



International
Standard

ISO 11366

**Petroleum and related products —
In-servicing of steam, gas and
combined cycle turbines lubricating
oils — Guidance and requirements**

*Produits pétroliers et produits connexes — Suivi en service
des huiles lubrifiantes pour turbines à vapeur, à gaz et à cycle
combiné — Recommandations et exigences*

First edition
2025-05



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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 4, *Classifications and specifications*.

This first edition of ISO 11366 cancels and replaces ISO/TS 11366:2011, which has been technically revised.

The main changes are as follows:

- addition of [Clause 3](#) “Terms and definitions” and renumbering of the other clauses accordingly;
- addition of subclauses [6.10](#) “Flash point”, [7.6](#) “Wear metals” and [7.9](#) “Membrane patch colorimetry (MPC)”, and [Clause 11](#) “Prolonging an oil in service”;
- inclusion of additional tests and update of recommended test results;
- update of the normative references and the Bibliography.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The in-service monitoring of turbine oils is largely recognized by the power generation industry as necessary to insure long and trouble-free operation of turbines.

There are three main types of stationary turbines used in power generation plants: steam turbines, gas turbines and combined cycle turbines. The combined cycle turbines consist of two types:

- the first type associates a gas turbine with a steam turbine, with separated lubricating circuits;
- the second type is called a single shaft combined cycle turbine, in which the steam and the gas turbines are on the same shaft and are lubricated with the same oil.

The lubrication requirements of gas turbines and steam turbines are quite similar, but there are some big differences. Gas turbine oils are submitted to localized hot spots and water contamination is less likely.

Gas turbine oils have shorter service life than steam turbine oils, which can range from 10 to 20 years, depending on the top-up level. The lifetime of gas turbine oils can range from five to 10 years, or more.

The values of the various characteristics mentioned in this document are purely indicative. For proper interpretation of the results, many factors should be taken into account, such as the type of equipment, design of the lubricating oil circuit and top-up level.

It is expected that the manufacturer's instructions are followed.

This document is intended to:

- help power equipment operators evaluate the conditions of the oil in their equipment and maintain oils in-serviceable conditions;
- help users to understand how the oils deteriorate and to carry out a meaningful programme of sampling and testing of oils in use.

Petroleum and related products — In-servicing of steam, gas and combined cycle turbines lubricating oils — Guidance and requirements

1 Scope

This document provides guidance and requirements for the maintenance in service of mineral oils used as lubricating oils and control fluids used to lubricate steam, gas and combined cycle turbines in service.

This document is applicable to lubricants classified in ISO 6743-5 and specified in ISO 8068, except the grades TSD, TGD and TCD (phosphate esters) for which ISO 11365 is more relevant, and the grades TGCE, THA, THCH, THCE and THE.

This document also gives guidance and requirements with respect to the corrective actions that are taken to maximize service life.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2049, *Petroleum products — Determination of colour (ASTM scale)*

ISO 2592, *Petroleum and related products — Determination of flash and fire points — Cleveland open cup method*

ISO 2719, *Determination of flash point — Pensky-Martens closed cup method*

ISO 3104, *Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity*

ISO 3170, *Petroleum liquids — Manual sampling*

ISO 3722, *Hydraulic fluid power — Fluid sample containers — Qualifying and controlling cleaning methods*

ISO 4021, *Hydraulic fluid power — Particulate contamination analysis — Extraction of fluid samples from lines of an operating system*

ISO 4405, *Hydraulic fluid power — Fluid contamination — Determination of particulate contamination by the gravimetric method*

ISO 4406, *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles*

ISO 4407, *Hydraulic fluid power — Fluid contamination — Determination of particulate contamination by the counting method using an optical microscope*

ISO 6247, *Petroleum products — Determination of foaming characteristics of lubricating oils*

ISO 6296, *Petroleum products — Determination of water — Potentiometric Karl Fischer titration method*

ISO 6614, *Petroleum products — Determination of water separability of petroleum oils and synthetic fluids*

ISO 6618, *Petroleum products and lubricants — Determination of acid or base number — Colour-indicator titration method*

ISO 6619, *Petroleum products and lubricants — Neutralization number — Potentiometric titration method*

ISO 7120, *Petroleum products and lubricants — Petroleum oils and other fluids — Determination of rust-preventing characteristics in the presence of water*

ISO 9120, *Petroleum and related products — Determination of air-release properties of steam turbine and other oils — Impinger method*

ISO 11500, *Hydraulic fluid power — Determination of the particulate contamination level of a liquid sample by automatic particle counting using the light-extinction principle*

ISO 12937, *Petroleum products — Determination of water — Coulometric Karl Fischer titration method*

ISO 20764, *Petroleum and related products — Preparation of a test portion of high-boiling liquids for the determination of water content — Nitrogen purge method*

ASTM D2272, *Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel*

ASTM D2273, *Standard Test Method for Trace Sediment in Lubricating Oils*

ASTM D5185, *Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma*

ASTM D6595, *Standard Test Method for Determination of Wear Metals and Contaminants in Used Lubricating Oils or Used Hydraulic Fluids by Rotating Disc Electrode Atomic Emission Spectroscopy*

ASTM D7596, *Standard Test Method for Automatic Particle Counting and Particle Shape Classification of Oils Using a Direct Imaging Integrated Tester*

ASTM D7843, *Standard Test Method for Measurement of Lubricant Generated Insoluble Color Bodies in In-Service Turbine Oils using Membrane Patch Colorimetry*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

4 Description of turbine oils

Steam- and gas-turbines oils consist of highly refined hydrocarbon-origin base stocks in which additives are added to provide or to improve oxidation stability, as well as rust-protection properties, corrosion-protection properties (mainly for copper and copper containing materials). Additional foam suppressants can be added to limit the foaming tendency. However, care should be taken to avoid adding too much foam suppressant, which can have detrimental effect on air release properties. Demulsifiers can also be used to improve the water-shedding properties, but this should not be a common practice.

To formulate turbines oils, base stocks of API groups I and II are used with success. For special applications, e.g. high-temperature gas turbines, API groups III, III+ and IV base stocks can also be used. In most instances, API group I and group II base stocks are largely sufficient. The refining degree of group I and group II base stocks vary from one producer to another. Hydrogen treatment is essential to get a good response to the antioxidants and to obtain good water-shedding and air-release properties.

Numerous technologies are available to provide the necessary performance in terms of oxidation stability, and rust and corrosion protection. Combination of phenol- and amine-type antioxidants, associated with proper rust inhibitors (either ashless or ash containing) and copper corrosion inhibitors, are commonly used.

For some applications, mainly when the turbine is coupled to gears, extreme-pressure additives are required. These extreme-pressure additives shall be chosen so as to not impair the oxidation stability.

The use of viscosity modifiers (viscosity index improvers) is not permitted.

All new oils shall comply with ISO 8068, which includes requirements with respect to the most important properties, as follows:

- oxidation stability;
- low tendency to sludge forming;
- rust-protection properties;
- copper corrosion-protection properties;
- foaming tendency;
- air-release ability;
- water-shedding characteristics.

However, it cannot be expected that all these properties remain unchanged for the life of the oil.

The oil unavoidably undergoes deterioration. Some deterioration can be tolerated without prejudice to the safety and efficiency of the system. Good monitoring procedures are necessary to determine when the oil characteristics have reached the condemning limits, i.e. critical values for the most important characteristics that can be deleterious to the function of the installation.

5 Factors affecting the service life

5.1 General

The following factors can affect the service life of turbine lubricating oils:

- oil system design;
- condition of the oil system at start-up;
- original oil quality;
- system operating temperature and duty cycle;
- contamination rates and oil purification provisions;
- oil make-up rates.

