Syntax Literate: Jurnal Ilmiah Indonesia p–ISSN: 2541-0849
e-ISSN: 2548-1398
Vol. 9, No. 7, Juli 2024

MANAGING A MAJOR LUBE OIL LEAK ON A 150 MW STEAM TURBINE POWER PLANT

Msy Cahaya Dinda Pamungkas[1], Chelsi[2]
PT DSSP Power Sumsel, South Sumatera, Indonesia[1,2]
Email: msy.cahaya.dinda@dsspower.co.id[1], chelsi@dsspower.co.id[2]

Abstract

The reliable operation of steam turbines is paramount for the sustained performance of electric power generation facilities. Any malfunction or breakdown in these high-speed rotating machines can lead to significant operational disruptions, causing energy production losses and jeopardizing safety. Lubricating oil leaks represent a common challenge faced by power plants, impacting operational efficiency, safety, and environmental sustainability. Despite extensive research efforts to mitigate oil leakage, challenges persist due to the unique design characteristics of power stations. This paper addresses the management of a major lube oil leak in Unit No. 2 of the Sumsel-5 Power Plant in Indonesia, focusing on innovative strategies for mitigation. The aim of this research is to assess the effectiveness of various rectification measures in reducing lubricating oil leaks in steam turbines. Methods employed include detailed inspections, analysis of oil quality, and implementation of targeted rectification strategies. The results demonstrate a significant reduction in the oil leakage rate, from approximately 67-68 liters per day to around 1.5-2 liters per day, following the implementation of rectification measures. This remarkable decrease of around 97.3% underscores the effectiveness of the strategies in mitigating the oil leakage problem. The implications of this study extend beyond operational efficiency to encompass safety and environmental protection. By reducing the volume of oil lost to leakage, safety hazards associated with fire accidents are mitigated, enhancing safety for plant personnel and equipment integrity.

Key Words: Steam Turbine, Oil Deflector, Lube Oil

Introduction

The steam turbine holds a critical position within electric power generation facilities due to its pivotal role in converting thermal energy from boiler steam into rotational motion. Unlike auxiliary equipment such as feed pumps or fans, which offer redundancy to sustain operations at full or partial load, the turbine's downtime directly translates to energy production losses (Chanda & Mukhopaddhyay, 2016; Idoniboyeobu & Ojeleye, n.d.).

The performance of high-speed rotating machinery, which is closely intertwined with extensive and intricate industrial processes, is of utmost importance. Any malfunction or breakdown of key components such as bearings, seals, and shafts can result in either partial operational disruptions or complete shutdowns of production systems (Ashraf et al., 2022; Portos et al., 2019).

It is widely recognized that a catastrophic failure of a steam turbine, regardless of its size, can have severe consequences, including causing serious injuries or fatalities, leading to the complete loss of the machine, prolonged plant shutdowns, and significant damage to the plant's reputation (Benammar & Tee, 2023). Despite extensive research

How to cite:	Pamungkas, M. C. D., & Chelsi. (2024). Managing a Major Lube Oil Leak on a 150 MW Steam Turbine Power Plant. *Syntax Literate. (9)7.* http://dx.doi.org/10.36418/syntax-literate.v9i7
E-ISSN:	2548-1398

and development efforts aimed at preventing sudden rotor failures caused by bending, such failures continue to occur in practice, resulting in substantial revenue losses for plants. The costs associated with repairing turbines are exorbitant, and the repair process often extends over lengthy periods. Therefore, ensuring the reliability of rotor blades is paramount for the safe and successful operation of steam turbines (Katinić & Kozak, 2018).

In today's era of advanced aerodynamics, sophisticated rotordynamics capabilities, and modern internal labyrinth seals made of polymer materials, it can be incredibly frustrating for rotating equipment engineers to still grapple with oil leaks. While these leaks must be addressed due to the genuine fire hazard they pose and the risks associated with oil-coated surfaces, as well as the time and resources expended on cleaning up and replenishing the wasted oil, environmental considerations regarding oil containment and disposal also come into play when dealing with machinery oil leaks (Rath et al., 2022). Often, the root cause of these leaks is straightforward yet elusive, with issues such as excessive clearance during seal installation, over-application of sealing compounds on split lines, or blocked vents proving difficult to identify once the machine is operational (Whalen & Krieser, 1998).

