THE INFLUENCE OF B-35 DIESEL FUEL TESTING PARAMETERS ON THE EFFICIENCY AND PERFORMANCE OF DIESEL ENGINES

Irene Nindita Pradnya[1*] **, Shendy Krisdayanti**[1] **, Nurul Komariyah**[2]
[1] Department of Chemical Engineering, Faculty of Engineering, Semarang State University Gunungpati, Semarang, Central Java, 50299, Indonesia .
[2] Oil and Gas Human Resource Development Center, Pusat Pengembangan Sumber Daya Manusia Minyak dan Gas Bumi, Jl. Sorogo No. 1, Karangboyo, Cepu, Blora, Central Java, 58315
[*] Email: irene.nindita@mail.unnes.ac.id

Abstract

The use of biodiesel as a mixture of diesel fuel has become one of the solutions to reduce dependence on fossil fuels and reduce greenhouse gas emissions. The B-35 diesel program, consisting of a mixture of 35% biodiesel with 65% diesel, is an initiative of the Indonesian government to realize more sustainable energy. This study aims to analyze various test parameters of B-35 diesel, including density (ASTM D 1298), viscosity (ASTM D 445), and residual carbon content (ASTM D 4350), and analyze their impact on diesel engine efficiency and performance. The test method is carried out by measuring density using a hydrometer, viscosity using a kinematic viscometer, and carbon residue by heating the sample at a temperature of 500°C. The results showed that the B-35 diesel mixture had a higher density (855,72 kg/m^3) and viscosity (3,150 mm^2/s) compared to pure diesel, which was 840 kg/m^3 and 2,8 mm^2/s, making the fuel injection process uniform. The residual carbon content of 0.14%, which is lower than pure diesel, which is 0.18%, helps reduce the potential for the formation of combustion residue buildup in the engine, thereby helping to maintain engine performance. Based on these results, the use of B-35 diesel can be a more environmentally friendly alternative and support the improvement of diesel engine performance.

***Keywords** : biodiesel, diesel, efficiency, emissions, oil.*

Abstrak

Pemanfaatan biodiesel sebagai campuran bahan bakar solar menjadi salah satu solusi untuk mengurangi ketergantungan terhadap bahan bakar fosil dan mengurangi emisi gas rumah kaca. Program solar B-35 yang terdiri dari campuran 35% biodiesel dengan 65% solar merupakan inisiatif pemerintah Indonesia untuk mewujudkan energi yang lebih berkelanjutan. Penelitian ini bertujuan untuk menganalisis berbagai parameter uji solar B-35, meliputi densitas (ASTM D 1298), viskositas (ASTM D 445), dan kadar karbon residu (ASTM D 4350), serta menganalisis dampaknya terhadap efisiensi dan kinerja mesin diesel. Metode pengujian dilakukan dengan mengukur densitas menggunakan hidrometer, viskositas menggunakan viskometer kinematik, dan residu karbon dengan memanaskan sampel pada suhu 500°C. Hasil penelitian menunjukkan bahwa campuran solar B-35 memiliki densitas (855,72 kg/m^3) dan viskositas (3.150 mm^2/s) yang lebih tinggi dibandingkan solar murni, yaitu 840 kg/m^3 dan 2,8 mm^2/s, sehingga proses injeksi bahan bakar menjadi seragam. Kandungan karbon residu sebesar 0,14% yang lebih rendah dibandingkan solar murni yaitu 0,18% membantu mengurangi potensi terbentuknya timbunan sisa pembakaran di dalam mesin, sehingga membantu menjaga kinerja mesin. Berdasarkan hasil tersebut, penggunaan solar B-35 dapat menjadi alternatif yang lebih ramah lingkungan dan mendukung peningkatan kinerja mesin diesel.

Kata kunci : biodiesel, efisiensi, emisi, minyak, solar.

1. INTRODUCTION

The need for diesel oil in Indonesia is increasing along with the development of the transportation and industrial sectors, while Indonesia still relies on fossil fuels. Currently, 95% of Indonesia's energy comes from fossil fuels, and petroleum stocks are expected to run out in 2028 (Afriyanti, Sasana and Jalunggono, 2018; Ma'arief and Susanto, 2022) . This increases energy security risk, especially with unstable world oil price fluctuations. In addition, the combustion of fossil fuels causes greenhouse gas emissions that contribute to climate change (Pradnya dkk., 2023).