5.2 Oil system design

Most modern turbine-lubricating systems are very similar in design, especially for the larger units. The usual practice is to pressurize feed oil directly from the main pump oil. To maintain reliability, after start-up of the turbine, the main pump is directly actuated by the turbine rotor. The oil is pumped from a reservoir of sufficient capacity to ensure a residence time of about 10 minutes for the turbine oil, so as to allow complete air release by the oil. The rest of the circulating system consists of an oil cooler, a strainer, a purification and filtration system, an oil tank vapour extractor and hydrogen removing units. The purification equipment includes centrifuging to remove water and is of utmost importance for achieving satisfactory oil lives.

For the larger turbines, high-pressure hydraulic pumps (up to 50 MPa outlet pressure) are used to lift the turbine shaft to allow for turning.

5.3 Conditions of the oil system at start-up

The individual components of a turbine lubrication system are usually delivered on-site before the system is installed. These components are generally pre-cleaned and delivered with a protection system to prevent corrosion or contamination ingress. The length of on-site storage and the means taken to preserve the integrity of the protection of the internal surfaces of the lubricating system will affect the amount of contamination introduced prior to use. During the installation of the lubricating-oil system components, attention should be paid to minimizing openings in the system and to maintaining cleanliness. Guidance on contamination control, flushing and purification can be sought from the equipment supplier or other industry experts.

Turbine-oil system contamination before start-up can consist of preservatives, paint, rust particles and various types of solid matter which range from dust, weld and metal chips, to rags, bottles and cans. Minute amounts of remaining preservatives can largely impair the water shedding and air release properties; the remaining particles can induce filter clogging and abrasive wear.

5.4 Original oil quality

Use of a high-quality oil is the best assurance for achieving long service life. The turbine oil is expected to meet the generally available recognized standards (e.g. ISO 8068) and the requirements of the turbine manufacturer.

It is recommended to obtain typical test data from the oil supplier. Upon receipt of the first oil charge, a sample of oil should be taken and tests should be conducted to confirm the typical test data. Another sample should be collected 2 h to 24 h after the initial operation and tested for all parameters listed in [Table 5](#). The analytical data obtained will be used as a baseline for future comparison with information on used oil. Recommended tests for new oil are given in [9.4](#).

When new turbine oil is required to be mixed with a charge of a different composition, preliminary tests should be made to ensure that there will be no loss of expected properties due to incompatibility. The preliminary tests should include functional tests such as water-shedding properties; foaming and air-release properties and checks for formation of insoluble matter. Turbine oil compatibility assessments such as ASTM D7155^[16] may be used.

5.5 System operating temperature

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

Many turbine-oil systems are provided with oil coolers to control the temperature. In many cases, oil bulk temperature is maintained below 60 °C, which promotes moisture condensation. However, even with low bulk temperatures, hot spots can be localized in bearings, at gas seals or in throttle-control mechanisms. This can cause significant oil degradation and will eventually cause the oil in the system to show signs of deterioration.

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

5.6 Contamination rates and purification provisions

Contamination of turbine oils during service occurs both from outside (external contamination) and inside (internal contamination) the system due to the oil degradation, moisture condensation or leaks.

Achieving a clean turbine lubrication-oil system at start-up is of utmost importance. Once attained, the danger of external contamination decreases but caution should still be maintained against it. External contamination can enter the lubrication system through bearing seals and vents, as air (i.e. oxygen) and moisture are always present in the oil systems. The oil can also be contaminated by the introduction of oils of

different types, either of the wrong type or a type incompatible with the system oil. Either the oil supplier or the turbine manufacturer, or both, should be consulted before different oils are mixed or additives are used.

Internal contaminants, on the other hand, are generated within the system all the time. Such contaminants can include water, metal-wear particles and oil degradation by-products. Metal particles can occur due to wear in journal and thrust bearings, gear, pumps, servo-valves and seals. Metal particles can also occur as a result of rusting, especially if the oil has relatively high moisture content.

All these contaminants should be removed continuously by properly designed purification devices: filters, centrifuges, coalescers, vacuum dehydrators, and varnish removal technology. With respect to varnish removal, it is possible to apply electrostatic purification (the varnish precursors charge and agglomerate into larger particles that are captured by a filter mat or attracted to a charged, disposable surface), filtration using absorbent media (fuller's earth, activated carbon), or a varnish removal filter based on the physisorption phenomenon.

5.7 Oil make-up rates

The frequency and the amount of make-up oil added to the system play a very significant part in determining the life of a system oil charge. Make-up varies from below 5 % per year (8 000 h of service) to as much as 30 % in extreme cases. In turbines where make-up is relatively high compared to the oil degradation rate, the degree of degradation is compensated, and a long life can be expected. In turbines where the make-up is less than 5 %, a real picture of the actual oil degradation is obtained. However, such a system should be carefully watched, since the oil life depends almost exclusively of its original quality.

Most generally, the average make-up lies between 7 % to 10 % per year.

6 Deterioration of turbine oils in service

6.1 General

Irrespective of their initial quality, turbine oils will deteriorate due to the conditions of use. This is quite normal. However, the degradation shall be monitored and reduced, if possible, when it is considered to be excessive.

6.2 Viscosity

Most commercial turbine oils fall into ISO VG 32, ISO VG 46, ISO VG 68 and ISO VG 100 grades as described in ISO 3448. Most gas-turbines are lubricated with ISO VG 32 grade oils and most steam turbines are lubricated with ISO VG 46 grade oils. The use of ISO VG 68 and ISO VG 100 grade oils is less common.

The main purpose of checking the viscosity of turbine oil in service is to determine whether the correct oil is being used and to detect contamination. Turbine oils rarely show significant viscosity changes due to degradation. Viscosity increase can result from oxidation, volatilization of the lighter fractions of the base stock or emulsion with water. Viscosity decrease is most likely the result of contamination; it can also be the result of cracking by prolonged thermal effect, e.g. malfunctioning of a heater.

6.3 Oxidation stability

One of the most important parameters of turbine oil is its oxidation stability.

The oxidation stability will gradually decrease in service owing to the catalytic effect of the dissolved metals (iron, copper, tin, etc.) and the depletion of the anti-oxidant system. The latter occurs as a result of the normal functioning of the additive (i.e. a chemical reaction with the oxidation precursors, giving rise to inactive species). Other causes of the anti-oxidant system depletion include volatilization (i.e. fumes extraction by putting the main oil tank under depression), and the wash-out by water in wet systems.

The rate of removal is, to some extent, dependent on the method and conditions of oil purification, because centrifuges and coalescers tend to remove more of the antioxidant additive with the water than vacuum dehydrators. On the other hand, too high a vacuum in conjunction with a high oil temperature for the vacuum

dehydrator type purifiers or seal oil degasifier can pull out some of the volatile antioxidants. This will often be evident as deposits in the top of the vacuum chamber.

As the oxidation-stability reserve decreases, acidic compounds that undergo further reactions are formed, leading to more complex compounds. The cross-linking of the acids formed gives rise to a more-or-less soluble sludge. The solubility of the sludge depends on the type of base stocks used to formulate the products and the temperature of the lube oil. The sludge generally settles in areas of the lubricant circuit, including the reservoir and other critical areas, interfering with the lubrication and cooling of bearings and moving parts. The presence of oxidation products leads also to the deposits of lacquer and varnish, possibly provoking sticking of valves.

6.4 Solid particles

The most deleterious contaminants found in turbine oils 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-oil systems is emphasized. In addition to these types of contaminants, there are further opportunities for solids to enter the lubricant oil system, e.g. improperly installed or maintained vents, mainly in dusty and hostile environments, or bad shop-floor practices when performing make-ups.

