



Designation: D6810 – 22

Standard Test Method for Measurement of Hindered Phenolic Antioxidant Content in Non-Zinc Turbine Oils by Linear Sweep Voltammetry¹

This standard is issued under the fixed designation D6810; 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 test method covers the voltammetric determination of hindered phenol antioxidants in new or in-service non-zinc turbine oils in concentrations from 0.0075 % by weight up to concentrations found in new oils by measuring the amount of current flow at a specified voltage in the produced voltammogram.

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

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

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

2. Referenced Documents

2.1 *ASTM Standards:*²

[D1193 Specification for Reagent Water](#)

[D4057 Practice for Manual Sampling of Petroleum and Petroleum Products](#)

[D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants](#)

[D4378 Practice for In-Service Monitoring of Mineral Turbine Oils for Steam, Gas, and Combined Cycle Turbines](#)

[D6224 Practice for In-Service Monitoring of Lubricating Oil](#)

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.09.0C on Oxidation of Turbine Oils.

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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.

[for Auxiliary Power Plant Equipment](#)

[D6447 Test Method for Hydroperoxide Number of Aviation Turbine Fuels by Voltammetric Analysis](#)

[D6971 Test Method for Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry](#)

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminology [D4175](#) for a more extensive list of terms used in this test method.

3.1.2 *electrolytic cell, n*—an electrochemical cell in which chemical reactions are caused by applying an external potential difference greater than, and opposite to, the galvanic electromotive force of the cell. **IUPAC³**

3.1.3 *linear sweep voltammetry, n*—a technique applied to the monitoring of antioxidant additive content in lubricants, where the current is detected as an applied potential is increased linearly over a period of time.

3.1.4 *voltammogram, n*—the plot of current versus voltage.