Replacing fossil fuels with biodiesel is a solution to Indonesia's depletion of fossil fuel sources. Biodiesel is a mono-alkyl ester fuel derived from fatty acids, which is used as a substitute for diesel (Habibah, Putri and Silitonga, 2022). Biodiesel has good potential to replace fossil fuels whose availability is decreasing. Diesel fuel consumption in Indonesia is in the range of 2.5 million tons to 3.5 million tons per year from 2010-2019 (Budiman and Samik, 2023). The Indonesian government has initiated a program to mix biodiesel into diesel fuel, one of which is B-35 diesel oil, which is a mixture of 35% biodiesel with 65% diesel oil (Purnomo *et al.*, 2024), This program aims to increase the use of renewable energy and reduce greenhouse gas emissions. Biodiesel is biodegradable and has lower carbon emissions compared to fossil oil (Suherman *et al.*, 2022).

The B-35 program focuses on the transportation sector with diesel engines, such as heavy vehicles and ships, and must meet the standards issued by the Directorate General of Oil and Gas Number 170.K/HK.02/DJM/2023. Biodiesel has different physical and chemical properties from fossil diesel, such as higher viscosity and higher oxygen content, which affect combustion efficiency and emissions (Dwipayana, 2017) . In the B-35, biodiesel functions not only as an alternative fuel but also as a supplementary material that improves combustion properties and reduces the level of carbon residue in the engine, which ultimately improves engine performance (Pradnya dkk., 2022).

This research aims to discover how key parameters of B-35 diesel fuel such as density, viscosity, and carbon residue influence the combustion efficiency and performance of diesel engines. This study is conducted to explore how these physical characteristics of B-35 influence fuel injection, energy output, and overall engine performance, aiming to provide insights for optimizing the use of B-35 in reducing emissions and enhancing engine efficiency in the industrial and transportation sectors.

Several previous studies have discussed using biodiesel as a diesel fuel blend, including the B-35 mixture. The study by Purnomo *et al.*, (2024) found that using B-35 fuel could reduce exhaust emissions and improve fuel efficiency, however, this study did not thoroughly investigate the effect of density and viscosity parameters on combustion efficiency. The study by Dwipayana, (2017) also found that the physical properties of biodiesel, including viscosity and oxygen content, affect the combustion process. Still, this research focused on the application of biodiesel in boilers, rather than on diesel engine performance. Meanwhile, the study by Wahyudi, Caroko and Sampurna, (2023) evaluated the effect of density and viscosity of Jatropha-corn biodiesel on fuel injection angles, but it did not include an analysis of carbon residue and used a different biodiesel blend.

The innovation of this study is the testing of the impact of carbon residue on engine performance, which has not been widely explored in previous studies. In addition, this study is more specific in looking at the correlation between density and viscosity with fuel injection efficiency in B-35-based diesel engines. Thus, this study not only focuses on the environmental impact of using B-35 but also technically examines how the characteristics of this fuel can be optimized to improve diesel engine performance, Table 1 shows the standards and quality (specifications) of diesel fuel according to the Directorate General of Oil and Natural Gas.

Table 1. Standards and Quality (Specifications) of Diesel Fuel (B-35)

No	Characteristics	Min	Max	ASTM
1	Density (at 15°C)	815 kg/m^3	880 kg/m^3	D1289/D4052
2	Viscosity (at 40°C)	2 mm^2/s	5 mm^2/s	D445
3	Carbon Residue	-	0,1 %m/m	D189/D4530

Source: (Director General of Oil, Gas and Natural Resources, Ministry of Energy and Mineral Resources, 2023)

2. METHODOLOGY

2.1 Materials and tools

The materials used in this study were diesel oil (B-35). The tools used were a 1000 mL measuring cylinder, Hydrometer, 12C thermometer, Kinematic viscosity apparatus, 100 glass capillary viscometer, Bath viscometer, Thermometer, Stopwatch, Pump, Beaker, Micro carbon residue tester, Analytical scales, Desiccator, Tweezers, Vial.

2.2 Method

2.3.1 Density (ASTM D 1298)

The sample is placed in a 1000 mL measuring cylinder, then a thermometer is inserted to measure the initial sample temperature. Density is measured by inserting a hydrometer into the sample and then the final temperature is measured again as a constant temperature calibration. For transparent samples, how to read the scale on the hydrometer can be seen in Figure 2. Record and calculate the results of temperature and density measurements at a temperature correction of 15°C using Table 53B in Figure 1.

