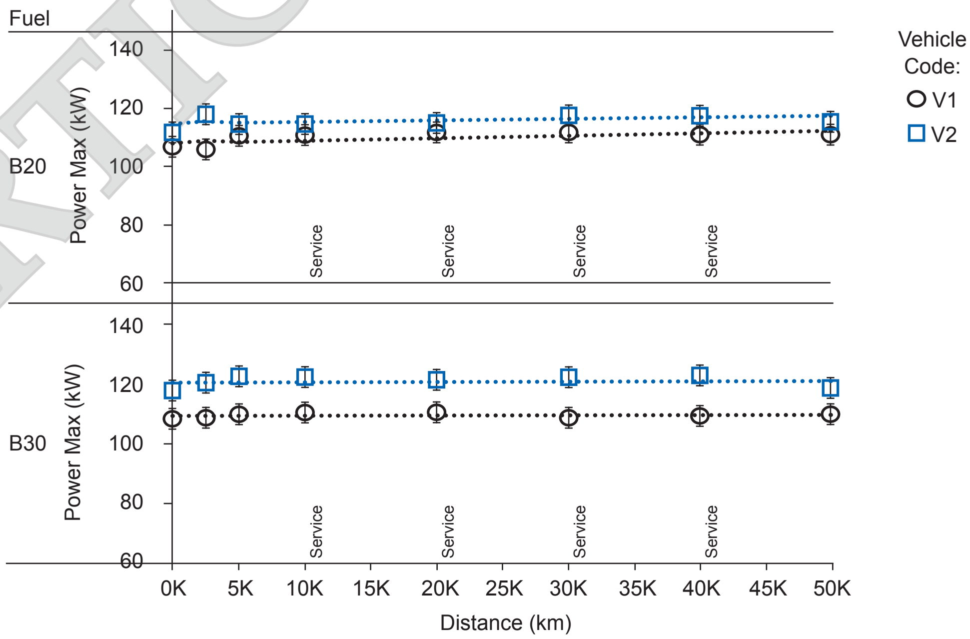

Figure 3. Power during road test.

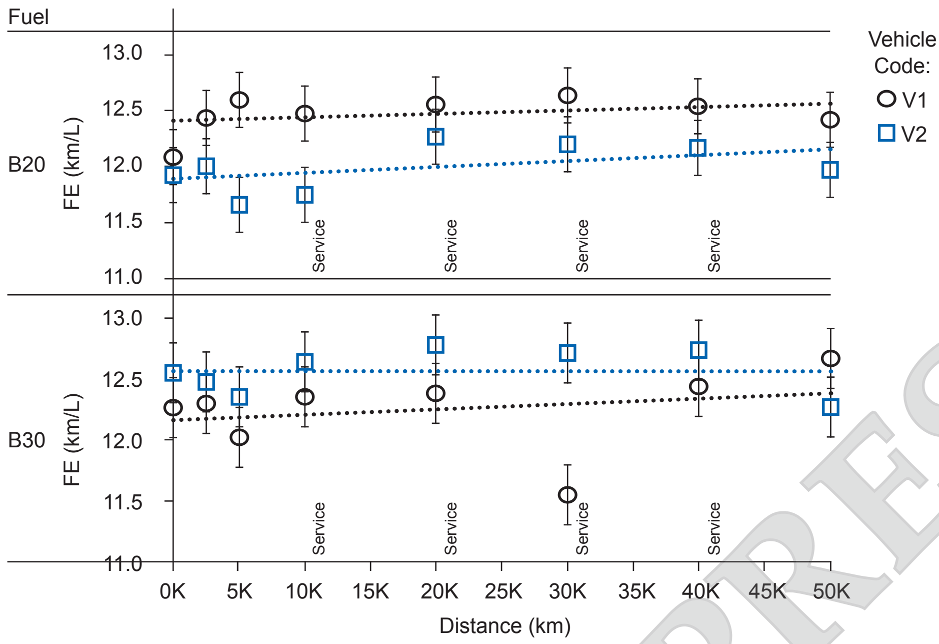

Figure 4. Fuel economy (FE) during road test 50 000 (50K) km.

