Standard Practice for
In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment[1]

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INTRODUCTION

A more systematic approach to monitoring auxiliary power plant equipment can help to minimize the high cost of oil changes and unplanned shutdowns. These avoided costs must be balanced against the cost of sampling and laboratory testing.

This practice is designed to assist the user in planning and implementing a meaningful, cost-effective program of sampling and testing of oils in use. Also covered are some important aspects of interpretation of results and suggested action steps so as to maximize service life of the oil and equipment.

1. Scope

1.1 This practice covers the requirements for the effective monitoring of mineral oil and phosphate ester fluid lubricating oils in service auxiliary (non-turbine) equipment used for power generation. Auxiliary equipment covered includes gears, hydraulic systems, diesel engines, pumps, compressors, and electrohydraulic control (EHC) systems. It includes sampling and testing schedules and recommended action steps, as well as information on how oils degrade.

NOTE 1—Other types of synthetic lubricants are sometimes used but are not addressed in this practice because they represent only a small fraction of the fluids in use. Users of these fluids should consult the manufacturer to determine recommended monitoring practices.

1.2 This practice does not cover the monitoring of lubricating oil for steam and gas turbines. Rather, it is intended to complement Practice D 4378.

1.3 The values stated in SI units are to be regarded as the standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*

D 92 Test Method for Flash and Fire Points by Cleveland Open Cup[2]

D 95 Test Method for Water in Petroleum Products and Bituminous Materials by Distillation[2]

D 96 Test Method for Water and Sediment in Crude Oil by Centrifuge Method Field Procedure[2]

D 257 Test Methods for D-C Resistance or Conductance of Insulating Materials[3]

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)[2]

D 664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration[2]

D 665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water[2]

D 892 Test Method for Foaming Characteristics of Lubricating Oils[2]

D 893 Test Method for Insolubles in Used Lubricating Oils[2]

D 943 Test Method for Oxidation Characteristics of Inhibited Mineral Oils[2]

D 974 Test Method for Acid and Base Number by Color-Indicator Titration[2]

D 1169 Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids[4]

D 1298 Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[2]

D 1401 Test Method for Water Separability of Petroleum

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[2] *Annual Book of ASTM Standards*, Vol 05.01.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 10.03.

Oils and Synthetic Fluids[2]

D 1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)[2]

D 1533 Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration[4]

D 1744 Test Method for Water in Liquid Petroleum Products by Karl Fischer Reagent[2]

D 2272 Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel[2]

D 2273 Test Method for Particulate Contamination in Aviation Fuel by Line Sampling[2]

D 2422 Classification of Industrial Fluid Lubricants by Viscosity System[2]

D 2668 Test Method for 2,6-Ditertiary-Butyl Para-Cresol and 2,6 Ditertiary-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption[4]

D 2896 Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration[2]

D 2982 Test Method for Detecting Glycol-Base Antifreeze in Used Lubricating Oils[2]

D 3427 Test Method for Air Release Properties of Petroleum Oils[5]

D 3524 Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography[5]

D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[5]

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[5]

D 4378 Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines[5]

D 4739 Test Method for Base Number Determination by Potentiometric Titration[5]

D 5185 Test Method for the Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively-Coupled Plasma Atomic Emission Spectrometry (ICP-AES)[5]

E 1064 Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration[6]

3. Significance and Use

3.1 This practice is intended to assist users, particularly power plant operators, in maintaining effective control over their lubricating oils and lubrication monitoring program. This practice may be used to perform oil changes based on test results rather than on the basis of service time or calendar time. It is intended to save operating and maintenance expenses.

3.2 This practice is also intended to assist users in monitoring lubricating oils and guarding against excessive component wear, oil degradation, or contamination, thereby minimizing the potential of catastrophic machine problems that are more likely to occur in the absence of such a monitoring program.

3.3 This practice does not necessarily reference all of the current oil testing technologies and is not meant to preclude the use of alternative instrumentation or test methods which provide meaningful or trendable test data, or both. Some oil testing devices (typically used for screening oils which will be tested according to standard methods) provide trendable indicators which correlate to water, particulates, and other contaminants but do not directly measure these.

4. General Properties of Lubricating Oils

4.1 In general, lubricating oils are designed to reduce friction and wear, provide cooling, control deposits, and combat the effects of contamination. A base oil's lubricating properties are enhanced by selected additives. Different machines have different lubricant additive requirements, some of which are described in this section. A lubricating oil prevents contact between metal surfaces by the formation of a very thin protective film (that is, elastohydrodynamic lubrication).

4.2 *Gear (Circulating) Oils*—The primary requirement of gear oils is that they prevent wear and minimize other forms of damage such as pitting and scuffing by maintaining a lubricant film between the moving surfaces. Although gears are of many types including spur, helical, worm, bevel, and hypoid, they all function with some combination of rolling and sliding motion. The unit loadings of gear-tooth surfaces are relatively high compared with ordinary bearing surfaces. Where the gear loadings are relatively heavy, mineral oils containing extreme pressure (EP) or anti-wear additives may be used as the lubricant. For highly loaded spiral bevel, worm, or hypoid gears where sliding contact predominates over rolling contact between gear teeth, lubricating oils with special wear-reducing additives are used. Sulfur, boron, and phosphorous compounds can be used for this purpose. Anti-foaming additives are also important in gear lubricants.

4.3 *Hydraulic Oils*—A hydraulic fluid is required to transmit hydraulic pressure and energy, minimize friction and wear in pumps, valves and cylinders, and protect metal surfaces against corrosion. To obtain optimum efficiency of machine operation and control, the viscosity of the oil should be low enough to minimize frictional and pressure losses in piping. However, it also is necessary to have a sufficiently high viscosity to provide satisfactory wear protection and minimize leakage of the fluid. High-viscosity index fluids help to maintain a satisfactory viscosity over a wide temperature range. The anti-wear properties of high-quality hydraulic oils usually are improved by suitable additives. Since the clearances in pumps and valves tend to be critical, it is important to provide adequate filtration equipment (full flow or bypass, or both) to maintain a minimum particle content and thus minimize wear. The oil should have good oxidation stability to avoid the formation of insoluble gums or sludges; it should have good water separation properties, and, because air may be entrained in the system, the oil should have good air-release properties and resistance to foaming. Similarly, good rust protection properties will assist in keeping system metals in satisfactory condition.