During operation, the equipment can accumulate a significant amount of particulate matter, entering during the topping-up operations through the bearing shaft seals. Other contaminants include the particles created by abrasive wear and those created by rust or corrosion.

Whatever the source, the presence of abrasive solids cannot be tolerated since they promote scoring and damages to the bearing and journals; moreover, they can cause malfunction and sticking of control mechanisms. In addition, solid particles can favour air entrainment, foaming, water emulsification and oxidation.

The particulate matters shall be removed by efficient means, like filtration on a cartridge filter with an appropriate pore size and filtration ratio, combined or not with centrifuges. In well maintained systems, the abrasive solids are removed before the occurrence of any damage.

6.5 Sludge

The term sludge is usually applied to the sediments deposited as the end result of the ageing process. Sludge can be formed in the oil by its oxidation at hot spots, e.g. in bearing housings, seals, gears and control pistons, and its build-up in a normally operated system is dependent upon the oxidation stability of the oil, the temperature of the oil, flow rates and operating duty cycles. Other types of sludge can also be formed in wet systems at the oil/water interface by the emulsification of certain additives by water, by the hydrolysis of additives, by bacterial and fungal growth and by corrosion products. In the case of growth of bacteria and fungi, the sludge can have a pungent odour.

The presence of sludge in oil has similar effects to those cited for solid particles in [6.4](#).

6.6 Antirust properties

Antirust protection provided by the lubricant is significant for turbine systems. Protection is required in areas of fluid flow, for surfaces covered by static drops of water, and for areas that are only occasionally splashed by the lubricant.

Modern steam- and gas-turbine oils, often used in combined cycle systems, are formulated to provide rust protection. Therefore, they contain rust-protection additives. The rust protection additive can be of various types, depending on the options taken by the formulator: acidic products (e.g. hemi-esters of succinic acid) or metallic soaps (e.g. neutral calcium soaps of benzene sulfonic acids).

In service, the rust-protection additive can be depleted by performing its normal function (e.g. plating out on steel surfaces), by removal with water, by removal with wear and corrosion debris, and by chemical reaction with contaminants. In exceptional circumstances where alkaline or polluted water enters the system, acidic rust inhibitors can be depleted much more rapidly.

6.7 Water separability

Water can get into steam-turbine systems as a result of oil-cooler leaks, normal tank breathing and gland seal steam. Water adversely affects turbine oils by reacting with metals to catalyse oxidation. It also depletes water-sensitive oil additives, such as some rust inhibitors, and can cause rusting and corrosion. In gas turbines, minor amounts of water are normally driven off during normal operation. In steam turbines, if the oil is in a good condition, water settles at the bottom of the tank and can be easily drained off as a routine operating procedure. Purification systems will also assist in removing water. If, during aging, the turbine oil has developed poor water-shedding characteristics, significant amounts of water will remain in the system and create problems.

In addition to chemical effects on the oil and additives, the lubricating properties of the oil can also be adversely affected. Adequate lubrication cannot be maintained by oil that contains a significant amount of free or dispersed water. Free water can cause hard, brittle deposits to form on bearings with a Babbitt layer.

It should be noted that the water separability characteristics of oil can be dramatically affected by contamination with small quantities of detergent-type oils. This is often the result of improper oil topping-up operations or by residual quantities of detergent oil in a tank that is subsequently used for a steam turbine.

The water separability characteristics can also be affected by contamination with the residue of cleansing products containing surface-active agents.

6.8 Foaming and air release characteristics

Foaming problems have generally three possible origins:

- mechanical design: usually the most difficult to overcome but can often be alleviated either by preventing suction line air injection, or by oil tank design changes, or both;
- mechanical assembly and operation: due to air or gas leaks resulting from mis-assembly, excessive seal clearances, operating wear or failure;
- anti-foam agent depletion and contamination: usually can be corrected with an antifoam agent.

Determination of the cause is necessary to come up with a solution to the problem.

Some foam on the top of the oil reservoir is normal and is a cause of concern only if it becomes excessive. In some cases, foam can block vents or interfere with the tank air extraction fans.

In turbine operation, air release properties are essential to avoid air entrainment in the circuit with effects of cavitation in the bearings and decrease of the rigidity of the oil film. Care should be taken to use the correct anti-foam agent at the right concentration. Excess anti-foam agent can promote foam and impair the air-release properties. Anti-foam agents, to be efficient, should be correctly dispersed in the oil; the anti-foam agent is not completely soluble and excess anti-foam agent can be removed by the centrifuge. Addition of extra anti-foam agent to the oil in service should be done under the supervision of the oil supplier using the same anti-foam agent as in the original oil.

6.9 Total acid number

When turbine oil deteriorates because of oxidation, acidic by-products are formed. This will increase the acidity of the oil as measured by titration. Consequently, an increasing total acid number is indicative of oil oxidation and can be used as a monitor for this. A high total acid-number value can also be of concern, as it can lead to a corrosive attack on bearing materials and other bare metal surfaces. It should be noted that a higher total acid number can also be the result of an improper make-up.

6.10 Flash point

The turbine oils viscosity grades currently used (see [6.2](#)) have normally high flash points. Any decrease of this flash point is the sign of release of light products by cracking or the pollution by lighter products (e.g. solvents or fuel).

7 Recommended tests and interpretation

7.1 Appearance and odour

The appearance of the oil is examined in transmitted light (e.g. bottom lighting), using a sample of approximately 10 cm thickness at room temperature.

The appearance of in-service oil is significant for detecting cloudiness or sediments that can indicate the presence of free water, insoluble sludge, carbon, fibres, dirt, etc.

An unusual smell, for example pungent, burnt, rotten eggs or solvents, indicates a change in the oil, possibly as a result of degradation, high temperature, bacterial growth or contamination, respectively.

7.2 Colour

The test method described in ISO 2049 shall be used to determine the colour.

The colour of lubricating oil is determined in transmitted light and is expressed by a numerical value based on a comparison with a series of standardized colours. This is not a critical property, but it is quite useful for comparative evaluation. New turbine oils are normally light in colour; a slow darkening is normal over years of service. This darkening is characteristic of the presence of oxidation by-products in the oil. A rapid darkening can be an indication of oil degradation or contamination requiring investigation. Colour darkening alone is not itself a cause for alarm, unless supported by other evidence of degradation.

7.3 Total acid number

To determine total acid number, the test method described in ISO 6618 (i.e. colour indicator titration) or the test method described in ISO 6619 (i.e. potentiometric method) shall be used. ISO 6618 requires less equipment to perform the determination.

Total acid-number changes give an indication of the lubricant condition. The total acid number slightly decreases during the first hours of service and then increases. The increase of the total acid number indicates the presence of acidic oxidation products or, a less likely case of contamination with acidic substances. The values are often very low and accurate determination is important. It should be kept in mind that the total acid number does not strictly measure oxidation stability reserve.

Instead of the acid number, it is possible to use Fourier transform infrared (FTIR) spectroscopy to evaluate the degree of oxidation of the oil. ASTM D7214^[4] enables evaluation of the peak area increase (PAI) by recording the infrared spectrum of the new oil and of the used oil in the range of 1 650 cm⁻¹ to 1 820 cm⁻¹ and by comparing the two spectra. Nevertheless, ISO 6618 or ISO 6619 shall be used.

7.4 Sludge and deposits

As the oxidation stability decreases, oil will eventually reach a stage when small volumes of oil are oxidized to the sludging stage in areas of the system where conditions are severe. This sludging can occur without any increase in acid value.

The accumulation of sludge or deposits in any part of the turbine system is a cause of concern. During outages, inspection should be made of all accessible parts of the system, in particular the reservoir, the turning gear, etc. Varnishing is usually an indication that the oil has been in service too long. If significant amounts of sludge, arising from oil oxidation, are found in the circuit, action should be taken to clean out the system and replace the oil charge. If the deposits consist essentially of contaminant material, such as fly ash or other debris, appropriate action, e.g. filtration or centrifuging, is necessary to remedy the cause.