Lubricating oil leakage in power plants poses significant challenges, impacting operational efficiency, cost-effectiveness, safety, and environmental sustainability. Various studies have highlighted the detrimental effects of oil leaks, emphasizing the need for effective mitigation strategies. Sun et al. (2022) conducted research on a hydropower plant in China, where the oil level in the tank decreased at an average rate of 5–8 mm per day, with the water guide mechanism accumulating a large amount of oil. Similarly, Deng et al. (2019) addressed the importance of re-designing cover plate structures, achieving a notable reduction in oil mist leakage rates. These studies underscore the complexity of the issue and the importance of innovative solutions.

Lubricating oil leaks can have multifaceted impacts, as noted by Wu (2017), who investigated the activation of low oil level alarms due to leakage, leading to increased operational costs and safety concerns. Liu and Deng (2010) observed significant oil throwing on seals, causing rapid oil level drops in thrust tanks and posing risks to personnel and equipment. Moreover, oil leakage can have environmental consequences, as evidenced by research conducted by Jin and Bao (2017), where leaked lubricating oil damaged water quality in a hydropower station in China.

In response to these challenges, researchers have explored comprehensive measures to address oil leakage problems. Wang et al. (2012) proposed the installation of comb labyrinth oil-retaining tubes and oil baffle plates, while Cao (2010) increased the height of oil-retaining tubes and installed oil-pressing vanes to mitigate leakage in hydropower stations in China. However, due to the unique design characteristics of power stations, there is no one-size-fits-all solution, emphasizing the need for tailored approaches. In essence, while the challenge of addressing oil waste in power plants remains complex and multifaceted, the shift towards detailed characterization of oil flow fields offers a promising avenue for developing customized, context-specific solutions (Sun et al., 2022). By understanding the nuances of each power station's design and operation, engineers can devise renovation plans that not only address current oil waste issues but also anticipate and mitigate potential challenges in the future

Despite extensive research on lubricating oil leaks in various types of power plants, including hydropower facilities, limited attention has been given to steam power plants, particularly those in Indonesia. The Sumsel-5 Power Plant in South Sumatera, Indonesia, has been in operation for almost 8 years since its commissioning in 2016. The Sumsel-5 power plant is facing persistent lube oil leakage issues in Unit No. 2, necessitating effective management strategies. This paper addresses this gap by discussing the management of a major lube oil leak on Unit no. 2 of the Sumsel-5 Power Plant, with a focus on innovative strategies for mitigating such issues.

In addition, this research introduces a novel method for managing lubricating oil leaks, particularly in steam turbines, by creating ventilation channels to reduce leakage. The effectiveness of these improvements is evaluated based on oil flow leak rates, cost savings, and ensuring that leakage rates are minimized to manageable levels, allowing the power plant unit to operate at full load. This study aims to contribute to the body of knowledge on lubricating oil leak management in steam power plants, providing insights into effective mitigation strategies for similar facilities worldwide.

Research Method

Chronology of Failure and Fact-Finding

Steam Turbine Technical Data

The steam turbine is super high pressure, intermediate reheating, double casing, double exhaust, sigle shaft and condensing type manufactured by Dongfang Steam Turbine Co., LTD with a model N175-13.24/535/535. Sumsel-5 turbine has been in operation since April 2016. The turbine structure can be seen on Fig. 1.

