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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[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 Oil[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 Oils and Synthetic Fluids[2]
D 1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)[2]
D 1533 Test Methods for Water in Insulating Liquids (Karl Fischer Reaction Method)[4]

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[1] This practice is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.C on Turbine Oils.

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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.

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 Bomb[2]
D 2276 Test Method for Particulate Contaminant 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[5]
D 2982 Test Method for Detecting Glycol-Base Antifreeze in Used Lubricating Oils[5]
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[6]
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)[6]
E 1064 Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration[7]

2.2 *ISO Standard:*[8]

ISO 4406 Hydraulic Fluid Power - Fluids - Method for Coding Level of Contamination by Solid Particles

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 05.03.

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

[8] Available from American National Standards Institute, 11 W. 42nd St., 13th floor, New York, NY 10036.

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 5 %), oil oxidation and additive depletion are the primary

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			
Oxidation stability (RBOT)	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.

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 4406 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*—A common method for measuring the concentration of phenolic (or amine) antioxidants is infrared spectrometry. Each antioxidant is a specific chemical substance and will absorb infrared light at a particular wavelength and with its own absorptivity; some antioxidants may not be detectable by infrared spectroscopy. (Test Method