



Designation: **D6971–09 (Reapproved 2014) D6971 – 22**

Standard Test Method for Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry¹

This standard is issued under the fixed designation D6971; 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 and aromatic amine antioxidants in new or in-service type non-zinc turbine oils in concentrations from ~~0.0075–0.0075 % by mass %~~ up to concentrations found in new oils by measuring the amount of current flow at a specified voltage in the produced voltammogram.

1.2 *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 ~~health~~ environmental practices and determine the applicability of regulatory limitations prior to use.*

1.3 *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
- D2272 Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel
- 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 for Auxiliary Power Plant Equipment
- D6810 Test Method for Measurement of Hindered Phenolic Antioxidant Content in Non-Zinc Turbine Oils by Linear Sweep Voltammetry

2.2 ISO Standards:³

- ISO 6743 Part 4, Lubricants, Industrial Oils, and Related Products

3. Terminology

3.1 Definitions:

3.1.1 See Terminology **D4175** for a more extensive list of terms used in this test method.

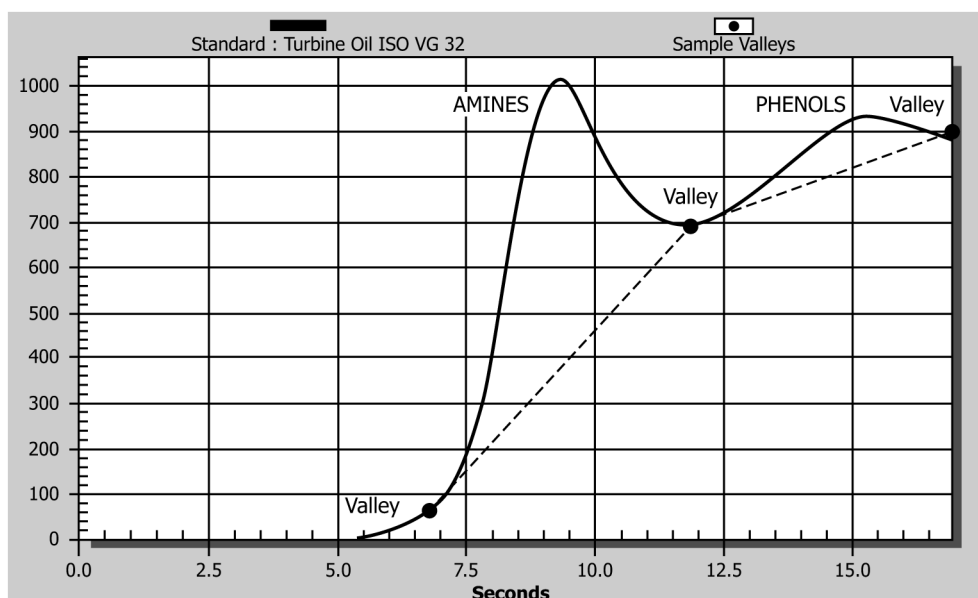
¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.09.0C on Oxidation of Turbine Oils.

Current edition approved May 1, 2014; Nov. 1, 2022. Published July 2014; November 2022. Originally approved in 2004. Last previous edition approved in 2009/2014 as D6971–09; D6971 – 09 (2014). DOI: 10.1520/D6971-09R14.10.1520/D6971-22.

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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

***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 indicators before and after antioxidant valleys.

FIG. 1 Aromatic Amine and Hindered Phenol Voltammetric Response in the Neutral Test Solution with Blank Response Zeroed

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. IUPAC⁴

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.