that play a significant role in uncertainty analysis. These factors encompass exhaust diluted volume, emission concentration, weighted particulate mass, distance, and environmental conditions. In particular, the uncertainty measurements for CO, HC, NOx, and PM are 0.063 g/km, 0.006 g/km, 0.039 g/km, and 0.007 g/km, respectively. *Figure 5* shows the results of exhaust gas emissions of all vehicles during road test 50 000 km. The V1-20 vehicle shows a decreasing trend of CO, while the V2-20 shows an increasing trend that could reach twice the initial condition. The same trend is shown for B30, where V1-30 vehicles showed a decrease in CO while V2-30 produced a significant increase that can reach up to 50%. The use of biodiesel with a higher cetane number and oxygen content can theoretically reduce CO emissions (Ge *et al.*, 2020; Kodate *et al.*, 2022; Williams *et al.*, 2021). The trend of increasing CO emissions for V2 with both B20 and B30 for all road test mileages could be considered to correlate with the power results in *Figure 3*.

The V2 power results, indicating a power increase for both B20 and B30, which can lead to more amount of fuel supplied to the combustion chamber, thereby affecting an increase in CO emissions. Furthermore, the test results also show that V1 and V2 vehicles fueled with B30 exhibit lower CO levels compared to B20 across all mileage intervals during the 50 000 km road test. This finding aligns with the study conducted by Rajaeifar *et al.* (2021) and Soudagar *et al.* (2019) who also observed an increase in CO emission during low engine speed operations.

HC emissions for V1-20 show a decreasing trend with increasing road test mileage, while for V2-20, the results are reversed, where HC emissions increase with distance travelled. The B30 vehicle tends to produce similar HC emissions for the whole travelled distances, while for the V2-30 the emissions increase along with the distance travelled. HC emissions exhibit a similar pattern to CO emissions, with V1 and V2 vehicles consistently showing slightly lower HC values when using B30 in contrast to B20 across all mileage during the conducted road test. This decrease in HC emission with B30 can be attributed to the higher cetane number and oxygen content, as shown in *Table 2*, resulting in improved combustion.

Biodiesel with higher cetane number and increased oxygen content tends to raise NOx emissions, and a higher ratio of biodiesel in the blend fuel further contributes to increased NOx emission. This issue presents a challenge when it comes to utilising biodiesel blends since emission reduction requires to encompass not only CO and HC but also for NOx (Yilmaz *et al.*, 2022). *Figure 5* shows that NOx emissions of V1-20 vehicles tend to increase along with distance travelled, with a maximum increase of 7.4% at a distance of 20 000 km. V2-20 produced different results, in which emissions decreased with mileage and could reach over 20%. B30-fueled vehicles have the same trend of NOx emissions as B20 where the V1-30 tends to increase while the V2-30 has a decreasing NOx emission along with the distance travelled. An increase in NOx emissions with biodiesel is usually a result of an increase in maximum combustion temperature due to the oxygen content of the biodiesel (Abu-Hamdeh and Alnefaie, 2015; Hadhoum *et al.*, 2021). NOx emissions for vehicles with B20 and B30 fuel are comparable for V1 vehicle types, but for V2 vehicle types, NOx emissions with B30 are higher than B20 for each mileage due to its higher cetane number as shown in *Table 2*. This comparable NOx result for V1 can be attributed to engine settings including exhaust gas recirculation (EGR) rate and pilot injection (Altarazi *et al.*, 2022; Fernandes *et al.*, 2022).