4.4 *Diesel Engine Oils*—In addition to the typical role of lubricating oils which is to lubricate, clean, cool and seal, diesel engine oils are formulated to provide protection from acids and disperse soot particles that are created during the combustion process. Diesel engine oils are compounded with alkaline additives to neutralize the sulfuric acids that are

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[5] *Annual Book of ASTM Standards*, Vol 05.02.

[6] *Annual Book of ASTM Standards*, Vol 15.05.

produced when the diesel fuel is combusted. They are also compounded with dispersant/detergents to keep the engine clean and the by-products of combustion (fuel soot) suspended. The combination of wear regimes found in the diesel engine require the lubricants to have high levels of anti-wear additives to protect the engine from wear during the most severe condition. Multi-grade lubricants (high viscosity index) are often employed in diesel engine lubricants that are required to operate over a wide temperature range.

4.5 *Turbine-type (Pump) Oils*—Turbine oils provide satisfactory lubrication and cooling of bearings and gears (for example, in auxiliary turbines and gearboxes). They also can function as a governor hydraulic fluid. The oil must have a viscosity high enough to maintain a sufficiently thick film of oil on load-bearing surfaces, but low enough to minimize energy losses while providing adequate cooling. These oils are recommended where the degree of loading on bearings and gears is less than in gear oil applications. Turbine oils have excellent oxidation resistance and contain rust inhibitors; they are often referred to as R & O oils. Turbine oils can also contain additives to improve water separability and decrease foaming tendency.

4.6 *Compressor Oils*—In addition to possessing the correct viscosity for satisfactory bearing and cylinder lubrication, particularly for air compressors, very good oxidation resistance is required to avoid degradation of the lubricant in the presence of heated air. This is particularly important for mineral oils where discharge temperatures are high, since carbon and oxidized oil deposits may autoignite if exposed continuously to temperatures above 148°C (300°F). The fire potential that exists under these conditions make low volatility and high auto-ignition values equally or more important than high-flash or fire points. In compressor lubrication, condensed water is present frequently. For this reason, the oil must possess properties that ensure that the oil rather than water wets the metal surfaces. Also, to avoid the accumulation of water-in-oil emulsions in the after coolers, the water should separate out rather than form an emulsion.

4.7 *Electrohydraulic Control (EHC) Fluids*—Triaryl phosphate ester EHC fluids are inherently fire-resistant and maintain this property throughout their service life. The very low vapor pressure and chemical nature of these fluids result in high flash point, fire point, and autoignition temperature. EHC fluids should be continuously purified using bypass systems to maintain acid number, moisture, and particulates at low levels. Moisture can cause hydrolysis of EHC fluids which results in elevated acid number. Components constructed of copper and lead alloys should be avoided. These fluids are chemically different from mineral oils; consequently, the interpretation of test results will be significantly different. The fluid supplier should be consulted if there is a question about interpretation of analytical results.

5. Factors Affecting the Service Life of Oils

5.1 *New Oil Quality and Suitability for Intended Use*—Use of high-quality oils that meet recognized standards (such as manufacturer or military specifications) is the best assurance of potentially long service life.

5.1.1 Viscosity is the most important characteristic of an oil. An oil's load bearing and lubricating properties are related directly to its viscosity. The use of oil with incorrect viscosity can increase wear rates, heat build-up, and lube degradation. In extreme cases, the use of oils with incorrect viscosities can result in rapid catastrophic failures.

5.1.2 Oils that meet the equipment manufacturers' requirements should be used. For situations where the manufacturer simply offers a generic viscosity classification without specific performance criteria, the user should consult the equipment manufacturer, lubricant suppliers, and experts in the field of lubrication.

5.1.3 When fresh, unused lubricants are received, a representative sample of oil may be taken and tested (see Table 1) to ensure that general specifications are met. This test data should be compared to a reference baseline from the lubricant supplier and then used for future condition monitoring.

5.1.4 Manufacturer shelf life recommendations should be observed. Oils should be stored to preserve their original quality and prevent contamination. Stored oils may be tested to ensure and document their quality, cleanliness, and continued suitability for their intended use.

5.1.5 Make-up oils should normally be of the same type, quality, and manufacturer. Available formulations may change over a period of time. Lubricant incompatibility can arise from mixing differing base stocks and additive packages and should be avoided. When oils must be mixed, testing should be performed in an attempt to determine compatibility. Consideration should be given to consulting the lubricant supplier(s) and equipment manufacturer prior to mixing oils.

5.2 *Deterioration of Oils in Service*—Air (oxygen), elevated temperatures, metals, and water are present to some extent in oil systems. These factors promote oil degradation. Deterioration occurs by one or more of the following processes:

5.2.1 *Oxidation Degradation*—Chemical changes are brought about by oxygen in the atmosphere forming oxidation by-products which degrade the performance of the oil. These changes can adversely affect the oils viscosity and acidity.

5.2.2 *Thermal/Oxidation Degradation*—At elevated temperatures, hydrocarbons are subject to thermal cracking which forms unstable compounds. Performance additives in the oil may also degrade at high temperatures. The unstable compounds are easily oxidized and also tend to polymerize to form resins, waxes, and sludge. Thermal oxidation can occur at local hot spots within a system and as a result of high bulk oil temperatures.

5.2.3 *Loss of Additives*—Additives are used to protect the oil and enhance its performance abilities. When these additives are depleted with service, oil oxidation, foaming, excessive wear, or premature rusting may result.

5.2.4 *New Oil Make-up*—Addition of new oil is required in nearly every system to make up for losses due to leakage, filter changes, or other maintenance. The amount and frequency of added make-up oil sometimes plays a very significant part in determining the life of a system oil charge. Make-up can vary from less than 5 % per year to greater than 30 % in extreme cases. In equipment where the make-up is very low (below

TABLE 1 Guidelines For Sampling and Testing New Oils[A]

NOTE 1—Legend–R = Recommended; O = Optional.

NOTE 2—An infrared spectrum may be obtained for new oil to ensure that the oil is not contaminated and to provide a baseline for comparison to spectra of in-service oil.

