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Cause Analysis and Preventive Measures for Deterioration of Steam Turbine Lubricating Oil

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ABSTRACT

Lubricating the oil system of the steam turbine in the power plant is an important part of maintaining the normal operation of a steam turbine. The quality of oil directly affects the safe and stable operation of steam turbines. If the oil quality deteriorates, it is very easy to cause major accidents such as wear of steam turbine bearings, jamming of the speed control system, and even burning of bearings, failure of steam turbine speed control system leading to overspeed. This research method uses a literature review.

In the operation of the power plant, it is common for lubricating oil to exceed the standard particle size and water content, and there are many reasons for this. This article analyzes the causes of lubricating oil deterioration and explains more specific preventive measures. Conclusion Deterioration in oil quality and excessive particle size can easily lead to serious consequences. Therefore, it must be controlled from the inspection of new oil entering the factory, sampling and testing, and monitoring of the operation stage, to improve the maintenance process.

Introduction

The function of the steam turbine lubricating oil system is to provide lubrication for the support bearings, thrust bearings, and turning devices of the steam turbine generator, to supply spare oil for the hydrogen sealing system, and to supply pressure oil for the overspeed release device of the operating machinery of some models (Tang & Wu, 2011). In the case of oil quality deterioration, the particle size and water content exceed the standard, which leads to the wear of the bearing and rotor in serious cases, which is the main reason threatening the safe operation of the steam turbine generator set and the service life of the equipment (Hildreth & Tymvios, 2016). When the particle size and water content exceed the standard during the operation of the power plant, the oil filtering measures are taken immediately. Although it can ensure the continuous operation of the system, the cause of the oil quality deterioration is unknown, resulting in a serious waste of resources due to long-term oil filtering. Taking certain effective measures in the storage of new oil at the factory, sampling and testing, operating conditions, maintenance quality, and oil replenishment rate will greatly reduce the phenomenon of oil quality deterioration during the operation of the oil system (Chowdhury et al., 2021).

Most steam turbine lubricating oils are made of highly refined paraffin-based mineral oils compounded with antioxidants and rust inhibitors. Depending on the quality grade, there may also be a small amount of other additives, such as metal passivation, extreme pressure additives, and defoamers. Steam turbine lubricating oils are mainly used to lubricate and cool bearings and gears. (Gulfam & Zhang, 2019).

New steam turbine lubricating oil should have good oxidation resistance and provide adequate rust resistance, demulsibility, and anti-foaming properties while inhibiting the formation of sludge and varnish deposits. Factors that affect the service life of turbine lubricating oil include system design and type, system pre-operation conditions, original oil quality, system operating conditions, oil contamination, oil replenishment rate, and oil handling and storage conditions.

Recent studies have investigated various analyses and preventive actions for the deterioration of steam turbine lubricating oil. Li et al. (2022) Studied and demonstrated that high-temperature and high-stress conditions accelerate the degradation of turbine oils, leading to significant changes in their chemical and physical properties. Understanding these mechanisms is crucial for improving the durability and reliability of turbine systems. Xu, Wang, Liang, Lv, & Chen, (2024) Explained that oxidation is a predominant factor affecting the properties of turbine oils. Our review highlights that oxidation leads to increased acidity, viscosity changes, and formation of sludge, which ultimately compromise the oil's performance and longevity. Liu et al., (2016) Mentioned that spectroscopic techniques such as FTIR are invaluable for assessing turbine oil degradation. These methods provide detailed insights into the chemical changes occurring in the oil, including oxidation and additive depletion.

Gao & Liu, (2021) Explained that contamination and degradation of turbine oils in power generation systems can lead to operational inefficiencies and increased maintenance costs. Our study emphasizes the need for regular monitoring to mitigate these issues. Zhou et al., (2023) Mentioned that thermal stress has a profound impact on turbine oil stability. Our findings reveal that elevated temperatures accelerate oil degradation, necessitating enhanced oil formulations or improved cooling systems. (Zhang et al., 2021) Investigated that water contamination significantly affects turbine oil performance. Our research indicates that even small amounts of water can lead to accelerated degradation, reduced lubrication effectiveness, and increased risk of corrosion.

