Jurnal Pendidikan Teknologi dan Kejuruan
Vol. 31, No. 1, May 2025, pp. 15-28
https://journal.uny.ac.id/index.php/jptk/issue/view/2802
DOI: https://doi.org/10.21831/jptk.v31i1.81436

Feasibility study of engine oil concerning the kinematic viscosity, water contamination, and dissolved solids pollutants on locomotive CC 206

Akbar Zulkarnain[1*], Dehar Bagas Saefullah[2], Damar Isti Pratiwi[3], Dimas Adi Perwira[4], Arif Devi Dwipayana[5], Triana Sharly Permaisuri Arifin[6]

[1,2, 3, 4] Politeknik Perkeretaapian Indonesia Madiun, Indonesia
[5]Politeknik Transportasi Darat Bali, Indonesia
[6]University of Leeds, United Kingdom
Email: akbar@ppi.ac.id *
*Corresponding author

ABSTRACT

Lubrication is defined as the process of supplying lubricating materials to a machine with the aim of preventing direct contact between moving surfaces. Viscosity is a critical property of lubricating oil. Engine oil samples were taken from locomotives CC 206 13 18 and CC 206 13 45 at Sidotopo Locomotive Depot, Daop 8 Surabaya. The testing of the engine oil was conducted at the ITS Surabaya Laboratory and PT Sucofindo Surabaya, using ASTM D 445-97, ASTM D 95-13, and ASTM D 482 standards. The results were then compared to the standard limits for locomotive engine oil feasibility. Based on the tests, the oil from CC 206 13 18 had a kinematic viscosity of 15.86 cSt, water contamination of 0.07%, and dissolved solid contaminants of 0.973%. The oil from CC 206 13 45 showed a kinematic viscosity of 15.38 cSt, water contamination of 0.06%, and dissolved solid contaminants of 0.917%. The test results indicate that the kinematic viscosity, water contamination, and dissolved solid content in the engine oils of both locomotives are still within acceptable limits. Furthermore, kinematic viscosity has a significant effect on the maximum operational distance of the locomotive. For CC 206 13 18, the recorded distance was 186,962 km, and for CC 206 13 45, it was 194,352 km. Therefore, the engine oil in both locomotives can still be used beyond the distance limit set by the manufacturer.

Keywords: *water contamination, lubrication, dissolved solid pollutants, kinematic viscosity*

Article history

Received:	*Revised:*	*Accepted:*	*Published:*
24 December 2025	*21 January 2025*	*30 May 2025*	*30 May 2025*

Citation (APA Style): Zulkarnain, A., Saefullah, D. B., Pratiwi, D. I., Perwira, D. A., Dwipayana, A. D., Arifin, T. S. P., (2025) Feasibility study of engine oil concerning the kinematic viscosity, water contamination, and dissolved solids pollutants on locomotive CC 206. *Jurnal Pendidikan Teknologi dan Kejuruan*, 31(1), 15-28. https://doi.org/10.21831/jptk.v31i1.81436

INTRODUCTION

Refers to the use of lubricating oil—a thick fluid derived from petroleum—to reduce friction between machine components. This oil originates from fossil deposits formed millions of years ago and is essential for maintaining engine performance. Its primary functions include reducing friction between components, preventing wear and tear, stabilizing engine temperature, preventing corrosion, and extending the lifespan of engine parts (Hudoyo, 2013).

In the railway sector, lubrication plays a critical role in locomotive maintenance. Due to its importance, lubrication is included in the periodic maintenance schedule of locomotives. Periodic maintenance is a form of preventive action aimed at avoiding component failures, ensuring engine reliability, and preventing costly damage to engine systems (Ikechukwu, 2023).

