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

This standard is issued under the fixed designation D4378; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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),~~ a wide range of temperatures from ambient conditions to normal operating 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum 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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***A Summary of Changes section appears at the end of this standard**

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
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 Absorp
D3427 Test Method for Air Release Properties of Hydrocarbon Based Oils
D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
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
D6450 Test Method for Flash Point by Continuously Closed Cup (CCCFP) Tester
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
D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)
D7094 Test Method for Flash Point by Modified Continuously Closed Cup (MCCCFP) Tester
D7155 Practice for Evaluating Compatibility of Mixtures of Turbine Lubricating Oils
D7464 Practice for Manual Sampling of Liquid Fuels, Associated Materials and Fuel System Components for Microbiological Testing
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
D7687 Test Method for Measurement of Cellular Adenosine Triphosphate in Fuel and Fuel-associated Water With Sample Concentration by Filtration
D7720 Guide for Statistically Evaluating Measurand Alarm Limits when Using Oil Analysis to Monitor Equipment and Oil for Fitness and Contamination
D7843 Test Method for Measurement of Lubricant Generated Insoluble Color Bodies in In-Service Turbine Oils using Membrane Patch Colorimetry
D7978 Test Method for Determination of the Viable Aerobic Microbial Content of Fuels and Associated Water—Thixotropic Gel Culture Method
D8072 Classification for Reporting Solids and Insoluble Water Contamination of Hydrocarbon-Based Petroleum Products When Analyzed by Imaging Instrumentation

[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.

D8112 Guide for Obtaining In-Service Samples of Turbine Operation Related Lubricating Fluid
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 the Level of Contamination by Solid Particles, Second Edition, 1999
ISO 4407 Hydraulic Fluid Power—Fluid Contamination—Determination of Particulate Contamination by Counting Method Using an Optical Microscope, Second Edition, 2002
ISO 11500 Hydraulic Fluid Power—Determination of the Particulate Contamination Level of a 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

3. Terminology

3.1 For definitions of terms used in this practice, refer to Terminology D4175.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bulk oil tote, n*—any container for lubrication or control fluid with working volume approximately 1000 L to 1300 L designed for fluid storage at atmospheric pressure.

3.2.2 *continuous sampling loop, n*—a limited flow of fluid from a point in a pressurized system to a point of lower pressure used to decrease required purge fluid and sample time during the sampling process.

3.2.3 *disposable sample tubing, n*—any single-use flexible plastic tubing used to transfer fluid during the sampling process.

3.2.4 *drain sampling, n*—a method of sampling used fluid for non-pressurized reservoirs or lines occurring when the lubricating fluid is being drained from the reservoir during a fluid change.

3.2.4.1 *Discussion*—
As part of a fluid change, the drain plug is removed to allow the fluid to drain into an appropriate container under gravity. Mid way through the draining, a sample bottle is filled by placing it in the fluid stream and once filled immediately capped.

3.2.5 *drop tube sampling, n*—a method of sampling used fluid for non-pressurized reservoirs when sampling is completed by dropping an appropriate length of sampling tubing into the reservoir and using a vacuum generating device to extract the sample.

3.2.6 *permanent sample tube, n*—any tubing installed in a reservoir or pipe used to extract a sample from a specific location within the system.

3.2.7 *purge, v*—to remove the existing non-representative fluid and contaminants from the sample valve and tubing during the sampling process.

3.2.8 *remote access hose, n*—any permanently installed metallic or elastomeric tube or hose used to transfer fluid from the system to a point outside the system to facilitate sampling.

3.2.9 *reservoir, n*—any equipment-based container that holds a volume of fluid, usually under atmospheric condition, for use in the lubrication, sealing or control process.

3.2.10 *sample container, n*—a clean, fresh plastic bottle used for system fluid analysis (see Section 7).

3.2.11 *sample valve, n*—a system consisting of a male and female component used specifically for the extraction of a fluid sample either by internal system pressure or by an externally generated vacuum.

3.2.11.1 *Discussion*—
The male component, referred to as a probe, may be for one time use or permanently attached to the female component, referred

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

to as a sample valve, is used by either threading the probe onto the valve or pushing the probe into the valve for the purpose of opening the valve and allowing fluid to flow out.

3.2.12 *sample valve sampling, v*—to obtain a sample from either pressurized or non pressurized lines or reservoirs.

