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Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam, Gas, and Combined Cycle Turbines[1]

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INTRODUCTION

The in-service monitoring of turbine oils has long been recognized by the power-generation industry as being necessary to ensure long trouble-free operation of turbines.

The two main types of stationary turbines used for power generation are steam and gas turbines; the turbines can be used as individual turbines, or can be configured as combine cycle turbines. Combined cycle turbines are of two types; the first type connects a gas turbine with a steam turbine, with separate lubricant circuits, and the second type mounts a steam and a gas turbine on the same shaft and has a common lubricant circuit. The lubrication requirements are quite similar but there are important differences in that gas turbine oils are subjected to significantly higher localized "hot spot" temperatures and water contamination is less likely. Steam turbine oils are normally expected to last for many years. In some turbines up to 20 years of service life has been obtained. Gas turbine oils, by comparison, have a shorter service life from 2 to 5 years depending on severity of the operating conditions. One of the benefits of the gas turbine is the ability to respond quickly to electrical power generation dispatching requirements. Consequently, a growing percentage of modern gas turbines are being used for peaking or cyclic duty (frequent unit stops and starts) that subjects the lubricant to variable conditions (very high down to ambient temperatures), which put additional stresses on the lubricant.

This practice is designed to assist the user to validate the condition of the lubricant through its life cycle by carrying out a meaningful program of sampling and testing of oils in service. This practice is performed in order to collect data and monitor trends which suggest any signs of lubricant deterioration and to ensure a safe, reliable, and cost-effective operation of the monitored plant equipment.

1. Scope*

1.1 This practice covers the requirements for the effective monitoring of mineral turbine oils in service in steam and gas turbines, as individual or combined cycle turbines, used for power generation. This practice includes sampling and testing schedules to validate the condition of the lubricant through its life cycle and by ensuring required improvements to bring the present condition of the lubricant within the acceptable targets. This practice is not intended for condition monitoring of lubricants for auxiliary equipment; it is recommended that the appropriate practice be consulted (see Practice D6224).

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum ~~Products~~ Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.C0.01 on Turbine Oil Monitoring, Problems and Systems.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water
D892 Test Method for Foaming Characteristics of Lubricating Oils
D943 Test Method for Oxidation Characteristics of Inhibited Mineral Oils
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1401 Test Method for Water Separability of Petroleum Oils and Synthetic Fluids
D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)
D2272 Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel
D2273 Test Method for Trace Sediment in Lubricating Oils
D2422 Classification of Industrial Fluid Lubricants by Viscosity System
D2668 Test Method for 2,6-*di-tert*-Butyl- *p*-Cresol and 2,6-*di-tert*-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption
D3427 Test Method for Air Release Properties of Petroleum Oils
D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D4898 Test Method for Insoluble Contamination of Hydraulic Fluids by Gravimetric Analysis
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D6224 Practice for In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6439 Guide for Cleaning, Flushing, and Purification of Steam, Gas, and Hydroelectric Turbine Lubrication Systems
D6810 Test Method for Measurement of Hindered Phenolic Antioxidant Content in Non-Zinc Turbine Oils by Linear Sweep Voltammetry
D6971 Test Method for Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry
D7155 Practice for Evaluating Compatibility of Mixtures of Turbine Lubricating Oils
D7647 Test Method for Automatic Particle Counting of Lubricating and Hydraulic Fluids Using Dilution Techniques to Eliminate the Contribution of Water and Interfering Soft Particles by Light Extinction
D7669 Guide for Practical Lubricant Condition Data Trend Analysis
D7720 Guide for Statistically Evaluating Measurand Alarm Limits when Using Oil Analysis to Monitor Equipment and Oil for Fitness and Contamination
F311 Practice for Processing Aerospace Liquid Samples for Particulate Contamination Analysis Using Membrane Filters
F312 Test Methods for Microscopical Sizing and Counting Particles from Aerospace Fluids on Membrane Filters

2.2 *International Organization for Standardization Standards:*[3]
ISO 4406 Hydraulic fluid power—Fluids—Method for ~~coding~~Coding the ~~level~~Level of ~~contamination~~Contamination by ~~solid particles,~~Solid Particles, Second Edition, 1999
ISO 4407 Hydraulic Fluid ~~Power - Fluid Contamination - Determination~~ Power—Fluid Contamination—Determination of Particulate Contamination by Counting Method Using an Optical Microscope, Second Edition, 2002
ISO 11500 Hydraulic ~~fluid power - Determination~~ Fluid Power—Determination of the ~~particulate contamination level~~Particulate Contamination Level of a ~~liquid sample by automatic particle counting using the light extinction,~~Liquid Sample by Automatic Particle Counting Using the Light Extinction, Second Edition, 2008
ISO 11171 Hydraulic Fluid ~~Power – Calibration of automatic particle counters for liquids~~Power—Calibration of Automatic Particle Counters for Liquids