According to an interview with a technician at the Sidotopo Locomotive Depot, an issue related to engine oil was identified—a water hammer in the engine. This problem was indicated by continuous white smoke emitted from the exhaust pipe, which occurred in one of the eight-cylinder assemblies. The water hammer was caused by a coolant leak that entered the combustion chamber, contaminating both the combustion process and the engine oil (C.M. Bartolini, 2003). Further examination showed a decrease in coolant levels and off-white, foamy oil under the camshaft cover, indicating water contamination. This condition can lead to severe engine damage, such as the bending or breaking of pistons due to obstruction in the compression process. Repairs carried out included replacing the engine oil and coolant, replacing the cylinder assembly, and inspecting for other potential leaks. These actions were taken during the locomotive's Monthly Check 12 (MC12) (General Electric Transportation, 2012).

Engine oil changes are scheduled every six months, specifically during Monthly Check 6 (MC6) and Monthly Check 12 (MC12) (PT Kereta Api Indonesia, 2022). During these checks, approximately 1,000 liters of engine oil are drained and replaced. This practice, which follows the Time-Based Maintenance (TBM) approach, aims to maintain optimal engine performance. However, TBM has its drawbacks; components that are still functional may be replaced prematurely, leading to unnecessary waste and costs. A more efficient alternative is to base oil changes on mileage and engine condition, maximizing oil usage while being cost-effective and environmentally friendly (Isrofi, 2018).

Observations at the Sidotopo Locomotive Depot (Daop 8 Surabaya) revealed that the depot operates three locomotive series: CC 201, CC 203, and CC 206. The CC 201 and CC 203 locomotives have irregular monthly check cycles due to limited parts availability, resulting in extended delays. In contrast, the CC 206 locomotives, which are still under General Electric (GE) warranty, follow a regular maintenance schedule, as spare parts are provided and managed by GE.

This research aims to determine the relationship between the maximum feasibility limit of engine oil and locomotive mileage. The goal is to identify the mileage at which engine oil remains in good condition. The results are expected to serve as a valuable reference and offer a solution for PT KAI in managing engine oil feasibility more effectively.

In this study, the feasibility of CC 206 engine oil service life was evaluated based on three parameters: kinematic viscosity, water contamination (water content), and dissolved solids (ash content) (Sejkorová et al., 2021). These parameters were selected because they represent standard indicators of locomotive engine oil condition. All three play a critical role in determining the suitability of engine oil, as they directly affect its performance and safety. The mileage variation analyzed in this study includes the last recorded mileage at the time of the 12-Monthly Check and two weeks prior. The reference standards for determining oil feasibility were taken from the *GE Locomotive Instruction Manual (MI)* published by General Electric Transportation (2012). A notable development in this study is the use of a vacuum pump to extract engine oil samples directly from the engine compartment. The primary objective of the research is to assess the feasibility of engine oil through laboratory testing and compare the results against established locomotive engine oil standards (General Electric Transportation, 2014).

METHOD

A. Viscosity

Viscosity plays an important role in reducing wear between interacting machine components. Lubricating oil with excessively high viscosity can be difficult to flow through engine channels, causing energy loss as the engine must work harder (Blanco-Rodríguez et al., 2024). On the other hand, lubricating oil with too low or thin viscosity leads to increased friction between components, resulting in a higher wear rate. In general, the acceptable limit for used lubricating oil viscosity is 50% of the viscosity of new lubricating oil. If the viscosity of used oil drops below this threshold, the oil is considered unsuitable and must be replaced. Field observations and data from the Instruction Manual indicate that lubricating oil is deemed unfit if its viscosity decreases by 25% from the original value or falls below 12.5 cSt at a testing temperature of 100ºC (Darmawan, 2018). To determine the eligibility limit of oil viscosity, the following formula can be used:

$$\mathbf{v_t} = \propto \times \mathbf{v_0} \quad (1)$$

Description:

$\propto$ = *Percentage of eligibility limit*

v_0 = *Initial kinematic viscosity (cSt)*

vt = *Final kinematic viscosity (cSt)*

Based on this calculation, vtv_tvt represents the final kinematic viscosity value, which also serves as the minimum limit for oil eligibility. This limit provides a basis for assessing the relationship between kinematic viscosity and mileage, and for determining whether the oil remains suitable for use. If the calculated value falls below the acceptable standard, the kinematic viscosity must be adjusted to meet the required specifications (Ajimotokan & Ilorin, 2024).