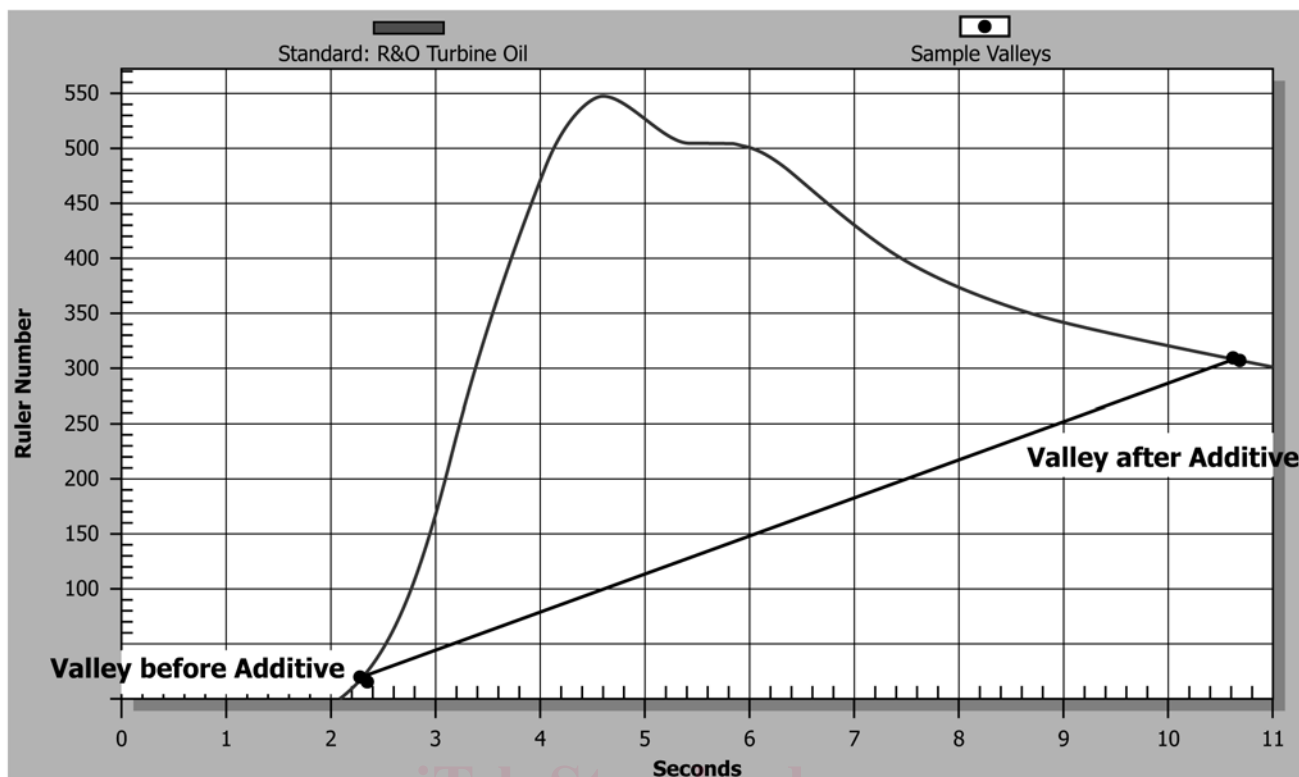
4. Summary of Test Method

4.1 A measured quantity of sample is dispensed into a vial containing a measured quantity of alcohol-based electrolyte solution and containing a layer of sand. When the vial is shaken, the hindered phenol antioxidants and other solution soluble oil components present in the sample are extracted into the solution and the remaining droplets suspended in the solution are agglomerated by the sand. The sand/droplet suspension is allowed to settle out and the hindered phenol antioxidants dissolved in the solution are quantified by voltammetric analysis. The results are calculated and reported as weight percent of antioxidant or as millimoles (mmol) of antioxidant per litre of sample for prepared and fresh oils and as a percent remaining antioxidant for used oils.

4.2 Voltammetric analysis is a technique that applies electro-analytic methods when a sample to be analyzed is mixed with an electrolyte and a solvent and placed within an

³ Inczedy, J., Lengyel, T., and Ure, A. M., *Orange Book: IUPAC Compendium on Analytical Nomenclature, Definitive Rules 1997*, 3rd Edition, Blackwell Science, 1998.

*A Summary of Changes section appears at the end of this standard



NOTE 1—x-axis = time (seconds) and y-axis is current (arbitrary units). Top line in Fig. 1 is voltammogram of a fresh R&O turbine oil showing valley indicator before and after standard.

FIG. 1 Hindered Phenol Voltammetric Response in Basic Test Solution with Blank Response Zeroed