3. Significance and Use

3.1 This practice is intended to assist the user, in particular the power-plant operator, to maintain effective lubrication of all parts of the turbine and guard against the onset of problems associated with oil degradation and contamination. The values of the various test parameters mentioned in this practice are purely indicative. In fact, for proper interpretation of the results, many factors, such as type of equipment, operation workload, design of the lubricating oil circuit, and top-up level, should be taken into account.

4. Properties of Turbine Oils

4.1 Most turbine oils consist of a highly refined paraffinic mineral oil compounded with oxidation and rust inhibitors. Depending upon the performance level desired, small amounts of other additives such as metal deactivators, pour depressants, extreme

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

pressure additives, and foam suppressants can also be present. The turbine oil's primary function is to provide lubrication and cooling of bearings and gears. In some equipment designs, they also can function as a governor hydraulic fluid.

4.2 New turbine oils should exhibit good resistance to oxidation, inhibit sludge and varnish deposit formation, and provide adequate antirust, water separability, and nonfoaming properties. However, these oils cannot be expected to remain unchanged during their use in the lubrication systems of turbines, as lubricating oils experience thermal and oxidative stresses which degrade the chemical composition of the oil's basestock and gradually deplete the oil's additive package. Some deterioration can be tolerated without harming the safety or efficiency of the system. Good monitoring procedures are necessary to determine when the oil properties have changed sufficiently to justify scheduling corrective actions which can be performed with little or no detriment to production schedules.

5. Operational Factors Affecting Service Life

5.1 The factors that affect the service life of turbine lubricating oils are as follows: (*1*) type and design of system, (*2*) condition of system on startup, (*3*) original oil quality, (*4*) system operating conditions, (*5*) contamination, (*6*) oil makeup rate, and (*7*) handling and storage.

5.1.1 *Type and Design of System*—Most modern turbine lubricating systems are similar in design, especially for the larger units. For lubrication, the usual practice is to pressure-feed oil directly from the main oil pump. The rest of the system consists of a reservoir, oil cooler, strainer, piping and additional purification or filtration equipment, or a combination thereof. Miscellaneous control and indicating equipment completes the system.

5.1.2 *Condition of System on Start-up:*

5.1.2.1 The individual components of a lubrication system are usually delivered on-site before the system is installed. The length of on-site storage and means taken to preserve the integrity of the intended oil wetted surfaces will determine the total amount of contamination introduced during this period, the magnitude of the task of cleaning and flushing prior to use, and the detrimental effects of the contaminants. Guidance on cleaning, flushing, and purification of steam, gas, and hydroelectric turbine lubrication systems is provided in Guide D6439 or may be sought from the equipment/lubricant supplier or other industry experts.

5.1.2.2 Turbine oil system contamination prior to startup usually consists of preservatives, paint, rust particles, and the various solids encountered during construction, which can range from dust and dirt to rags, bottles, and cans. Their effect on turbine oil systems is obvious.

5.1.2.3 Ongoing purification may be required to maintain the in-service oils at an acceptable particle cleanliness level and water content level in the case of steam turbines for reliable lubrication and control systems operation. In operational systems, the emphasis is on the removal of contaminants that may be generated due to normal oil degradation or ingressed during operation and by malfunctions that occur during operation or contaminants that are introduced during overhaul, or both.

5.1.3 *Original Oil Quality:*

5.1.3.1 Use of a high-quality oil is the best assurance of potentially long service life. Oils meeting recognized standards are generally available, and one that at least meets the requirements of the turbine manufacturer shall be used. Careful oil storage, including labeling and rotation of lubricant containers, is vital to ensure proper use and prevent degradation of the physical, chemical, and cleanliness requirements of the lubricant throughout storage and dispensing.

5.1.3.2 It is advisable to obtain typical test data from the oil supplier. Upon receipt of the first oil charge, a sample of oil should be taken to confirm the typical test data and to use as a baseline. This baseline should act as a starting point for the physical and chemical properties of the lubricant, and for future comparisons with used oil information. This is most important! Recommended tests for new oil are given in the schedules of this practice (see Tables 1 and 2).