3.2.12.1 *Discussion—*

When sampling non-pressurized reservoirs this sampling method usually applies a vacuum generating device and sampling tubing to extract a sample into a sampling container from a strategically located sampling valve. When sampling pressurized reservoirs or lines, this sampling method is completed by using system pressure to force lubricating fluid into a sampling container through a sampling valve.

3.2.13 *vacuum generating device, n*—a pump used to create a low pressure in a sample container to cause fluid to move from a non-pressurized reservoir to the container through disposable tubing.

3.2.14 *weighted drop tube device, n*—a mass attached to a piece of steel or stainless steel tubing with a method to attach disposable sampling tubing to the steel or stainless steel tubing.

3.2.14.1 *Discussion—*

This device is used during drop tube sampling.

4. Significance and Use

4.1 This practice is intended to assist the user, in particular the power-plant ~~operator,~~ operations and maintenance departments, 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.

5. Properties of Turbine Oils

5.1 Most turbine oils consist of a highly refined paraffinic mineral oil compounded with oxidation and rust ~~inhibitors.~~ inhibitors with a lesser number of turbines using a synthetic type of fluid. Depending upon the performance level desired, small amounts of other additives such as metal deactivators, pour depressants, extreme 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.

5.2 New turbine oils should exhibit good resistance to oxidation, inhibit sludge and varnish deposit formation, and provide adequate antirust, water separability, and non-foaming 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.

6. Operational Factors Affecting Service Life

6.1 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.

6.1.1 *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.

6.1.2 *Condition of System on Start-up:*

6.1.2.1 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.

6.1.2.2 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. Incompatible fluid is also considered a contaminant and can include system flushing lube oil from improper drain and clean-out.

6.1.2.3 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.

6.1.3 *Original Oil Quality:*

6.1.3.1 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.

6.1.3.2 It is advisable to obtain typical test data from the oil supplier. Upon receipt of the first oil charge, take a ~~sample~~ baseline sample from the barrel, tote or tanker to ensure the oil meets quality standards. A sample of the oil should be taken after charging the new oil and circulating (24 h) 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).

6.1.3.3 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 insoluble materials. Guidance for such compatibility testing can be referenced in Practice D7155 for evaluating compatibility of mixtures of turbine lubricating oils.

6.1.4 *System Operating Conditions:*

6.1.4.1 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.

6.1.4.2 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.

6.1.4.3 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.

6.1.5 *Contamination:*

6.1.5.1 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 oil system on start-up or following maintenance is essential (following the steps in Guide D6439) prior to filling with the new oil. 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).

6.1.5.2 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, insoluble particulate oil degradation products and microbial growth.

TABLE 1 Minimum Sampling and Inspection Testing Schedule for New Oils

Tests	Method	Recommended Minimum Requirements for Acceptance of New Oil as Received
Schedule 1 New Oil-All Turbine Types		
Samples: (a) From transport or drums (b) From storage tank		
Viscosity	D445, D7042	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.

From whatever source, contamination must be dealt with by monitoring oil condition and the use of purification devices such as filters, centrifuges, coalescers, and vacuum dehydrators on a regular basis. Contamination of the system oil is a valid reason to change oil or flush a unit, or both, to restore system cleanliness.

6.1.6 *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.

6.1.7 *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.

6.2 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 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.

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, D7042	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 or F312 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.

7. Sampling

7.1 *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 recommended guidelines for proper sampling technique and sample handling techniques are part of Guide D8112. The user should have written standard operating procedures to ensure that samples are taken consistently according to good maintenance practices. In addition to the Guide D8112 method the following recommendations are to be considered:

7.1.1 *Microbiological Testing*—When sampling in order to perform microbiological testing, refer to Practice D7464 for guidance on sample collection and handling.

NOTE 1—For samples intended for microbiological testing, see Practice D7464. Although the guidance provided in Practice D7464 is nominally for fuel sample collection, the procedures provided are equally applicable to turbine oils.

7.2 *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:

7.2.1 Customer name (if appropriate),

7.2.2 Site (or plant name),

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

7.2.4 Turbine serial number (or other ID), 7.2.5 Turbine service hours,

7.2.6 Oil service hours,

7.2.7 Date sample taken,

7.2.8 System operating temperature and temperature of oil at sampling point,

7.2.9 Type of oil sampled (lubricant ID),

7.2.10 Sampling point/port ID,

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

7.2.12 Makeup (volume) since last sample was taken.

7.3 *Sampling of New Oil Deliveries:*

7.3.1 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.

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

7.3.3 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.

7.3.4 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.

7.3.5 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.

7.3.6 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.

7.3.7 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.