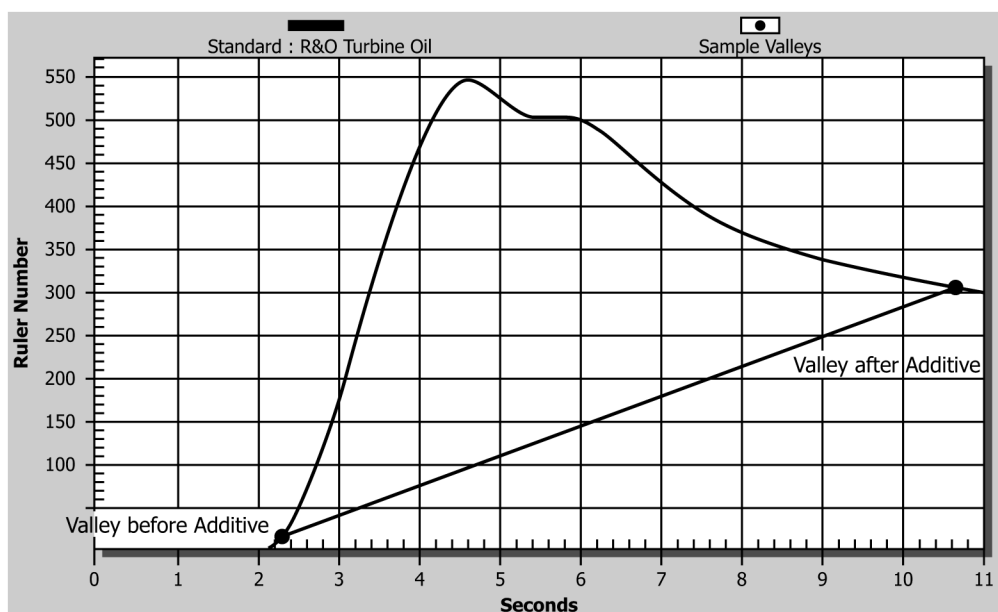
3.1.4 *voltammogram, n*—the plot of current versus voltage.

4. Summary of Test Method

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

4.2 Voltammetric analysis is a technique that applies electro-analytic methods wherein a sample to be analyzed is mixed with an electrolyte and a test solution, and placed within an 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, non-polarizable, 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, such as auxiliary electrodes, can be added to the electrode system to eliminate the effects of resistive drop for high resistance test 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

⁴ Inczedy, J., Lengyel, T., and Ure, A. M., *Orange Book: IUPAC Compendium on Analytical Nomenclature, Definitive Rules 1997*, 3rd Edition, Blackwell Science, 1998.



NOTE 1—x-axis = time (seconds) and y-axis is current (arbitrary units) with top line in Fig. 2 showing the fresh oil.

FIG. 2 Hindered Phenol Voltammetric Response in Basic Test Solution with Blank Response Zeroed

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 and aromatic amine antioxidants in a new turbine oil measures the amount of these compounds 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 in-service oil, the determination measures the amount of original (hindered phenol and aromatic amine) antioxidants remaining after oxidation has 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 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 in-service oil, which might result in the replacement of the oil reservoir, it is advised to perform additional analytical techniques (as in accordance with Test Methods D6224 and D4378; see also Test Method D2272), having the capability of measuring remaining oxidative life of the in-service oil.

5.1.1 This test method is applicable to non-zinc type of turbine oils as defined by ISO 6743 Part 4, Table 1. These are refined mineral oils containing rust and oxidation inhibitors, but not antiwear additives.

5.2 The test 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 synergistic mixture of hindered phenol and aromatic amine antioxidants, there is an increase in the current of the produced voltammogram between 88 s to 12 s (or 0.80.8 V to 1.2 V applied voltage) (see Note 1) for the aromatic amines, and an increase in the current of the produced voltammogram between 13 s and 16 s (or 1.3 V to 1.6 V applied voltage) (see Note 1) for the hindered phenols in the neutral acetone test solution (Fig. 1: x-axis 1 s = 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). Aromatic amine antioxidants detected by voltammetric analysis include, but are not limited to, phenyl alpha naphthylamines, and alkylated diphenylamines.

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 turbine oil containing only aromatic amines as antioxidants, there will only be an increase in the current of the produced voltammogram between ~~8 s~~ to ~~12 seconds~~ 12 s (or ~~0.80.8 V~~ to ~~1.2 V~~ 1.2 V applied voltage) (see **Note 1**) for the aromatic amines, by using the neutral acetone test solution (first peak in **Fig. 1**).

5.5 For turbine oils containing only hindered phenolic antioxidants, it is preferable to use a basic alcohol test solution rather than the neutral acetone test solutions, as there is an increase in the current of the produced voltammogram between ~~3 s~~ to ~~6 seconds~~ 6 s (or ~~0.30.3 V~~ to ~~0.6 V~~ 0.6 V applied voltage) (see **Note 1**) in basic alcohol test solution (**Fig. 2**: x-axis 1 second = 0.1 V) in accordance with Test Method **D6810**.