5.1.3.3 When new turbine oil is to be mixed with a charge of a different composition prior checks should be made to ensure no loss of expected properties due to incompatibility (see lubricant suppliers' specifications). These should include functional tests and checks for formation of insolubles. Guidance for such compatibility testing can be referenced in Practice D7155 for evaluating compatibility of mixtures of turbine lubricating oils.

5.1.4 *System Operating Conditions:*

5.1.4.1 The most important factors affecting the anticipated service life of a given lubricating oil in a given turbine system are the operating conditions within the system. Air (oxygen), elevated operating temperatures, metals, and water (moisture) are always present to some extent in these oil systems. These elements promote oil degradation and must consequently be recorded.

5.1.4.2 Most turbine oil systems are provided with oil coolers to control temperature. In many cases, bulk oil temperatures are maintained so low, below 60°C (140°F), that moisture condensation can occur. Even with low bulk oil temperatures, however, there can be localized hot spots such as in bearings, at gas seals, and in throttle control mechanisms that can cause oil degradation and eventually cause system oil to show signs of deterioration.

5.1.4.3 Under the higher temperature conditions which are present in gas and steam turbines, oxidation of the oil can be accelerated by thermal-oxidative cracking leading to the production of viscous resins and deposits particularly at the point of initiation.

5.1.5 *Contamination:*

5.1.5.1 Contamination of turbine oils is often the most significant factor affecting oil service life. Contamination occurs both from outside the system and from within due to oil degradation and moisture condensation or leaks. Development of a clean turbine

TABLE 1 Minimum Sampling and Inspection Testing Schedule for New Oils

Schedule 1 New Oil-All Turbine Types

Samples:
(a) From transport or drums
(b) From storage tank

Tests	Method	Recommended Minimum Requirements for Acceptance of New Oil as Received
Viscosity	D445	Should meet Classification D2422 consistent with user purchase specifications or manufacturer's requirements.
Acid Number	D974 or D664	Acceptance limits should be consistent with user purchase specifications, new oil reference or manufacturer's requirements or a combination thereof.
Appearance	visual	clear and bright
Water Content	visual	no free water
Color	D1500	Acceptance limits should be consistent with user purchase specifications, new oil reference or manufacturer's requirements or a combination thereof.
Rust Test	D665	Required for Steam and Single Shaft combined cycle turbines. Should pass D665A for land-based turbines and D665B for marine turbines.
Oxidation Stability or Inhibition (RPVOT/Voltammetry/FTIR)	D2272 , D6810, D6971	Most suitable methods and acceptance limits should be consistent with user purchase specifications, new oil reference or manufacturer's requirements or a combination thereof.
Elemental Analysis (Suggested)	D5185	Comparison with new oil reference on delivery may indicate the presence of contaminants or mislabeled oil shipment. (Other spectrochemical method may be substituted for the ICP method.)
Air Release (Suggested)	D3427	Comparison with new oil reference on delivery may indicate the presence of contaminants or mislabeled oil shipment.
Water Separation (Suggested)	D1401	Steam Turbine and Combined Cycle Systems only.
Foam (Suggested)	D892	Comparison with new oil reference on delivery may indicate the presence of contaminants or mislabeled oil shipment.

oil system on start-up or following maintenance is essential. Once attained, the danger of external contamination is less but should be guarded against. The oil can be contaminated by the introduction of different type oils, which are of the wrong type or are incompatible with the system oil. The oil supplier or the turbine manufacturer, or both, should be consulted before additions are made (see Practice D7155).

5.1.5.2 External contamination can enter the system through bearing seals and vents. Internal contaminants are always being generated. These include water, dirt, fly ash, wear particles, and insoluble particulate oil degradation products. From whatever source, contamination must be dealt with by monitoring oil condition and the use of purification devices such as filters and centrifuges on a regular basis. These can be removed by purification devices such as filters, centrifuges, coalescers, and vacuum dehydrators. Contamination of the system oil is a valid reason to change oil or flush a unit, or both, to restore system cleanliness.

5.1.6 *Oil Makeup Rate*—The amount and frequency of makeup oil added to the system plays a very significant part in determining the life of a system oil charge. Makeup varies from below 5 % per year to as much as 30 % in extreme cases. In turbines where makeup is relatively high compared to the oil degradation rate, the degree of degradation is compensated for and long oil life can be expected. In turbines where the makeup is very low (below 5 %), a truer picture of oil degradation is obtained. However, such a system should be carefully watched since the oil life is dependent almost exclusively on its original quality. In the United States, the average makeup is typically around 7 to 10 % per year.