DENSITY AT OBSERVED TEMPERATURE

TEMP. C	833.0	835.0	837.0	839.0	841.0	843.0	845.0	847.0	849.0	851.0	853.0	TEMP. C
	CORRESPONDING DENSITY AT 15 C											
27.00	841.3	843.3	845.3	847.3	849.3	851.3	853.2	856.2	857.2	859.2	861.2	27.00
27.25	841.5	843.5	845.5	847.4	849.4	851.4	853.4	855.4	857.4	859.4	861.4	27.25
27.50	841.6	843.6	845.6	847.6	849.6	851.6	853.6	855.6	857.6	859.6	861.6	27.50
27.75	841.8	843.8	845.8	847.8	849.8	851.8	853.8	855.8	857.8	859.7	861.7	27.75
28.00	842.0	844.0	846.0	848.0	850.0	852.0	853.9	855.9	857.9	859.9	861.9	28.00
*28.25	842.2	844.1	846.1	848.1	850.1	852.1	854.1	856.1	858.1	860.1	862.1	28.25
28.50	842.3	844.3	846.3	848.3	850.3	852.3	854.3	856.3	858.3	860.3	862.3	28.50
28.75	842.5	844.5	846.5	848.5	850.5	852.5	854.5	856.4	858.4	860.4	862.4	28.75
29.00	842.7	844.7	846.7	848.7	850.6	852.6	854.6	856.6	858.6	860.6	862.6	29.00
29.25	842.8	844.8	846.8	848.8	850.8	852.8	854.8	856.8	858.8	860.8	862.8	29.25
29.50	843.0	845.0	847.0	849.0	851.0	853.0	855.0	857.0	859.0	860.9	862.9	29.50
29.75	843.2	845.2	847.2	849.2	851.2	853.2	855.1	857.1	859.1	861.1	863.1	29.75
30.00	843.4	845.4	847.4	849.3	851.3	853.3	855.3	857.3	859.3	861.3	863.3	30.00
30.25	843.5	845.5	847.5	849.5	851.5	853.5	855.5	857.5	859.5	861.5	863.5	30.25
30.50	843.7	845.7	847.7	849.7	851.7	853.7	855.7	857.6	859.6	861.6	863.6	30.50
30.75	843.9	845.9	847.9	849.9	851.8	853.8	855.8	857.8	859.8	861.8	863.8	30.75
31.00	844.1	846.0	848.0	850.0	852.0	854.0	856.0	858.0	860.0	862.0	864.0	31.00
31.25	844.2	846.2	848.2	850.2	852.2	854.2	856.2	858.2	860.2	862.1	864.1	31.25
31.50	844.4	846.4	848.4	850.4	852.4	854.4	856.3	858.3	860.3	862.3	864.3	31.50
31.75	844.6	846.6	848.6	850.5	852.5	854.5	856.5	858.5	860.5	862.5	864.5	31.75
32.00	844.7	846.7	848.7	850.7	852.7	854.7	856.7	858.7	860.7	862.7	864.6	32.00
32.25	844.9	846.9	848.9	850.9	852.9	854.9	856.9	858.9	860.8	862.8	864.8	32.25
32.50	845.1	847.1	849.1	851.1	853.1	855.0	857.0	859.0	861.0	863.0	865.0	32.50
32.75	845.3	847.3	849.2	851.2	853.2	855.2	857.2	859.2	861.2	863.2	865.2	32.75
33.00	845.4	847.4	849.4	851.4	853.4	855.4	857.4	859.4	861.4	863.3	865.3	33.00
33.25	845.6	847.6	849.6	851.6	853.6	855.6	857.5	859.5	861.5	863.5	865.5	33.25
33.50	845.8	847.8	849.8	851.8	853.7	855.7	857.7	859.7	861.7	863.7	865.7	33.50
33.75	846.0	847.9	849.9	851.9	853.9	855.9	857.9	859.9	861.9	863.9	865.9	33.75
34.00	846.1	848.1	850.1	852.1	854.1	856.1	858.1	860.0	862.0	864.0	866.0	34.00
34.25	846.3	848.3	850.3	852.3	854.3	856.2	858.2	860.2	862.2	864.2	866.2	34.25
34.50	846.5	848.5	850.5	852.4	854.4	856.4	858.4	860.4	862.4	864.4	866.4	34.50

* DENOTES EXTRAPOLATED VALUE

OBSERVED DENSITY – 833.0 TO 853.0

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WHEN USING A DENSITY IN G/ML, G/CC, OR KG/L, MULTIPLY BY 1000 BEFORE ENTERING THE ABOVE TABLE