Measurement of the amount of sludge in turbine oils shall be performed in accordance with the membrane filtration method described in ISO 4405 or in accordance with the centrifuging method described in ASTM D2273. Ultracentrifugation has been also suggested to detect very fine pollution.

7.5 Particle counting

The methods used for particle counting shall be:

- ISO 4407, for microscope counting;
- ISO 11500, for automatic counting.

The calibration of the automatic particles counters is performed using ISO 11171 with ultra-fine test dust (UFTD).

To report the contamination, the ISO 4406 contamination code shall be used. The NAS 1638^[6] code or the SAE AS4059^[15] code may also be used.

Fluid samples shall be taken from the circuit at sampling valves in accordance with ISO 4021 in bottles specially cleaned in accordance with ISO 3722. This will ensure that no foreign material is introduced that would interfere and distort the result. It should be emphasized that new oil systems and operating systems should be properly cleaned and flushed after maintenance on the oil system. In certain cases, the use of extra oil filtration equipment on a temporary basis can be an advantage. If the concentration of particles increases suddenly, investigate immediately to determine the source and check the functioning of the purification equipment. In the case of corrosion products, check the rust-corrosion properties of the oil.

The presence of moisture as very finely dispersed particles, the presence of air bubbles, or the antifoam additive can be at the origin of high counts in the automatic method specified in ISO 11500. In case of doubt, the microscope counting as described in ISO 4407 or the test method described in ASTM D7596 shall be used.

It is important that the filtration level is adapted to the required cleanliness level. Generally, a filter with $\beta_{10(c)} \geq 100$ is recommended. The target is to reach the recommended cleanliness level established by the turbine manufacturer. A level of —/14/11 to —/16/13 as specified in ISO 4406 is generally considered as acceptable.

The analysis of the particles by any suitable mean [e.g. inductively coupled plasma (ICP), ferrography] can be very useful to determine the origin of the contamination.

7.6 Wear metals

Metals content shall be determined in accordance with the test method specified in ASTM D5185 [i.e. inductively coupled plasma atomic emission spectrometry (ICP-AES)] or in accordance with the test method specified in ASTM D6595 [rotary disk electrode atomic emission spectrometry (RDE-AES)]. If the particles are larger than 3 µm for ICP-AES or larger than 8 µm for RDE-AES, this can result in loss in accuracy.

Journal bearings of turbines are operating in hydrodynamic conditions, which is a “no-wear” lubrication regime. In lubrication circuits of turbines, high-pressure hydraulic pumps are provided to lift the rotor of the turbines, while it is being rotated. Multiplying or reducing gears can also be lubricated by the turbine oil. Wear metals can originate from these hydraulic pumps or from these gears. This analysis is limited to dissolved metals and to particles with a size below 8 µm.

The presence of wear metals is neither normal nor desirable. Large amounts of metal contaminants indicate serious machine problems. The analysis of the shape of particles is important to identify the type of wear: adhesive wear or abrasive wear. Adhesive wear (i.e. scuffing) reveals a lubrication problem (i.e. the lubricant is not adapted to the operating conditions). Abrasive wear is generally associated with the presence of aluminium and silicon from the surrounding environment, and is the consequence of insufficient sealing of the oil circuit. See [Table 1](#) for a list of sources of potential inorganic elemental contaminants in oil.

Table 1 — Sources of potential inorganic elemental contaminants in oil

Element	Wear metal	Additive	Contaminant	Primary sources	Secondary sources
Al	x		x	Pistons, journal bearings, blowers, turbocharger vanes, torque converters, pumps vanes	Dirt, alloy with copper, in rolling element bearings cages, housings and cases
Sb	x	x	x	Journal bearings	Grease, anti-scuff additive
Cd	x			Journal bearings	Plating
Ca		x ^a	x	Additive	Water, grease
Cr	x			Compression rings, chrome cylinders	Alloyed with iron found in rolling element bearings, shafts found in hard steels
Cu	x	x		Bearings, cages, bushings, thrusts, valve guides, oils coolers, bearing cages, pumps	Automotive lubricant additives
Fe	x		x	Cylinders, shafts, gears, rolling elements bearings, housings, cases	Rust, fretting corrosion
Pb	x		x	Journal bearings, main bearings, platings, pumps	Paint, solder, seals
Mn	x			Shafts, valves, blowers	Few
Mo	x			Additive	Compression rings
Ni	x			Alloyed with iron for hard steel shafts, rolling elements bearings	Few
P	x	x		Additive	Surface finish for gears
Si	x	x	x	Sand, dirt, dust, antifoam additives	Alloyed with iron (cast iron)
Ag	x			Flashing	Solder
Sn	x			Journal bearings, alloyed with copper in rolling element bearing cages, flashing	Solder
Ti	x			Turbine blades	Paint, esterification catalyst in ester-based oils
V	x			Turbine blades	Valves
Zn		x ^a	x	Additive	Galvanized steel, platings, grease

Key
x indicates whether the element can be the result of wear on metal parts, additives, contaminants or a combination of these sources
^a While they can be present from additives, many specifications preclude the use of inorganic elements including Calcium or Zinc.

7.7 Kinematic viscosity

To measure kinematic viscosity, the test method in ISO 3104 shall be used. ASTM D7279^[Z] (i.e. determination using the automated Houillon viscometer) and ISO 23581 (i.e. determination using the Stabinger viscometer) may be used as alternative methods. When determining the viscosity with the Stabinger viscometer, to avoid the interference with magnetic wear particles, suppliers propose devices to trap these particles.

Viscosity values that are well outside the specifications can cause operational problems.

However, the main purpose for checking the viscosity of in-service turbine oils is to determine if the correct oil is being used and added as make-up, and for detecting other liquid contamination.

7.8 Remaining oxidation stability

To determine the remaining oxidation stability, the rotary pressure vessel oxidation test (RPVOT) specified in ASTM D2272 shall be used.

One of the most important properties of turbine oil is its oxidation stability. Traditionally, oxidation stability is evaluated using the test described in ISO 4263-1, with the method in ASTM D2272 being used as an ancillary method for following changes of oil condition in service. The remaining oxidation stability is expressed as a percentage of the oil's initial RPVOT value.

The possibility also exists to determine the remaining quantity of antioxidants present in the oil by linear sweep voltammetry. ASTM D6971^[10] and ASTM D6810^[11] allow the phenolic-type and amine-type antioxidants in zinc free turbine oils to be checked. ASTM D7590^[12] permits the measurement of the remaining primary antioxidant content in in-service industrial lubricants.

The determination of the oxidation induction time (OIT) by pressure differential scanning calorimetry (PDSC) as described in ASTM D6186^[13] is also a useful tool. The comparison of the OIT of the new oil and of the oil in service permits to evaluate, like RPVOT, the remaining oxidation stability.

7.9 Membrane patch colorimetry (MPC)

For membrane patch colorimetry, the method in ASTM D7843 shall be used. Deposits left on a fine pore size (0,45 µm) nitro-cellulose membrane after filtration of 50 ml of product diluted in 50 ml of petroleum ether are analysed in terms of colour and intensity using a spectrophotometer. The measurements are done against a control patch (unused oil) and the spectrophotometer calculates the colour difference, ΔE value. The ΔE value and the corresponding propensity for the formation of lubricant varnish deposits are then assessed according to an MPC scale. The higher the MPC value, the higher the amount of varnish deposits and precursors and the greater the propensity of the lubricant to form harmful deposits.