Particulate matter (PM) measurement results for B20 fuelled vehicles increase significantly, potentially increasing by 60% over a 20 000 km travelled distance, as shown in *Figure 6*. Here, the V1-20 vehicle produced a maximum PM increase of 60% at a mileage of 20 000 km, while the V2-20 produced a maximum PM emission of 44%. B30-fueled vehicles resulted in a different trend for V1 and V2. The V1-30 vehicle resulted in increased emissions for each road test distances, while the V2-30 vehicle resulted in a reduction in PM emissions of up to 30%. Most of studies concluded that utilisation of biodiesel could reduce PM emission by shortening the ignition delays and promoting the PM oxidation due to its oxygenate and high cetane number (Chiavola and Recco, 2018; Ge *et al.*, 2020). An increase in PM with biodiesel fuel was also reported by Hadhoum *et al.* (2021). A high PM value was considered due to the larger droplet size of fuel spray due to injector degradation as well as higher viscosity and high density of biodiesel (Altarazi *et al.*, 2022; Ge *et al.*, 2020).

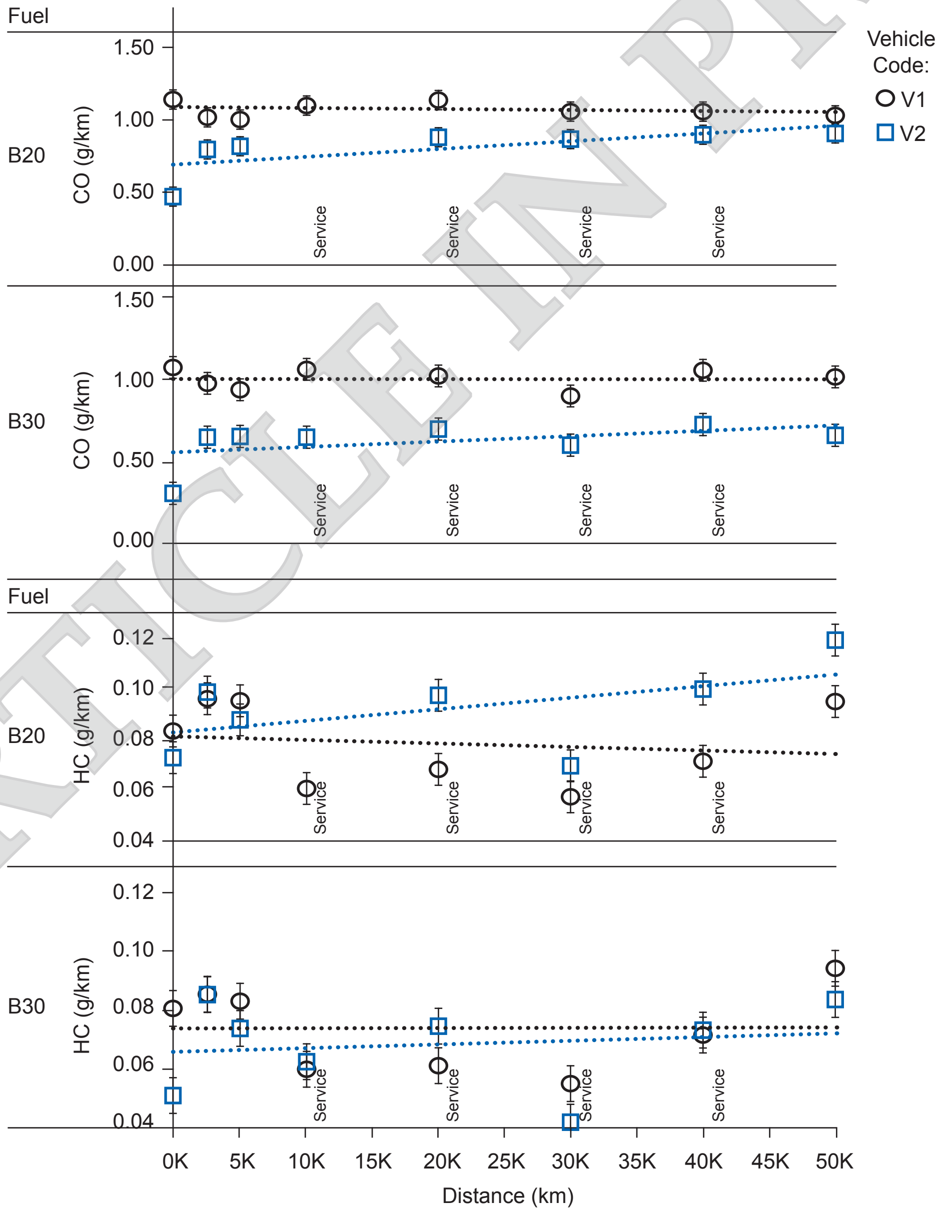

Figure 5. An emission of CO and HC during road test.

