Designation: D 7416 – 09

Standard Practice for Analysis of In-Service Lubricants Using a Particular Five-Part (Dielectric Permittivity, Time-Resolved Dielectric Permittivity with Switching Magnetic Fields, Laser Particle Counter, Microscopic Debris Analysis, and Orbital Viscometer) Integrated Tester[1]

This standard is issued under the fixed designation D 7416; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for analysis of in-service lubricant samples using a particular five-part (dielectric permittivity, time-resolved dielectric permittivity with switching magnetic fields, laser particle counter, microscopic debris analysis, and orbital viscometer) integrated tester to assess machine wear, lubrication system contamination, and lubricant dielectric permittivity and viscosity. Analyzed results trigger recommended follow-on actions which might include conducting more precise standard measurements at a laboratory. Wear status, contamination status, and lubricant dielectric permittivity and viscosity status are derived quantitatively from multiple parameters measured.

1.2 This practice is suitable for testing incoming and in-service lubricating oils in viscosity grades 32 mm^2/s at 40°C to 680 mm^2/s at 40°C having petroleum or synthetic base stock. This practice is intended to be used for testing in-service lubricant samples collected from pumps, electric motors, compressors, turbines, engines, transmissions, gearboxes, crushers, pulverizers, presses, hydraulics and similar machinery applications. This practice addresses operation and standardization to ensure repeatable results.

1.3 This practice is not intended for use with crude oils.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D 341 Test Method for Viscosity-Temperature Charts for Liquid Petroleum Products

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

D 924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids

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

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products

E 617 Specification for Laboratory Weights and Precision Mass Standards

E 1951 Guide for Calibrating Reticles and Light Microscope Magnifications

D 6300 Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products and Lubricants

2.2 *ISO Standards:*[3]

ISO 11171 Hydraulic fluid power—Calibration of automatic particle counters for liquids

3. Terminology

3.1 *Definitions:*

---

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.96 on In-Service Lubricant Testing and Condition Monitoring Services.

Current edition approved July 1, 2009. Published August 2009. Originally approved in 2008. Last previous edition approved in 2008 as D 7416–08.

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

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

3.1.1 *integrated tester*, *n*—automated, or semi-automated stand alone instrument utilizing multiple technologies to provide diagnostic recommendations (on-site or in-line) for condition monitoring of in-service lubricants.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *chemistry index (Chem Index)*, *n*—parameter computed from dielectric permittivity increase compared to new oil. The value is equal to dielectric difference multiplied by 100.

3.2.2 *chemistry status (Chem Status)*, *n*—diagnostic severity ranking having 0 to 100 score based on the highest alarm indication of dielectric permittivity and viscosity measurements.

3.2.3 *counts* ≥ *4*, *n*—sensor 3 measured particle counts per mL for particles ≥ 4 µm.

3.2.4 *counts* ≥ *6*, *n*—sensor 3 measured particle counts per mL for particles ≥ 6 µm.

3.2.5 *counts* ≥ *10*, *n*—sensor 3 measured particle counts per mL for particles ≥ 10 µm.

3.2.6 *counts* ≥ *14*, *n*— sensor 3 measured particle counts per mL for particles ≥ 14 µm.

3.2.7 *counts* ≥ *18*, *n*— sensor 3 measured particle counts per mL for particles ≥ 18 µm.

3.2.8 *counts* ≥ *22*— sensor 3 measured particle counts per mL for particles ≥ 22 µm.

3.2.9 *counts* ≥ *26*—sensor 3 measured particle counts per mL for particles ≥ 26 µm.

3.2.10 *counts* ≥ *32*— sensor 3 measured particle counts per mL for particles ≥ 32 µm.

3.2.11 *counts* ≥ *38*—sensor 3 measured particle counts per mL for particles ≥ 38 µm.

3.2.12 *contaminant status (Cont Status)*, *n*—diagnostic severity ranking having 0 to 100 score based on the highest alarm indication of all contamination related parameters.

3.2.13 *dual-screen patch maker*, *n*—apparatus with screens to support individual (most often) or stacked (occasionally for size segregation) filter patches used to extract solid particles from in-service lubricating fluid as the fluid is evacuated from sensor 2 test chamber. This item is often referred to simply as "patch maker."

3.2.14 *ferrous index (Fe Index)*, *n*—ferrous density type parameter measuring relative concentration and size of magnetically responsive iron particles ≥ 5 µm collected on a dielectric permittivity sensor.

3.2.15 *large contaminant droplet (LCont D)*, *n*—indication reporting sensor 2 detects presence of free-water drops in oil.