$\Delta E < 15$ indicates low varnish potential; $15 \leq \Delta E < 30$ indicates possible varnishing; $31 \leq \Delta E < 40$ indicates probable varnishing. $\Delta E > 41$ indicates fluid degradation leading to varnish. This is a critical value. The warning limit is $31 \leq \Delta E < 40$. It is recommended to maintain ΔE in service below 15.

Varnish precursors can be eliminated by appropriate filtration (see 5.6).

7.10 Water content

To determine water content, either the test method described in ISO 6296 or in ISO 12937 shall be used. However, some additives present in turbine oils can interfere with the Karl Fischer reagent, giving rise to erroneous results. In case of doubt or dispute, ISO 20764 shall be used to prepare the sample before test.

Water content is an important parameter. The presence of high quantities of water in turbine oil promotes deterioration by reacting with the additives and impairs the foaming and the air-release properties. Also, the presence of excessive water can indicate a malfunction of the purification equipment or of the turbine system. The cause of the presence of excessive water should be determined and corrected as soon as possible.

7.11 Rust prevention characteristics

To determine the rust prevention characteristics, the test method described in ISO 7120, procedure A, shall be used.

If the rust on the test probe is indicated as being “heavy” or “moderate” when tested with distilled water according to ISO 7120, procedure A, and if the oil sample is taken early in the life of the charge, the conditions in the system are very severe, i.e. the system is very wet or dirty, or is incorrectly maintained (i.e. water flushing from the bottom of the tank, neglected or bad operation of the purifier or centrifuge). The cause should be investigated immediately and corrected, and then the oil rechecked. The oil supplier should be consulted regarding possible re-inhibition.

After some years of service, a rating “moderate” in the rust test can indicate normal inhibitor depletion. The oil supplier should then be consulted regarding possible re-inhibition.

7.12 Water separability

To determine water separability, the test method described in ISO 6614 shall be used.

Water separability (or demulsibility) is certainly, with oxidation stability, among the most important property of steam turbine oil.

Many factors can cause a steam turbine oil to lose this property:

- pollution with a detergent, e.g. cross contamination by an engine oil, insufficient rinsing after use of alkaline agents for cleaning the oil system;
- high oxidation, resulting in the formation of polar compounds that have surface active properties;
- demulsifying agent wash-out losses: the water-separation properties of new turbine oil should be normally obtained without the help of a demulsifying agent, however, in some instances, the oil supplier has a valid reason to use a minute amount of demulsifier to meet a demulsibility target; the depletion of the demulsifier after repeated water contamination gives rise to a loss of the demulsibility.

In case of loss of water separability, addition of a demulsifying agent can be considered, but under the control of the oil supplier. In most instances however, it is recommended to change the oil.

7.13 Foaming characteristics

To determine foaming characteristics, the test method described in ISO 6247 shall be used. It is recommended to perform only the first sequence at 24 °C. It is suggested to check not only how the upper foam collapses, but also the time for the bulk of the fluid to become clear.

This test indicates the tendency of turbine oil to generate stable foam.

The presence of a small quantity of evanescent foam at the surface of the oil in the oil tank is generally not a problem. The foam becomes a problem when it is stable and when it is generated at a sufficiently high level to provoke an overflow. If foam reaches the inlet of the pump, air will be introduced in the system, resulting in lubrication problems.

The foaming properties of oil are affected by the degree of oxidation, the presence of water and of particles. Often, foaming problems can be solved applying fine filtration, removing water either by centrifuging or filtration using dehydrating filters, or both.

In case of foaming, the addition of extra anti-foam agent in the circuit can be envisaged, but this operation should not be performed except under the supervision of the oil supplier. In this case, it shall be verified that the treatment does not affect the air-release properties. If a treatment is envisaged, its efficacy shall be prior checked at laboratory scale on a sample taken from the system: the treat rate shall be adjusted so it is sufficient to overcome the foaming problem, while not impairing the air release properties. The target level for the treat rate is one that allows a foaming tendency in the first sequence below 300 ml of foam and does not allow stability. The antifoaming agent shall not be introduced pure in the oil, but added under the form of a mother solution, generally in a tertiary solvent, the nature of which depends on the antifoaming agent.

7.14 Air-release value

To determine air release value, the test method described in ISO 9120 shall be used.

This test indicates the ability of oil to block the entry of air into the oil circuit. This is a very sensitive property of a turbine oil, mainly affected by the quality of the base stock used, by the pollution or contamination and by the oxidation level. In contrast to the foaming or the water-separation properties, there is no additive to combat bad air-release properties.

High air-release values can induce cavitation in the bearings and in the pumps, leading to a “spongy” response of the hydraulic circuits.

When an air-release value becomes high, the oil shall be changed.

Results should be treated with caution because the precision of the test is questionable. The repeatability, r , and the reproducibility, R , as described in ISO 9120, are given in [Formulae \(1\)](#) and [\(2\)](#):

$$r = 0,5 \cdot X^{0,5} \quad (1)$$

$$R = 1,3 \cdot X^{0,5} \quad (2)$$

where X is the average of the values being compared, in minutes (min).

For an average value of 6 min, the reproducibility is 3 min.

The instructions given in ISO 9120 with respect to the chemical cleanliness of the glassware shall be strictly followed, to avoid any interference with the results.

7.15 Flash point

For the determination of flash point, either the test method described in ISO 2592 or in ISO 2719 shall be used.

8 Sampling

8.1 General

When taking lubricant samples from equipment in service, proper sampling techniques should be followed. See [8.2](#) to [8.5](#) for guidelines and requirements for proper sampling techniques. For particle counting, cleaning of the sample containers shall be carried out in accordance with ISO 3722, and sampling practice in accordance with ISO 4021.

8.2 Sampling point

For a sample to be representative, it shall be obtained from a suitable point.

The recommended sampling method for in-service oil from an operating unit is sampling from a line. The line should contain oil that is free-flowing and that is not deadheaded. For instance, the line in the bearing header, the active filter and active heat exchanger are free-flowing; the lines to the gauge cabinet are deadheaded. The oil standing in the sample line and sample line valve shall be drawn off and discarded. The sample should be taken without further adjustment of the valve.

An alternative sampling method is dipping from the tank. If the system is not operating, the oil should be thoroughly circulated before a sample is taken. If this is not possible, then samples from different depths are required.

For trouble-shooting purposes, it is desirable to obtain samples at different locations on the system so as to trace sources of contamination or to determine the effectiveness of the purifiers, etc.

8.3 Sampling line

When using a sampling line, ensure that the line has been thoroughly flushed before taking a sample. The amount of flushing oil required will depend on the sampling line dimensions, length and diameter.

Test results can differ, depending on the location of the sampling point in the lubricating oil circuit. For the follow-up of an oil charge, always compare results of samples taken at the same sampling point.

8.4 Containers

Samples should be taken in a suitable container, i.e. the container should be:

- a) clean: if in doubt about its cleanliness, use another container; if it is not possible, flush it out with the fluid to be sampled;
- b) resistant to the material to be sampled: the container's resistance can be verified, if time permits, by allowing the sample to stand in the container and observe the effects; aluminium foil makes a good, resistant cap liner;
- c) appropriate for whatever handling is required: containers with leaking tops and glass containers improperly protected are not suitable for shipment;
- d) appropriate for the analysis required: an extensive analysis of the sample, if it is required, cannot be done on the contents of a container that is too small.

For visual inspection, always use a clean glass container.

Where possible, the container opening should be covered with foil prior to screwing on the cap. This is to prevent the ingress of contaminants from the cap.

Some lubricants suppliers and commercial laboratories provide sample containers which meet these requirements. These should be used whenever possible. If frequent samples are taken, an adequate supply of containers should be kept.