5.1.7 *Handling and Oil Storage*—Handling and dispensing methods must ensure that the quality and the cleanliness of the lubricant meet the specifications required by the equipment. Oils must be properly labeled to ensure proper selection and use. Proper stock rotation and storage methods must be considered to prevent the possible degradation of the physical and chemical properties of the lubricant during storage and dispensing.

5.2 The combination of all of the preceding operational factors for a given turbine determines its *severity level* . Each unit is different and the equilibrium operating conditions for each system must be determined in order to fix its severity level; OEM

TABLE 2 Minimum Sampling and Inspection Testing Schedule for New Oil Charge[A]

Schedule 2 Installation of a New Oil Charge

Samples:
After 24-h circulation in Turbine
Retain approximately 4 L (1 gal)

Tests	Method	Recommended minimum requirements for assessment of new oil charge
Viscosity	D445	Should meet Classification D2422 consistent with user purchase specifications or manufacturer's requirements.
Acid Number	D974 or D664	Should be consistent with user purchase specifications and new oil reference.
Appearance	visual	clear and bright
Water Content	visual	no free water
Color	D1500	Should be consistent with user purchase specifications and new oil reference.
Particle Count--Cleanliness (after filtration into equipment)	F311 orF312 or user defined	Definition of suitable cleanliness levels determined by particle count distribution depends on turbine builder and user requirements Filtration or centrifugation, or both of oil into turbine and during in-service is recommended.
Oxidation Stability or Inhibition (RPVOT/Voltammetry/FTIR)[B]	D2272 , D6810, D6971	Should be consistent with user purchase specifications and new oil reference.
Elemental Analysis (Suggested)	D5185	Comparison with new oil reference on delivery may indicate the presence of contaminants or mislabeled oil shipment. (Other spectrochemical method may be substituted for the ICP method.)
Air Release (Suggested)	D3427	Comparison with new oil reference on delivery may indicate the presence of contaminants or mislabeled oil shipment.
Water Separation (Suggested)	D1401	Steam Turbine and Combined Cycle Systems only.
Foam (Suggested)	D892	Comparison with new oil reference on delivery may indicate the presence of contaminants or mislabeled oil shipment.

[A] Follow recommended flushing procedures prior to installing initial fill or replacement oil charge. For general guidance, see Guide D6439.
[B] Important as a baseline to determine turbine system severity. It is recommended that all tests which are performed on in-service oils for trending purposes should also be performed on a new oil charge for baseline information.

operating and maintenance specifications can also be used in setting the severity levels. The more severe a turbine system, the shorter the service life for a given oil. A useful approach to determine the severity of a turbine is given in Appendix X1.

6. Sampling

6.1 *General*—When taking oil samples from storage tanks or equipment in service, it is important that the extracted sample is representative and is taken from a specified location(s) to monitor the properties of the lubricant. Correct and consistent sampling techniques are vital to achieve this. The following are some suggested guidelines for proper sampling technique and sample handling techniques (see also Practice D4057). The user should have written standard operating procedures to ensure that samples are taken consistently according to good maintenance practices.

6.2 *Representative Sampling*—A sampling location that supports repeatable and representative sampling to monitor the health of the equipment and the properties of the lubricant. The sample location should be upstream of filters and downstream of machine components such as bearings and gears to obtain the best data. To be representative, oil samples should be collected when the turbine is running at normal operating temperatures, loads, pressures, and speeds. This ensures insoluble material is suspended evenly throughout the system.

6.2.1 *Sampling Location*—The primary sampling port is the location where routine oil samples are taken for monitoring oil contamination, wear debris and the chemical and physical properties of the oil. Possible locations include:

6.2.1.1 *Dipping from the Tank*—Oil samples should be taken by dipping from the tank. Lubricant should be thoroughly circulated before the sample is taken.

6.2.1.2 *Oil Return Line Sampling Port* —For circulating systems, the preferred location for oil samples is on a single return line prior to entering the sump or reservoir.

6.2.2 Secondary sampling methods are to be used for measuring contamination and wear debris contributed by individual components, and can be located anywhere on the system to isolate upstream components. This is where contamination and wear debris contributed by individual components will be found:

6.2.2.1 *Sampling from a Line*—The line should contain lubricating oil which is free flowing and not deadheaded. For instance, the lines in a bearing header, an active filter, and active heat exchanger are free flowing; the lines to a gage cabinet are deadheaded. In equipment with dual filters or heat exchangers, the inactive filters or heat exchangers do not have flowing fluid and are not suitable sampling points. When using a sampling line, it is necessary that the line has been thoroughly flushed before taking a sample. Adequate amount of flushing will depend on sampling line dimensions, length, and diameter.