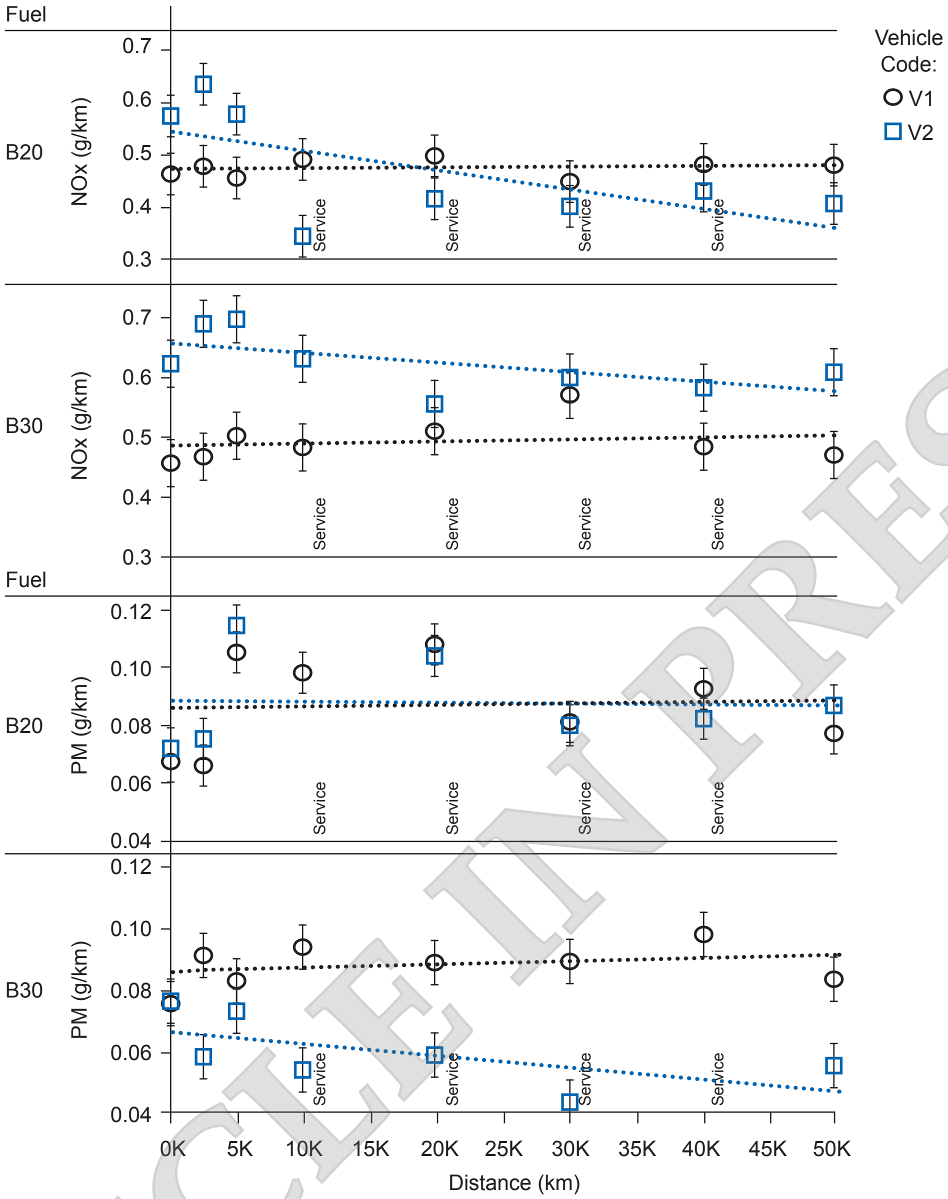

Figure 6. *An emission of NOx and PM during road test.*

Fuel Filter Mileage and Cold Start Ability

One of the issues at the beginning of B20 implementation in Indonesia in 2016 was shortened fuel filter mileage. In this road test, an evaluation of fuel filter changing was investigated by measuring the pressure difference at the inlet and outlet of the fuel filter. Here, replacement of the fuel filter on V1 and V2 vehicles, according to the recommendation from the vehicle manufactures, was at every 20 000 km. *Figure 7* shows the value of the pressure difference at the fuel inlet and outlet of the fuel filter for V1 and V2 vehicles. The fuel filter was changed three times for both V1 and V2 during the 50 000 km, as shown in *Figure 7*. The value of delta pressure increases slowly at the beginning and increased sharply at 10 000 km, indicating that the filter started to clog due to various impurities presented in the fuel filter for V1 and V2 vehicles. This phenomenon also occurred after the second and third filter replacements, where the differential pressure increased algorithmically after 10 000 km. *Figure 7* also shows that the trend of increasing differential pressure (dP) at each filter change is identical for both of B20 and B30. The sudden increase in the value of the differential pressure indicates that it is time for filter replacement to be carried out for both V1 and V2 vehicles (Petiteaux and Monsallier, 2009). The maximum differential pressure for V1 during the first filter change could exceed 40 kPa for both of B20 and B30, which is notably higher than V2, where the maximum remains around 20 kPa. However, the variance in differential pressure between B20 and B30 was not particularly significant for travelled distances of below 10 000 km for both V1 and V2, especially when considering an uncertainty measurement of 0.419 kPa.