The user should always draw off a sample of sufficient size to be able to keep a retain sample than can be used in case of analytical problems or for further investigations in case of problems.

8.5 Samples marking

A sample should always be properly marked. Marking should include at least the following information:

- a) customer name, if appropriate;
- b) site;
- c) location;
- d) turbine serial number;
- e) turbine service hours;
- f) oil references;
- g) oil service hours;
- h) oil volume in service;
- i) oil make-up quantity since the last analysis;
- j) sampling point;
- k) date of sample;
- l) type of purification system;
- m) oil appearance at sampling and after standing for 1 h;
- n) health and safety labels, where appropriate.

9 Examination of new oil

9.1 General

Experience has shown that there is a growing need to standardize procedures for the sampling, examination and acceptance of incoming supplies of turbine oils.

The personnel responsible for sampling and testing are expected to have the necessary experience and skills, and scrupulous attention should be paid to details at all times to avoid erroneous results, repeated samplings and unwarranted delivery rejections.

All incoming supplies of oil shall be adequately monitored to guard against incorrect or contaminated material being delivered.

Contamination of lubricating oils with particulates or detergent oils has been noted, especially when suppliers make deliveries in tanker vehicles not adequately cleaned for steam- or gas-turbine oils. The tanker contents can become contaminated by residual material left in the bottom valve manifold or by inadequate sealing of hose and pipe ends. The former is most likely to 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. Different products should not be transported in the same tanker.

9.2 Sampling of new oil deliveries

Sampling of oncoming supplies shall be in accordance with the sampling techniques described in ISO 3170.

Samples taken should be representative of the oil examined but obtained from the point(s) most indicative of the gross contamination by debris and water, that is, just above the bottom of the drum or tanker compartment bottom.

Sampling consignments of oil in drums shall be performed in accordance with ISO 3170. Bottom samples shall be collected by either a tube or thief sampler. These samplers permit the collection of settlings on the bottom of the container without introducing false contamination by scraping the container liner wall. In cases where the product is suspected of being non-uniform, sample a larger number of drums. Where contamination is suspected, there is no alternative to sampling every drum.

For bulk consignments, the samples should be taken either from the bottom of the tanker compartment as above, or when the oil is first being discharged. Each tanker compartment should be sampled. If these samples are clear of debris or water, then the samples can be combined for subsequent laboratory analysis of the consignment. In addition to sampling individual tanker compartment, further sample(s) should be taken 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.

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.

9.3 Examination of new oil deliveries

All samples should be immediately examined for appearance.

With drums, tests should be completed on the combined sample before the oil is used in service. Individual drum samples should be retained until the combined sample is passed as being satisfactory.

With tanker deliveries, the decision regarding additional tests should not be made before the tanker is discharged or the oil put in service, based on an assessment of the risk involved by the acceptance of an off-specifications product, i.e. whether or not the charge can be readily recovered and corrected before passing

into service if the subsequent tests indicate that this is required. This oil correction is possible if there is a separate make-up tank or a new oil tank, the size of which should be sufficient to hold at least one tanker delivery.

9.4 Testing schedules

9.4.1 Minimum requirements

The minimum requirements for an acceptance test at the time of delivery are given in [Table 2](#) for steam- and gas-turbines. The data given in [Table 2](#) also applies for single-shaft, combined cycle turbines. Sampling should be made from transport or drums, or from a storage tank.

Table 2 — Minimum sampling inspections for new steam- and gas-turbine oils

Test	Notes
Viscosity (see 7.7)	Viscosity should comply with the limits specified in ISO 3448 for the viscosity grade agreed between the buyer and the seller
Acid number (see 7.3)	Should be consistent with user purchase specifications, new oil reference, or the manufacturer's requirements, or a combination thereof
Appearance (see 7.1)	Bright and clear
Water content (see 7.10)	No free water
Colour (see 7.2)	Should be consistent with user purchase specifications, new oil reference, or the manufacturer's requirements, or a combination thereof
Rust test (see 7.11)	Should pass ISO 7120, procedure A, for land-based turbines and ISO 7120, procedure B, for marine turbines
Cleanliness (see 7.5)	Definition of suitable cleanliness levels depends on turbine builder and user requirements. Filtration or centrifugation, or both, of oil into the turbine and during service is recommended.
RPVOT (see 7.8)	Should be consistent with user purchase specifications, new oil reference, or the manufacturer's requirements or a combination thereof
Key RPVOT rotating pressure vessel oxidation test	

9.4.2 Installation of a new oil charge

The minimum requirements for an acceptance test at installing a new oil charge are given in [Table 3](#) for steam- and gas-turbines. Follow the recommended flushing procedures prior to installing a new oil charge, whether it is an initial fill or an oil replacement. The sampling shall be done minimally after 24 h of circulation. It is recommended to retain 4 l for further reference. The data given in [Table 3](#) also applies for single-shaft, combined cycle turbines.

Table 3 — Minimum sampling inspections for a new oil charge for steam- and gas-turbines

Test	Notes
Viscosity (see 7.7)	Should be consistent with user purchase specifications and new oil reference
Acid number (see 7.3)	Should be consistent with user purchase specifications and new oil reference
Appearance (see 7.1)	Bright and clear
Water content (see 7.10)	No free water
Colour (see 7.2)	Should be consistent with user purchase specifications and new oil reference
Key RPVOT rotating pressure vessel oxidation test	

Table 3 (continued)

Test	Notes
Cleanliness (see 7.5)	Should be consistent with user purchase specifications and new oil reference. Definition of suitable cleanliness levels depends on turbine builder and user requirements. Filtration or centrifugation, or both, of oil into the turbine and during service is required.
RPVOT (see 7.8)	Should be consistent with user purchase specifications and new oil reference. Important as a baseline to determine the turbine system severity.
Air release (see 7.14)	Comparison with new oil air release characteristics on delivery can indicate the presence of contaminants.
Key RPVOT rotating pressure vessel oxidation test	

10 Examination of oils in service

10.1 Testing procedures

10.1.1 General

Two types of test can be distinguished:

- field screening tests, which are completed by the unit operator or equivalent, and are performed at the location of the equipment;
- laboratory tests, which are those normally performed in a qualified laboratory, for example by the oil supplier or at the central facility of the user.

10.1.2 Field screening tests

The field screening tests mainly consist of a visual inspection of the sample collected in a clean glass bottle. Careful visual inspection can be advantageously used to extend the period between the more detailed routine laboratory tests. Table 4 gives the parameters which should be checked visually and the significance of the observations carried out. It is good practice to carry out this visual inspection, preferably on a daily basis, but at least on a weekly basis.

The principle of these visual inspections is to check the appearance of the sample immediately after sampling and after standing for 1 h.

Table 4 — Visual inspection of the samples

Appearance of the oil		Probable cause	Recommended actions
Immediately after sampling	After standing 1 h		
Clear	Clear	—	—
Foam at the surface	Foam collapsed	Air entry in the circuit	Seek origin.
	Persistent foam	High foaming tendency	Control foaming.
Sample cloudy and becoming clear from the bottom	Clear	Aeration	Seek origin.
	Persistent cloudiness	High air entrainment	Seek origin and laboratory control.

Table 4 (continued)

Appearance of the oil		Probable cause	Recommended actions
Immediately after sampling	After standing 1 h		
Sample cloudy, becoming clear from the top	Clear, or slightly opaque, decanted water	Unstable water emulsion	Seek origin of water ingress.
	Milky	Stable emulsion with water	Seek origin and laboratory control.
Dirty	Presence of decanted solid particles	Contamination, filtration problem	Seek origin and control of the circuit.
Strong colour, rapid and unusual darkening		Contamination or excessive degradation	Seek origin and control of the oxidation.
Unusual odour	Acre	Oil cracking	Seek origin, control total acid number, flash or fire points.
	Rotten egg	Bacteria growing in an anaerobic medium	Check for the presence of water. Withdraw the decanted water and consider a biocide treat.