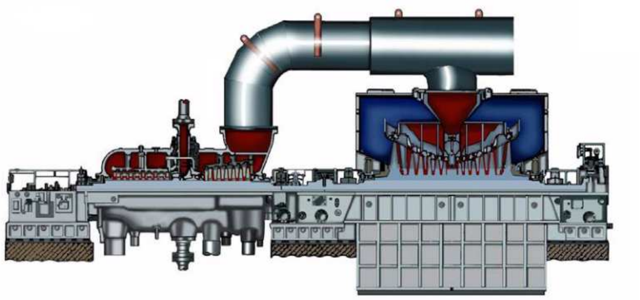

Figure 1. Turbine structure

The turbine's rotation direction is clockwise when viewed from the turbine towards the generator. This sophisticated turbine consists of a total of 31 stages, divided across high-pressure (HP), intermediate-pressure (IP), and low-pressure (LP) sections. The HP section includes one governing stage and eight pressure stages, while the IP section comprises ten pressure stages. The LP section consists of two sets of six pressure stages each. Furthermore, the turbine incorporates a regenerative extraction system, featuring two HP heaters, one deaerator, and four LP heaters. The main technical data of the steam turbine are shown in Table 1.

Table I. Technical Data of The Turbine

No	Name	Data
1	Rated output	175 MW
2	Throttle pressure (before MSV)	13.24 MPa
3	Throttle temperature (before MSV)	535 ℃
4	Reheat pressure (before combined reheat valve)	2.571 MPa
5	Reheat temperature (before combined reheat valve)	535 ℃

No	Name	Data
6	Throttle flow (TMCR)	541200 kg/h
7	Rated exhaust pressure	9.0 kPa
8	Speed	3000 r/min
9	Final feed water temperature	249.7 °C
10	Design heat rate (TMCR)	8430 Kj/kWh
11	Maximum output	185.628 MW
12	Maximum throttle flow	580000 kg/h

The whole shaft system is consisting of HIP rotor, LP rotor, generator rotor and the connected main oil pump and exciter with total 5 bearings (3 bearings for turbine and 2 for generator).

Short Chronology of Oil Leak

From the inception of its operation in April 2016, the turbine functioned smoothly, exhibiting consistently low shaft vibration levels across all bearings. However, on January 26, 2018, the turbine encountered high bearing vibrations on bearings No. 1 and 2 during startup. By 14:55, the rotor speed had reached 1100 rpm, escalating turbine bearing vibrations at 15:24 (1X: 161 µm, 2X: 168 µm). Subsequent speed reductions to 800 rpm (max Vibration 2X: 145 µm) and then to 500 rpm (max Vibration 1Y: 212 µm) ensued, until the turbine was manually halted at 400 rpm. The high vibration resulted from rubbing between the rotating and stationary parts at the HIP turbine, notably from the radial side, potentially involving components such as labyrinth packing and diaphragm tip seals.

Possible causes of rubbing at the HIP turbine were considered, including bearing alignment, clearance inside the HIP TBN, and thermal expansion differences. Despite analysis revealing no alarms or abnormalities in operational parameters, lube oil leakage was discovered from bearing box No. 2 shortly after successful synchronization on January 27, 2018. This incident led to a fire, promptly extinguished through various corrective actions, including turbine rotor cooling, dismantling and adjusting bearing No. 2 casing oil deflectors, insulation work on the HIP line, and resetting lube oil and jacking oil pressures before running the turning gear.

The first overhaul conducted from September 22nd to October 27th, 2019. During this period, vibration levels increased during startup on October 25th and 27th, 2019, resulting in the failure of both rolling attempts due to uncontrollable increases in vibration. Subsequent inspection and treatment revealed rubbing at both horizontal positions of the steam deflector plates and abnormalities in the main oil pump, necessitating grinding, gap enlargement, and sharp-making of the inner rings, as well as readjustment of bearing clearances.

The turbine was restarted on October 27th, 2019, with the rolling process eventually stabilizing at the rated speed of 3000 rpm, albeit displaying characteristic forced vibration during speed rises, indicating the presence of internal friction points within the casing. However, through the running-in process, accompanied by casing warming and expansion, the internal friction points gradually diminished, leading to decreased and stabilized vibrations. Fig. 2 shown the whole rolling process was as follows (speed-trend diagram, taking 1x as example).