Test	Common Methods	Gear/ Circulating Oils	Hydraulic Oils	Diesel Engine Oils	Turbine-Type Oils	Air Compressor Oils[B]	EHC (PO_4 Esters)	EHC (Min. Oils)
Appearance[C]	Visual	R	R		R	R	R	R
Viscosity, (40°C)	D 445	R	R	O[D]	R	R	R	R
Viscosity (100°C)	D 445			R				
Acid number	D 664 D 974	R	R		R	R	R	R
Water	D 1744[E] D 95	O[F]	O[F]	R[F]	O[F]	O[F]	R	O[F]
Oxidation inhibitor	D 2668				O			
	Voltammetry	O	O		O	O		O
Oxidation stability (RPVOT)	D 2272		O		O	O		
API gravity or density	D 1298 D 4052						O	
Flash point (COC)	D 92			O				
Water separability	D 1401		O		O			
Particle counts	Equipment Manufacturer's Method		R				O	O
Base number	D 974 D 2896 D 4739			R				
Electrical resistivity	D 257/D 1169						R	
Elemental Analysis	D 5185[G]	O	O	O	O	O	O	O

[A] Tests which are performed on in-service oils for trending purposes should also be performed on new oils for baseline information.

[B] Does not include refrigeration (chiller) oils.

[C] Appearance includes observations such as color, clarity, odor, and sediment.

[D] A diesel engine oil must be tested at 40 and 100°C if it is necessary to determine whether it is the proper multi-grade oil.

[E] Test Method D 1744 is not recommended for certain lube oils because of additive interferences. Results from Test Method D 1744 should be viewed as relative rather than absolute due to additive interferences and other reasons. Test Methods E 1064 and D 1533 may be used for certain lubricants.

[F] Recommended if oil is not clear and bright.

[G] Another spectrochemical method such as rotating disk electrode (RDE), atomic absorption (AA), or x-ray fluorescence (XRF) may be substituted for the ICP method.

5 %), oil oxidation and additive depletion are the primary determinants of service life. In-service oil should be tested at sufficient intervals to detect contamination, oxidation, and additive depletion. In equipment where make-up is relatively high, the degree of degradation is minimal because the additives are being replenished.

5.3 *Contamination*—Contamination of lubricating oils occurs both from outside and from within the system. Common types of contamination are: debris introduced at initial startup or after an overhaul, lube degradation byproducts, component wear debris, airborne particulates, and water. Contamination is often the most significant factor affecting oil service life. Contamination of oil is a valid reason to change oil and flush to restore system cleanliness.

5.3.1 *Condition of Equipment on Start-up*—Oil system contamination prior to start-up usually consists of preservatives, paint, moisture, rust particles, and construction debris such as dust, dirt, or welding spatter. Extreme care must be taken to avoid the introduction of any contamination into a machine during manufacture, assembly, installation, servicing, or repair. Whenever practical, flushing the system before starting operation is recommended. Fluid cleanliness should be brought to a level of one to two ISO FDIS 4406.2 classes below warning levels before beginning operation. If flushing is not performed, oils should be tested soon after startup or repair to verify their cleanliness.

5.3.2 *External Contamination-Solids*—Solid contamination consists of any material small enough to pass through bearing seals and vents or which can be introduced with make-up oil. Consideration may be given to *prefiltering* make-up oil to prevent introducing contaminants into an otherwise clean system.

5.3.3 *External Contamination-Liquid*—Coolant leaks, moisture or steam condensation, or introduction of improper lubricating oils can compromise the oil. Accumulated water promotes oil degradation as well as interfering with lubrication. Contamination with an improper lubricant is not easily corrected without a complete oil change. An oil monitoring program may be used to monitor and identify contaminants likely to be encountered in service.

5.3.4 *Internal Contamination*—Contaminants include wear debris and oil degradation products. The types of internal contaminants will vary by equipment type and oil type; the rate of generation will be highly dependent on the equipment operating conditions. The analysis methods employed must be able to identify expected wear debris and degradation products. Testing frequencies should be sufficient to account for operating conditions.

6. Sampling

6.1 *General*—When taking lubricant samples from storage tanks or equipment in service, it is important that proper sampling techniques are followed. The following are some suggested guidelines for proper sampling technique and sample handling techniques. (See also Practice D 4057.) The user should have written procedures to insure that samples are taken consistently according to good maintenance practices.

6.2 *Representative Sampling*—To be representative, a sample must be obtained either from an agitated tank or a free flowing line. A sample line should always be flushed before a sample is taken. The system should be in steady state operation. An agitated tank is one which is currently in use or is within 25 minutes of shutdown. A fluid sample is probably not representative if: (1) the system fluid is hot while the sample is cold, (2) the fluid in the system is one color or clarity in an in-line sight glass while the sample is a different color or clarity, and (3) the fluid viscosity of the reservoir fluid is different from that of the sample when both are at the same temperature. Samples should be taken in the same manner each time to allow reliable trending of oil properties.

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

6.3 *Sample Container*—Samples should be taken in a container which should be:

6.3.1 *Clean*—If in doubt about its cleanliness, use another container. If this is not possible, flush it out with the fluid to be sampled. Special care should be taken to ensure that sample containers for water separability, particle count, and wear debris testing are clean.

6.3.2 *Resistance to the Material Being Sampled*—For example, fire-resistant phosphate ester fluids will dissolve certain plastics. (This includes the liner in bottle caps.) To verify the container's resistance, if time permits, allow the sample to stand in the container and observe its effects. Aluminum foil or polytetrafluoroethylene (PTFE) make good, resistant cap liners.

6.3.3 *Appropriate for Required Handling*—Containers with leaking tops and glass containers improperly protected are not suitable for shipment. Stringent packaging requirements must be followed if shipment is to be made by air.

6.3.4 *Appropriate for the Analyses Required*—As an example, some plastic containers may not be acceptable for flash point testing (per Test Method D 92) because volatile materials may leak through the container walls. Containers should be either glass or polyethylene for wear debris analysis samples (to avoid material leaching).

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

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

6.4.1 Customer name,

6.4.2 Site (or plant name),

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

6.4.4 Equipment serial number (or other ID),

6.4.5 Oil and machine service hours,

6.4.6 Date sample taken,

6.4.7 Type of fluid sampled,

6.4.8 Sampling point,

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

6.4.10 Make-up (volume) since last sample was taken, and

6.4.11 Coolant additives.

6.5 *Sampling of New Oil Deliveries*—All sampling devices should be thoroughly cleaned before use to avoid cross-contamination.

