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Impact of Extended Intervals on Diesel Engine Performance with 15W-40 DH1 Lubricant Oil

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Abstract

Engine lubricant oil is crucial for minimizing friction between moving components within an engine, directly influencing the engine's reliability and lifespan. Determining the appropriate oil replacement intervals is essential, as extending these intervals necessitates more rigorous monitoring of both oil quality and engine condition. This study investigated the performance of SAKAI 15W-40 DH1 engine oil in the SAKAI Vibrating Roller SV526 over varying operational periods: 125 hours, 250 hours, 375 hours, and 500 hours. The research involved analyzing oil samples for viscosity, metal additives, total base number (TBN), and contaminants using Fourier Transform Infrared Spectroscopy (FTIR). Additionally, key engine performance indicators, including fuel consumption, valve clearance, and compression pressure, were measured. The findings revealed a gradual decrease in oil viscosity from 13.48 cSt to 11.56 cSt, approaching the minimum acceptable threshold of 11.45 cSt. Concurrently, the Fe content in the oil increased to 11 ppm, indicating wear, while the valve clearance in cylinder number three expanded to 0.48 mm, and compression pressure dropped from 31 kg/cm^2 to 28 kg/cm^2. Despite these changes, the oil remained within the standard operational limits, and the engine continued to perform adequately. However, based on the observed trends, extending the oil replacement interval to 500 hours cannot be conclusively recommended, as the oil's condition and engine performance may begin to decline beyond this point.

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1. Introduction

Mineral lubricating oil (base mineral oil) is one of the products of the petroleum fraction (crude oil) which has gone through various refining processes at the refinery. In order to obtain lubricating oil fractions from petroleum, various processes are needed to obtain important properties of lubricating oil, because the content in petroleum has a large number of hydro-carbon compounds and is very complex. Lubricating oil or engine oil is a liquid that is needed by vehicles, the role of lubricating oil or oil is also very important to maintain the durability or durability of the engine for a long period of time. Besides being able to keep the engine from friction that occurs, oil is also useful for making the vehicle engine performance remain stable when used continuously. Because when the engine works oil lubricates the parts that are exposed to friction and makes these parts smooth when moving and rotating [1].

In the operation of heavy equipment vehicles, particularly the road compactor vibrating machines such as the SAKAI SV526 equipped with the ISUZU 4BG1T diesel engine, ensuring maximum lubrication is crucial for maintaining engine performance, durability, and longevity. The replacement time for engine oil in the SAKAI Vibrating Roller SV526 engine is a critical aspect of maintenance that directly impacts engine performance and longevity. The general consensus in the literature suggests that engine oil replacement intervals can vary significantly based on operational conditions, oil formulation, and the specific engine type. This is essential to prevent severe damage that could lead to breakdowns and incur high repair costs. Various factors determine the quality of lubricating oil,

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including specific gravity, evaporation temperature, spillage temperature, combustion temperature, viscosity, and carbon content. Despite these criteria, the market commonly uses the SAE rating as a standard for lubricant quality [2].

Research indicates that the optimal replacement interval for 15W-40 engine oil, particularly in heavy-duty applications, is often around 500 hours of operation. For instance, a study focusing on the Volvo FMX 440 dump truck found that using Petronas SAE 15W-40 engine oil allowed for oil changes every 500 hours, which was deemed cost-effective compared to more frequent changes at 250 or 750 hours [3]. This finding aligns with the operational characteristics of the SAKAI Vibrating Roller, which operates under similar heavy-duty conditions.

Lubricating oil that has been used for a certain time (based on working time) must also be replaced because the viscosity of the oil has generally changed (getting thinner) and along with the time of oil use, the color of the oil will also change [4]. Not only does it cause metal wear on the engine, but it also causes deposits or scale due to too many impurities in the lubricating oil. Thus condition-based maintenance, one of which is monitoring oil analysis, is the right maintenance strategy to increase equipment life and reduce time lost due to equipment damage, or to increase the reliability and availability of equipment.