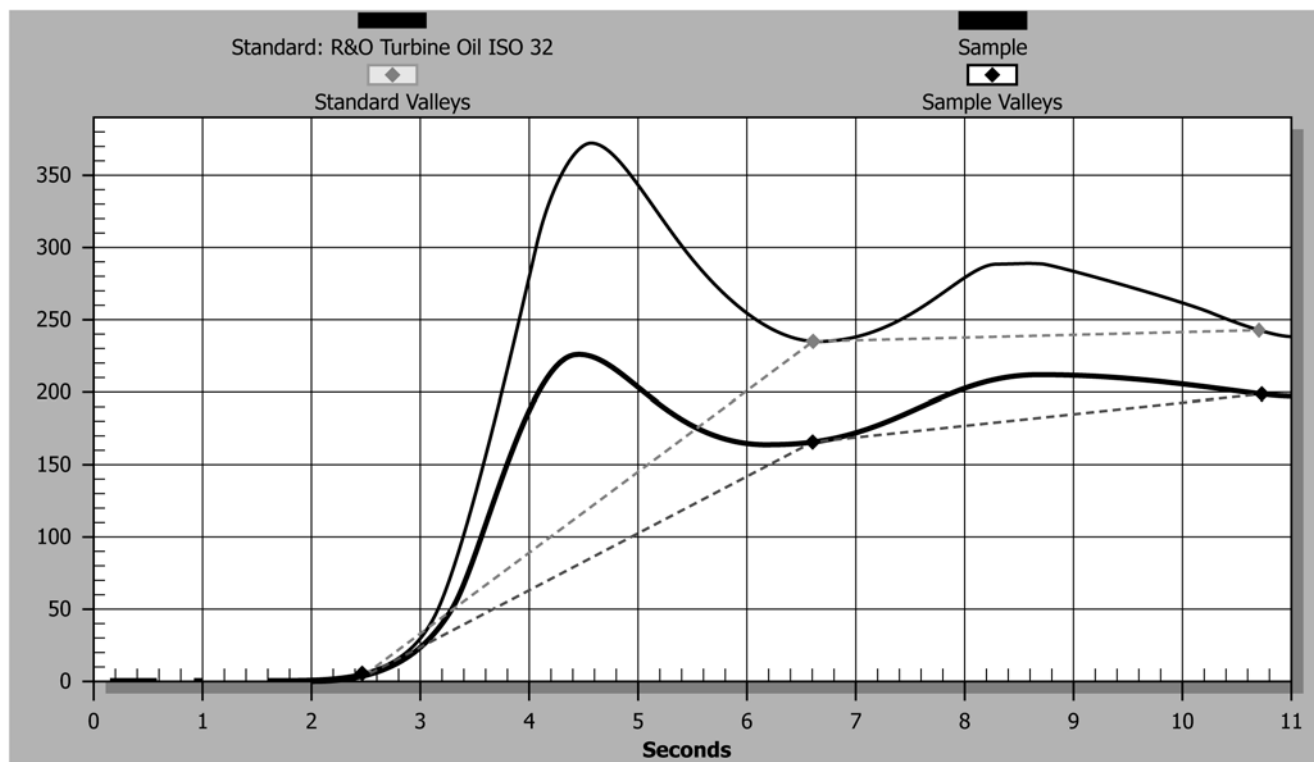
electrolytic cell. Data is obtained by measuring the current passing through the cell as a function of the potential applied, and test results are based upon current, voltage and time relationships at the cell electrodes. The cell consists of a fluid container into which is mounted a small, easily polarized working electrode, and a large nonpolarizable reference electrode. The reference electrode should be massive relative to the working electrode so that its behavior remains essentially constant with the passage of small current; that is, it remains unpolarized during the analysis period. Additional electrodes, auxiliary electrodes, can be added to the electrode system to eliminate the effects of resistive drop for high resistance solutions. In performing a voltammetric analysis, the potential across the electrodes is varied linearly with time, and the resulting current is recorded as a function of the potential. As the increasing voltage is applied to the prepared sample within the cell, the various additive species under investigation within the oil are caused to electrochemically oxidize. The data recorded during this oxidation reaction can then be used to determine the remaining useful life of the oil type. A typical current-potential curve produced during the practice of the voltammetric test can be seen by reference to Fig. 1. Initially, the applied potential produces an electrochemical reaction having a rate so slow that virtually no current flows through the cell. As the voltage is increased, as shown in Fig. 1, the electro-active species (for example, substituted phenols) begin to oxidize at the working electrode surface, producing an anodic rise in the current. As the potential is further increased, the decrease in the electro-active species concentration at the

electrode surface and the exponential increase of the oxidation rate lead to a maximum in the current-potential curve shown in Fig. 1.

5. Significance and Use

5.1 The quantitative determination of hindered phenol antioxidants in a new turbine oil measures the amount of this material that has been added to the oil as protection against oxidation. Beside phenols, turbine oils can be formulated with other antioxidants such as amines which can extend the oil life. In used oil, the determination measures the amount of original (phenolic) antioxidant remaining after oxidation have reduced its initial concentration. This test method is not designed or intended to detect all of the antioxidant intermediates formed during the thermal and oxidative stressing of the oils, which are recognized as having some contribution to the remaining useful life of the used or in-service oil. Nor does it measure the overall stability of an oil, which is determined by the total contribution of all species present. Before making final judgment on the remaining useful life of the used oil, which might result in the replacement of the oil reservoir, it is advised to perform additional analytical techniques (in accordance with Practices D6224 and D4378), having the capability of measuring remaining oxidative life of the used oil.

5.1.1 This test method is applicable to non-zinc turbine oils. These are refined mineral oils containing rust and oxidation inhibitors, but not antiwear additives. This test method has not yet been established with sufficient precision for antiwear oils.



NOTE 1— x -axis = time (seconds) and y -axis is current (arbitrary units). Top line in Fig. 2 is fresh oil, and lower line is used oil.