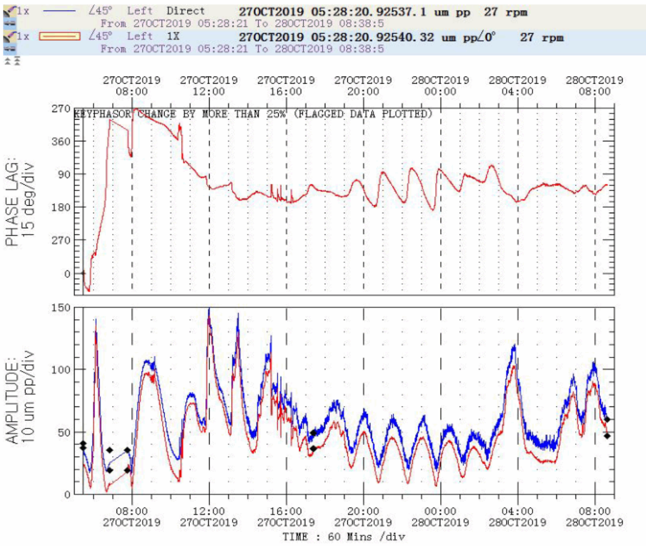

Figure 2. Vibration trend

Despite the high vibration of all bearings remaining within acceptable range values, the lube oil leak persisted from bearing box No. 2. This underscored the importance of addressing the underlying issues causing the leakage, even in the presence of acceptable vibration levels across other bearings.

Rectification Works

Oil Deflector Replacement and Clearance Adjustment

The oil deflector plays a crucial role in driving the power generation turbine. During the operation of lubrication equipment, oil leakage may occur. The oil deflector serves as a device assembled on the bearing side and the exterior of the rotor. It operates by creating negative pressure inside the oil tank, which in turn draws external air into the interior of the oil deflector. This mechanism effectively prevents foreign substances and fine dust particles from the atmosphere from penetrating the system (Benammar & Tee, 2023).

After the turbine overhaul process was carried out in 2019, wear was discovered on the oil deflector labyrinth seals of bearing No. 1 and No. 2, induced oil leaks. The solution involved replacing the oil deflector with a new spare part and adjusting the radial clearance according to the design specifications, as depicted in Figure 3.

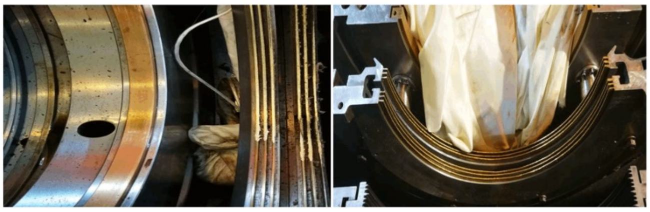

Figure 3. Oil deflector replacement and clearance adjustment

It was also found that the clearance of the Front & Rear End Gland Sealing was outside the design range of 0.8-1.1 mm, measuring instead between 1.8-2.0 mm. To address this issue, adjustments were made to the clearance of the end gland sealing to align with the design specifications. The occurrence of oil leak phenomenon is attributed to the clearance of the gland sealing being outside the designated range. This deviation may lead to steam leakage during operation, allowing for increased levels of oil and steam condensate, ultimately resulting in overflow flow into the bearing box.

Oil Sealing Labyrinth Inspection

During the Class A Turbine Overhaul conducted in August - September 2023, the inspection of oil sealing wear and clearance was repeated. It was discovered that there was wear on the blocking teeth (labyrinth) of the oil seal, as depicted in Fig. 4. Additionally, the clearance on the bottom oil sealing was found to be excessively large, measuring approximately 0.3 mm, whereas the design requirement specifies a clearance of 0.05 mm - 0.10 mm. To address this issue, repairs were undertaken by reinstalling the oil sealing in accordance with the specified clearance requirements.