B. Kinematic Viscosity Testing

Kinematic viscosity testing was conducted using a Bath Koehler Viscometer in accordance with ASTM D445-97 standards. The Bath Koehler Viscometer is an instrument used to measure the viscosity of lubricating oil through two temperature-based testing methods, specifically at 40ºC and 100ºC. The principle of kinematic viscosity testing is based on measuring the time it takes for a fluid to flow under gravity at specified temperatures (Setia Budi Kurniawan, 2018). Kinematic viscosity is determined by measuring the flow time of the oil at the test temperatures of 40ºC and 100ºC (Nugraha, 2018). The following is the calculation used in kinematic viscosity testing:

$$\boldsymbol{kinematic\ viscosity = C \times t} \quad (2)$$

Description:

C = *Capillary viscometer constant*

t = *Flow time*

C. Water Contamination Testing

Water contamination testing is carried out with the *Karl Fischer Coulometric Titration* tool using the ASTM D 95-13 standard. *Karl Fischer Coulometric Titration* is a measuring instrument to measure water contamination in lubricating oil. The principle of water contamination testing (Maulida, R.H dan Rani, 2010) i.e. a certain volume of sample is injected into the titration cell, where iodine for the Karl Fisher reaction is generated coulometrically at the anode. When all the water has been titrated, excessive iodine is detected by an *endpoint* electrometric detector and the titration is stopped. Based on the stoichiometry of the reaction, 1 mole of iodine reacts with 1 mole of water (Nalumenya et al., 2024). The following is the calculation in testing for water contamination (Bañón et al., 2021):

$$\boldsymbol{water\ content = F \times \frac{moisture}{W_1 - W_2}} \quad (3)$$

Description:

F = *Value factor*

W_1 = *Weight of sample + syringe before injection*

W_2 = *Weight of sample + syringe after injection*

D. Dissolved Solid Pollutant Testing

Testing of dissolved solid pollutants is conducted using an Ash Analyzer in accordance with ASTM D482 standards (Drews, 2008). The Ash Analyzer is an instrument used to measure the content of dissolved solid pollutants in lubricating oil. According to the testing principle of dissolved solid pollutants (Naccarato & Tagarelli, 2019), a sample is placed in a porcelain cup and burned over a burner until it becomes charcoal. The resulting charcoal residue is then heated in a furnace at 775°C until it turns to ash, after which it is cooled and weighed until a constant mass is achieved (Pushpa Y G, 2018)(Juarez et al., 2023). The calculation for determining the content of dissolved solid pollutants is as follows (Sitogasa et al., 2023):

$$\textbf{ash content} = \frac{(C-A)}{(B-A)} \times \mathbf{100}\% \quad (4)$$

Description:

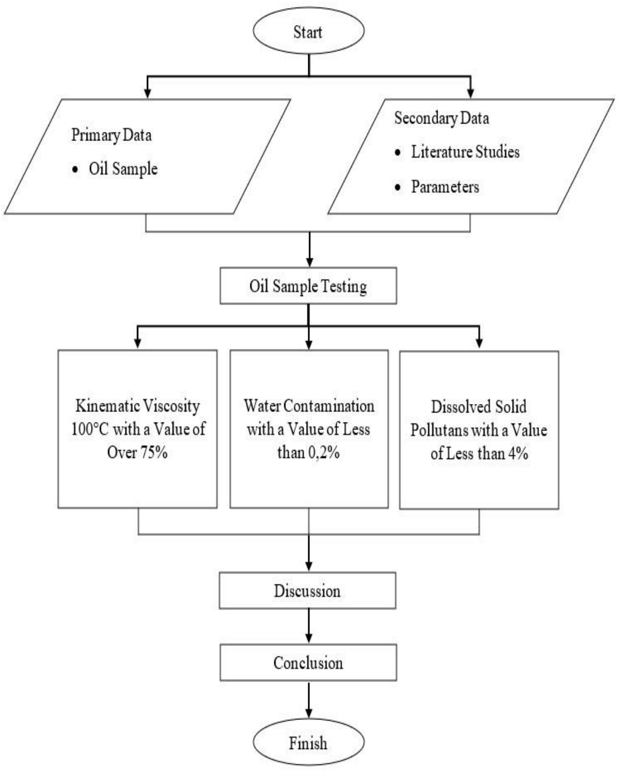
A = *Weight of empty cup*

B = *Weight of empty cup + initial sample*

C = *Weight of empty cup + fumigated sample*

E. Flowchart

The flowchart used in this study is as follows:



F. Methodology

The methodology of thought used in this research is the Experimental Method (Bibliography, 1966)(Quality, 2016), these are the steps:

1. Engine oil sampling as much as 350 ml
2. Engine oil sample testing in the oil laboratory
3. Data tabulation
4. Data analysis of results of engine oil

G. Tools and Materials

The tools and materials used in this research include:

1. Engine Oil Sample (350 ml)
2. Engine Oil Sample Container
3. Vacuum Pump
4. Bath Koehler Viscometer
5. Karl Fischer Coulometric Titration
6. Ash Analyzer

Figure 1 Vacuum Pump

H. Engine Oil Sampling Procedure

The following is the procedure for taking engine oil samples using a vacuum pump (Wolak et al., 2021) (An et al., n.d.)(Chen-Wishart, 2014):

1. Open the access cover on the tank.
2. Insert the vacuum pump hose into the tank until it is in the centre of the oil level (not too high and not too low).

3. Pump the vacuum pump lever until the oil can be sucked up and into the sample container.
4. Fill the engine oil sample container between $\frac{2}{3}$ or $\frac{3}{4}$ of the volume of the container.
5. Ensure that all sample containers are closed and close the tank from which the oil is taken.
6. Identify the sample with the locomotive series, sampling date, and volume of oil taken.
7. Clear the site of oil spills and other debris before leaving the site.

Figure 2 Oil Sample

I. Engine Oil Sample Testing

The engine oil samples that were collected were tested in laboratories to determine their contents. The kinematic viscosity test at 100°C was conducted at the ITS Laboratory in Surabaya. Testing for water contamination and dissolved solid pollutants was carried out at the PT Sucofindo Laboratory in Surabaya.

RESULT AND DISCUSSION

Table 1 is the result of testing engine oil samples in the form of 3 parameters, namely kinematic viscosity, water contamination, and dissolved solid pollutants. CC 206 13 18 produces a kinematic viscosity of 15.86 cSt, 0.07% water contamination, and 0.973% dissolved solid pollutants. CC 206 13 45 resulted in a kinematic viscosity of 15.38 cSt, water contamination of 0.06%, and dissolved solid pollutants of 0.917%. These parameters were compared with the locomotive engine oil eligibility limit standards, namely the Instruction Manual (MI) Book.

Table 1. Testing Results of Engine Oil Samples CC 206 13 18 and CC 206 13 45

Engine Oil Sample	Distance Traveled (km)	100ºC Kinematic Viscosity (cSt)	Water Contamination (%)	Dissolved Solid Pollutants (%)
CC 206 13 18	0	15,59	0,05	0,676
	129.040	16,43	0,1	0,947
	137.441	15,86	0,07	0,973
CC 206 13 45	0	15,59	0,05	0,676
	125.734	15,91	0,12	0,904
	136.399	15,38	0,06	0,917