10.1.3 Laboratory tests

The laboratory tests should include the determination of the characteristics given in [Table 5](#). Some of these tests can be performed in the user’s laboratory; other tests, requiring sophisticated equipment, are carried out either in the laboratory of the turbine oil supplier or in any other laboratory having the expertise for analysing used oils.

The list of the laboratory tests is not exhaustive; it includes the minimum tests to perform on a regular basis to have a good picture of the status of the oil in service. Turbines manufacturers or users can have additional requirements or can propose other warning limits for the characteristics.

Additional requirements concern, for example:

- a) a determination of the sediments by filtration according to ISO 4405, with warning limits ranging from 20 mg/l to 50 mg/l;
- b) the determination of the wear metals by ICP in accordance with ASTM D5185 out of warning limits of 20 mg/kg;
- c) the record of an infrared spectrum to eventually follow the eventual depletion of the antioxidant system and the oxidation of the oil.

The most complicated and delicate determination among all the tests mentioned is the air-release value: the precision of the test is questionable. Users and turbine manufacturers generally indicate much lower air-release maximum values than those given in [Table 5](#), e.g. values of 6 min maximum for an ISO VG 32 grade and 8 min maximum for an ISO VG 46 grade.

NOTE ISO VG 32 grade and ISO VG 46 grade are specified in ISO 3448.

Table 5 — Laboratory tests for the inspection of (steam- and gas-) turbine oils in service

Property	Test method	Unit	Warning limit	Type	Oil life (running hours)	Interpretation	Recommended actions
Acid number increase over new oil	ISO 6618	mg KOH/g	0,1 to 0,2	S	Up to 20 000 h	This represents above-normal deteriora- tion. Possible causes are: a) system very severe; b) antioxidant depleted; c) wrong oil used; d) oil contaminated.	Investigate cause. Increase frequency of testing; com- pare with RPVOT data. Con- sult oil supplier for possible re-inhibition.
				G	Up to 3 000 h		
			0,3 to 0,4	S, G	At any time during life of the oil charge	Oil at or approaching end of service life: Possible causes can be: a) wrong oil used; b) oil contaminated.	Look for sign of increased sediments on filters and centrifuge. Check RPVOT. If RPVOT is less than 25 % of original, review status with oil supplier and consider oil change. Increase test fre- quency if left in system.
MPC varnish test	ASTM D7843		15 ≤ ΔE < 30 increased amount of varnish requires attention 31 ≤ ΔE < 40 cautionary limit re- quiring corrective actions	S, G	At any time during life of the oil charge	Source of insoluble col- our bodies may be soft contaminants due to oil degradation.	Locate and eliminate any source of contaminant. Clean system using appropriate filtration techniques.
RPVOT	ASTM D2272		< 50 % of original	S	Up to 20 000 h	Above normal degrada- tion.	Investigate cause; increase frequency of testing.
				G	Up to 3 000 h		
			< 25 % of original	S, G	At any time	Together with high acid number, indicates oil at or approaching end of service life.	Resample and retest; if same, consider oil change.
Key G gas RPVOT rotating pressure vessel oxidation test S steam							

Table 5 (continued)

Property	Test method	Unit	Warning limit	Type	Oil life (running hours)	Interpretation	Recommended actions
Water content	ISO 6296 or ISO 12937	%	> 0,1	S	At any time	Oil contaminated; poten- tial water leak.	Check water separability. In- vestigate and remedy cause. Clean system by appropriate method. If still unsatisfac- tory, consider oil change or consult oil supplier.
Cleanliness			Exceeds accepted limits	S, G	At any time	Source of particulates may be: a) oil make-up; b) dust or ash entering the system; c) wear condition in the system.	Locate and eliminate source of particulates. Clean system oil by filtration or centrifug- ing, or both.
Wear metals	ASTM D5185	mg/kg	Greater than 10 to 20	S, G	At any time	Indicates the presence of either wear conditions or contamination, or both.	Perform wear debris analy- sis (shape, type, size, etc.).
Rust test	ISO 7120, pro- cedure A		Light fail	S	Up to 20 000 h	a) The system is dirty, wet, or both. b) The system is not maintained properly (e.g. water drainage neglected, centrifuge not operating).	Investigate cause and make necessary maintenance and operating changes. Check rust test. Consult oil supplier regarding re-inhibi- tion if test result unchanged.
				S, G	After 20 000 h dur- ing life of oil charge	Normal additive depletion in wet system.	Consult oil supplier regard- ing re-inhibition.
Appearance	visual	rating	Hazy	S, G	At any time	Oil contains water or solids, or both.	Investigate cause and rem- edy. Filter or centrifuge oil, or both.
Colour	ISO 2049	rating	Unusual and rapid darkening	S, G	At any time	This is indicative of: a) contamination; b) excessive degradation.	Determine cause and rectify.
Key G gas RPVOT rotating pressure vessel oxidation test S steam							

Table 5 (continued)

Property	Test method	Unit	Warning limit	Type	Oil life (running hours)	Interpretation	Recommended actions
Viscosity	ISO 3104	mm ² /s	5 % change from original	S, G	At any time	a) oil is contaminated; b) oil is severely degraded; or c) higher or lower viscosity oil is added.	Determine cause. If viscosity is low, determine flash point. Change oil if necessary.
Flash point	ISO 2592 or ISO 2719	°C	Drop of 15 °C or more, compared to new oil	S, G	At any time	Probably contaminated.	Determine cause. Check other quality parameters. Consider oil change.
Foam test Sequence I at 24 °C	ISO 6247	ml	Exceeds the limits: Tendency – 450 Stability – 10	S, G	At any time	Possibly contamination or anti-foam depletion. In new turbines, residual rust preventives absorbed by oil may cause problem.	Rectify cause. Check with oil supplier regarding re-inhibition. NOTE Plant problem is often of mechanical origin.
Air release	ISO 9120	min	When required 8 for VG 32 10 for VG 46 12 for VG 68	S, G	At any time	Pollution, degradation.	Watch the system as required. Rectify cause. Compare with other results.
Water separability	ISO 6614	min	> 60 for 3 ml of emulsion	S	At any time	Pollution, contamination, degradation.	Compare with other test data indicating degree of degradation. No action required if water content acceptable.
Key G gas RPVOT rotating pressure vessel oxidation test S steam							

10.2 Frequency of the testing

As already indicated, the field screening test (visual inspection) shall be performed daily or, at least, once a week. The frequency of the laboratory tests is given in [Table 6](#) for steam turbines and in [Table 7](#) for gas turbines. The frequency differs according to the time of operation of the oil. Testing is more frequent when considering the first 12 months of operation.

Table 6 — Testing frequency for steam-turbine oil

Test ^a	Frequency ^b	
	New turbine ^c (first 12 months of operation)	Normal operation
Viscosity (see 7.7)	Every 1 month to 3 months	Every 3 months to 6 months
Acid number (see 7.3)	Monthly	Every 1 month to 3 months
Appearance (see 7.1)	Daily ^d	Daily ^d
Water content (see 7.10)	Monthly ^d	Every 1 month to 3 months ^d
Colour (see 7.2)	Weekly	Weekly
Rust test (see 7.11)	Every 6 months	Every year
Cleanliness (see 7.5)	Every 1 month to 3 months	Every 1 month to 3 months
RPVOT (see 7.8)	Every 2 months to 3 months	Every 6 months to 12 months
Key RPVOT rotating pressure vessel oxidation test ^a If contamination is suspected, additional tests, such as flash point, foam, and water separability can be useful to determine the degree and the effect of contaminants present. An outside laboratory or oil supplier can also assist in a more in-depth analysis. ^b Frequency is based on continuous operation or total accumulated service time. ^c This schedule should be used only as guidance. Increased frequency is required for a severe turbine or for oils approaching the end of their service. Most turbines should be covered by this schedule. ^d If product is hazy or contains water in suspension, check water content.		