Moreover, the degradation of engine oil over time is influenced by several factors, including temperature, load, and the presence of contaminants. The aging of mineral oils, such as SAE 15W-40, has been shown to significantly affect their tribological performance, which in turn influences the wear and tear on engine components [5], [6]. This degradation necessitates regular monitoring of oil properties, such as viscosity and total base number (TBN), to determine the appropriate replacement time [7]. Specifically, the TBN is a critical indicator of the oil's ability to neutralize acids formed during combustion, and a drop in TBN can signal the need for an oil change [7].

In addition, the incorporation of additives, such as hexagonal boron nitride nanoparticles, has been shown to enhance the performance of 15W-40 engine oils by improving their load-carrying capacity and reducing friction [8], [9]. This suggests that the formulation of the oil can also affect the replacement interval, as oils with superior additive packages may maintain their performance characteristics longer than standard formulations. Furthermore, environmental factors, such as ambient temperature and humidity, can also impact oil performance. A study on the performance of engine oils under varying climatic conditions highlighted those higher temperatures can accelerate oil degradation, necessitating more frequent changes in hotter environments [10]. This is particularly relevant for the SAKAI Vibrating Roller, which may operate in diverse conditions depending on the job site.

The purpose of this study is to evaluate the optimal replacement interval for SAKAI 15W-40 DH1 engine oil in the SAKAI Vibrating Roller SV526, a key piece of heavy machinery. This research is driven by the need to validate the quality and performance of SAKAI 15W-40 DH1 as a genuine, high-quality lubricating oil, specifically designed for diesel engines under demanding conditions. By conducting a series of tests and analyses, the study aims to provide empirical data that can be used to establish a reliable oil change interval, ensuring that the engine operates at peak performance while avoiding unnecessary wear and tear. Additionally, the findings of this research will serve to reinforce the value of using genuine SAKAI engine oil, thereby helping to protect market demand against competitive alternatives. Ultimately, the goal is to offer a comprehensive reference that heavy equipment operators can rely on for maintaining their machinery, while also highlighting the superior quality of SAKAI's genuine oil products [11].

2. Methods

2.1. Materials

The study utilized SAKAI engine oil, SAE 15W-40 DH-1, an engine lubricant oil that meets the JASO DH-1 standard. This oil is specifically formulated to provide optimal protection for modern diesel engines equipped with technologies such as common rail, EGR, and turbochargers. The oil exhibits excellent viscosity stability and is fortified with antioxidant, anti-wear, anti-corrosion, and anti-foam properties. These attributes help prevent the formation of acidic and corrosive deposits on critical engine components, such as bearings and cylinder walls, which are especially vulnerable in engines employing EGR systems due to elevated nitrogen oxide levels [12].

2.2. Experimental design

This experimental study was conducted to evaluate the impact of extended oil change intervals on engine performance parameters in the SAKAI Vibrating Roller SV526, powered by an ISUZU 4BG1T diesel engine. The primary objective was to assess the changes in the oil's physical and chemical properties, as well as the corresponding effects on engine performance metrics, over a series of operating intervals: 0 hours, 125 hours, 250 hours, 375 hours, and 500 hours.

Engine oil samples were collected at each of the designated operating hour intervals. Concurrently, engine performance parameters, including fuel consumption, valve clearance, and compression pressure, were measured to provide a comprehensive assessment of the engine's operational condition.

The viscosity of the oil samples was determined according to the ASTM D7279 standard, which involves using an automated Houillon viscometer to measure the kinematic viscosity at 100°C. This test aimed to monitor the oil's ability to maintain its lubricating properties over extended use [13].

The wear metal content in the oil was analyzed using ASTM D5185, which employs an inductively coupled plasma (ICP) method to quantify the concentration of metals such as iron (Fe), copper (Cu), aluminum (Al), chromium (Cr), nickel (Ni), tin (Sn), and lead (Pb). These measurements indicate the level of wear on engine components and the presence of potential contaminants [14].

Fourier Transform Infrared Spectroscopy (FTIR) was used to assess the presence of contaminants such as water, soot, ethylene glycol, and fuel in the oil. The analysis also monitored oil degradation markers, including oxidation, nitration, and sulfonation, which are critical in diagnosing the engine's operating condition and determining the oil's remaining service life [15].