7.4 *Preservation of Sample and Analysis of Oil Samples*—It is generally advised to ship the oil samples immediately to the oil analysis laboratory, as ideally, oil should be analyzed as soon as reasonably achievable after being sampled. If oil samples are stored for an extended period of time, this may result in a non-representative sample.

7.4.1 If the samples are to be retained for extended periods of time, special arrangements should be made in agreement with the oil analysis laboratory to ensure that the integrity of the sample is not compromised. The special arrangement may include storing in dark amber glass bottles in an ambient temperature area as the longer an oil sample is stored in the container/bottle, the more oxidation products will be generated.

7.4.2 Store the sample(s) away from strong light and as close to room temperature as possible.

8. Examination of New Oil on Delivery

8.1 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.

8.2 It is equally essential that all incoming supplies of oil be adequately monitored to guard against incorrect or contaminated material being delivered. Cleanliness of the delivery container should be noted; if the container is dirty on the outside, there may be particulate contamination on the inside. Particulate contamination can also be a problem when the lubricant comes in contact with dirty or poorly maintained equipment.

8.3 Sampling of incoming supplies should be in accordance with proper sampling procedures (see Section 7).

8.4 All samples should be immediately examined for appearance.

8.5 A testing schedule for new oil is included in this practice (see Table 1 and Table 2). With drums, tests should be completed on the bulk sample before the oil is used in service. Individual samples should be retained until the bulk sample is passed as satisfactory.

8.6 With tanker deliveries the additional tests to be completed before the tanker is discharged can only be judged from the risk involved by the acceptance of nonspecification product, that is, can the charge be readily recovered and corrected before passing into service if the subsequent tests indicate this to be necessary.

8.7 Handling and dispensing methods contribute to the required health and cleanliness specifications of the lubricant. All sources and opportunities of contamination must be avoided.

9. Deterioration of Turbine Oils in Service

9.1 *How Turbine Oils Degrade*—Irrespective of initial quality, during their use in lubrication systems of turbines, lubricating oils will experience thermal and oxidative stresses, loss of foam control, poor oil demulsibility and loss of wear protection, which degrade the chemical composition of the oil. In order to avoid these degradation problems, lubricating oils are developed with a strong ability to control oxidation processes, degradation by wear, and other degradation mechanisms, by using a combination of good quality base oil together with a mixture of additives. For turbine oils, it is very common for high quality products to have long periods of successful field operation, so that for many years the oil may perform like new. Lubricant deterioration occurs by one or more of the following processes:

~~9.1.1 *Oxidative Degradation*—This occurs as the result of chemical changes brought about by oxygen in the atmosphere and proceeds by a chain reaction.~~

9.1.1 ~~*Thermal/Oxidative*~~*Oxidative Degradation*—This ~~degradation can occur when the oil encounters hot spots or experiences electrostatic discharges, or microdieseling in turbines. During thermal degradation at elevated temperatures, hydrocarbons may form unstable and insoluble compounds. These unstable compounds are easily oxidized and also tend to polymerize to form resins and sludge.~~occurs as the result of chemical changes brought about by oxygen in the atmosphere and proceeds by a chain reaction.

9.1.1.1 *Thermal/Oxidative Degradation*—This degradation can occur when the oil encounters hot spots or experiences electrostatic discharges, or microdieseling in turbines. During thermal degradation at elevated temperatures, hydrocarbons may form unstable and insoluble compounds. These unstable compounds are easily oxidized and also tend to polymerize to form resins and sludge. For example, adiabatic compression of bubbles can cause small localized hot-spots of 3000° or the arc quenching high temperatures.

9.1.2 *Water Accumulation in the System*—Accumulated water promotes oil degradation as well as additive depletion, corrosion, reduced lubricating film thickness and microbial growth. It is advised to operate without the presence of free or emulsified water.

9.1.3 *Loss of Additives*—This can result in more rapid oxidation and premature rusting.

9.1.4 *Influx of Contaminants*—Contaminants arising within the system (corrosion and wear products) or from without (fly ash, dirt, and fluids) cause lubrication and wear problems.

9.2 *Properties of Oils That Must Be Retained*—In determining the condition of the system oil for continued service, the most important properties of the in-service oil are: ~~(1)~~ viscosity, ~~(2)~~ oxidation stability reserve, ~~(3)~~ freedom from sludge/varnish, ~~(4)~~ freedom from abrasive contaminants, ~~(5)~~ anticorrosion protection, ~~(6)~~ demulsibility, ~~(7)~~ air release, and ~~(8)~~ freedom from water contamination. (See Table 3.)