a. Kinematic Viscosity

It can be observed that the kinematic viscosity of locomotives CC 206 13 18 and CC 206 13 45 differs. For CC 206 13 18, the kinematic viscosity at distances of 129.040 km and 137.441 km is higher than at 0 km. In contrast, for CC 206 13 45, the kinematic viscosity at 0 km and 125.734 km is higher than at 136.399 km. An increase in kinematic viscosity may result from oxidation processes, the formation of ash or soot, and the accumulation of carbon deposits that are insoluble in oil. However, the kinematic viscosity of the engine oil in both locomotives generally decreases as mileage increases. Additionally, the kinematic viscosity of the used engine oil is higher than that of new engine oil, likely due to the presence of contaminants that increase oil thickness. Based on this discussion, it can be concluded that engine oil condition should not be assessed solely based on a high kinematic viscosity value.

b. Kinematic Viscosity Calculation

Calculation of the feasibility limit of kinematic viscosity of engine oil as follows:

$v_t = \propto \times v_0$

$v_t = 75\% \,.\, 15{,}59$

$v_t = 11{,}69\ cSt$

Description:

$\propto$ = Percentage of eligibility limit

v_0 = Initial kinematic viscosity (cSt)

v_t = Final kinematic viscosity (cSt)

So, the result of the above calculation yields $v_t = 11{,}69\ cSt$. The feasibility limit of the kinematic viscosity of engine oil when it has dropped by 25% or at least 12,5 cSt. The results of the above calculations are below the minimum value of the feasibility limit, so the kinematic viscosity in this calculation is adjusted to 12,5 cSt.

c. Kinematic Viscosity Extrapolation Calculation CC 206 13 18

Calculation of the extrapolation of the kinematic viscosity of CC 206 13 18 is as follows:

$$\frac{s - s_1}{s_2 - s_1} = \frac{v - v_1}{v_2 - v_1}$$

$$\frac{s - 129040}{137441 - 129040} = \frac{12{,}5 - 16{,}43}{15{,}86 - 16{,}43}$$

$$\frac{s - 129040}{8401} = \frac{-3{,}93}{-0{,}57}$$

$$s - 129040 = 8401\left(\frac{-3{,}93}{-0{,}57}\right)$$

$$s = 129040 + 57922$$

$$s = 186962\ km$$

Description:

v = Kinematic viscosity eligibility limit

v_1 = Distance kinematic viscosity 129.040 km (cSt)

v_2 = Distance kinematic viscosity 137.441 km (cSt)

s = Distance travelled when kinematic viscosity reaches 75%

s_1 = Distance travelled 129.040 km.

s_2 = Distance traveled 137.441 km.

d. Kinematic Viscosity Extrapolation Calculation CC 206 13 45

Calculation CC 206 13 45

Calculation of the extrapolation of the kinematic viscosity of CC 206 13 45 is as follows:

$$\frac{s - s_1}{s_2 - s_1} = \frac{v - v_1}{v_2 - v_1}$$

$$\frac{s - 125734}{136399 - 125734} = \frac{12{,}5 - 15{,}91}{15{,}38 - 15{,}91}$$

$$\frac{s - 125734}{10665} = \frac{-3{,}41}{-0{,}53}$$

$$s - 125734 = 10665\left(\frac{-3{,}41}{-0{,}53}\right)$$

$$s = 125734 + 68618$$

$$s = 194352 \text{ km}$$

Description:

v = *Kinematic viscosity eligibility limit*

v_1 = *Distance kinematic viscosity 125.734 km (cSt)*

v_2 = *Distance kinematic viscosity 136.399 km (cSt)*

s = *Distance travelled when kinematic viscosity reaches 75%*

s_1 = *Distance traveled 125.734 km*

s_2 = *Distance traveled 136.399 km*

e. Water Contamination

Increased water contamination in engine oil can be caused by several factors, such as water leaks in the cylinder jackets, leaks in the oil cooler, or a malfunctioning injector in the oil drain vacuum pump that remains open. Another contributing factor may be the use of a new engine oil storage bin, especially when the tank is placed in an open area, making it more susceptible to contamination. The decline in oil quality can also be attributed to the quality of the new engine oil itself, particularly if the oil has already been contaminated before entering the crankcase. The graph shows a noticeable decrease in water contamination during the Monthly Check 12 (MC12). This decrease is attributed to the addition of 100 liters of new engine oil during the Daily Check (DC), which helps dilute the contaminated oil, reducing water content and bringing the contamination level closer to that of the new oil. Water contamination in both locomotives tends to increase with mileage, due to prolonged engine operation. However, periodic additions of new oil during DC help reduce the level of water contamination, as the oil volume is replenished. Therefore, based on this observation, water contamination in engine oil can be effectively reduced by adding fresh engine oil at regular intervals.

f. Dissolved Solid Pollutants

Dissolved solid pollutants in engine oil are primarily caused by wear on the piston rings, which can lead to leaks. These leaks result in partial combustion of engine oil during the compression process, forming crusts on the piston surface as well as ash and soot. Additional pollutants can arise from erosion of the engine oil filter during the filtration process, or from residual deposits of previous oil contaminants that are not completely removed during oil draining. Another potential source of contamination is during engine maintenance—specifically when disassembling the cylinder—where dust or other small particles may inadvertently enter the oil system. Test results indicate that the level of dissolved solid pollutants in the engine oil of both locomotives increases with mileage. The longer the locomotive operates, the more pollutants accumulate, which in turn raises the viscosity of the engine oil. Excessively viscous oil can lead to elevated engine temperatures, formation of additional pollutants, and increased wear on engine components. In conclusion, dissolved solid pollutants in engine oil consistently increase with greater locomotive mileage, highlighting the need for regular oil checks and timely maintenance

RESULTS AND DISCUSSION

The results of the kinematic viscosity extrapolation for locomotives CC 206 13 18 and CC 206 13 45 indicate the maximum mileage achievable before reaching the oil feasibility limit. For CC 206 13 18, the maximum mileage achieved is 186,962 km, with a difference of 49,521 km between the mileage at MC12 and the maximum mileage. For CC 206 13 45, the maximum mileage is 194,352 km, with a difference of 57,953 km from the mileage at MC12. Based on these calculations, CC 206 13 45 demonstrates the longest maximum mileage and the greatest difference in mileage. Kinematic viscosity influences the maximum distance that can be traveled before the oil reaches its feasibility limit. If the mileage exceeds this limit, the kinematic viscosity of the oil will drop below the threshold, indicating that the oil must be replaced.

Based on the results of three parameter tests conducted on each locomotive, all three parameters remain within acceptable limits at the MC12 point. In the kinematic viscosity test, CC 206 13 18 recorded a viscosity of 15.86 cSt at 137,441 km, while CC 206 13 45 recorded 15.38 cSt at 136,399 km. Both values are above the minimum feasibility threshold of 12.5 cSt for locomotive engine oil. In the water contamination test, CC 206 13 18 showed a contamination level of 0.07% at 137,441 km, and CC 206 13 45 showed 0.06% at 136,399 km. These values are still below the maximum acceptable limit of 0.2%. In the test for dissolved solid pollutants, CC 206 13 18 recorded a value of 0.973%, while CC 206 13 45 recorded 0.917%, both at their respective mileages. These results are also within the acceptable limit of 4% for dissolved solids in locomotive engine oil.

These three parameters are interconnected and contribute to the overall quality and eligibility of the oil. In the kinematic viscosity test, the viscosity was found to have increased compared to its previous value. This increase is influenced by oxidation processes, the formation of ash or soot, and the accumulation of carbon scale, which cannot dissolve in the oil and causes the engine oil to become thicker. Another contributing factor is water contamination. Water in the oil can lead to corrosion, degrade the chemical structure of the oil, and reduce its lubricating ability. These effects are harmful to the engine, as they can increase wear and friction between components.