The TBN of the oil samples was measured to evaluate the oil’s capacity to neutralize acids produced during combustion. This was done using ASTM D4739, where a potentiometric titration method was applied. The TBN values were tracked over time to determine the oil’s ability to maintain engine cleanliness and prevent corrosive wear [16].

3. Results and Discussion

3.1. Viscosity

The lubricating oil exhibited a decrease in viscosity over 535 hours of operation, although it remained within the specified limits, as shown in Table 1 and Figure 1. However, by the 535-hour mark, the viscosity was approaching the critical threshold of 11.45 cSt. This reduction in viscosity is likely attributed to two primary factors: fuel dilution and the degradation of polymer additives caused by shear forces. These shear forces can arise from the operation of the oil pump, the narrow clearances within the engine bearings, and the submersion of the crankshaft in the lubricating oil within the crankcase.

Table 1. Viscosity (cSt) test results of oil sampel, at 100 °C

Operating Hours	Viscosity @100 °C (cSt)	Standard Value	
		Min.	Max.
0	13.48	11.45	15.50
154	12.41		
265	12.76		
375	12.24		
535	11.56		

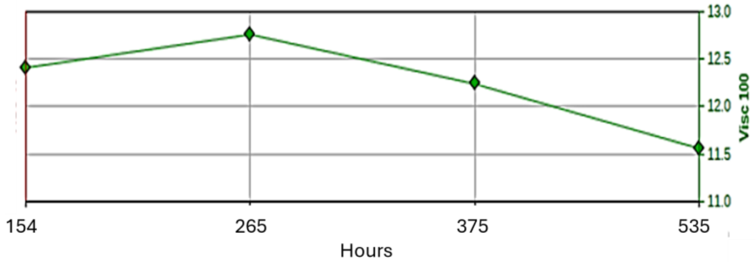

Figure 1. Viscosity test results of oil sampel

3.2. Wear trending and metal additive

Laboratory tests on the SAKAI genuine 15W-40 DH1 engine oil sample revealed an increase in metal content, indicating wear and tear on engine components, as shown in Table 2 and Figure 2.

Specifically, the Fe (iron) content in the lubricating oil reached 11 ppm during the engine's operating hours, which, while still below the critical threshold of 75 ppm, suggests wear within the combustion chamber, particularly affecting the piston rings and liners. Additionally, the concentrations of copper (Cu) and lead (Pb) in the oil also rose with extended operating hours. Copper levels increased from 1 ppm initially to 2 ppm, and lead levels increased from 2 ppm to 3 ppm by 535 hours of operation. Similarly, aluminum (Al) content remained at 3 ppm throughout the testing period. Although these values are still below the critical limits, they point to ongoing wear, particularly abrasive wear, which poses significant risks if the particles infiltrate the bearings or the gap between the piston and cylinder liner. On the other hand, the concentrations of chromium (Cr) and nickel (Ni) remained below their respective threshold limits throughout the testing period.

Table 2. Wear trending & metal additive (ppm) of oil sampel

Operating hours	Fe	Cu	Al	Cr	Ni	Sn	Pb
0	0	0	0	0	0	0	0
154	4	1	3	< 1	< 1	< 1	2
265	3	1	3	< 1	< 1	< 1	2
375	6	1	3	< 1	< 1	1	2
535	11	2	3	< 1	< 1	1	3