Sun et al (2016) Advanced monitoring techniques are essential for maintaining turbine oil quality. Our review covers various methods, including spectral analysis and particle counting, to ensure that oil remains within optimal performance parameters. Wang et al., (2023) High-performance liquid chromatography (HPLC) provides a detailed analysis of turbine oil degradation. This method allows for precise detection of degradation products and helps in understanding the oil's degradation pathways.

Method

The study began with a literature review, including an examination of the Dongfang Turbine manual, international journals, and other relevant sources. Field visits were conducted to take samples for analysis of quality lube oil turbines. During normal operation, quality lube oil was inspected. The following steps were taken to complete the research methodology:

1. Research Location:

   This research was conducted at a Thermal Power Plant utilizing the Turbine N56-8.83/535 Lube oil system. The research site is located at [PT DSSP Power Kendari, IPP PLTU kendari-3], [Jl. Poros Kdi.- Moramo, Tj. Tiram, Kec. Moramo Utara, Kabupaten Konawe Selatan, Sulawesi Tenggara 93891], [Indonesia]. This location was selected due to the issue of lube oil pressure sometimes dropping in the turbine units, which became the focus of this study.

2. Research Subjects:

   The research subjects were Precilia ISO VG 32 of unit 2 in the N56-8.83/535 turbine operating at the power plant. Lube oil in a turbine is crucial for the reliable and efficient operation of the turbine system, making this the target for analyzing and resolving this issue.

3. Data Processing Techniques:

   a. Data Collection: Oil samples are collected from the equipment at regular intervals using standardized methods to ensure consistency. Key properties of the oil are measured, such as viscosity, Total Acid Number (TAN), Total Base Number (TBN), water content, particulate contamination, wear metals, and oxidation levels. Instruments like viscometers, spectrometers, and infrared analyzers are used for this purpose.

   b. Data Preprocessing: The measurement data is logged into a database or an oil analysis management system. This includes details like the sample date, equipment ID, and environmental conditions. Any outliers or erroneous data points are identified and corrected or removed. This ensures that the analysis reflects accurate and reliable data. Data may need to be normalized to account for varying conditions, such as temperature, which can affect oil properties like viscosity.

c. Data Analysis: Historical data is compared over time to identify trends, such as gradual increases in wear metals or changes in viscosity. These trends can help predict potential equipment failures. Relationships between different oil properties are analyzed. Specific peaks in the spectrum can indicate types of degradation or contamination. Statistical methods, such as regression analysis, are used to model the behaviour of the oil over time and under different conditions. This modelling can help predict future oil conditions and equipment health.

d. Condition Monitoring and Diagnostics: Measured values are compared against established thresholds or standards. Exceeding certain limits (e.g., high water content, and low viscosity) may trigger alerts for maintenance actions. Microscopic or spectroscopic analysis of particles in the oil can reveal wear patterns and potential sources of wear within the machinery. Predictive algorithms process the data to forecast when the oil or equipment might reach a critical condition, enabling maintenance to be scheduled before failures occur.

e. Reporting and Visualization: Analysis results are compiled into reports that include charts, graphs, and interpretations, providing actionable insights for maintenance teams. Data visualization tools like dashboards present real-time data and trends, helping to quickly identify issues and make informed decisions. Based on the processed data, recommendations are made regarding oil changes, equipment maintenance, or further investigation.

f. Feedback and Continuous Improvement: The results of the analysis and any subsequent actions are fed back into the system to improve future analyses. For instance, if certain trends consistently predict failures, the predictive model can be refined. Predictive models are updated regularly with new data to enhance their accuracy and reliability.

4. Research Instruments:

a. Viscometer: Measures the viscosity of the oil, which is crucial for understanding its lubrication properties.

b. Fourier Transform Infrared (FTIR) Spectrometer: Analyzes the chemical composition of the oil by identifying specific molecular bonds.

c. Inductively Coupled Plasma (ICP) Spectrometer: Measures the concentration of wear metals, additives, and contaminants in the oil.

d. Total Acid Number (TAN) and Total Base Number (TBN) Analyzers: TAN measures the acidity, and TBN measures the alkalinity of the oil.

e. Particle Counter: Counts and sizes of particles suspended in the oil.

f. Karl Fischer Titrator: Measures the water content in the oil.

g. Rotating Disc Electrode (RDE) Spectrometer: Analyzes metal content in used oil.