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

6.5.2 When consignments of oil are in drums, sample them in accordance with Practice D 4057.

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

6.5.4 For bulk consignments, each tanker compartment should be sampled. If these are clear of debris and water, then the samples can be combined for subsequent laboratory analysis of the consignment. The user may decide to perform a limited number of tests on individual compartment samples; a composite sample may be tested for other properties.

6.5.5 From tanker deliveries, individual tanker compartments should be sampled. The sample should be taken preferably from the outlet of the flexible pipework or at least from the tanker bottom valve manifold. This is important 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. Dead leg piping should always be drained and flushed prior to sampling.

6.5.6 Bottom samples (if desired) 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 containers without introducing false contamination by scraping the container lining or wall.

6.6 *Preservation of Sample*—Samples should be tested as soon as possible. Store the sample(s) away from strong light and as close to room temperature as possible. If the samples are to be retained for extended periods of time, special arrangement should be made to ensure that the integrity of the sample is not compromised. The special arrangement may include storing in dark amber glass bottles in a cool area.

7. Examination of New Oil on Delivery

7.1 Deliveries of new oil should be examined when (*1*) the criticality of the equipment warrants the testing, (*2*) there is a question about the oil quality, or (*3*) baseline data is desired for trending purposes. The size of the reservoir which could potentially be contaminated should also be considered.

7.2 Experience has shown the need for standardizing procedures and acceptance criteria for the sampling, examination, and acceptance of incoming supplies of lubricating 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.

7.3 It is equally essential that all incoming supplies of oil be adequately monitored to guard against incorrect or contaminated material being delivered. The cleanliness of the delivery container should be noted; if the container is dirty on the outside, there may be particulate contamination of the oil inside. Particulate contamination can also be a problem when the lubricant comes in contact with dirty or poorly maintained equipment. Final filtration while filling equipment may be used in lieu of or in addition to particle counting. The final filter should be as fine or finer than the lubrication system filter of the equipment being filled.

7.4 Sampling of incoming supplies should be in accordance with proper sampling procedures (see Section 6.)

7.5 All samples should be immediately examined for appearance.

7.6 Testing schedule guidelines for various types of new oils are provided in Table 1. With drums, tests should be completed on a composite (or bulked) sample before the oil is used in service. Individual samples should be retained until the bulk sample is passed as satisfactory.

7.7 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 is necessary.

7.8 The product specifications for new oils should be clearly communicated between the user and supplier. If a sample of oil fails to meet the product specifications agreed upon by user and supplier, the sample should be retested to verify the initial test result. A resample should be taken and tested if needed to verify that the sample is representative of the shipment. If the retest or resample still fails to meet product specification, an investigation should be made to determine whether the problem is due to transportation, handling, or product formulation. The user must recognize that *typical values* are not the same as *purchase specifications*.

8. Significance of Tests

8.1 In determining the condition of the oil and equipment for continued service, important properties of used oils include:

8.2 *Viscosity*—Most commercial oils are sold under ISO (International Standards Organization) viscosity classification system. Industrial fluids fall into ISO VG-32, VG-46, VG-68 and higher viscosity grades corresponding to 32, 46, 68 cSt at 40°C (Classification D 2422). Diesel engine oils are tested at 100°C with cSt units and use the SAE classification. Gear oils are tested at 40°C with cSt units and use the AGMA or SAE classification. The viscosity (for example, for multi-grade oils) can be measured at 40° and 100°C in order to calculate the viscosity index and determine that the correct oil has been used. The main purpose for checking the viscosity of used oil is to determine if the correct oil is being used and to detect contamination. In extreme cases, used oils will experience a significant increase in viscosity due to thermal or oxidative degradation. Contamination can cause the viscosity to either increase or decrease, depending on the contaminant. Emulsified water and diesel fuel soot will increase the viscosity, while diesel fuel, Freon, or solvents will decrease the viscosity. Dissolved water in phosphate ester fluids can reduce the fluid viscosity slightly. Contamination from a different lubricant can change the viscosity of the oil in either direction. The method normally used for viscosity determinations is Test Method D 445.

8.3 *Acid Number*—The test most used to indicate the extent of oxidation is the acid number (Test Method D 664 or D 974). With phosphate esters, acidity is most frequently an indication of hydrolysis. Many rust inhibitors used in lubricating 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 or, less likely, contamination with acidic substances. The acid numbers determined by these two test methods are not identical and only loosely correlate; a single method should be used consistently. The use of Test Method D 974 on aged phosphate ester fluids which have significantly darkened in color, and especially those which have been dyed prior to use, is not recommended.

8.4 *Water Content*—If a mineral oil is clear and bright, the amount of dissolved water present is of little significance. Most mineral oils will remain clear with up to 75 ppm water at room temperature. Phosphate ester fluids can hold more than 1000 ppm water at ambient temperature and still be clear and bright. The presence of water determined by screening methods (such as the hot plate splatter test for mineral oils) may be confirmed using a standard test method. Adequate lubrication cannot be maintained by an oil which contains a significant quantity of water. The analytical range for Test Method D 95 is 0.05 % to 25 % and the range for Test Method D 1744 is 50 to 1000 µg/g. Other methods (such as Test Methods D 96, D 1533 and E 1064) are available for measuring the water content in oils.

8.5 *Oxidation Inhibitor Level*—The measurement of antioxidant concentration is important for monitoring 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.

8.5.1 *FTIR*—The Fourier Transform Infrared (FTIR) practice is a refined infrared spectroscopy method, which can be used to monitor the remaining antioxidants blended into the oil. It can also be used to monitor the increase in oxidation products as the oil degrades. Each antioxidant is a specific chemical substance and will absorb infrared light at particular wavelengths and absorptivities; some antioxidants may not be detectable by infrared spectroscopy. (Test Method D 2668 may be used for antioxidants if the wavelengths and absorptivities are known.)

8.5.2 *Voltammetry*—Voltammetry is an electrochemical test technique, which can be used for measuring many antioxidant additives. The technique applies a voltage ramp through a 3 electrode sensing system and measures the current flow that occurs when the applied voltage equals the oxidation potential of the antioxidant. The potential at peak current is diagnostic for the antioxidant, and the amplitude of the peak is proportional to the concentration of the antioxidant. Antioxidants such as hindered phenols, amines and zincdithiophosphates can be measured.