3.2.16 *large contaminant ferrous (LCont Fe)*, *n*—indication reporting sensor 2 detects presence of very large ferrous-metal particles in oil, which are often the kind produced by abrasive wear mechanisms.

3.2.17 *large contaminant non-ferrous (LCont NF)*, *n*—indication reporting sensor 2 detects presence of very large non-ferrous-metal particles in oil, which are often the kind produced by abrasive wear mechanisms.

3.2.18 *orbital viscometer*, *n*—four-pole, magnetically driven, orbital viscometer.

3.2.19 *new oil*, *n*—sample of as-purchased new oil as supplied by a manufacturer for use to measure baseline reference values for the following reference oil properties: dielectric permittivity, specific gravity (Test Method D 1298), kinematic viscosity at 40°C (Test Method D 445), kinematic viscosity at 100°C (Test Method D 445), and sensor 2 water factor.

3.2.20 *particular five-part integrated tester*, *n*—integrated tester including these five parts:[4,5] sensor 1 (dielectric permittivity sensor), sensor 2 (time-resolved dielectric permittivity sensor with switching magnetic fields),[5,6] sensor 3 (laser particle counter),[5,7] dual-screen patch maker (initial step in microscopic debris analysis),[5,8] and orbital viscometer.[5,9]

3.2.21 *particle count ppm by volume < 6 µm (PC Vol < 6 µm)*, *n*—volume of particulate debris detected using a laser particle counter in size range ≥ 4 µm and < 6 µm compared to volume of oil × 10^{-6}.

3.2.22 *particle count ppm by volume ≥ 6 µm and < 14 µm (PC Vol 6-14 µm)*, *n*—volume of particulate debris detected using a laser particle counter in size range ≥ 4 µm and < 6 µm compared to volume of oil × 10^{-6}.

3.2.23 *particle count ppm by volume ≥ 14 µm (PC Vol ≥14 µm)*, *n*—volume of particulate debris detected using a laser particle counter in size range ≥ 14 µm compared to volume of oil × 10^{-6}.

3.2.24 *particle count ppm by volume total (PC Vol Total)*, *n*—volume of all particulate debris detected using a laser particle counter in size range ≥ 4µm compared to volume of oil × 10^{-6}.

3.2.25 *Sensor 1*, *n*—dielectric permittivity sensor having oil-filled cavity between central oscillating electrode and grounded concentric-shell.

3.2.26 *Sensor 2*, *n*—concentric-electrical-trace-type time-resolved dielectric permittivity sensor using a ceramic fiber filled printed circuit board and including pair of coaxial, switching electromagnets proximate to the underside of the surface supporting the concentric electrical traces.

3.2.27 *Sensor 2 water factor*, *n*—proportional measure of time-resolved-dielectric permittivity per 1% emulsified water-in-oil.

3.2.28 *Sensor 3*, *n*—light-blocking-type (also called light-extinction-type) laser particle counter sensor.

---

[4] The analyzer is described in and covered by the following U.S. Patents: 5,262,732; 5,394,739; 5,604,441; 5,614,830; 5,656,767; 5,674,401; 5,817,928; 6,064,480; 6,418,799; 6,582,661; 7,027,959; and 7,065,454. The sole source of supply of the apparatus known to the committee at this time is Machinery Health Management, Emerson Process Management, 835 Innovation Drive, Knoxville, TN 37932.

[5] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[6] The time-resolved dielectric sensor with switching electromagnets is described in and covered by U.S. Patent 5,604,441.

[7] Sensor 3 uses methods described in and covered by U.S. Patents 6,064,480 and 7,065,454.

[8] The patch maker with dual screens is described in and covered by U.S. Patent 6,418,799.

[9] The orbital viscometer is described in and covered by U.S. Patent 5,394,739. The sole source of supply of the apparatus known to the committee at this time is Machinery Health Management, Emerson Process Management, 835 Innovation Drive, Knoxville, TN 37932.

TABLE 1 Oil and Solvent Solubility[A]

NOTE—Y=Yes, N=No

Oil Class	Dielectric	Original Lamp Oil or Kerosine	Ultra Pure Lamp Oil	Original Lamp Oil + Fluid B	Toluene	Hexane	Fluid A	Fluid B	Fluid C	
Mineral Oil	2.1–2.4	Y	Y	Y	Y	Y	Y	Y	N	Most industrial lubricants
PAO	2.1– 2.4	Y	Y	Y	Y	Y	Y	Y	N	Synthetic Hydrocarbon
Diester	3.4– 4.3	Y	Y	Y	Y	Y	Y	Y	Y	Diester
POE + PAG	4.6– 4.8	Y	Y	Y	Y	Y	Y	Y	Y	Polyol Ester + Polyalkylene Glycol
PAG	6.6–7.3	N	N	N	Y	Y	N	N	N	Polyalkylene Glycol
PhE	6.0–7.1	sometimes	N	Y	Y	Y	N	Y	Y	Phosphate Ester

[A] (**Warning—**Both Toluene and Isopropyl Alcohol have flash points below room temperature. They require an explosion proof vacuum pump.)