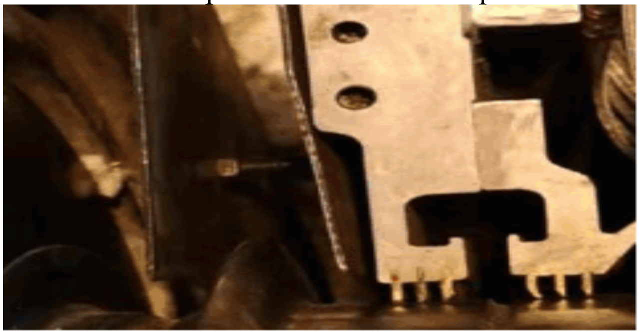

Figure 4. Wearing at blocking teeth (labyrinth) of the oil seal

It was also discovered that the first row of rear shaft steam sealing on the Intermediate Pressure Turbine side was covered with oil sludge, as depicted in Fig. 5. Additionally, an inspection of the oil return pipeline was conducted, revealing no defects or blockages in the pipeline.

Figure 5. Oil sludge on the intermediate pressure rear shaft steam sealing ring

The monitoring results of the oil leakage rate after the overhaul are illustrated in Fig. 6. It is evident that there has been a notable increase in the oil leakage rate. This escalation may have been caused by improper gasket installation, leading to heightened vibration during startup and exacerbating the oil leakage issue. In order to reduce the vibration to within acceptable range values, adjustments were made by uninstalling the gasket. Consequently, the vibration issues were resolved, but the oil leakage rate from bearing box No. 2 increased, reaching 2800 ml/h at a full load of 174 MW.

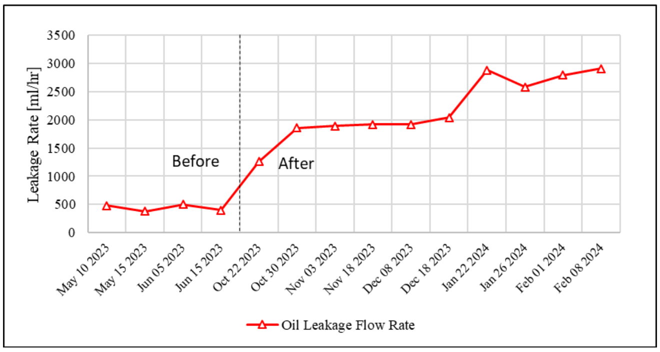

Figure 6. Increment of oil leakage rate

Additional Venting Line to the Main Oil Tank

The decision to adjust the vacuum of the Main Oil Tank to a more negative pressure of -900 Pa was a proactive measure aimed at mitigating the risk of oil leakage from bearing No. 2 during continuous operation. By increasing the vacuum, the pressure within the system is reduced, potentially preventing the exacerbation of oil leaks. However, while this adjustment helped maintain the severity of the oil leakage, it did not effectively reduce the overall rate of oil leakage. This suggests that there may be other contributing factors to the ongoing issue. One potential cause identified is the possibility of the bearing box being completely filled with oil, leading to trapped condensate pressure. This scenario can result in the continuous decrease in the main oil tank level, requiring more frequent and larger oil refills. Moreover, if the main oil tank level reaches the minimum low alarm value, it could trigger a turbine trip, posing a significant operational risk.

Figure 7. Piping & instrumentation diagram of the lube oil system

Figure 8. Installation of the venting line

To address this issue, rectification measures were implemented during the maintenance outage in February 2024. An additional venting line was installed, connecting the oil level sight glass of bearing box No. 2 to the main oil tank (Fig. 7 and Figure 8). This new venting line serves to release condensate pressure within the bearing box, preventing overfilling and reducing the risk of oil leaks. Furthermore, the improvement resulted in a reduction of the main oil tank vacuum pressure from -900 Pa to -500 Pa. This adjustment was crucial in controlling the oil level, alleviating the leakage rate, and preventing overflow incidents.

Install Gasket at Side Cover Plate of Bearing Box No. 2

The installation of a fiber gasket at the side before the cover plate of the sealing oil ring at bearing box No. 2 represents a targeted rectification strategy aimed at reducing and managing the oil leakage rate. The position of gasket installation is shown in Fig. 9. The decision to utilize a proper fiber gasket with a thickness of 3 mm is based on its ability to provide a reliable seal, effectively preventing oil leaks from occurring at this critical juncture.