FIG. 2 Amine and Hindered Phenols Peaks in the Basic Test Solution with Blank Response Zeroed

5.2 This test method is also suitable for manufacturing control and specification acceptance.

5.3 When a voltammetric analysis is obtained for a turbine oil inhibited with a typical hindered phenol antioxidant, there is an increase in the current of the produced voltammogram between 3 s to 5 s (or 0.3 V to 0.6 V applied voltage) (see Note 1) in the basic test solution (Fig. 1— x -axis 1 second = 0.1 V). Hindered phenol antioxidants detected by voltammetric analysis include, but are not limited to, 2,6-di-*tert*-butyl-4-methylphenol; 2,6-di-*tert*-butylphenol and 4,4'-methylenebis(2,6-di-*tert*-butylphenol).

NOTE 1—Voltages listed with respect to reference electrode. The voltammograms shown in Figs. 1 and 2 were obtained with a platinum reference electrode and a voltage scan rate of 0.1 V/s.

5.4 For non-zinc turbine oils containing aromatic (aryl) amine compounds (antioxidants and corrosion inhibitors), there is an increase in the current of the produced voltammogram between 7 s to 11 s (0.7 V to 1.1 V applied voltage in Fig. 2) (see Note 1) which does not interfere with the hindered phenol measurement in the basic test solution. For the measurement of these aromatic amine antioxidants, refer to Test Method D6971, where the neutral test solution shall be used.

6. Apparatus

6.1 *Voltammetric Analyzer*—The instrument used to quantify the hindered phenol antioxidants is a voltammograph equipped with a three-electrode system and a digital or analog output. The combination electrode system consists of a glassy carbon disc (3 mm diameter) working electrode, a platinum

wire (0.5 mm diameter) auxiliary electrode, and a platinum wire (0.5 mm diameter) reference electrode, as described in Test Method D6447. The voltammetric analyzer applies a linear voltage ramp (0 V to -1.8 V range with respect to the reference electrode) at a rate of 0.01 V/s to 0.5 V/s (0.1 optimum) to the auxiliary electrode. The current output of the working electrode is converted to voltage by the voltammetric analyzer, using the gain ratio of 1 V/20 μ A, and is outputted to an analog or digital recording device (0 V to 1 V full scale) as shown in Figs. 1 and 2.

6.2 *Vortex Mixer*, with a 2800 rpm to 3000 rpm motor and a pad suitable for mixing test tubes and vials.

6.3 *Pipette*, or equivalent, capable of delivering sample volumes required in this test method, from 0.10 mL to 0.50 mL.

6.4 *Solvent Dispenser*, or equivalent, capable of delivering volumes of analysis solution (see 8.3) required in this test method, such as 3.0 mL and 5.0 mL.

6.5 *Glass Vials*, with caps, 4 mL or 7 mL capacity; and containing 1 g of sand white quartz suitable for chromatography, within the size range of 200 μ m to 300 μ m \pm 100 μ m.

7. Sampling

7.1 Obtain the sample in accordance with Practice D4057.

8. Reagents

8.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that

all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁴ Other grades may be used, provided it is first ascertained that the reagent is sufficiently pure to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water*—Unless otherwise specified, references to water that conforms to Specification **D1193**, Type II.

8.3 *Analysis Materials:*

8.3.1 *Alcohol Test Solution (Basic Test Solution)*—Proprietary Yellow solution,⁵ ethanol solvent (1:10 ethanol solution/distilled water) containing a dissolved base electrolyte. (**Warning**—Corrosive, poison, flammable, skin irritant; harmful if inhaled.)

8.3.2 *Alcohol Cleansing Pads*—70 % isopropyl alcohol saturated cleansing pads.

9. Procedure

9.1 The voltammetric analyzer used in this test method gives linear results between 2 mmol to 50 mmol for hindered phenols using an oil sample size of 0.40 mL and 5.0 mL of the analysis solvent. The corresponding range of weight percents depends on the molecular weight of the hindered phenol and the density of the base oil. For instance, the weight % range of 0.044 to 1.1 is equal to 2 mmol/L to 50 mmol/L for a hindered phenol containing one hydroxyl group and with a molecular weight of 220 g/mol (2,6-di-tert-butyl-4-methylphenol) and an oil density of 1 g/mL. Below 2 mmol, the noise to signal ratio becomes large decreasing the accuracy of the measurements. For measurements below 2 mmol or for fresh oils with high noise to signal ratios, the sample size should be increased to 0.60 mL and the volume of analysis solvent decreased to 3.0 mL.