3.2.29 *system debris*, *n*—calculated volume of debris in entire oil compartment (PC Vol Total multiplied by volume of oil compartment).

3.2.30 *orbital viscosity at 25°C (Visc 25C)*—orbital viscometer viscosity measurement reported as absolute viscosity (mPa × s at 25°C).

3.2.31 *orbital viscosity at 40°C (Visc 40C)*—orbital viscometer viscosity measurement reported as kinematic viscosity (mm^2/s) at 40°C.

3.2.32 *percent change in viscosity at 40°C (Visc%Chng)*—parameter comparing Visc 40C between new in-service oil.

3.2.33 *wear debris analysis classification (WDA classification)*—microscopic debris analysis classification method that closely identifies particulate debris from an oil sample.

3.2.34 *wear debris analysis severity (WDA severity)*—score-type parameter or alarming system assigned by an analyst that reflects a qualitative assessment of risk to machine health as evidenced by microscopic viewing of collected contamination and wear debris.

3.2.35 *wear status*—diagnostic severity ranking having 0 to 100 score based on the highest alarm indication of all wear related parameters.

4. Summary of Practice

4.1 *Measurements Made*—The particular five-part integrated tester sequentially measures viscosity, dielectric permittivity, water-in-oil, ferrous debris, particle count and distribution, and microscopic wear debris analysis for in-service oil samples.

4.1.1 Absolute viscosity is measured based on speed of an orbiting steel ball forced by controlled magnetic fields. Temperature of fluid under test is also measured.

4.1.2 Dielectric permittivity is measured using a concentric-shell-type capacitive sensor.

4.1.3 Water-in-oil and ferrous debris are each measured using time-resolved dielectric sensor and are differentiated by using a switching dual-coil electromagnet.

4.1.4 Particle counting is measured using a laser particle counter gated to detect and count individual particles at eight size ranges.

4.1.5 Microscopic wear debris analysis is performed after collecting solids on a filter patch and placing the filter patch under an optical microscope.

4.2 *Computer Application Software*—A computer application software program guides the test sequence and provides analysis, diagnostic determination, data storage, and reporting.

5. Significance and Use

5.1 *In-plant Oil Analysis*—The particular five-part integrated tester practice is primarily used by plant maintenance personnel desiring to perform on-site analysis of as-received and in-service lubricating oils.

5.2 *Detect Common Lubrication Problems*—The software application interprets data from integration of multiple sensing technologies to detect common lubrication problems from inadvertent mixing of dissimilar lubricant viscosity grades and from particulate or moisture contamination. The redundant views of ferrous particulates (sensor 2), all particulates larger than 4-µm (sensor 3), and all solid particulates larger than filter patch pore size (patch maker) provides screening for oil wetted mechanical system failure mechanisms from incipient to catastrophic stages.

5.3 *Supported by Off-Site Lab Analysis*—The particular five-part integrated tester is normally used in conjunction with an off-site laboratory when exploring the particular nature of an alarming oil sample. An off-site laboratory should be consulted for appropriate additional tests.

6. Interferences

6.1 *Wrong Solvent Selection*—The particular five-part integrated tester testing almost always requires the use of dilution with a solvent that is soluble with the in-service lubricant being tested. All petroleum-based and most synthetic lubricants dissolve very well in kerosine or lamp oil, so this is most often used. However, certain synthetics remain immiscible in these solvents. See 8.3 and Table 1. It is therefore very important to verify solubility of synthetic-based lubricants being tested with the diluents and cleaning solvents being used. To do this, add a 50:50 mixture of solvent and sample in a bottle, shake vigorously, and allow settling for 1 min. Layered fluids or emulsion are signs of insolubility. This is likely to cause erroneous measurements using sensors 2 and 3.

6.2 *Improper Sampling Techniques*—Interferences can be produced by improper sampling techniques. Practice D 4177 should be followed. Samples collected from cold, not operating machinery are not likely to properly represent contaminants and wear debris since these settle when the system is not hot