



Designation: D 6894 – 03

An American National Standard

Standard Test Method for Evaluation of Aeration Resistance of Engine Oils in Direct- Injected Turbocharged Automotive Diesel Engine¹

This standard is issued under the fixed designation D 6894; 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.

INTRODUCTION

Any properly equipped laboratory, without outside assistance, can use the procedure described in this test method. However, the ASTM Test Monitoring Center (TMC)² provides reference oils and an assessment of the test results obtained on those oils by the laboratory. By these means, the laboratory will know whether their use of the test method gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory utilize the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army imposes such a requirement in connection with several Army engine lubricating oil specifications.

Accordingly, this test method is written for use by laboratories that utilize the TMC services. Laboratories that choose not to use those services may simply ignore those portions of the test method that refer to the TMC.

This test method may be modified by means of information letters issued by the TMC. In addition, the TMC may issue supplementary memoranda related to the method. For other information, refer to the research report for this test method.³

1. Scope

1.1 This test method was designed to evaluate an engine oil's resistance to aeration in automotive diesel engine service. It is commonly referred to as the Engine Oil Aeration Test (EOAT). The test is conducted using a specified 7.3L, direct-injection, turbocharged diesel engine on a dynamometer test stand. This test method was developed as a replacement for Test Method D 892 after it was determined that this bench test did not correlate with oil aeration in actual service. The EOAT was first included in API Service Category CG-4 in 1995.

NOTE 1—Companion test methods used to evaluate engine oil performance for specification requirements are discussed in the latest revision of Specification D 4485.

1.2 The unit values stated in this test method shall be regarded as the standard. The values given in parentheses are provided for information only. SI units are considered the primary units for this test method. The only exception is where there is no direct SI equivalent, for example, screw threads, national pipe threads/diameters, and tubing size.

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

1.4 This test method is arranged as follows:

	Section
Scope	1
Referenced Documents	2
Terminology	3
Summary of Test Method	4
Significance and Use	5
Apparatus	6
Reagents and Materials	7
Preparation of Apparatus	8
Calibration	9
Test Procedure	10
Determination of Test Results	11
Report	12
Precision and Bias	13
Keywords	14
Engine System Drawings	Annex A1

2. Referenced Documents

2.1 ASTM Standards:

- D 86 Test Method for Distillation of Petroleum Products⁴
- D 93 Test Method for Flash Point by Pensky-Martens Closed Cup Tester⁴

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants.

Current edition approved July 10, 2003. Published September 2003.

² ASTM Test Monitoring Center (TMC), 6555 Penn Avenue, Pittsburgh, PA 152006-4489.

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02-1379.

⁴ *Annual Book of ASTM Standards*, Vol 05.01.

- D 97 Test Method for Pour Point of Petroleum Products⁴
- D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test⁴
- D 287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)⁴
- D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids⁴
- D 482 Test Method for Ash from Petroleum Products⁴
- D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products⁴
- D 613 Test Method for Ignition Quality of Diesel Fuels by Cetane Method⁴
- D 664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration⁴
- D 892 Test Method for Foaming Characteristics of Lubricating Oils⁴
- D 1250 ASTM-IP Petroleum Measurement Tables⁴
- D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Absorption⁴
- D 2500 Test Method for Cloud Point of Petroleum Products⁴
- D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry⁵
- D 2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge⁵
- D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter⁵
- D 4175 Terminology Relating to Petroleum, Petroleum Products and Lubricants⁵
- D 4485 Specification for Performance of Engine Oils⁵
- D 4737 Test Method for Calculated Cetane Index by Four Variable Equation⁵
- D 5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting⁶
- D 5862 Test Method for Evaluation of Engine Oils in the Two-Stroke Cycle Turbocharged 6V92TA Diesel Engine⁵
- D 6082 Test Method for High Temperature Foaming Characteristics of Lubricating Oils⁶
- D 6557 Test Method for Evaluation of Rust Preventative Characteristics⁶
- D 6594 Test Method for Evaluation of Corrosiveness of Diesel Engine Oil at 135°C⁶
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications⁷
- IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System⁷
- 2.2 *SAE Standard:*
- J 304 Engine Oil Tests⁸
- 2.3 *API Standard:*

API 1509 Engine Oil Licensing and Certification System⁹

3. Terminology

3.1 Definitions:

3.1.1 *automotive, adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines. **D 6594**

3.1.2 *calibrate, v*—to determine the indication or output of a measuring device with respect to that of a standard.