8.6 *Oxidation Stability (RPVOT)*—One of the most important properties of new oil containing oxidation inhibitor is its ability to resist oxidation while in service. This is accomplished by the addition of antioxidants that are formulated to protect the oil itself from degradation. Measuring the concentration of the antioxidant additive or the ability of the additive to resist oxidation (as compared to the new oil) is an important factor in monitoring the degradation of industrial lubricants. The result of this measurement will offer the user a rating of *oxidation stability reserve*. When the operating conditions of a machine are known (that is, oil temperature, oil service time), the oxidation stability reserve serves as an indication of the optimum oil change interval. Methods of measuring the resistance to oxidation are generally thermal, catalytic degradation techniques such as Test Method D 943 or D 2272. Test Method D 943 is generally reserved for new lubricant comparison and is too lengthy to be used for in-service monitoring. Test Method D 2272, however, is widely used for in-service monitoring of oxidation stability reserve when compared to the new oil.

8.7 *Color*—New lubricating oils have colors ranging from light to moderately-dark. Darkening will occur in service but the change is usually slow over a period of time. Frequent checks for color are therefore useful as a quick on-the-spot test. A significant color change would be indicative that something has changed. A more detailed examination would be necessary to find the cause. Test Method D 1500 is the standard method for defining the color of lubricants. Color darkening alone is not itself a cause for alarm (unless supported by additional tests).

8.8 *Gravity or Density*—This test only has significance with respect to contamination. As an example, phosphate ester EHC fluid cannot tolerate contamination with mineral oil. This test is of little value to determine the degree of degradation. The method normally used is Practice D 1298 (hydrometer).

8.9 *Flash Point*—Lubricants must have flash points well above the minimum applicable safety requirements. Flash point is useful for detecting contamination with diesel fuel oil or low-boiling solvents. However, flash point is of little significance for determining the degree of degradation of used oils, since normal degradation has little effect on the flash point. The method in common use is Test Method D 92 (Cleveland Open Cup).

8.10 *Insolubles*—Pentane insolubles (Test Method D 893) may include oil-insoluble materials and some oil-insoluble resinous matter originating from oil or additive degradation, or both. Toluene insoluble materials may come from (*1*) external contamination, (*2*) fuel carbon and highly carbonized materials from degradation of fuel oil, and additives, and (*3*) engine wear and corrosion materials. Industrial oils may also be tested for insolubles using Test Method D 2273. A significant increase in insolubles indicates a potential lubrication problem. The measurement of insolubles can also assist in evaluating the performance characteristics of a new oil or in determining the cause of equipment failure.

8.11 *Water Separability*—Water can get into lubrication systems due to oil cooler leaks, normal system breathing, and other means. Water adversely affects oils by acting with metals to catalyze oxidation. It also depletes water sensitive oil additives such as some types of rust inhibitors, and can cause rusting and corrosion. For some oils, water will settle to the bottom of the storage tank where it should be drained off as a routine operating procedure. Purification systems will also assist in removing the water. Unfortunately, if the oil has developed poor water separability properties (poor demulsibility), significant amounts of water may stay in the system and create problems. In addition to chemical effects on the oil and additives, the lubricating properties of the oil can be adversely affected. The water separability characteristics of an oil are adequately measured using Test Method D 1401. This test determines the time required for significant amounts of water to separate from an oil-water emulsion. By design, water will not separate from some lubricating oils such as engine oils. The dispersant additive present in these oils disperses water as well as combustion residues, dirt, and oxidized compounds.

8.12 *Rust Evaluation*—Anti-rust protection provided by the lubricant is important for certain systems. Protection is required in areas of fluid flow, for surfaces covered by static drops of water, and for areas which are only occasionally splashed by the lubricant. New oil containing an anti-rust inhibitor additive must meet test requirements such as Test Method D 665. In service, this additive can become depleted by (*1*) performing its proper function, (*2*) by removal with water, (*3*) by adsorption on wear particles and other solid debris, or (*4*) by chemical reaction with contaminants. In exceptional circumstances where alkaline or polluted water enters the system, additive removal will be much more rapid. Test Method D 665 Procedure A (distilled water rust test) is usually adequate for determining a satisfactory level of anti-rust inhibitor for inland equipment. For marine usage, Test Method D 665 Procedure B (seawater rust test) is recommended.

8.13 *Foaming Characteristics*—Foaming characteristics are measured by Test Method D 892 which indicates both the tendency of the oil to foam and the stability of the foam after it is generated. This test may be useful in troubleshooting oil foaming problems in equipment. System foaming problems have three possible origins.

8.13.1 *Mechanical*—The system design can have a major impact on the foaming tendency of a lubricant.

8.13.2 *Antifoam Additive Depletion*—Anti-foam agents may be removed mechanically (due to fine filtration, centrifuging, mechanical shearing, or adsorption) because they are dispersed and not dissolved in the oil.

8.13.3 *Contamination*—An attempt should be made to identify and remove the contaminants. In cases where this cannot be done adequately, this may be corrected with an addition of defoamant.

8.14 *Air Release Properties*—Agitation of lubricating oil with air in equipment such as bearings, couplings, gears, pumps, and oil return lines may produce a dispersion of finely divided air bubbles in the oil. If the residence time in the reservoir is too short to allow the air bubbles to rise to the oil surface, a mixture of air and oil will circulate through the lubricating oil system. This may result in an inability to maintain oil pressure (particularly with centrifugal pumps), incomplete oil films in bearings and gears, and poor hydraulic system performance or failure. The time required for air entrained in the oil (in Test Method D 3427) to reduce in volume to 0.2 % is recorded as the air bubble separation time.

8.15 *Base Number*—New and used petroleum products (especially diesel engine lubricants) can contain basic additives. The relative amount of these materials can be determined by titrating with acids. This *base number* is a measure of the amount of basic substances in the oil and, hence, is a measure of additive depletion. Condemning limits must be empirically established. The base number methods do not provide equivalent test results; one method should be used consistently.

8.16 *Chlorine Content*—The chlorine content in phosphate ester EHC fluids can be determined via microcoulometry. Excessive chloride ion can cause electrochemical corrosion since the fluid flows through small openings at a rapid velocity.

8.17 *Resistivity*—Phosphate ester EHC fluids with low electrical resistivity can cause servo valve erosion.

8.18 *Mineral Oil Content*—The mineral oil content in phosphate ester EHC fluids must be minimized to preserve the fire-resistant properties.