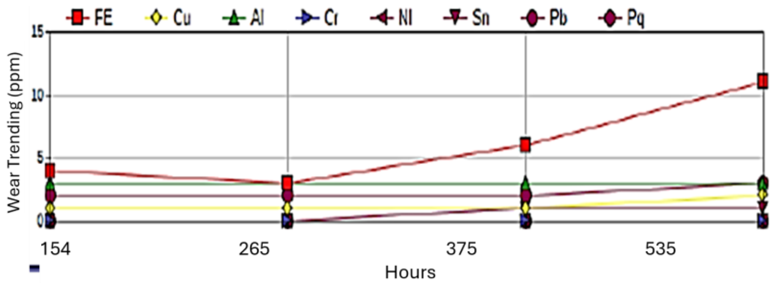

Figure 2. Wear trending & metal additive of oil sampel

3.3. Contamination – FTIR

The contaminants monitored in this study included water, soot, ethylene glycol, fuel, and degraded oil [15]. Additionally, the oxidation, nitration, and sulfonation of the base stocks were tracked as indicators of oil degradation, and the results are shown in Table 4 and Figure 3. The primary goal of this monitoring was to assess the engine's operating condition by identifying any faults reflected in the oil's condition. FTIR testing of SAKAI genuine 15W-40 DH1 engine oil samples revealed that oxidation levels increased significantly, ranging from 0.16 Abs/0.1mm to 0.18 Abs/0.1mm at 535 hours of operation, nearing the standard laboratory limit of 0.2 Abs/0.1mm. In contrast, the levels of soot, nitration, sulfation, fuel dilution, and glycol remained relatively stable throughout the 535-hour testing period. The observed increase in oxidation can be attributed to chemical changes in the oil over time, with results trending close to the maximum allowable limit.

The results presented in Table 3 show the levels of sodium (Na), silicon (Si), and soot in the oil samples collected at various operating hours, measured in Abs/0.1mm. Sodium levels remained relatively low throughout the testing period, fluctuating slightly between 0 and 2 Abs/0.1mm. The presence of sodium in the oil could indicate coolant leakage (if the coolant contains sodium), contamination from external sources, or additives in the oil. Furthermore, silicon levels showed a gradual increase from 0 Abs/0.1mm at the start to a maximum of 3 Abs/0.1mm at 375 operating hours, followed by a slight decrease to 2 Abs/0.1mm at 535 hours. Silicon in oil is typically associated with dirt or dust ingress, which can be abrasive and cause wear on engine components. The soot levels in the oil increased steadily from 0 at the start to 0.05 Abs/0.1mm at 535 hours. Soot is a byproduct of incomplete combustion and can contribute to oil thickening and increased engine wear if not properly managed. The contaminant levels in the oil samples indicate that while there are some signs of contamination and combustion byproducts (e.g., silicon and soot), these levels remain relatively low and within acceptable limits throughout the operating hours tested.

Table 3. Contaminant of oil sampel (Abs/0.1mm)

Operating hours	Na	Si	Soot
0	0	0	0
154	2	1	0.01
265	1	2	0.005
375	2	3	0.02
535	1	2	0.05

Table 4. FTIR of oil sampel (Abs/0.1mm)

Operating hours	Oxidation	Nitration	Sulfation
0	0	0	0
154	0.16	0.03	0.05
265	0.11	0.02	0.05
375	0.18	0.03	0.05
535	0.18	0.04	0.06

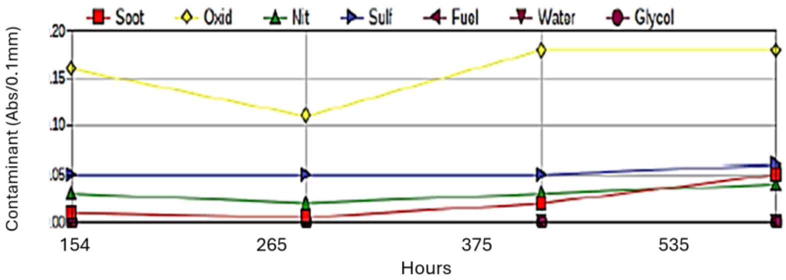

Figure 3. Contaminant – FTIR of oil sampel

3.4. Total Base Number

The test results, as presented in Table 5 and Figure 4, indicate that the Total Base Number (TBN) of the lubricating oil consistently decreased throughout the road test period. The TBN started at 10.98 mgKOH/g and gradually declined to 10.58 mgKOH/g, with an average reduction of 0.1 mgKOH/g per oil sampling up to 535 hours of operation.