3.1.3 *candidate oil, n*—an oil that is intended to have the performance characteristics necessary to satisfy a specification and is to be tested against that specification. **D 5844**

3.1.4 *engine oil, n*—a liquid that reduces friction or wear, or both, between the moving parts within an engine; removes heat particularly from the underside of pistons; and serves as combustion gas sealant for the piston rings.

3.1.4.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples. **D 5862**

3.1.5 *foam, n—in liquids*, a collection of bubbles formed in or on the surface of a liquid in which the air or gas is the major component on a volumetric basis. **D 6082**

3.1.6 *heavy-duty, adj—in internal combustion engine operation*, characterized by average speeds, power output and internal temperatures that are close to the potential maximums. **D 4485**

3.1.7 *heavy-duty engine, n—in internal combustion engines*, one that is designed to allow operation continuously at or close to its peak output. **D 4485**

3.1.8 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D 5862**

3.1.9 *non-reference oil, n*—any oil other than a reference oil; such as a research formulation, commercial oil, or candidate oil. **D 5844**

3.1.10 *reference oil, n*—an oil of known performance characteristics, used as a basis for comparison. **D 5844**

3.1.11 *test oil, n*—any oil subjected to evaluation in an established procedure. **D 6557**

3.1.12 *used oil, n*—any oil that has been in a piece of equipment (for example, an engine, gearbox, transformer, or turbine), whether operated or not. **D 4175**

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *aeration, n—in liquids*, the action of impregnating with air that forms foam bubbles in or on the surface of a liquid or is entrained as a dispersion in that liquid.

3.2.2 *flush, n*—the action of cleaning out the engine oil system using new test oil to remove any residues as well as to minimize possible carryover effect from the previous test oil.

3.2.3 *HEUI, n*—hydraulically-actuated, electronically-controlled, unit injector.¹⁰

⁵ Annual Book of ASTM Standards, Vol 05.02.

⁶ Annual Book of ASTM Standards, Vol 05.04.

⁷ Annual Book of ASTM Standards, Vol 14.02.

⁸ Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001. This standard is not available separately. Either order the SAE Handbook Vol. 3 or the SAE Fuels and Lubricants Standards Manual HS-23.

⁹ Available from The American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005.

¹⁰ Glassey, S. F., Stockner, A. R., and Flinn, M. A., "HEUI—A New Direction for Diesel Engine Fuel System," SAE Publication 930270; Hower, M. J., Mueller, R. A., Oehlerking, D. A., and Zielke, M. R., "The New Navistar T444E Direct-Injection Turbocharged Diesel Engine," SAE Publication 930161.

4. Summary of Test Method

4.1 The test engine is a 1994 unit built by International Truck and Engine Corporation¹¹ (Model No. A215). This engine is equipped with the HEUI fuel system.¹⁰ It is installed in a fully instrumented test cell.

4.2 The test sequence consists of a five-step, warm-up period followed by a one-step evaluation period for 20 h at maximum power.

4.3 Aerated oil samples are taken after 1 h, 5 h, and 20 h and the percent oil aeration is calculated from the initial volume and the final volume after sitting undisturbed for 30 min.

5. Significance and Use

5.1 *Background*—In the HEUI fuel system, the engine oil from the oil sump not only lubricates the engine, it also supplies a high-pressure oil system that takes oil from the main gallery and pressurizes it up to 20.7 MPa (3000 psi) in a plunger pump (see Fig. A1.1). This oil is used to operate unit injectors that, when used in combination with intensifiers, increase the fuel injection pressure up to 145 MPa (21 000 psi), independent of engine speed. The electronic controls permit varied injection timing and duration to provide optimum fuel economy and emissions. This system may, however, circulate all the oil in the sump in approximately 8 s; as a consequence, aeration of the oil can occur with some engine oils. International determined that 8 % oil aeration was the limit beyond which engine operation and performance would be impaired in actual service.

5.1.1 Prior to 1994, the ability of an engine lubricant to resist aeration was measured by Test Method D 892. During the development of the API CG-4 category in 1994, however, it was found¹² that this bench test did not correlate with aeration in the International T 444E engine. The EOAT was developed, therefore, to provide a better measurement of the ability of a lubricant to resist aeration during engine operation. This test has been included in API CG-4, CH-4, and CI-4 categories for heavy-duty diesel engine oils.

5.2 *Method*—The data obtained from the use of this test method provide a comparative index of the aeration resistance of engine oils used in medium- and heavy-duty truck diesel engines.

5.3 *Use*—The tendency of engine oils to aerate in direct-injection, turbocharged diesel engines is influenced by a variety of factors, including engine oil formulation variables, oil temperature, sump design and capacity, residence time of the oil in the sump, and the design of the pressurized oil systems. In some engine-oil-activated injection systems, the residence time of the oil in the sump is insufficient to allow dissipation of aeration from the oil. As a consequence, aerated oil can be circulated to the injector intensifiers, adversely affecting the injection timing characteristics and engine operation.