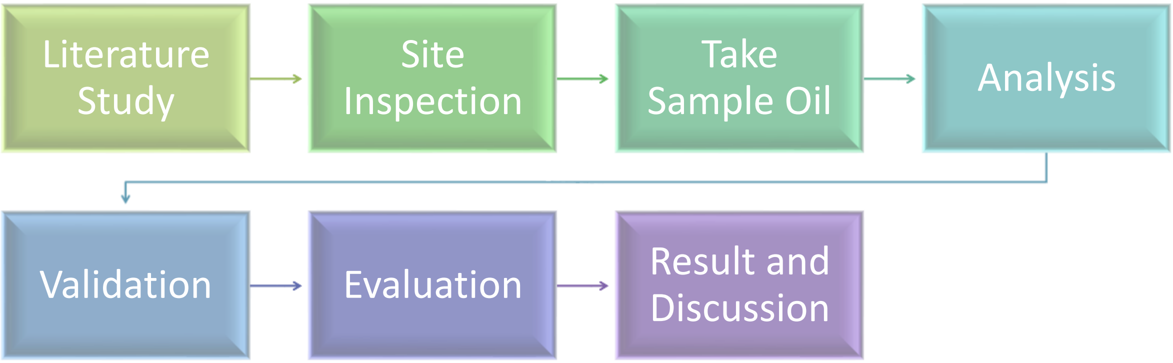
h. Wear Particle Analyzer (Ferrography): Analyzes the size, shape, and composition of wear particles in the oil.

i. Flash Point Tester: Determines the temperature at which the oil produces enough vapour to ignite.

j. Oxidation Stability Tester: Evaluates the oil's resistance to oxidation.

5. Field Visits and Inspections:

During normal operation, conditions within the oil tank and lube oil were thoroughly inspected. Inspections were conducted to identify some issues that might affect the quality of the lube oil system.



Results and Discussion

1. Acceptance of New Oil

When new oil is delivered, it should be inspected and accepted by GB11120. In addition, the rotating oxygen bomb should also comply with the provisions of Table 1.

Table 1
Quality standards for new turbine oil rotary oxygen bomb

Project	Quality Index	Experiment Method
Rotating oxygen bomb (150°)/insolvent refined mineral oilHydrogenated mineral oil	> 300 > 1000	SH/T0193

The inspection items shall at least include appearance, colour, kinematic viscosity, viscosity index, pour point, density, flash point, acid value, moisture, foaming, air release valve, copper corrosion, liquid phase rust, anti-emulsification, rotating hydrogen bomb and cleanliness (particle pollution level). At the same time, the test results of oxidation stability, carrying capacity, and filterability should be obtained from the oil supplier, and it should be ensured that they meet the requirements of the GB11120 standard.

Ask the oil supplier for information on the type of antioxidants, and test the antioxidant content according to the test method required by GB/T7596 or ASTMD6971, and use this as a benchmark value to guide the supervision and addition of antioxidants during operation.

Acceptance may also be based on relevant international standards or indicators agreed upon by both parties in the contract. All samples should be inspected immediately after sampling, and the acceptance test should be completed before the equipment is filled with oil.

2. Steam turbine lubricating oil operation quality standard

The lubricating oil of the steam turbine in operation shall comply with the standard of GB/T7596. See Table 2 for details.

Table 2
Quality standards of turbine oil in operation

No.	Project		Quality Index	Testing Method
1	Exterior		Transparent, no ㎜≤ impurities or suspended matter	DL429.1
2	Chroma		<5.5	GB/T6540
3	Kinematic viscosity a/(40℃）mm2/s	3 2	Not more than 5% of the new oil test value	GB/T265
4	Flashpoint (open cup)℃		>180, and not less than 10℃ higher than the previous measured value	GB/T3536
5	Particle pollution level		<8	DL/T432
6	Acid value (in KOH) / (㎎/g)		<0.3	GB/T264
7	Liquid phase corrosion degree c		Rust-free	GB/T11143 (Method A)
8	Demulsification c (54℃)/min		<30	GB/T7605
9	Moisture c/㎎/L		<100	GB/T7600
10	Foaming property/(foaming tendency/foaming quality)	24℃ or after 24℃	<500/10	GB/T12579
		93.5 ℃	<100/10	
11	Air release valve (50℃)/min		<10	SH/T0308
12	Rotating oxygen bomb value (150℃)/min		Not less than 25% of the new oil test value, and the turbine oil ≥ 100	SH/T0193
13	Antioxidant content/%	T50 Antioxidant	Not less than 25% of the new oil test value	GB/T7602
		Hindered phenol or aromatic amine antioxidants		ASTMD69 71