6. Apparatus

6.1 *Voltammetric Analyzer*—The instrument used to quantify the hindered phenol and aromatic amine 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 **D6810**. The voltammetric analyzer applies a linear voltage ramp (~~0 V~~ to ~~-1.8 V~~ -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~~ 1 V full scale) as shown in **Figs. 1 and 2**.

6.2 *Vortex Mixer*, with a ~~2800~~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 the test method, from ~~0.10 mL~~ to 0.50 mL.

6.4 *Test Solution Dispenser*, or equivalent, capable of delivering volumes of analysis test solution (see **6.37.3**) required in the test method, such as ~~3.0 mL~~ and 5.0 mL.

6.5 *Glass Vials*, with caps, 44 mL or 7 mL capacity and containing 1 g of sand. White quartz suitable for chromatography, within the size range of ~~200~~200 μ m to 300 μ m \pm 100 μ m.

7. Reagents

7.1 *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.⁵ Other grades may be used, provided it is first ascertained that the reagent's purity suffices to permit its use without lessening the accuracy of the determination.

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

7.3 Analysis Materials:

7.3.1 *Acetone Test Solution (Neutral)*—Proprietary Green Test Solution, Acetone test solution (1:10 distilled water/acetone test solution) containing a dissolved neutral electrolyte. (**Warning**—Corrosive, poisonous, flammable, and a skin irritant. Harmful if inhaled.)

7.3.2 *Alcohol Test Solution (Basic)*—Proprietary Yellow Test Solution, Ethanol test solution (1:10 distilled water/ethanol test solution) containing a dissolved base electrolyte. (**Warning**—Corrosive, poisonous, flammable, and a skin irritant. Harmful if inhaled.)

⁵ *Reagent Chemicals, American Chemical Society Specifications, ACS Reagent Chemicals, Specifications and Procedures for Reagents and Standard-Grade Reference Materials*, American Chemical Society, Washington, DC. For ~~Suggestions~~ suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Analytical 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.

7.3.3 *Alcohol Cleansing Pads*—70 % isopropyl alcohol saturated cleansing pads (alcohol prepared skin cleansing pads, for the preparation of the skin prior to injection (antiseptic)).

8. Sampling

8.1 Obtain the sample in accordance with Practice [D4057](#).

9. Procedure

9.1 The voltammetric analyzer used in this test method gives linear results between 22 mmol to 50 mmol for hindered phenols and aromatic amines using an oil sample size of 0.40 mL and 5.0 mL of the analysis test solution. The corresponding range of mass % depends on the molecular weight of the hindered phenol and aromatic amine, and the density of the base oil. For instance, the mass % range of 0.044 to 1.1 is equal to 22 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 test solution 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 sample (in-service oil) reading.

9.2.1 *Blank Reading*—($0 \text{ mmol/L} = 0 \text{ mass \%}$)- 0 \% by mass).

9.2.1.1 The blank reading (voltammetric number) is a measurement of the analysis test 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 —mass % dependent on density of fresh oil and molecular weight of antioxidant).

9.2.2.1 The standard reading is a measurement of a fresh, unused oil (containing hindered phenol and amines antioxidants) mixed with an appropriate analysis test solution. This measurement gives you a voltammetric reading (standard reading) that indicates the voltammetric response for the concentration hindered phenol and aromatic amines antioxidants being analyzed for the oil being tested.

9.2.3 *Sample (In-service Oil) Reading*.

9.2.3.1 The sample reading is a measurement of a fresh or in-service oil mixed with the same type of analysis test solution 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 and aromatic amine antioxidant present (fresh oil) or remaining (in-service oil) in the oil sample. Voltammetric readings for in-service oils will decrease as hindered phenol and aromatic amine 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-DMS⁶) will automatically identify and calculate the area above the baseline between the two valley indicators. This calculated area is then used for the 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 910](#)).

9.3.1 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 is occurring again, 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 test 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 test solution to wet the bottom surface

⁶ R-DMS is a software package trademarked by and available from Fluitec International, 1997 Newborn Rd., Rutledge, GA 30663, USA and Nieuwbrugstraat 73, B-1830, Machele, Belgium.