Figure 9. Cross sectional drawing of bearing ped between HP & IP turbine

The addition of the fiber gasket serves to enhance the sealing effectiveness, thereby reducing the likelihood of oil leakage and mitigating associated risks, such as fire hazards and operational disruptions. Furthermore, by ensuring a tight and secure seal, the fiber gasket helps maintain optimal operating conditions within the bearing box, minimizing the ingress of external contaminants and preserving the lubrication system's functionality.

Results and Discussion

The Decrease in Oil Leak Flow Rate

The implementation of various rectification measures to address the lube oil leakage issue from bearing box No. 2 has yielded commendable results, leading to a significant reduction in the oil leakage rate. As shown in Fig. 10, during full load operation, the average oil leakage flow rate has decreased substantially from approximately 2826 ml/hr, equivalent to 67-68 litres per day, to a mere 75 ml/hr, equivalent to 1.5-2 litres per day. This remarkable reduction represents a decrement of around 97.3%, indicating the effectiveness of the rectification efforts in mitigating the oil leakage problem.

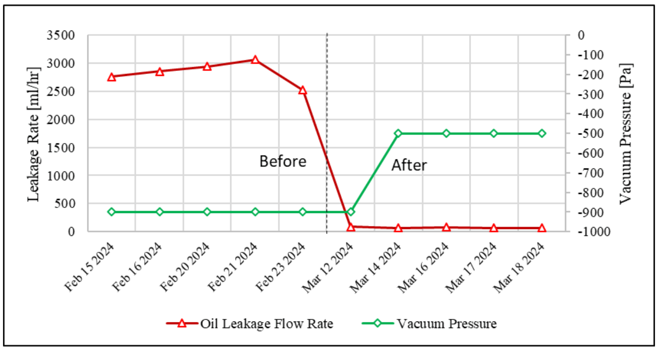

Figure 10. Decrement of oil leakage rate

The Decrease in the Frequency of Lube Oil Top-Ups

Before rectification, in order to maintain smooth operations and prevent the main oil tank from reaching its low limit level alarm during major oil leakage incidents, the plant incurred substantial costs. It necessitated the frequent replenishment of lubrication oil, requiring the refill of 3 drums every 10 days, totaling approximately 9 drums per month and 108 drums annually. Considering the use of Turbo Shell T-32 lubrication oil, priced at IDR 7,659,850 per drum, the cumulative costs amounted to IDR 827,263,800 per year.

However, following the rectification measures and the subsequent reduction in the oil leakage rate, there has been a significant decrease in the frequency of main oil tank lube oil top-ups. Now, only 3 drums of oil are required for an entire year, representing a considerable reduction in operational expenses. With the decreased frequency of oil top-ups, the annual cost for lubrication oil now amounts to IDR 22,979,550, resulting in substantial cost savings of approximately IDR 804,284,250 per year.

Safety in Operations and Environmental Protection

The rectification measures undertaken to address the lube oil leakage from the turbine bearing box not only contributed to operational efficiency but also yielded significant benefits from a safety and environmental perspective. Before rectification, the presence of a major oil leak posed a serious fire hazard due to the highly flammable nature of the lubricating oil and the proximity of the leak to high-temperature components within the turbine. The potential for a fire accident was a significant safety concern, posing risks to personnel safety, equipment integrity, and overall plant operations.

Moreover, the continuous oil leakage resulted in wastage of oil, leading to environmental concerns. Oil spills can contaminate soil, water sources, and surrounding ecosystems, posing risks to aquatic life and vegetation. Additionally, the improper disposal of waste oil can further exacerbate environmental damage, contributing to pollution and ecological degradation.

However, with the implementation of rectification measures, the benefits in terms of safety and environmental protection are substantial. By significantly reducing the volume of oil lost to leakage, the risk of a fire accident has been mitigated, enhancing safety for plant personnel and preventing potential damage to equipment. Furthermore, the reduction in oil leakage minimizes environmental impact by decreasing the amount of oil released into the surrounding environment.