After the turbine oil system is overhauled and before the unit is started, the oil pollution grade and particle size should not be greater than SAEAS4059F, and the kinematic viscosity, flash point, acid value, moisture, foaming properties, and anti-emulsification properties should comply with the requirements of Table 2.

3. Abnormal oil quality of steam turbine during operation and treatment measures

The oil quality test results should be analyzed according to the quality standards of the running turbine oil in Table 2. If the oil quality exceeds the standard, the cause should be found and corresponding treatment measures should be taken. The possible causes and reference treatment methods of the running turbine oil exceeding the standard are shown in Table 3.

Table 3
Abnormal oil quality of steam turbine during operation and treatment measures

No.	Project	Warning limit	Abnormal	Treatment measures
1	Exterior	1. Emulsified and opaque 2. Contains suspended particles 3. Contains oil sludge	1. Oil contains water or other liquid pollution 2. Oil impurity pollution 3. Deep deterioration of oil quality	1. Dehydration or oil change 2. Filtration 3. Invest in an oil regeneration device or change the oil
2	Chroma	Rapidly darkening Abnormal color	1. Other pollutants 2. Oil impurities pollution 3. Additive oxidation discoloration	1. Invest in an oil regeneration device or change the oil
3	Kinematic viscosity a/(40°C） mm2/s	More than 5% of the new oil value	1. The oil is contaminated 2. The oil quality is seriously deteriorated 3. Add high or low-viscosity oil	If the viscosity is low, measure the flash point and change the oil if necessary.
4	Flashpoint (open)℃	15℃ higher or lower than new oil	Oil is contaminated or overheated	Find out the cause and compare it with other test results to consider treatment or oil change.

No.	Project	Warning limit	Abnormal	Treatment measures
5	Particle pollution level	>8	1. Particles are introduced during oil replenishment 2. Dust and impurities enter the system 3. Parts in the system are worn or corroded 4. The precision filter is not put into operation or fails 5. Particles are generated by oil ageing	Identify the source of particles and check and start the precision device cleaning oil system.
6	Acid value (in KOH) / (mg/g)	The added value exceeds that of new oil by more than 0.1	1. High oil temperature or local overheating 2. Antioxidant depletion 3. Oil contamination and oil quality deterioration	1. Take measures to control oil temperature and eliminate local overheating 2. Add antioxidant 3. Put into oil regeneration device 4. Change oil when necessary based on the results of rotating oxygen bomb
7	Liquid phase corrosion degree c	There is rust	Rust inhibitor depleted	Add rust inhibitor
8	Demulsification c (54°C)/min	>30	Oil contamination or deterioration	Put into oil regeneration device or change oil
9	Moisture c/ mg/L	>100	1. Oil cooler drainage leakage 2. The oil seal is not tight 3. The oil tank is not	Check the demulsification degree, use the filtering equipment to remove water, and pay attention to the system conditions to eliminate defects.

No.	Project	Warning limit		Abnormal	Treatment measures
10	Foaming property/(foaming tendency/foaming quality)	24℃ and after 24℃	Tendency >500 Stability >10	1. Oil aging 2. Defoamer disappears 3. Oil is contaminated	1. Put into oil regeneration device 2. Add defoamer 3. Change oil if necessary
		93.5 ℃	Tendency >500 Stability >10		
11	Air release valve (50℃)/min	>10		Oil contamination or deterioration	Change oil when necessary
12	Rotating oxygen bomb value (150℃)/min	Not less than 25% of the new oil test value, and the turbine oil ≥ 100		Antioxidant depletion Oil ageing	Add antioxidants Regeneration and oil change when necessary
13	Antioxidant content/% T50 Antioxidant Hindered phenol or aromatic amine antioxidants	Less than 25% of the new oil value		1. Antioxidant depletion 2. Incorrect oil filling	1. Add antioxidants 2. Check other items and change oil if necessary