Figure 1. Table 53B density correction 15°C

(source: American Society for Testing and Materials, 1980)

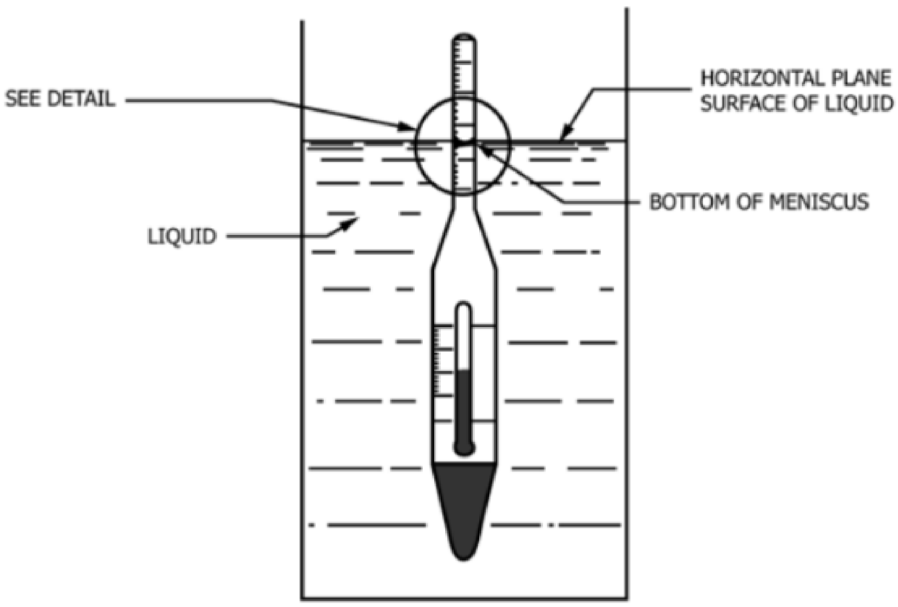

Figure 2. Hydrometer Scale for Transparent Samples

(source: ASTM D 1298 - 12b, 2017)

2.3.2 Viscosity (ASTM D 445)

The ASTM D 445 kinematic viscosity instrument (see Fig. 3) was turned on to a constant temperature of 40°C. The sample was inserted into a 100 glass capillary viscometer with the help of a pump up to the boundary line. The viscometer containing the sample was inserted into the viscometer bath and waited for 30 minutes so that the temperature between the sample and the liquid in the viscometer bath was uniform. The liquid was sucked using a pump up to the upper boundary line. The flow time of the liquid from the upper boundary line to the lower boundary was recorded.

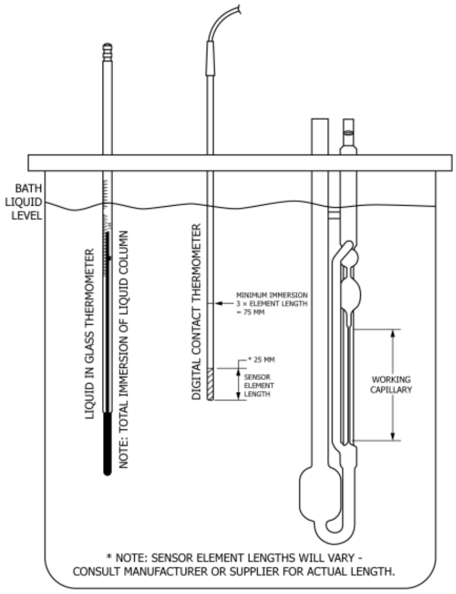

Figure 3. Kinematic Viscosity Tool

(source: ASTM D445 - 23b, 2023)

2.3.3 Carbon Residue (ASTM D 4350)

Empty vials are weighed first and then 1-2 grams of sample is added. The vials containing the sample are placed in a heating container (see Fig. 4). The sample is heated at a temperature of 500°C and then cooled in a desiccator for 1 hour (to room temperature). The vials containing the sample are weighed again and the results are recorded.