Monitoring of Lube Oil Quality

After many years of operation, lubrication systems can suddenly fail due to degradation in lubricating oil quality. Therefore, regular monitoring is essential. Although failures are rare, they can result in major damage to turbine bearings and extended plant outages. Table 2 shows the analysis results of the lubrication oil for turbine unit 2, which has remained normal for an extended period. Wear metal analysis indicates no significant metal wear contaminants, suggesting no substantial metal abrasion or wearing caused by inappropriate operational conditions or lubrication. While the number of particles counted does increase, it remains within normal limits, indicating that the lubricant oil is still in good condition for circulation.

Table 2. Oil Analysis Monitoring Result

No	Parameter	Unit	Method	Result					Limit	
				Jan-23	Apr-23	Aug-23	Nov-23	Jan-24	Min	Max
1	Kinematic Viscosity at 40°C	cSt	ASTM D445-21e2	31.46	31.56	32.03	32.07	31.95	25	38.4
2	Total Acid Number (TAN)	Mg KO/g	ASTM D474-22	0.03	0.03	0.05	0.05	0.05		0.45
3	Wear Metal	ppm	ASTM D5185-18							
	Iron (Fe)			<1	<1	<1	<1	<1		30
	Copper (Cu)			<1	<1	<1	<1	<1		35
	Aluminium (Al)			<1	<1	<1	<1	<1		15
	Chromium (Cr)			<1	<1	<1	<1	<1		9
	Nickel (Ni)			<1	<1	<1	<1	<1		8
	Tin (Sn)			<1	<1	<1	<1	<1		10
	Lead (Pb)			<1	<1	<1	<1	<1		15
	Sodium (Na)			<1	<1	<1	<1	<1		60
	Silicon (Si)			2	1	1	1	1		15
4	Metal Additive	Ppm	ASTM D5185-18							
	Calcium (Ca)			<1	<1	<1	<1	<1		
	Magnesium (Mg)			<1	<1	<1	<1	<1		
	Zinc (Zn)			5	5	4	5	5		
5	Flash Point COC	°C	ASTM D92-18	228	223	226	232	223		
6	Water Content by Karl Fisher	ppm	ASTM D6304-20	27	84	104	42	39		500
7	FTIR	Abs/0.1 mm	ASTM E2412-23							
	Oxidation			<0.02	0.02	<0.02	<0.02	<0.02		0.3
8	Particle Counter		ISO 4406:2021 and ISO 11500:2022							
	4 µm	Counts/ml		509	199	1468	484	1581		
	8 µm	Counts/ml		130	28	274	71	34		
	16 µm	Counts/ml		4	2	9	1	1		
	ISO Code 4406	-		16/14/9	15/12/8	18/15/10	16/13/8	18/12/8		18/15
9	NAS Class		NAS Class 1638							
	5-15 µm	Counts/100 ml		12280	2860	28140	6140	3600		
	15-25µm	Counts/100 ml		290	80	640	220	100		
	25-50 µm	Counts/100 ml		70	0	80	20	20		
	50-100 µm	Counts/100 ml		0	0	0	0	0		
	>100 µm	Counts/100 ml		0	0	0	0	0		
	NAS Class	Counts/100 ml		6	4	7	5	4		10

Conclusion

The inspections conducted, along with subsequent investigations and rectification efforts, were unable to completely eliminate the oil leak. Nevertheless, the Sumsel-5 power plant succeeded in significantly reducing the volume of oil lost to a manageable level. This allowed the machine to remain in operation, effectively meeting the demand for electricity. The oil leakage rate was notably diminished from approximately 67-68 liters per day to around 1.5-2 liters per day. Despite the ongoing oil leak, the steam turbine has continued to operate smoothly, even under full load conditions, demonstrating its ability to function with a manageable level of oil leakage.

Acknowledgment

The authors gratefully acknowledge Mr. Lyu Yong Jun (CTO) and Mr. Chong

Chee Shang (IPP Plant Head) for their continuous effort in the characterization part of the paper and their constant source of inspiration in writing it. The authors are also grateful to all personnel at PT DSSP Power Sumsel for providing the information necessary for the completion of this work.

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