9.2.1 *Viscosity*—Viscosity is the most important characteristic of a turbine oil, as the oil film thickness under hydrodynamic lubrication conditions is critically dependent on the oil's viscosity characteristics. The viscosity of most commercial turbine oils are classified according to ISO (International Standards Organization) viscosity classification system. Oils fall into ISOVG32, VG46, VG68, and VG100 viscosity grades corresponding to ~~32~~32 mm^2 ~~cSt, 46~~/s (cSt), 46 mm^2 ~~cSt, 68~~/s (cSt), 68 mm^2 ~~cSt,~~/s (cSt), and ~~100~~100 mm^2 ~~cSt~~/s (cSt) at 40 °C and to approximately 165 SUS, 240 SUS, 350 SUS, and 515 SUS at 100 °F (Classification D2422). The main purpose for checking the viscosity of used turbine oil is to determine if the correct oil is being used and to detect contamination. Used turbine oils rarely show significant viscosity changes due to degradation. Occasionally, viscosity increases due to an emulsion with water contamination. The method normally used for viscosity determinations is Test Method D445 or D7042.

9.2.2 *Oxidation Inhibitor*—The monitoring of antioxidant concentration is important for controlling the oxidation of industrial lubricants and their remaining useful life. Some practices for measuring the concentration of phenolic (or amine) antioxidants include infrared spectrometry (including Fourier Transform Infrared) and voltammetry. When setting up one of these techniques, it is advisable to consult with the lubricant supplier who has a working knowledge of the antioxidants used in the turbine oil formulation.

9.2.2.1 *FTIR*—The Fourier Transform Infrared (FTIR) practice is a refined infrared spectroscopy method, which can be used to monitor change in the availability of the original antioxidants blended into the oil. It can also be used to monitor the change in oxidation products as the oil degrades. Each oil will produce a unique spectrum and a baseline must be established to obtain benefit from this technique. Each antioxidant is a specific chemical substance and will absorb infrared light at a particular wavelengths and absorptivities; some antioxidants may not be detectable by infrared spectroscopy. (Test Method D2668 may be used for antioxidants if the wavelengths and absorptivities are known and in the case the lubricant contains no antioxidant other than 2,6-di-t-butyl-p-cresol or 2,6-di-t-butylphenol.)

9.2.2.2 *Voltammetry*—Voltammetry is an electrochemical test technique, which can be used for measuring primary antioxidant additives. The technique applies a voltage ramp through a three electrode sensing system and measures the current flow that occurs

TABLE 3 Visual Inspection of In-service Oil Samples[A]

NOTE 1—For consistency, the following are suggested: (*1*) visual inspections be performed after a 5 min settling time, (*2*) use of clear sample containers, and (*3*) use of focused lighting to enhance visual observations.

Appearance of Oil just after Sampling	Appearance of Oil after 1 h Settling[B]	Possible Cause	Action Steps
Clear	Clear	...	...
Foam at the Surface	Foam collapsed	Air entry likely of mechanical origin or from sampling process	Investigate cause
	Stable persistent foam	High foaming tendency- Possibly contamination or antifoam depletion.	Investigate cause and conduct laboratory control test for foam
Sample contains small air bubbles at sampling then becomes clear from the bottom	Clear	Aeration if bubbles persist for more than 5 min.	Investigate cause
	Persistent entrained small air bubbles	High air entrainment- Possibly contamination, oil degradation	Investigate cause and conduct laboratory control test for air release
Sample cloudy and becoming clear from the top	Clear or slightly opaque, decanted free water	Unstable water emulsion	Determine source of water ingress
	Hazy	Presence of soft contaminants and insolubles	Determine possible presence of varnish contaminants
	Milky	Stable water emulsion	Investigate cause and conduct laboratory control test for water separation
Dirty	Presence of decanted solid particles	Contamination, possible filtration problem	Investigate cause and re-filter
Strange color, rapid and unusual darkening	...	Contamination or excessive degradation	Investigate cause and conduct laboratory control test for oxidation
Unusual odor	Acrid	Oil cracking due to overheating	Investigate cause. Check Viscosity, Acid No, Flash point
	Putrid or rancid Rotten eggs	Growth of bacteria or fungi Growth of anaerobic Sulfate Reducing Bacteria	Check for presence of water. Withdraw the separated water. Test for microbial contamination and consult with oil supplier regarding biocide treat

[A] These visual screening tests can be performed on site by the turbine unit operator.
[B] A complete reference to visual inspection definitions can be found in D7155.

when the applied voltage equals the oxidation potential of the antioxidant. The potential of the produced voltammetric peak aids in the identification of the antioxidant and the height of the produced peak is proportional to the concentration of the antioxidant. Antioxidants such as phenols (in accordance with Test Method D6810 and D6971), amines, and ZDDP can be measured. A product type baseline must be available ~~for use as a comparison to report a change.~~to a baseline test from a new oil sample of that fluid product name.