Fuel filter replacements of V1 were shorter in the first replacement period but return to periodic filter replacements in the next km. While fuel filter replacement for V2 vehicles was still in accordance with manufacturer recommendations. The shorter fuel filter lifetime of biodiesel was also revealed by Graver *et al*. (2016), Komariah *et al*. (2018) and Paryanto *et al*. (2022). Meanwhile, an improvement of biodiesel quality as well as biodiesel handling and storage could enhance fuel filter mileage (Ma'ruf and Haryono, 2020). The mileage of the fuel filter is not only determined by the amounts of impurities and contaminants contained in B20 or B30 but is also influenced by the specifications of the fuel filter. The porosity of the filter paper determines the life of the filter. The smaller the pores of the filter paper, the faster the filter blocking occurs. Field and laboratory tests concluded that the biodiesel fuel filter will have filter blocking for a porosity of 5 µ, but not for porosity of 8 µ (Petiteaux and Monsallier, 2009).

In addition, this road test also investigated the effect of low temperature ambient in Indonesia on vehicle fuelled with B30. Cold-start ability was studied at Wonosobo in Central Java, which represents the operability of a vehicle fuelled with B30 in a low-temperature environment. Twelve vehicles were prepared for various soaking periods of 3, 7, 14 and 21 days. Here, three vehicles were prepared for each soaking period which fuelled with pure diesel fuel (B0), B30 with MG of 0.40% and B30 with MG of 0.55%. Its goal is to investigate the effect of MG content on cold start ability at low ambient temperature area in Indonesia. MG could influence on precipitation of B30 so that it is possible to clog the fuel filter (Camerlynck *et al*., 2012; Paryanto *et al*., 2019a). As a result, the vehicle will either fail to start or start after longer times.