4. **Analysis of causes of particle size exceeding the standard during operation**
   a) Contaminants left over from the manufacturing and equipment process of oil system components, such as unpolished processing burrs on equipment pipelines, uncleaned sand used for sandblasting at dead corners, welding slag generated by welding pipelines and workpieces, dust on the inner wall of pipelines, and sealants on the dividing surface of the bearing box and flange joints, etc. These contaminants were not effectively removed during the installation and oil flushing stages. Although the oil quality test was qualified when the whole set was started for the first time, with the change in the unit's operating conditions, the flow rate and temperature of the lubricating oil changed, and various impurities originally attached to the equipment and pipelines would be washed away and enter the oil system, causing intermittent oil quality failure.

b) Impurities enter the system with air at places where the oil system is not tightly sealed. Since the oil system generates oil smoke during operation, the exhaust fan is always in operation, and the bearing box and the oil return system are under negative pressure. If the seal is not tight, impurities will be sucked into the system with air, causing oil pollution. Due to the negative pressure of the system, dust, insulation cotton, and other impurities will inevitably enter the gap at the oil baffle of the bearing box. This requires that the sanitary environment in the main plant should be maintained after the oil system is put into operation, especially in the insulation stage of the later stage of the project, when the unit is overhauled, there is a lot of insulation and sanitation cleaning work. If conditions permit, the exhaust fan can be temporarily stopped.

c) Oil pollution caused by normal or abnormal wear of the oil pump and various speed regulating parts. Check at the bottom of the oil tank or the bottom of the bearing box. If newer metal residues are found, it can be concluded that the equipment running parts have abnormal wear. If the bottom inspection is mostly impurities such as sludge, the probability of abnormal wear is small.

d) The clearance of the steam turbine shaft seal exceeds the standard. The clearance adjustment during installation does not meet the design requirements or the shaft seal teeth are worn during operation, resulting in large steam leakage from the steam seal system, which leaks into the bearing box and causes oil emulsification.

5. Preventive measures to prevent particle size from exceeding the standard

a) Clean the impurities inside the equipment.

Bearing boxes, oil tanks, oil coolers, and other equipment, there are residual weld skin and slag in the internal dead corners of the welds, or residual sand, burrs, gaskets, etc. during casting; during operation, impurities in the pipeline accumulate at the bottom of the oil tank and the dead corners of the bearing seat. The measures are taken:

1) After the equipment arrives, it should be carefully inspected and any defective or impurity-attached parts should be cleaned and polished.
2) During the oil flushing process, the oil tank, bearing box, and other equipment should be cleaned in stages, which can not only help shorten the oil flushing time but also prevent impurities from remaining and causing wear on the equipment during operation.
3) For equipment such as oil coolers, jacking oil devices, sealing oil components, etc. that are difficult to dismantle on site but must be oil flushed, they should be oil flushed only after the system pipelines and other equipment have been flushed and qualified to prevent internal contamination.
4) The filter elements in all parts used in the oil flushing process should be replaced after the oil flushing is completed.
5) The sealant used for the centre dividing the surface of the bearing seat and the temporary oil flushing system restoration should be prevented from excessive

use, as it is easy to remain on the internal joint surface of the equipment and be washed by oil for a long time, resulting in oil pollution and sludge.

b) The oil system equipment is not sealed tightly.

The oil return system will draw impurities from the air into the system due to the slight negative pressure, causing the lubricating oil particle size to exceed the standard. During the installation process, reliable sealing measures should be taken at the following parts, such as applying Loctite 587 sealant, using flange gaskets with better-sealing properties, and rechecking whether the flange bolts are tightened in place.