¹¹ Hereinafter referred to as International, which is the trademark of the International Truck and Engine Corporation.

¹² McGeehan et al., "The World's First Diesel Engine Oil Category for Use with Low-Sulfur Fuel: API CG-4," SAE Publication 981371.

TABLE 1 Oil Circulation Rates in the International 7.3L Engine

Engine speed, r/min	Oil capacity, L (gal)	Oil flow rate, L/min (gal/min)	Time for one pass through, s	Circulation of oil in sump, times/min
3000	13.3 (3.5)	105 (27.6)	7.6	8

6. Apparatus

6.1 *Test Engine*—The test engine^{13,14} is an International 1994, 7.3L, direct-injection, turbocharged, V-8, diesel engine, rated at 160 kW at 3000 r/min. The engine model number is A215. The engine arrangement is shown in Figs. A1.2 and A1.3 and the lubrication system in Fig. A1.4. This engine is equipped with the HEUI fuel system (see 5.1 and Fig. A1.1). Details of the engine are documented in the International T 444E Diesel Engine Service Manual for Truck Application Form EGES-121 dated April 2002.¹⁵ The engine serial number carries the designation 7.4JU2UXXXXXX. The test engine is installed in a fully instrumented test cell.

6.1.1 *Engine Modification*—Install a ¼ in. male national pipe thread (NPT) stainless steel hex nipple^{14,16} in the threaded outlet on the right (passenger) side of the engine's high-pressure oil reservoir. Install a ¼ in. female NPT inlet and outlet, stainless steel, ball-valve onto the hex nipple with the flow arrow facing away from the reservoir. Install a ¼ in. male NPT to male No. 4 SAE (JIC) 37° flare stainless steel adapter fitting in the downstream side of the ball valve. Make up a polytetrafluoroethylene (PTFE)-lined, stainless steel braid, No. 4 hose, with female swivel No. 4 SAE (JIC) 37° female flare fittings on each end. The overall line length should be approximately 115 cm. Modify a male No. 4 SAE(JIC) 37° flare to ¼ in. fractional tube female compression adapter fitting so that there is a 0.394 mm orifice through the fitting. Insert a 37.5 cm long, ¼ in. thin-wall, steel, fractional tube (this is to be the sample wand) into the female compression adapter and tighten. For safety, install an insulating handle around the steel tube to avoid being burned while holding the wand.

6.2 *Power Absorption*—Install a 186 kW eddy-current absorption dynamometer in the test cell.

6.3 *Aeration*—The HEUI system takes oil from the main gallery and pressurizes it in a plunger pump up to 20.7 MPa (3000 psi). The arrangement is shown in Fig. A1.1. The pressurized oil operates unit injectors that increase the fuel pressure up to 145 MPa (21 000 psi) with the help of intensifiers (see Fig. A1.5). The electronic controls permit varied injection timing and duration to provide optimum fuel economy and emissions. As shown in Table 1, this operation

¹³ The sole source of supply of the engine known to the committee at this time is Franklin Power Products, 400 North Forsythe St., Franklin, Indiana 46131. Tel: 317-738-2117.

¹⁴ 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.

¹⁵ Available through any authorized International dealer.

¹⁶ The hardware specified in this section may be sourced from the following suppliers: Nupro Company, 4800 East 345th St., Willoughby, Ohio 44094; Parker Hannifin Corporation, 1300 North Freedom St., Ravenna, Ohio 44266; Swagelok Company, Solon, Ohio 44139.

can circulate all the lubricating oil in the sump in approximately 8 s. For oils with unsatisfactory aeration resistance, this very short residence time is insufficient to allow aeration in the oil to dissipate. As a consequence, aerated oil is circulated to the injector intensifiers, adversely affecting the injection timing characteristics and engine operation.

6.4 Instrumentation—The engine and dynamometer shall be instrumented to measure the following parameters:

- Engine speed, r/min
- Torque, N·m
- Power, kW
- Fuel flow rate, kg/h
- Coolant temperature, in and out, °C
- Oil gallery temperature, °C
- Intake air temperature, °C
- Fuel temperature, °C
- Intake manifold temperature after turbocharger, °C
- Ambient temperature, °C
- Oil gallery pressure, kPa
- Intake manifold pressure, kPa
- Exhaust pressure, after turbocharger, at left and right manifolds, kPa
- Crankcase pressure, kPa
- Intake air pressure after filter, kPa
- Tailpipe pressure, kPa

6.5 Miscellaneous:

6.5.1 Nine 100 mL graduated glass cylinders.

6.5.2 A weighed, glass sample bottle, of suitable capacity to hold 120 mL, with inert, lined lids.

6.5.3 A weighed oil-drain container, of suitable capacity, for collecting hot purged oil; a 20 L bucket is convenient.

7. Reagents and Materials

7.1 Engine Oil—Use only engine oils of performance category API CI-4, CH-4, and CG-4 or their equivalent performance replacements when running the engine for passivating sealants (see 8.3.3), breaking-in and other routine operations.