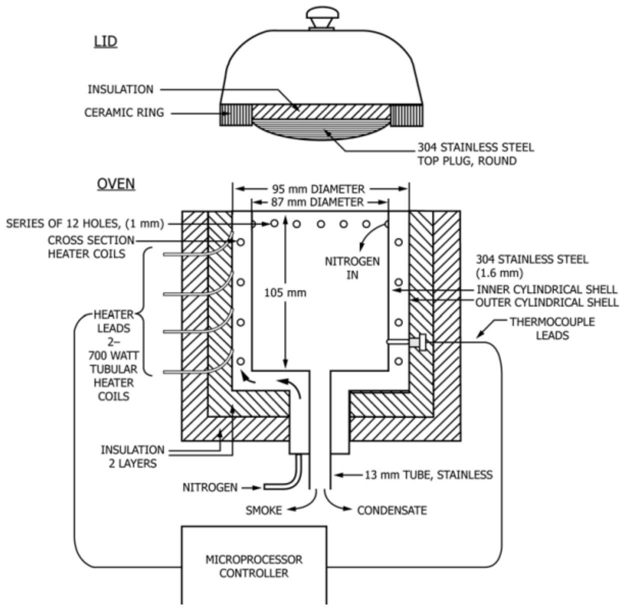

Figure 4. Carbon Residue Tool

(source: ASTM D4530 - 15, 2015)

3. RESULTS AND DISCUSSION

3.1 Effect of Density on Combustion Efficiency

Density is a critical parameter in determining the quality of diesel oil. Density measurement needs to be done because it is related to buying and selling factors, energy content, storage, transportation, and distribution processes (Abdurrojaq *et al.* , 2021). Density measurement is carried out using a hydrometer and is usually expressed in units of kg/m^3 or g/cm$^{3.}$ The results of the diesel oil density test with a cetane number of 48 using the ASTM D 1298 test method can be seen in Table 2. From the data obtained, the density value of the observation results can be converted into a standard density value of 15°C using the ASTM 1250 53B table.

Table 2. Diesel Oil Density Test Results

No	Observation 28,8°C (kg/m^3)	Correction 15°C (kg/m^3)	Average (kg/m^3)
1	846	855,48	855,72
2	846,5	855,96	

The first test result shows that the observation density at a temperature of 28,8°C is 846 kg/m^3 while the second test result shows that the observation density at the same temperature is 846,5 kg/m^3. The results of these two tests calculated the corrected density at a temperature of 15°C, which are 855,48 kg/m^3 and 855,96 kg/m^3 with an average of 855,72 kg/m^3.

Based on the standards and quality specifications for diesel fuel (B-35) with a cetane number (CN) of 48, the density limit is 815-880 kg/m^3 (Directorate General of Oil, Gas and Natural Resources, Ministry of Energy and Mineral Resources, 2023) . Based on the repeatability calculation, the test results still meet the ASTM D 1298 standard, which is below 0,5 kg/m^3. Thus, the tested diesel oil has met the standards set by the Directorate General of Oil and Natural Gas.

In a diesel engine, density affects the amount of energy available. Where the more tall density the more tall energy per unit volume (Wahyudi, Caroko and Sampurna, 2023) . In other words, diesel engines can produce more power. However, diesel oil with too high a density can cause incomplete combustion, thereby increasing carbon deposits in the combustion chamber and reducing the efficiency of the diesel engine (Amrullah *et al.* , 2021) . In addition, incomplete combustion also increases pollutant emissions (Jayanti, Hakam and Santiasih, 2014) . Therefore, it is important to ensure the density meets the standards because suitable fuel contains sufficient energy for efficient combustion, producing optimal power, and supporting engine performance.

3.2 Effect of Viscosity on Diesel Engine Performance

Diesel oil viscosity refers to how easily or difficulty the fuel can flow. Viscosity measurements are carried out using a viscometer and are expressed in centistokes (cSt). The viscosity value needs to be considered because it affects engine performance. The results of testing the viscosity of diesel oil with a cetane number of 48 using the ASTM D 445 method are shown in Table 3.

Table 3. Diesel Oil Viscosity Test Results

No	Results (mm^2/s)	Average (mm^2/s)	***Repeatability***
1	3,148	3,150	0,018
2	3,152		

Repeatability Calculation

$$r = 0{,}0043\ x\ (y + 1) \quad (1)$$
$$r = 0{,}0043\ x\ (3{,}15 + 1)$$
$$r = 0{,}01784$$
$$r = 1{,}78\%$$

$Note$

$r = repeatability$

$y = average\ viscosity$

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The first test result shows that the diesel flow time is 238,32 seconds while the second test result is 238,62 seconds. The results of these two tests are multiplied by the viscometer constant (0,01321 (mm^2/s)/s) which is 3,148 mm^2/s and 3,152 mm^2/s with an average viscosity of 3,150 mm^2/s.