NOTE 1—Test values obtained will differ depending on the sample locations. Use caution when comparing sample results from different sample points. Samples should be taken in the same manner each time to allow reliable trending of oil properties.

6.2.2.2 *Tapping from a Reservoir*—The lubricating oil must be thoroughly agitated in the reservoir and the tap line flushed before a sample can be taken.

6.2.3 An oil sample is probably not representative if: (*1*) the system oil is hot while the sample is cold, (*2*) the oil in the system is one color or clarity in a sight glass while the sample is a different color or clarity, and (*3*) the viscosity of the reservoir oil is different from that of the sample when both are at the same temperature.

6.2.4 It should be noted that on occasion a sample may be requested which will not be representative. At that time, sampling instructions, as specified by the requestor, must be followed. For example, a sample might be taken off the top or the bottom of a tank to check for contamination. In all cases the sample point should be marked on the sample bottle.

6.3 *Oil Sample Bottles*—Samples should be taken in a suitable sample bottle. To be suitable the bottle should be:

6.3.1 *Clean*—If in doubt about its cleanliness, use another bottle; if this is not possible, flush it out with the oil to be sampled.

6.3.2 *Resistant to the Material Being Sampled*—To verify the bottle's resistance, if time permits, allow the sample to stand in the bottle and observe its effects. Aluminum foil makes a good, resistant cap liner.

6.3.3 *Appropriate for Whatever Handling is Required*—Bottles with leaking tops and glass bottles improperly protected are not suitable for shipment. Appropriate regulations for handling and shipment of samples must be observed.

6.3.4 *Appropriate for the Analyses Required*—An extensive chemical analysis, if that is why a sample is required, cannot be done on the contents of a bottle which is too small.

NOTE 2—Some lubricant suppliers and commercial laboratories provide sample bottles which meet all these requirements. These should be used whenever possible. If frequent samples are taken, an adequate supply of containers should be available.

6.4 *Sample Labeling*—A sample bottle should be properly labeled in order to track the history of a particular piece of equipment. The equipment must be identified uniquely. Labels should include the following information as appropriate:

6.4.1 Customer name (if appropriate),

6.4.2 Site (or plant name),

6.4.3 Location (unit number, tank number, compartment number, and so forth),

6.4.4 Turbine serial number (or other ID),

6.4.5 Turbine service hours,

6.4.6 Oil service hours,

6.4.7 Date sample taken,

6.4.8 Type of oil sampled (lubricant ID),

6.4.9 Sampling point/port ID,

6.4.10 Type of purification system (filters/centrifuge, and so forth), and

6.4.11 Makeup (volume) since last sample was taken.

6.5 *Sampling of New Oil Deliveries:*

6.5.1 A sample of the new lubricant is required to provide a baseline for the physical and chemical properties of the lubricant. Also samples taken should be representative of the oil being examined but obtained from the point(s) most indicative of gross contamination by debris and water, that is, just above the bottom of the drum or tanker compartment bottom.

6.5.2 When consignments of oil are in drums, sample them in accordance with Practice D4057.

6.5.3 For bulk consignments, sample each tanker compartment. If these are clear of debris and water, then the samples can be combined for subsequent laboratory analysis of the consignment.

6.5.4 In cases where the product is suspected of being nonuniform, sample a larger number of drums. Where contamination is suspected there is no alternative to sampling every drum.

6.5.5 From tanker deliveries, in addition to sampling individual tanker compartments, further sample(s) should be taken preferably from the outlet of the flexible pipework or at least from the tanker bottom valve manifold. This further sampling is necessary because the tanker contents can become contaminated by residual material left in the bottom valve manifold. This can occur particularly when different products are being carried in separate compartments or previous deliveries of a different product have been made to other locations without subsequent adequate cleaning and flushing.

6.5.6 Bottom samples must be collected by either a tube or thief sampler (for example, Bacon bomb). These samplers permit collection of settlings on the bottom of the container without introducing false contamination by scraping the container lining or wall.

6.5.7 Take the sample(s) from the outlet of the flexible pipework or the tanker bottom valve manifold while maintaining a good flow after flushing the line.

6.6 *Preservation of Sample*—If tests are not run immediately, store the sample(s) away from strong light or excessive heat.

7. Examination of New Oil on Delivery

7.1 Experience has shown the need for standardizing procedures to be undertaken for the sampling, examination, and acceptance of incoming supplies of turbine oil. It is essential that personnel responsible for sampling and testing shall have the necessary experience and skills, and that scrupulous attention to detail be applied at all times to avoid erroneous results.