8.19 *Glycol Content*—Leakage of glycol-based antifreeze into the crankcase is serious because the coolant tends to interfere with the lubricant and its ability to lubricate; it also promotes sludging. Ethylene glycol present in the coolant can increase varnish deposit formation in the crankcase due to glycol oxidation and the interaction between glycol and lubricant. Lubricant displacement, sludging, and deposit formation all lead to engine malfunction and possible seizure. It is important to detect glycol-base coolant contamination at low levels because early detection enables corrective measures to be taken to prevent leaking coolant from accumulating and seriously damaging the diesel engine.

8.20 *Fuel Dilution*—Some fuel dilution of the diesel engine oil may take place during normal operation. However, excessive fuel dilution is of concern in terms of possible performance problems.

8.21 *Particle Counts*—The most deleterious solid contaminants found in 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 oil systems is emphasized. In operation, there are few opportunities for solids to enter the lube oil system, although in very dusty areas where units may be outdoors, some solids can enter through improperly installed or operating vents as well as seals and air intakes. During operation, the equipment may begin to accumulate significant particulates. Some may enter the system through the make-up oil when it is added. Fly ash may be drawn in with the air at bearing shaft seals. Other contaminants may be abrasive degradation (that is, wear particles) 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. Cleanliness of the system oil can be determined by particle counting (by means of electronic particle counters). Cleanliness levels can be represented by classification systems such as ISO FDIS 4406.2. ISO FDIS 4406.2 uses a numeric code to reference the number of particles larger than 4 µm (proposed), 6 µm, and 14 µm/mL of oil. ISO FDIS 4406.2 assigns integer values to denote a range of particles whose upper limit doubles with each successive number. Desired cleanliness levels are sometimes designated by the equipment manufacturer or user.

8.22 *Wear Particle Concentration (WPC)*—It has been shown that the separation and measurement of large and small wear particles is beneficial in the detection and diagnosis of related machine wear regimes. Techniques used to measure WPC should not be considered to be particle counts, rather a measurement of specific wear metal concentrations. Caution should be used when evaluating results since separation and measurement techniques may be alloy-specific. The wear particle concentration for a particular piece of equipment is monitored over time in order to detect a sudden increase in the wear trend and reduce the likelihood of catastrophic failure.

8.23 *Wear Debris Analysis (WDA)*—A microscopic analysis of wear debris can be used to describe a wear condition as normal rubbing wear, severe sliding wear, cutting wear, gear wear, or bearing wear. In addition, this debris analysis can reveal fibers, sand/dirt, lubricant degradation residue, red oxides, black oxides, and ferrous spheres. A rating can be given to each type of wear condition which is a combination of the size of the wear debris and the concentration of particles of the same type.

8.24 *Elemental Analysis*—Emission spectroscopy can be used to analyze for elements found in used lubricating oil. This analysis is generally limited to dissolved materials or particles smaller than about 8 µ. The elements found derive from wear debris, additives, and contamination. (See 9.5.)

8.24.1 Some wear on metal parts can be considered to be normal (although not desirable). Large amounts of metal contaminants usually indicate a serious machine problem. Since different machine parts are made from different metals, the presence of particular metals indicate which components are wearing. When a machine has been sampled several times (or when multiple machines of the same type have been tested), an evaluation is made to determine whether the metal concentrations are outside of the normal range. Samples from a piece of equipment that have metal concentrations increasing at an unusually high rate or outside of the normal range indicate that the equipment may have a problem. When no historical data is available, there is a chance that not enough significance will be given to a particular wear metal and its concentration.

8.24.2 Certain elements which are found as lubricant oil additives can also be analyzed to ensure that the appropriate additives are present and that there are no other inorganic additives which indicate that cross-contamination has occurred. An analysis should be performed on unused oil in order to establish a baseline for future comparisons.

8.24.3 Contaminants (such as dirt and water) in the oil can be carried throughout the machine and cause severe wear or corrosion. The presence of dirt can be detected by the presence of silicon (or aluminum). Inorganic constituents of fresh and treated water may be detected using elemental analysis. Examples of these may be: calcium from untreated water, sodium and magnesium from sea water, and potassium, sodium or boron from cooling water. In EHC fluids, the presence of sodium, aluminum, calcium, and magnesium is most commonly found as a result of either release of Fuller's earth or activated alumina into the system or the production of soluble/insoluble metal soaps in the fluid (which can have an adverse effect on foaming and air release properties).

9. Monitoring Program

9.1 A sound monitoring program is based on four factors: (*1*) obtaining representative samples and testing at appropriate intervals; (*2*) logging, trending, and interpretation of test data; (*3*) action steps; and (*4*) insurance of maintenance follow-up.

9.2 *Sampling and Testing of Oil Samples*—Schedules should be tailored to the individual facility depending on the criticality and severity of usage of the equipment. The schedules included in Table 2 are typical and should only be used as a guide. Refer to the OEM (original equipment manufacturer) instructions or other regulatory guidelines for lubricant testing requirements. In addition to the tests in Table 2, any deposits found in the oil or removed from the system should be examined and identified (if possible).

9.2.1 Recommended (R) tests represent the minimum level of monitoring. These tests provide the most information about the quality of a particular fluid and about the condition of the equipment in which the in-service fluid is used. (Alternate testing devices which indirectly measure these properties may be substituted at the discretion and risk of the user.)

9.2.2 Optional (O) tests are those which may provide additional information on the oil or equipment condition. These tests may be beneficial in certain but not all facilities. If sample amount or analysis time is limited, omitting these tests would generally have less impact than omitting recommended tests.

9.2.3 As needed (AN) tests may provide information about operational problems. For example, the foaming characteristics test would determine whether a foaming problem was due to the oil or mechanical reasons. As needed tests may also be performed based on results from other tests. For example, a wear debris analysis may be performed when the wear particle concentration is above a certain level.

9.3 *Logging, Trending, and Interpretation of Test Data*—It is important to keep accurate records of test results and make-up. Graphical representations are highly recommended for key parameters such as acid number, oxidation inhibitor, wear particle concentration, base number, wear metals, and RPVOT. In this way, unusual trends become apparent and better estimates made of remaining service life. Interpretation of test data should take into account such factors as oil addition (make-up or replacement oil), possible intermixing of oils, newly installed parts, and recent system inspections. Guidelines for warning levels are provided for various lubricant types in Table 3. Oil supplier and/or original equipment manufacturer (OEM) guidelines supersede Table 3. These warning levels should also be considered with trending information.