Based on the standards and quality specifications of diesel fuel (B-35) with a cetane number (CN) of 48, the viscosity has a limit value of 2 - 5 mm^2/s (Directorate General of Oil, Gas and Natural Resources, Ministry of Energy and Mineral Resources, 2023) . Based on the repeatability calculation in the ASTM D 445 standard, the diesel test results which is 1,78% still meet the standards because the difference in values is below the threshold of 7,88%. Thus, the diesel oil tested meets the standards set by the Directorate General of Oil and Gas.

In diesel engine performance, the lower the viscosity value, the better the combustion, increasing the ignition speed, and making it easier for fuel to be injected, atomized, and mixed with air (Pradnya, Am dan Pradani, 2023). Conversely, the higher the viscosity value, the lower the combustion rate due to poor fuel atomization (Laila and Oktavia, 2017) .

Therefore, it is important to use diesel oil with the appropriate viscosity to maintain the performance of the diesel engine. The correct viscosity will ensure smooth fuel flow, efficient injection, optimal combustion, and long engine life, as well as reducing maintenance requirements and improving overall operational efficiency.

3.3 Effect of Carbon Residue on Diesel Engine Performance

The rest of the heavy hydrocarbons or other components that are not burned during the combustion process are called carbon residues. One of the test methods used to measure the amount of carbon residue is MCRT *(Micro Carbon Residue Test)*. This method produces the amount of carbon residue formed after the sample is heated in an airless condition (pyrolysis) at high temperatures and is expressed in units of % m/m. The results of the viscosity test of diesel oil with a cetane number of 48 using the ASTM D 4530-15 method are shown in Table 4.

Table 4. Results of Solar Oil Carbon Residue Test

No	Carbon Residue (grams)	Carbon Residue (% m/m)	Average (% m/m)
1	0,00119	0,119	0,14
2	0,00159	0,159	

Calculation of carbon residue percentage:

$$\%CR = \frac{A}{W}\ x\ 100\% \quad (2)$$

$Note$
$\%CR\ = percentage\ of\ carbon\ residue$
$A\ = carbon\ residue\ (grams)$
$W\ = initial\ sample\ (grams)$

The first test result showed that the carbon residue of diesel oil was 0,00119 grams while the second test result was 0,00159 grams. The results of these two tests were calculated as the percentage of carbon residue, which were 0,119% m/m and 0,159% m/m with an average of 0,14% m/m.

Based on the standards and quality specifications of diesel fuel (B-35) with a cetane number (CN) of 48, the carbon residue has a limit value of 0,1% m/m (Director General of Oil and Gas, Ministry of Energy and Mineral Resources, 2023) . Thus, the diesel oil tested has not met the standards set by the Directorate General of Oil and Gas. This can happen because diesel oil that does not meet quality standards has a high sulfur content, high sulfur content can increase carbon residue due to more complex chemical reactions during the combustion process (Pattiruhu, Tupan and Tutuhatunewa, 2020) . In addition, the level of accuracy can also affect the test results (Mulyani, Solikha and Oktaviani, 2022) .

Fuels with high MCRT values tend to produce more carbon residue. When these fuels are used in diesel engines, carbon residues can accumulate in various parts of the engine, such as fuel injectors, combustion chambers, valves, and exhaust gas lines. The accumulation of carbon residues can interfere with the flow of fuel and air, reduce combustion efficiency, and accelerate the wear of engine components (Wahyu, Nurlina and Irawan, 2023) . In addition, high MCRT values will produce more carbon emissions that not only pollute the environment but also affect the performance of the engine emission control system (Jayanti, Hakam and Santiasih, 2014) .

Therefore, control of the MCRT value and proper fuel selection are very important to maintain performance and extend engine life.

4. CONCLUSION

The results of the 15°C correction density test were 855,72 kg/m^3 according to the Directorate General of Oil and Gas (2023) specification standards, which are 815-880 kg/m^3 so that diesel oil contains sufficient energy for efficient combustion in diesel engines. The results of the viscosity test were 3,150 mm^2/s according to the Directorate General of Oil and Gas (2023) specification standards, which are 2-5 mm^2/s so that diesel oil has a smooth flow in diesel engines. The MCRT test results were 0,14% above the Directorate General of Oil and Gas (2023) specification standards, which were 0,1%. This could happen because of the high sulfur content so that diesel oil causes residue buildup in diesel engines. Overall, the use of B-35 diesel oil provides significant environmental benefits by reducing exhaust emissions in diesel engine applications.

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