Wear and friction further lead to the formation of solid pollutants, which accelerate the deterioration of oil quality. These pollutants can also result from high engine operating temperatures and extended mileage, both of which contribute to the aging of the oil. This is supported by the test results showing that the concentration of dissolved solid pollutants increases with longer distances traveled. Based on the calculations and test results, engine oils CC 206 13 18 and CC 206 13 45 are still in acceptable condition at MC12. According to General Electric Transportation (2012), the acceptable limit for kinematic viscosity should not be less than 25% of the viscosity of new engine oil, or at least 12.5 cSt. The maximum acceptable limit for water contamination is 0.2%, and for dissolved solid pollutants, it is 4%. At both MC6 and MC12, the engine oil is drained using an oil pump and replaced with 1000 L of new oil (Maulida & Rani, 2010). This is part of PT KAI's preventive maintenance strategy, which aims to prevent major engine damage, maintain engine performance, and avoid significant repair costs.

CONCLUSION

Based on the results of extrapolation calculations, the kinematic viscosity of CC 206 13 18 can support a mileage of up to 186,962 km, while CC 206 13 45 can reach 194,352 km. It can be concluded that the kinematic viscosity of the oil is influenced by insoluble pollutants and mileage. A more stable decline in kinematic viscosity corresponds to a longer potential mileage. The test results of the three parameters measured for CC 206 13 18 and CC 206 13 45 indicate a decline in quality due to mileage. However, the decrease in all three parameters remains within the acceptable limits for locomotive engine oil. Therefore, if there is a delay in changing the engine oil every six months or if any engine oil-related issues arise, the oil can still be used safely for a certain period of time.

REFERENCES

Ajimotokan, H. A., & Ilorin, U. of. (2024). Viscosity of Fluid Lubricants. *Principles and Applications of Tribology*, 29–37.

An, T., Sample, O. I. L., & Valve, U. A. (n.d.). *Oil Sampling Procedures Overview*.

Bañón, S., Álvarez, S., Bañón, D., Ortuño, M. F., & Sánchez-Blanco, M. J. (2021). Assessment of soil salinity indexes using electrical conductivity sensors. *Scientia Horticulturae*, *285*(February). https://doi.org/10.1016/j.scienta.2021.110171

Bibliography, A. C. (1966). Lubrication, corrosion and wear. *Wear*, *9*(3), 241. https://doi.org/10.1016/0043-1648(66)90168-2

Blanco-Rodríguez, J., Porteiro, J., López-Campos, J. A., Cortada-García, M., & Fernández-Castejón, S. (2024). Wear protection assessment of ultralow viscosity lubricants in high-power-density engines: A novel wear prediction algorithm. *Friction*, *12*(8), 1785–1800. https://doi.org/10.1007/s40544-023-0854-3

C.M. Bartolini, F. C. (2003). Beneficial Use of Water Hammer in a Gasoline Direct Injection System. *ASME/JSME 2003 4th Joint Fluids Summer Engineering Conference*, *4*.

Chen-Wishart, M. (2014). Spectro Scientific's In-Service Oil Analysis Handbook Third Edition. *Vascular*, *January 2010*, 1–2.

Darmawan, D. (2018). Analisa kelayakan umur pakai oli yamalube matic sae 20w-40 berdasarkan viskositas kinematik dan total acid number pada sepeda motor yamaha x-ride. *Jurnal Teknis Mesin Industri*.

Drews, A. (2008). Standard Test Method for Ash from Petroleum Products. *Manual on Hydrocarbon Analysis, 6th Edition*, 141-141–143. https://doi.org/10.1520/mnl10845m

General Electric Transportation. (2012). *Recommended fuel, oil, and lubricants; ge diesel-electric locomotives*. General Electric and Confidential Information.

General Electric Transportation. (2014). *Lubricating oil system* (Indo Java (ed.); Issue March). GE Confidential.

Hudoyo, R. (2013). *Penentuan batas maksimal kontaminan air pada oli murni untuk memenuhi standar kelayakan bahan bakar*. Universitas Kristen Satya Wacana.