Table 5. Total Base Number (TBN) of oil sampel

Operating hours	TBN value (mgKOH/g)	Standard value	
		Max	Min
0	11.00	6.47	4.70
154	10.98		
265	10.80		
375	10.69		
535	10.58		

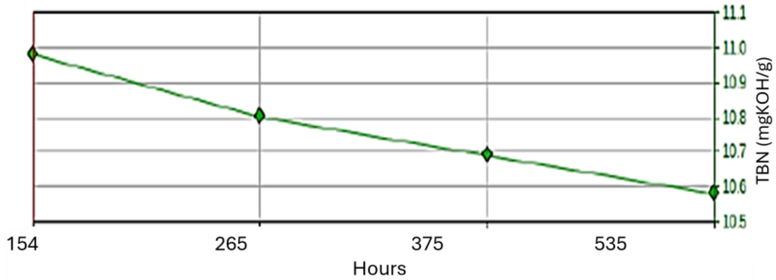

Figure 4. Contaminant – FTIR of oil sampel

Despite this decrease, the TBN remained above the minimum threshold of 6 mgKOH/g, indicating that the lubricating oil still retained sufficient capacity to be effective. The decline in TBN suggests a reduction in the oil's ability to neutralize acids generated by oxidation, as well as a decrease in its detergency and dispersing capabilities to clean the engine of dirt or deposits from fuel combustion and the oxidation of the oil itself. Should the TBN continue to decrease to the allowable limit, there is an increased risk of engine component corrosion.

3.5. Effects of Lubricant to ISUZU 4BG1T Diesel Engine

Valve gap measurements at 125 hours operating interval showed that in cylinder number 3, the valve gap tended to be larger until it reached 0.45 mm at the inlet valve (IN) and 0.48 mm at the outlet valve (EX) at 535 hours of operation. Valve gaps that do not match the standard values in diesel engines can have a detrimental impact on engine performance.

Based on actual operating data, the use of SAKAI genuine 15W-40 DH1 engine oil at extended intervals of up to 500 hours resulted in a notable improvement in fuel consumption efficiency for the evaluated engines. However, compression pressure measurements revealed a significant decrease in cylinder number 3. Diesel engines are designed to operate within specific compression pressure parameters, and substantial deviations from these specifications can disrupt engine balance and performance. Low compression pressure can lead to incomplete fuel combustion, leaving unburned fuel residues in the cylinder, which reduces the engine's thermal efficiency. This inefficiency can cause a decline in power and torque output, as the piston lacks sufficient pressure, potentially leading to excessive stress on components such as pistons, piston rings, and valves. Consequently, this can accelerate wear and increase the risk of engine damage. Additionally, valve gap measurements taken at the 125-hour operating interval indicated that the gap in cylinder number 3 gradually increased, reaching 0.45 mm at the inlet valve (IN) and 0.48 mm at the exhaust valve (EX) after 535 hours of operation. Valve gaps that fall outside standard specifications can significantly impair engine performance.

4. Conclusions

The study's findings indicate that the viscosity of SAKAI 15W-40 DH1 engine oil used in the SAKAI Vibrating Roller SV526 decreased from 13.48 cSt to 11.56 cSt over the course of 535 hours, approaching the critical threshold of 11.45 cSt. This reduction suggests a potential thinning of the oil, likely caused by oxidation, contamination, or fuel dilution. The wear trend analysis revealed a consistent increase in iron content, rising from 0 to 11 ppm, which may point to wear or leakage in iron or steel components within the engine. Additionally, oxidation levels were observed to rise significantly, approaching the standard limit, indicating the formation of acidic compounds that could potentially damage engine components. Despite these indications of oil degradation, the overall performance of the SAKAI 15W-40 DH1 engine oil remained adequate as a lubricant throughout the observation period. Continuous monitoring of these parameters is crucial to ensure the ongoing effectiveness of the oil in maintaining engine performance and preventing potential damage. Furthermore, extending the oil change interval to 500 hours led to a notable improvement in fuel consumption efficiency. However, this extended interval also resulted in a significant decrease in compression pressure in cylinder number 3, suggesting incomplete combustion and reduced thermal efficiency, which could negatively impact engine power and torque. The valve gap measurements in cylinder number 3 also showed substantial deviations, with the inlet valve gap reaching 0.45 mm and the exhaust valve gap reaching 0.48 mm after 535 hours of operation. Although the engine continued to function under these conditions, the observed decline in performance highlights the need for further evaluation to ensure the engine's long-term reliability. Implementing a more rigorous monitoring program for engines using SAKAI 15W-40 DH1 oil is crucial to ensuring optimal engine performance and longevity. This program should focus on key parameters, including viscosity, metal content, and oxidation levels, which are critical indicators of oil and engine health.

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