1) The oil return flanges, manholes, oil pumps, exhaust fans oil tank connection flanges, breathing holes, etc. above the oil level of the main engine oil tank.
2) The dividing surface, observation window, inspection hole, and the joint surface with the oil return pipe flange of each bearing box.
3) Inspection flanges, manholes and observation windows of generator end covers, oil return expansion tanks, float tanks, and other equipment.
4) The return oil filter and return oil observation window of the return oil pipeline.

c) Lubricating oil water content exceeds the standard

Excessive water content will cause oil emulsification. The main reason is that the clearance of the bearing seal exceeds the standard or the seal pressure is adjusted too high, steam enters the bearing box, and water enters the oil. Therefore, during operation, the following points should be noted:

1) The end seal clearance of each bearing shell should be checked carefully to ensure that the clearance is adjusted to the lower and middle limits of the design range.
2) Before operation, the shaft seal piping system should be inspected in detail. The water spray volume of some units' water spray coolers exceeds the design value or the nozzles are faulty, and the water is not in a mist shape, which not only fails to reduce the temperature but also causes more water to enter the shaft seal, causing water to enter the oil; the shaft seal return steam pipe installation slope is not enough or the return steam pipe is not smooth, which can also cause water to accumulate in the shaft seal, causing water to enter the oil.
3) When putting the shaft seal system into operation before the unit is started up, the shaft seal pressure should be carefully controlled to prevent water from entering the oil.
4) If there is an internal leak in the oil cooler, the water pressure will be higher than the oil pressure when the machine is shut down, which will cause water to enter the oil. Therefore, a water pressure test should be carried out before installing the oil cooler to prevent internal leakage.

Conclusion

The steam turbine lubricating oil system is the key to the operation of the unit. The deterioration of oil quality and the excessive particle size can easily cause serious consequences. Therefore, it should be controlled from the inspection of new oil entering the factory, sampling and testing, and monitoring of operation stages, to improve the maintenance process, ensure the internal cleanliness of the oil system, lay a good foundation for the smooth operation of the unit, and improve the reliability of the safe operation of the unit.

Bibliography

Chowdhury, S. N., Tung, T. T., Ta, Q. T. H., Castro, M., Feller, J. F., Sonkar, S. K., & Tripathi, K. M. (2021). Upgrading of diesel engine exhaust waste into onion-like carbon nanoparticles for integrated degradation sensing in nano-biocomposites. *New Journal of Chemistry*, *45*(7), 3675–3682.

Gao, Z., & Liu, X. (2021). An overview on fault diagnosis, prognosis and resilient control for wind turbine systems. *Processes*, *9*(2), 300.

Gulfam, R., & Zhang, P. (2019). Power generation and longevity improvement of renewable energy systems via slippery surfaces–A review. *Renewable Energy*, *143*, 922–938.

Hildreth, J. C., & Tymvios, N. (2016). *Preventive Maintenance Criteria*. Publication FHWA/NC/2015-11, North Carolina Department of Transportation.

Liu, Z., Wang, H., Zhang, L., Sun, D., Cheng, L., & Pang, C. (2016). Composition and degradation of turbine oil sludge. *Journal of Thermal Analysis and Calorimetry*, *125*, 155–162.

Tang, W. H., & Wu, Q. H. (2011). *Condition monitoring and assessment of power transformers using computational intelligence*. Springer Science & Business Media.

Wang, C., Du, C., Shang, J., Zhu, Y., Yao, H., Xu, M., Shan, S., Han, W., Du, Z., & Yang, Z. (2023). A comprehensive review of the thermal cracking stability of endothermic hydrocarbon fuels. *Journal of Analytical and Applied Pyrolysis*, *169*, 105867.

Xu, Y., Wang, F., Liang, D., Lv, G., & Chen, C. (2024). A Comprehensive Review of Waste Wind Turbine Blades in China: Current Status and Resource Utilization. *Journal of Environmental Chemical Engineering*, 113077.

Zhang, Q., Zhang, H., Yan, Y., Yan, J., He, J., Li, Z., Shang, W., & Liang, Y. (2021). Sustainable and clean oilfield development: How access to wind power can make offshore platforms more sustainable with production stability. *Journal of Cleaner Production*, *294*, 126225.

Zhou, S., Song, J., Xu, P., He, M., Xu, M., & You, F. (2023). A review of tribology, characterization and lubricants for water-based drilling fluids. *Geoenergy Science and Engineering*, 212074.