Ikechukwu, O. A. E. I. (2023). A technical report on the effects of lubricating fluids (lubricants) on service performance of machine parts. *International Summit Scientific Research Congress*.

Isrofi, N. (2018). *Evaluasi time based maintenance (tbm) dalam rangka menurunkan biaya maintenance*. https://repository.its.ac.id/52196/

Juarez, M. B., Mondelli, G., & Giacheti, H. L. (2023). An overview of in situ testing and geophysical methods to investigate municipal solid waste landfills. *Environmental Science and Pollution Research*, *30*(9), 24779–24789. https://doi.org/10.1007/s11356-023-25203-5

Maulida, R.H dan Rani, E. (2010). Analisis Karakteristik Pengaruh Suhu dan Kontaminan Terhadap Viskositas. *Jurnal Neotrino*, *3*(1), 18–31.

Maulida, R. H., & Rani, E. (2010). Analisis karakteristik pengaruh suhu dan kontaminan terhadap viskositas oli menggunakan rotary viscometer. *Jurnal Neutrino*, *3*(1), 18–31.

Naccarato, A., & Tagarelli, A. (2019). Recent applications and newly developed strategies of solid-phase microextraction in contaminant analysis: Through the environment to humans. *Separations*, *6*(4). https://doi.org/10.3390/separations6040054

Nalumenya, B., Rubinato, M., Catterson, J., Kennedy, M., Bakamwesiga, H., & Wabwire, D. (2024). Assessing the Potential Impacts of Contaminants on the Water Quality of Lake Victoria: Two Case Studies in Uganda. *Sustainability (Switzerland)*, *16*(20), 1–25. https://doi.org/10.3390/su16209128

Nugraha, G. N. (2018). Analisa Kelayakan Umur Pakai Minyak Pelumas Federal Oil Ultratec SAE 20W-50 Berdasarkan Viskositas Kinematik Dan Total Base Number Pada Sepeda Motor Honda Supra X 125. *Program studi diploma iii departemen teknik mesin industri Fakultas Vokasi Institut Teknologi Sepuluh Nopember Surabaya*, *372*(2), 2499–2508.

PT Kereta Api Indonesia. (2022). *Checksheet cc 206 perawatan 12 bulanan (p12)*. PT Kereta Api Indonesia.

Pushpa Y G, V. N. & G. G. (2018). An Improved Pollution Testing Methodology for Polymeric Insulators: Analysis on Surface Coating and Flashover Voltage Under Solid Layer Test. *Journal of The Institution of Engineers*, *100*, 1–8.

Quality, M. O. (2016). *Field Sampling Procedures for Fuel and Motor Oil Quality*.

Sejkorová, M., Hurtová, I., Jilek, P., Novák, M., & Voltr, O. (2021). Study of the effect of physicochemical degradation and contamination of motor oils on their lubricity. *Coatings*, *11*(1), 1–18. https://doi.org/10.3390/coatings11010060

Setia Budi Kurniawan, A. (2018). Pengaruh Jarak Tempuh Terhadap Viskositas Kinematik Dan Viskositas Index Oli AHM MPX 2 SAE 10W-30 Pada Sepeda Motor Honda Beat. *Jurnal*

Teknik Mesin Industri Surabaya, 1–88.

Sitogasa, P. S. A., Mohamad Mirwan, Firra Rosariawari, & Azizah M. Rizki. (2023). Analysis of Water and Ash Content in Biomass Briquettes from Durian Fruit Peel Waste and Sawdust. *Journal of Research and Technology*, *8*(2), 279–288. https://doi.org/10.55732/jrt.v8i2.712

Wolak, A., Zajac, G., & Słowik, T. (2021). Measuring kinematic viscosity of engine oils: A comparison of data obtained from four different devices. *Sensors*, *21*(7), 1–15. https://doi.org/10.3390/s21072530