9.4 *Action Steps*—The main purpose of a monitoring program is to ensure long trouble-free operation of the equipment. This can only be achieved by prompt and proper action steps when necessary. Such action steps must be based on a correct interpretation of test results (see Table 4), usually gathered over a period of time. Corrective action should generally never be taken on the basis of one test result since it may be incorrect due to poor sampling or faulty testing. Resampling and retesting is recommended before proceeding. Actions recommended by the oil supplier and/or original equipment manufacturer supersede those in Table 4.

9.5 Possible sources of wear metals, additive elements, and contaminants are presented in Table 5. This table is a compilation of information from industry. It is intended as a guide and should not be considered to be all encompassing. Any additive element from a lubricant other than the desired lubricant could be described as a contaminant.

9.6 *Maintenance Follow Up*—When maintenance is performed on equipment included in the oil monitoring program, the records of work performed and problems found should be documented and made available to those responsible for interpreting the oil test data. In this way, the test data interpreter can (*1*) ensure that recommended maintenance was performed, (*2*) make better recommendations, and (*3*) learn better how test data correlate with equipment problems.

10. Keywords

10.1 auxiliary power plant equipment; lubricating oil; monitoring program

TABLE 2 Guidelines For Sampling and Testing In-Service Oils

NOTE 1—Legend–R = Recommended; O = Optional; AN = As Needed.

NOTE 2—Infrared spectra of used oils may be compared to the new oil spectrum in order to detect degradation (such as oxidation) or contamination (such as water, fuel oil, or glycol).

Test	Common Methods	Gear/ Circulating Oils	Hydraulic Oils	Diesel Engine Oils	Turbine-Type Oils	Air Compressor Oils[A]	EHC (PO_4 Esters)	EHC Mineral Oils
Frequency		3 Mo.	3 months	[B]	3 months	3 months	3 months	6 months
Appearance[C]	Visual	R	R		R	R	R	R
Viscosity, (40°C)	D 445	R	R	O	R	R	R	R
Viscosity (100°C)	D 445			R				
Acid number	D 664 D 974	R	R		R	R	R	R
Water	D 1744[D] D 95	R[E]	R[E]	R[E]	R[E]	R[E]	R	R[E]
Oxidation inhibitor	D 2668 Voltammetry	O O	O O		O O	O O		O O
Oxidation stability (RPVOT)	D 2272				O	O		O
Color	D 1500		O		O	O	O	O
API gravity or density	D 1298/D 4052						O	
Flash point (COC)	D 92			O	O	O		O
Insolubles	D 893 D 2273	R	O	R (D 893)	R (D 2273)	R (D 2273)		
Water separability	D 1401				O	O		O
Rust evaluation	D 665	O	O		O	O		O
Foaming characteristics	D 892	AN	AN	AN	AN		AN	
Air release	D 3427		AN		AN		AN	
Base number	D 974 D 2896 D 4739			R				
Chlorine	Coul.						R	
Electrical resistivity	D 257/D 1169						R	
Mineral oil	Fluid Supplier's Method						O	
Glycol	D 2982			O				
Fuel dilution	D 3524			O				
Particle counts	Equipment Manufacturer's Method		R		O	O	R	R
Wear particle concentration	Equipment Manufacturer's Method	O	O	O	O	O		O
Wear debris analysis	Equipment Manufacturer's Method	AN	AN	AN	AN	AN		AN
Elemental analysis	D 5185[F]	R	R	R	R	R	O	R

[A] Does not include refrigeration (chiller) oils.

[B] Two hundred fifty to five hundred hours for continuously operated equipment; six months for standby equipment.

[C] Appearance includes observations such as color, clarity, odor, and sediment.

[D] Test Method D 1744 is not recommended for certain lube oils (for example, diesel engine oils) because of additive interferences. Results from Test Method D 1744 should be viewed as relative rather than absolute due to additive interferences and other reasons. Test Methods E 1064 and D 1533 may be used for certain lubricants.

[E] Recommended if oil is not clear and bright.

[F] Another spectrochemical method such as rotating disk electrode (RDE), atomic absorption, (AA), or X-Ray fluorescence (XRF) may be substituted for the ICP method.

TABLE 3 Warning Levels of In-Service Oil Test Data

Test	Gear/ Circulating Oils	Hydraulic Oils	Diesel Engine Oils	Turbine-Type Oils	Air Compressor Oils[A]	EHC (PO_4 Esters)	EHC Min. Oils
Appearance	Heavy, cloudy, visible debris. Not clear and bright.						
Viscosity	± 10 % of new oil, max.						
Acid Number	increase of 0.5	increase of 0.2		increase of 0.2	increase of 0.2	>0.2	increase of 0.2
Water[B]	>0.1 wt. %	>0.05 wt. %	>0.2 wt. %	>0.05 wt. %		>0.1 wt. %	>0.05 wt. %
Oxidation inhibitor	<25 % of new			<25 % of new			<25 % of new
Oxidation stability (RPVOT)				<25 % of new			<25 % of new
Color		unusual or rapid darkening		unusual or rapid darkening			
API gravity or density						±0.01 API	
Flash point			decrease of 30°C	decrease of 20°C from new oil			
Insolubles	>0.5 wt. %	>0.1 wt. %	>2.5 wt. % (pentane) >2.0 wt. % (toluene)	>0.1 wt. %			
Water separability[C]				>30 min			>30 min
Rust evaluation	light fail			light fail			light fail
Foaming characteristics (Sequence I)	tendency >450 stability >10			Tendency >450 Stability >10		tendency >450 stability >10	
Air release (50°C)		>5 - 20 min[D]		>5 - 20 min[D]		>10 min	
Base number			<20 % of new oil				
Chlorine						>100 ppm	
Resistivity						$<5 \times 10^9$ ohm/cm	
Mineral oil						>1 %	
Glycol			any detected				
Fuel Dilution			>1-5 %[E]				
Particle counts (ISO Code)	[F]	17/14 max.		17/14 max.			
Wear particle concentration	[G]	[G]	[G]	[G]	[G]		[G]
Wear metals	[G]	[G]	[G]	[G]	[G]	[G]	[G]
Additive elements	±25 % of new oil						

[A] Does not include refrigeration (chiller) oils.

[B] The maximum acceptable amount of water depends on the type of equipment and service. Reduced component life is generally correlated with greater amounts of water in the oil.