The cold start test was conducted at varying ambient temperature of 12°C to 18°C with an average of 16°C. In this study, the measurement uncertainty for cold start test was determined and found to be 0.12 s. The cold start time for all tested fuels were comparable across all soaking periods as shown in *Figure 8*. It can be considered that the cold start with B30 is still similar with ordinary diesel fuel in Indonesia, as the average testing temperature was still above the pour point temperature for the whole tested fuels. Furthermore, utilisation of B30 at temperatures lower than its pour point is still possible with the addition of a surfactant to improve its operability in cold temperatures (Prilla *et al*., 2020).

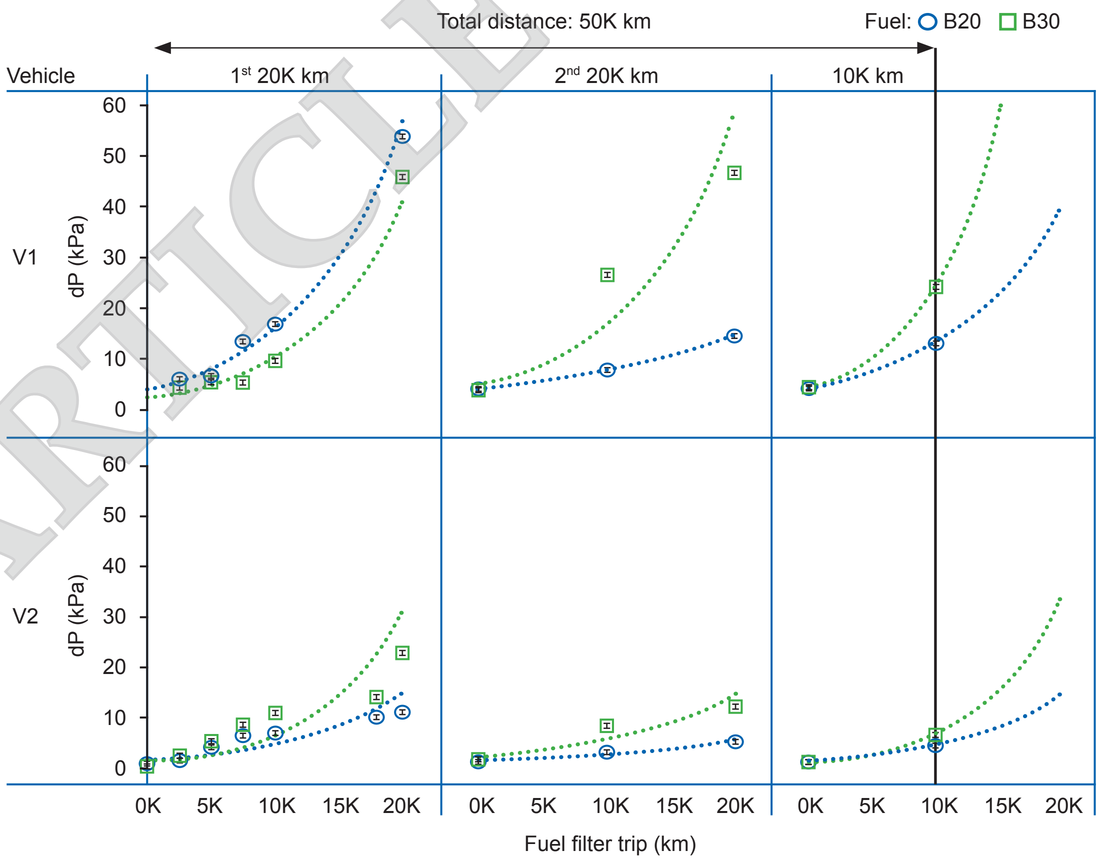

Figure 7. Measurement results of dP Fuel filter during road test of V1 and V2 vehicles.