7.2 Reference Oils—The TMC uses reference oils (TMC 1004 and TMC 1005) to establish test precision. Calibration tests using these two reference oils are required after 30 operationally valid non-reference oil test runs or one year, whichever is sooner. As new data are generated at the laboratories running this test, the TMC will update the test precision accordingly.

7.3 Test Fuel—Use low-sulfur reference diesel fuel (LSRD-4) containing 0.03 weight % to 0.05 weight % sulfur for this test.^{14,17} All fuel shall meet the fuel specifications shown in Table 2. Include in the final report the fuel analysis for the last batch of fuel used for the test. The fuel supplier provides the analysis. If more than one batch is used, note this in the comments section with the appropriate percentages of run time.

7.4 Engine Coolant—The engine coolant shall be 50/50 percent (by volume) commercially additized ethylene glycol coolant/water. To protect the cylinder walls from external cavitation, add commercially available supplementary coolant additives (SCAs), initially and after every 200 h of engine operation, at the SCA manufacturer's recommended treat rate. Water shall be deionized, demineralized, or distilled.

TABLE 2 Test Fuel Specifications

Measurement	Specification	Test Method
Total sulfur, wt %	0.03 to 0.05	D 2622
Gravity, API	32 to 36	D 287 or D 4052
Hydrocarbon Composition		
Aromatics, volume %	28 to 35	D 1319
Olefins, volume %	Report	D 1319
Saturates, volume %	Report	D 1319
Cetane Index	Report	D 4737
Cetane Number	42 to 48	D 613
Copper Strip Corrosion, rating after 3 h at 100°C	3 max	D 130
Total Acid Number, mg KOH/g	Report	D 664
Strong Acid Number, mg KOH/g	Report	D 664
Flash Point, °C	Report	D 93
Cloud Point, °C	−12 max	D 2500
Pour Point, °C	−18 max	D 97
Ash, weight %	0.01 max	D 482
Carbon residue on 10 % residium, %	0.3 max	D 524 (10 % bottoms)
Water and Sediment, % volume	0.05 max	D 2709
Kinematic viscosity at 40°C, mm ² /s	2.0 to 3.2	D 445
Distillation, °C		
IBP	177 to 199	D 86
10 %	210 to 232	D 86
50 %	249 to 277	D 86
90 %	299 to 327	D 86
EP	327 to 360	D 86

7.5 Cleaning Materials:

7.5.1 Solvent—Use aliphatic naphtha (Stoddard) hydrocarbon solvent. (**Warning**—Flammable. Eye irritant. Wear goggles or face shield (as for gasoline).)

7.5.2 Engine Cooling System Cleanser—Use the following:

7.5.2.1 Oxalic Acid Dihydrate Technical Grade. (**Warning**—Toxic Substance. Avoid contact with eyes, skin, and clothing.)

7.5.2.2 Petro Dispersant 425 surfactant (the sodium salt of alkylatid naphthalene).

NOTE 2—These chemicals can be purchased as a premixed pack.^{14,18}

8. Preparation of Apparatus

8.1 This section assumes that the engine test stand facilities and hardware as described in Section 6 are in place. Emphasis is on the recurring preparations needed in the routine conduct of the test.

8.2 Test Stand Preparation:

8.2.1 Instrument Preparation—Calibrate, and record for future reference, the temperature measuring system in a manner consistent with good laboratory practices.

8.2.2 Hose Replacement—Inspect all hoses and replace any that have deteriorated. Check for internal wall separations that would cause flow restriction.

8.3 Engine Preparation:

8.3.1 General Assembly Instructions—Assemble the external engine accessory components according to the detailed description in the International T 444E Diesel Engine Service Manual. In cases of disparity, however, the explicit instructions contained in this test method take precedence over the service manual.

¹⁷ The sole source of supply of the apparatus known to the committee at this time is .Haltermann Products, 1201 South Sheldon Road, PO Box 429, Channel View, TX 77530-0426.

¹⁸ The sole source of supply of the premixed cooling system cleanser known to the committee at this time is Wrico Corporation, 4835 Whirlwind, San Antonio, TX 78217.