Table 7 — Testing frequency for gas-turbine oil

Test	Frequency hours of actual service (h)	
	New turbine ^a (first 6 months of operation)	Normal operation
Viscosity (see 7.7)	500	500
Acid number (see 7.3)	500	500 to 1 000
Appearance (see 7.1)	100	100
Colour (see 7.2)	200	200
Cleanliness (see 7.5)	500	1 000
RPVOT (see 7.8)	500 to 1 000	1 500 to 2 000
Key RPVOT rotating pressure vessel oxidation test ^a This schedule should be used only as a guide. Frequency should be varied depending on turbine severity and oil condition.		

11 Prolonging an oil in service

11.1 General

The objective of many power generating plants is to avoid changing an oil charge completely, often due to the volumes involved, the cost of the disposal and the cost of a new charge.

Charges can be refortified as follows:

- with corrosion inhibitors when the corrosion test specified in ISO 7120 does not give satisfactory results;
- with oxidation inhibitors when the residual life reaches 25 % of the initial life;
- with foam inhibitors when the foaming test specified in ISO 6247 gives either high foaming tendency in the first sequence or foam stability, or both.

Generally, when water shedding properties are not good, it is possible to treat the charge with a demulsifying agent to re-establish some water separation. However, when air release time is high, there is no additive to improve air release properties.

The occurrence of water shedding and air release problems can be mostly attributed to polar species created by the oil oxidation (i.e. oxygenates); these species are generally oxidation precursors (i.e. peroxides, hydroperoxides, aldehydes and ketones undergoing the aldolization/crotonization reactions). If it is desirable to restore good water shedding and air release properties, these products shall be removed. Clay treatment is one of the possible operations; active clay has properties to fix these polar compounds.

Before envisaging any treatment of the oil charge in service, it is recommended to perform a complete oil analysis, including the test methods listed in [Table 8](#).

Table 8 — Analysis to perform before envisaging any treatment of the oil charge in service

Analysis	Unit	Test method
Acid number	mg KOH/g	ISO 6618 or ISO 6619
Demulsibility (time to reach 3 ml of emulsion)	min	ISO 6614
Air release value	min	ISO 9120
Foaming tendency, Sequence I at 24 °C	ml	ISO 6247
Foaming stability, Sequence I at 24 °C	ml	ISO 6247
Rust protection	rating	ISO 7120
RPVOT (rotating pressure vessel oxidation test)	min	ASTM D2272
Water content	mg/kg	ISO 6296 or ISO 12937
Sediments content	mg/l	ISO 4405 or ASTM D2273
Membrane patch colorimetry (MPC) varnish test		ASTM D7843

When planning to refortify an oil with an antioxidant, a rust inhibitor, an antifoam agent, or a demulsifier, this shall be performed under the supervision of the oil supplier and the turbine manufacturer. However, if most of the critical characteristics like foaming, air release, demulsibility and MPC are near or exceeding the condemning limits, meaning that the oil suffers high degradation, oil change should be performed.

11.2 Partial draining and refilling (bleed and feed)

To avoid changing the whole oil charge, it is possible to perform a partial draining, followed by a refilling with a new oil, possibly fortified with antioxidants. Taking this option requires laboratory testing to evaluate the quantity of oil to be drained off to recover the essential properties: oxidation stability, foaming and air release, and demulsibility after top-up.

This possibility should not be neglected. However, this approach is less efficient in the long term than a complete oil change with flushing, as oxidation or deposit precursors remain present in the oil.

11.3 Treatment with the oxidation inhibitor package

In the case where the residual life has reached 25 % of the initial life, and provided that demulsibility, air release and foaming are correct, it is possible to re-fortify the oil with the antioxidant. Preliminary laboratory checks shall be performed, using a sample drawn from the oil system of the turbine. The necessary amount of the antioxidant system shall be determined, checking the RPVOT life. The same antioxidant system as that used in the new oil shall be used. Once having recovered the initial RPVOT life, the sample treated at

laboratory scale shall be checked against demulsibility, foaming and air release. If the result of the check is acceptable, the treatment can be applied on the charge in service. The antioxidants shall be added under the form of a mother solution prepared by the addition of the necessary amount in a portion of the oil in service. Once the oil charge has been treated and recirculated until complete homogenization is achieved, draw a sample from the circulating system and check the RPVOT life. Ensure that foaming, air release and demulsibility are unchanged.

11.4 Treatment with the rust inhibitor

In the case where rust inhibition is the only characteristic raising problem, it is possible to refortify the charge. Rust inhibitors can be washed out from steam turbine oils in case of repeated leakages of water or steam condensates.

At laboratory scale, on a sample drawn from a system, add the necessary amount of rust inhibitor to recover a pass in the procedure A rust test specified in ISO 7120. Ensure that foaming, air release and demulsibility are unchanged. Apply on the oil charge in service, adding the additive pre-diluted in the oil. Once the oil charge has been treated and recirculated, achieving complete homogenization, draw a sample from the circulating system and check the rust protection properties. Ensure that foaming, air release and demulsibility are unchanged.

11.5 Treatment with antifoaming agent

The loss of the antifoaming properties can be attributed to many factors, including frequent centrifuging to withdraw water and particles, that eliminates the antifoaming agent. To be efficient, an antifoaming agent is not completely solubilized, but present under the form of a more or less fine dispersion. The size of the particles has an utmost importance with respect to the efficiency of the antifoaming agent. Preliminary tests at laboratory scale are required to check that the addition of antifoaming agent is effective and that the air release properties of the oil are not affected. The amount of antifoaming agent shall be adjusted accordingly. If the addition of extra antifoaming agent is proven to be efficient at laboratory scale, it can be envisaged to treat the charge. This shall be done under the supervision of the oil supplier, using the same antifoaming agent as in the initial charge. The additive shall be added under the form of a mother solution, prepared by dispersing the necessary amount of antifoaming agent into the oil in service.

Antifoaming properties can be lost when the oil is highly oxidized; high oxidation is also deleterious to water shedding and air release properties. If simultaneously foaming, air release and water shedding properties are affected, partial or complete draining of the oil charge should be envisaged. There is no additive treatment that can solve efficiently the problems. However, a treatment of the charge with attapulgite/fuller's earth treatment can be envisaged if facilities are available.

11.6 Clay treatment

When additive treatments prove inefficient at laboratory scale to improve or restore water shedding, air release and antifoaming properties, a clay treatment can be envisaged to save the charge. The clay/fuller's earth treatment can remove all polar products created by the oxidation reactions occurring during service.

This is a very heavy procedure which is rarely applied contrarily to the previous treatments.

11.7 Conclusion

It is possible to prolong a turbine oil charge, provided the oil characteristics are not near the condemning limits and provided that the ΔE of the MPC test is not too high (preferably below 25). "Bleed and feed" ([11.2](#)) is the recommended method. Treatment with oxidation inhibitor package, rust inhibitor, or antifoaming agent can be contemplated if it is desirable to avoid a "bleed and feed" operation. Additives losses can be compensated at any time provided that the essential turbine oil properties, i.e. demulsibility and air release are not too affected. Any attempt to extend the life of a turbine oil charge requires prior laboratory investigations. If the losses of demulsibility and air release properties are too high, the oil charge shall be changed.

In any case, all operations intended to extend the life of a turbine oil in service shall be performed under the supervision of the oil supplier and the turbine manufacturer.

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