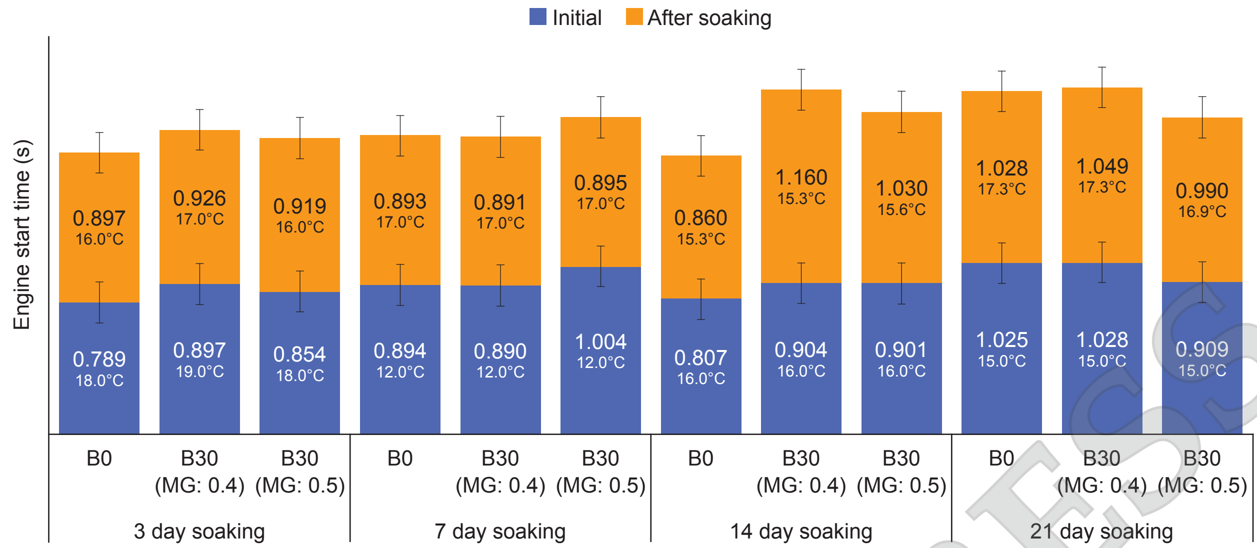

Figure 8. Cold start ability at various soaking period at low ambient temperature.

CONCLUSION

A comprehensive assessment showed that vehicles running on B20 and B30 could successfully cover 50 000 km in Indonesian operating conditions without encountering any operational problems. The road test further revealed that there was no need to change the fuel filters at the recommended 20 000 km interval, as both B20 and B30 maintained a differential pressure below 55 kPa. Moreover, even in Indonesia low-temperature conditions, B20 and B30 performed admirably, with engines starting times in less than five seconds without any noticeable issues.

Moreover, several conclusions have been derived from the laboratory testing of vehicles running on B20 and B30 fuel. The power and fuel economy of the B20 and B30 vehicles exhibited an average variation of 4.8 kW and 0.2 km/L, respectively. Notably, increasing the biodiesel ratio to 30% did not always lead to decreased power and FE, with results dependent on vehicle settings. Furthermore, B30 resulted in lower CO, HC, and PM, but exhibited a higher NOx value when compared to B20. This NOx increase can be attributed to the higher combustion temperature in B30, indicating more efficient combustion. Additionally, the differential pressure was consistently higher for B30, implying that the existing B20 fuel filter may have a shorter lifetime when used with B30. However, fuel filter lifetime was still comparable with fuel filter changing as manufacturer recommendations. Finally, B30 utilisation did not have a significant impact on the cold start ability of the vehicle.

This study demonstrates that the improved biodiesel properties for B30 implementation could maintain vehicle performance similar to that of B20 without requiring any changes to the periodic maintenance of the vehicles. Nevertheless, further research is crucial to verify that B30 meets the requirements for sustainable renewable fuel, which necessitates various assessment methods, including life cycle analysis. These studies are important to ensure that supply, demand, fuel prices, and manufacturing technology align adequately for the nationwide implementation of B30.

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