9.2.3 *Oxidation Stability Reserve:*

9.2.3.1 One of the important properties of new turbine oil is its oxidation stability. Traditionally, this has been measured by Test Method D943 with Test Method D2272 being used as an ancillary (rapid) method for following changes of oil condition in service. Oxidation stability will gradually decrease in service, deterioration being promoted by the catalytic effects of metals in the system (iron and copper) as well as by the depletion of the antioxidant. The latter occurs as a result of the normal function of the additive (chemically it acts as a chain-stopper in controlling oxidation), or by volatilization. As the oxidation stability reserve decreases, acidic compounds are produced which in turn undergo further reactions to form more complex compounds. The end products of these processes are insoluble sludge and lacquering. Although only a minute fraction of the oil is converted in this way, sufficient sludge and lacquering can form to settle in critical areas of the system, leading to filter blockage, interference with proper lubrication and cooling of bearings and moving parts.

9.2.3.2 The test method to detect severe oxidative degradation is the acid number (Test Methods D664 and D974). Most rust inhibitors used in turbine oils are acidic and contribute to the acid number of the new oil. An increase in acid number above the value for new oil indicates the presence of acidic oxidation products, microbial growth in the system or, less likely, contamination with acidic substances. An accurate determination of the acid number is very important. However, this test does not measure oxidation stability reserve, which is better determined by Test Method D2272. This latter test is included in the recommended testing schedules (see Table 1 and Table 2).

9.2.4 *Freedom from Sludge/Varnish:*

9.2.4.1 Due to the nature of the highly refined lubricant basestocks used in the manufacture of turbine oils, they are very poor solvents for sludge/varnish. This is the main reason why the oxidation stability reserve of the oil must be carefully monitored. Only a relatively small degree of oxidation can be permitted, otherwise there is considerable risk of sludge/varnish deposition in bearing housings, seals, gears, and pistons.

9.2.4.2 Measurement of the amounts of sludge/varnish as insoluble, soft contaminants (coloured bodies) in turbine oils (Test Method D7843) is possible. Sludge/varnish already laid down within the system would not be included in such a determination. Other tests, however, can signal deteriorating quality in the oil even before any significant formation of sludge/varnish occurs.

9.2.4.3 Filtration and centrifugation assist in removing sludge/varnish from the oil as it is formed but cannot protect the system if the oil is allowed to deteriorate too far before an oil change.

9.2.5 *Particle Counting:*

9.2.5.1 The most deleterious solid contaminants found in turbine oil systems are those left behind when the system is constructed and installed or when it is opened for maintenance and repair. The need for proper cleaning and flushing of new or repaired turbine systems is emphasized. Beyond these types of contaminants, there are few opportunities for solids to enter the lube oil system, although in very dusty areas where units may be out-of-doors, some solids can enter through improperly installed or operating vents.

9.2.5.2 During operation, the equipment begins to accumulate significant amounts of particulates. Some may enter the system through the makeup oil when it is added. Pre-filter fluid additions or make-up oil, maintaining proper reservoir vacuum to minimize debris ingress through gland seals. Fly ash may be drawn in with the air at bearing shaft seals. Other contaminants may be abrasive degradation and corrosion products developed in the system. Whatever the source, the presence of abrasive solids in the oil cannot be tolerated since they will promote scoring and damage to bearings and journals as well as causing malfunction and sticking of control mechanisms. These must be removed by the use of filters or centrifuge, or both. When the amount of makeup is low and the various filters and purifiers are operating satisfactorily, abrasive solids are generally removed before any damage is done. In a properly maintained system the particulate level presents no problem. Cleanliness of the system oil can be determined by gravimetric means (Practice F311 or Methods F312) or by particle counting (Test Method D7647), the latter normally by means of electronic particle counters. Cleanliness levels can be represented by classification systems such as ISO 4406:1999. ISO 4406:1999 uses a numeric code to reference the number of particles larger than 4 µm, 6 µm, and 14 µm/mL of oil. ISO 4406:1999