9.2 *General Voltammetric Test Procedure*—The test procedure for voltammetric analysis will consist of the blank reading (calibration), followed by a standard reading and finally the test sample (in-service oil) reading.

9.2.1 *Blank Reading*—(0 mmol/L = 0 % by weight).

9.2.1.1 *Definition*—The blank reading (voltammetric number) is a measurement of the analysis solution by itself. The blank measurement gives a reference number with no antioxidant present (the zero baseline).

9.2.2 *Standard Reading*—(30 mmol/L to 150 mmol/L—weight % dependent on density of fresh oil and molecular weight of antioxidant).

9.2.2.1 *Definition*—The standard reading is a measurement of a fresh, unused oil (containing phenolic antioxidant) mixed

with an appropriate analysis solvent. This measurement gives you a voltammetric reading (standard reading) that indicates the voltammetric response for the concentration hindered phenol antioxidant being analyzed for the oil being tested.

9.2.3 *Test Sample (In-Service Oil) Reading:*

9.2.3.1 *Definition*—The sample reading is a measurement of a fresh or in-service oil mixed with the same type of analysis solvent as the standard. This measurement will provide voltammetric readings that normally range between the blank and standard measurements, and reflect the concentration of hindered phenol antioxidant present (fresh oil) or remaining (in-service oil) in the oil sample. Voltammetric readings for in-service oil will decrease as hindered phenol antioxidants are depleted.

9.3 *Voltammetric Reading*—After the operator has selected the valleys before and after the antioxidant peaks (as shown in **Fig. 1**), the software (R-DMS) will automatically identify and calculate the area above the baseline between the two valley indicators. This calculated area is then used for the test sample reading (in-service oil), which will be established by comparing the in-service oil area to its standard (see **Fig. 3**) and make remaining antioxidant calculations (see Section 10). If peak shifting is occurring, it is advised to repeat the voltammetric test after performing the cleaning of the electrode. If after this second test the peak shifting remains persistent, it is advised to drag the valley indicators manually to their shifted locations.

9.4 *Calibration (Blank Reading) Procedure*—Pipette 5.0 mL of analysis solution into a 7 mL vial or other suitable container containing 1 g of sand. Insert the electrode of the voltammetric analyzer into the analysis solution to wet the bottom surface of the electrode, remove, and rub dry the bottom electrode surface with a lint-free paper towel. Insert the electrode into the vial so that the bottom of the electrode is submerged in the analysis solution without resting on the sand layer on the bottom of the vial. Place the vial/probe upright into the rack or foam block for testing. Perform the voltammetric analysis (see 6.1). Record the voltammetric reading in the voltage range of the phenols, 0.3 V to 0.6 V (see **Note 1**) in basic solution and **Fig. 1**. Remove the combination electrode from the blank solution and rub dry the bottom surface of the electrode with a lint free paper towel. Run at least two tests of the analysis solution to assure the electrode is clean and the minimal blank value has been obtained.

9.4.1 *Calibration Frequency*—Recalibration with freshly prepared blank solution can be performed before each testing session, or with the use of a new batch of test solutions.

9.5 *Standard and In-Service Oil Sample Preparation Procedures:*

9.5.1 *Preparing Solution Step*—Remove the seal and cap of the test solution vial. Pipette 5.0 mL of analysis solution into a 7 mL vial or other suitable container containing 1 g of sand. Pipette 0.40 mL of the selected oil sample also into the 7 mL vial.

9.5.2 For measurements below 2 mmol or for fresh oils with high noise to signal ratios, the sample size should be increased to 0.60 mL and the volume of analysis solvent decreased to 3.0 mL.

⁴ ACS Reagent Chemicals, Specifications and Procedures for Reagents and Standard-Grade Reference Materials, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

⁵ The sole source of supply of the apparatus known to the committee at this time is Fluitec International, Jersey City, NJ. 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.