[C] This represents the time required to reach the endpoint in Test Method D 1401 (≤3 mL emulsion).

[D] The maximum air release time depends on the oil viscosity.

[E] The maximum amount of tolerable fuel oil dilution depends on the type of diesel engine.

[F] The warning level ranges from 18/15 to 22/18 depending on the application. Longer component life is generally correlated with the cleanliness of the system.

[G] A recommended warning level is a concentration of two standard deviations above the mean of six or more prior results. In cases where there are insufficient analysis results to provide a good baseline or in cases where the increase in concentrations is steady but gradual, the equipment manufacturer should be consulted for guidance.

TABLE 4 Interpretation of In-Service Oil Test Data and Recommended Action

Test	Interpretation of Data Beyond Warning Levels	Recommended Action Steps
Appearance	Gross contamination of water or solids, or both.	Perform further analysis to identify contaminant, Remedy source. Investigate cause and remedy. Filter or centrifuge oil.
Viscosity	Oil is contaminated or severely degraded, or wrong oil.	Determine cause. If viscosity is low, determine flash point. Change oil. For EHC fluid, consult supplier.
Acid number	(a) Oil near end of life, (b) Oil Contaminated, or (c) Wrong oil	Look for increased sediment on filters or centrifuge. Change oil if RPVOT is <25 % of new oil. Test more frequently if oil is left in system. For EHC fluid, consult supplier.
Water	Oil contaminated. Potential water leak.	Investigate and remedy cause. Centrifuge oil or use vacuum dehydration, or change oil. For EHC fluid, consult supplier.
Oxidation inhibitor	Additive depleted. Oil approaching end of service life.	Check RPVOT, acid number, viscosity. Consider changing oil or consult with oil supplier regarding reinhibition.
RPVOT	Oil approaching end of service life.	Consider oil change or consult with oil supplier regarding reinhibition. Consider also the acid number.
Color	Indicates contamination, overheating, or excessive degradation.	Determine cause and rectify. Consider oil change.
API gravity or density	Oil contaminated, or wrong oil.	Investigate cause. Change oil.
Flash point	Probable contamination or severe degradation.	Determine cause. Check other parameters (such as viscosity). Consider oil change.
Insolubles	Indicates oil or additive degradation, or contamination of oil by equipment wear or other debris.	Centrifuge or filter oil, or consider oil change.
Water separability	Oil is contaminated or degraded, or demulsifier depleted.	Centrifuge, filter or purify by other process, consult with oil supplier and/or change oil.
Rust evaluation	Additive depletion, excessive contamination.	Change oil or consult with oil supplier regarding reinhibition.
Foaming characteristics (Sequence I)	Anti-foam depletion or contamination.	Rectify cause. Consult with oil supplier regarding inhibition.
Air release (50°C)	Contamination	Change oil. (For EHC fluid, consult the fluid supplier.)
Base number	The alkaline reserve is depleted.	Consider oil change.
Chlorine	Contamination.	Consult EHC fluid supplier.
Resistivity	Contamination.	Consult EHC fluid supplier.
Mineral oil (in EHC fluid)	Contamination.	Consult EHC fluid supplier.
Glycol	Glycol-base antifreeze has leaked into the oil.	Investigate and remedy cause. Change oil.
Fuel dilution	Excessive fuel has leaked into the oil.	Investigate and remedy cause. Change oil.
Particle counts	Source of particles may be make-up oil, dust, ash, or wear condition.	Locate and eliminate source of particulates. Filter or centrifuge oil.
Wear particle concentration	Possible wear condition.	Perform wear debris analysis.
Wear debris analysis	Possible wear condition.	Investigate source of particles and make necessary maintenance or operational changes.
Wear metals, contaminants	Indicates the presence of a wear condition or contamination. See Table 2.	Identify source and make necessary maintenance or operational changes. Then filter oil.
Additive elements	Additive nearly depleted, wrong oil added, oil dilution, or additive precipitation.	Consider changing oil or consult with oil supplier regarding situation. Check for excessive fuel or other dilution.

TABLE 5 Sources of Inorganic Elements in Oil

NOTE—Bronze alloys typically contain 88 % copper, 8 to 10 % tin, and 2 to 4 % zinc. Babbitt alloys typically contain 84 to 92 % tin, 4 to 8 % copper, and 4 to 8 % antimony. Lead-based babbitts typically contain 75 to 80 % lead, 5 to 10 % tin, and 15 % antimony.

Element/ Symbol	Wear Metal	Additive	Contaminant	Primary Sources	Secondary Sources
Aluminum/Al	X		X	pistons, journal bearings, blowers, turbo charge vans, thrusts, torque converters, pump vanes	dirt, alloy with copper in rolling element bearing cages, housings and cases
Antimony/Sb	X	X	X	journal bearings	grease, anti-scuff additive
Barium/Ba		X		additives	grease
Boron/B		X	X	additive, treated coolant water	few
Cadmium/Cd	X			journal bearings	plating
Calcium/Ca		X	X	additives	water, grease
Chromium/Cr	X			compression rings, chrome cylinders	alloyed with iron found in rolling element bearings, shafts found in hard steels
Copper/Cu	X	X		bearings, cages, bushings, thrusts, valve guides, oil coolers, bearing cages, pumps	automotive lubricant additive
Iron/Fe	X		X	cylinders, shafts, gears, rolling element bearings, housings, cases	rust, fretting corrosion
Lead/Pb	X		X	journal bearings, main bearings, platings, pumps	paint, solder, seals
Magnesium/Mg		X		additive	sea water
Manganese/Mn	X			shafts, valves, blowers	few
Molybdenum/Mo	X	X		additive	compression rings
Nickel/Ni	X			alloyed with iron for hard steel shafts, rolling element bearings	few
Phosphorus/P	X	X		additive	surface finish for gears
Potassium/K			X	coolant additive	few
Silicon/Si	X	X	X	sand, dirt, dust, antifoam additive	alloyed with iron (cast iron)
Silver/Ag	X			wrist pins (EMD), flashing	solder
Sodium/Na		X	X	found in some new oils, cooling additive	sea water, grease
Tin/Sn	X			journal bearings, alloyed with copper in rolling element bearing cages, flashing	solder
Titanium/Ti	X			turbine blades	paint
Vanadium/V	X			turbine blades	valves
Zinc/Zn		X	X	additive	galvanized steel, platings, grease