



Designation: D6681 – 15

Standard Test Method for Evaluation of Engine Oils in a High Speed, Single-Cylinder Diesel Engine—Caterpillar 1P Test Procedure¹

This standard is issued under the fixed designation D6681; 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 test method described in this standard. However, the ASTM Test Monitoring Center (TMC)² provides calibration oils and an assessment of the test results obtained on those oils by the laboratory. By this 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 has such a requirement in some of its engine oil specifications. Accordingly, this test method is written for those laboratories that use the TMC services. Laboratories that choose not to use these services should ignore those portions of the test method that refer to the TMC. Information Letters issued periodically by the TMC may modify this method.³ In addition, the TMC may issue supplementary memoranda related to the test method.

1. Scope*

1.1 This test method covers and is required to evaluate the performance of engine oils intended to satisfy certain American Petroleum Institute (API) C service categories (included in Specification D4485). It is performed in a laboratory using a standardized high-speed, single-cylinder diesel engine.⁴ Piston and ring groove deposit-forming tendency and oil consumption is measured. The piston, the rings, and the liner are also examined for distress and the rings for mobility.

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

1.2.1 *Exceptions*—Where there is no direct SI equivalent such as screw threads, National Pipe Threads/diameters, tubing size, or where there is a sole source supply equipment specification.

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.B0.02 on Heavy Duty Engine Oils.

Current edition approved April 1, 2015. Published May 2015. Originally approved in 2001. Last previous edition approved in 2014 as D6681 – 14. DOI: 10.1520/D6681-15.

² ASTM Test Monitoring Center (TMC), 6555 Penn Ave., Pittsburgh, PA 15206-4489.

³ This edition incorporates revisions contained in all information letters through 14-2. Users of this test method shall contact the ASTM Test Monitoring Center to obtain the most recent information letters.

⁴ Available from Caterpillar Inc., Engine System Technology Development, P.O. Box 610, Mossville, IL 61552-0610.

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.* Being an engine test method, this standard does have definite hazards that require safe practices (see Appendix X2 on Safety).

1.4 The following is the Table of Contents:

	Section
Scope	1
Referenced Documents	2
Terminology	3
Summary of Test Method	4
Significance and Use	5
Apparatus and Installation	6
Intake Air System	6.2.1
Exhaust System	6.2.2
Fuel System	6.2.3
Oil Consumption System	6.2.4
Engine Oil System	6.2.5
Oil Heating System	6.2.5.1
Oil Sample Valve	6.2.5.2
Engine Coolant System	6.2.6
Engine Instrumentation	6.2.7
Reagents and Materials	7
Oil Samples	8
Preparation of Apparatus	9
General Engine Assembly Practices	9.1
Complete Engine Inspection	9.2
Copper Components	9.3
Engine Lubricant System Flush	9.4
Engine Piston Cooling Jets	9.5
Engine Measurements and Inspections	9.6
Cylinder Head	9.7
Valve Guide Bushings	9.8

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

Fuel Injector	9.9
Piston and Rings	9.10
Cylinder Liner	9.11
Compression Ratio	9.12
Engine Timing	9.13
Engine Coolant System Cleaning Procedure	9.14
Calibration and Standardization	10
Test Cell Instrumentation	10.1
Instrumentation Standards	10.2
Coolant Flow	10.3
Re-calibration Requirements	10.4
Fuel Injectors	10.5
Air Flow	10.6
Intake Air Barrel	10.7
Fuel Filter	10.8
Oil Scale Flow Rates	10.9
Calibration of Test Stands	10.10
Extending Test Stand Calibration Period	10.11
Test Run Numbering	10.13
Humidity Calibration Requirements	10.14
Calibration of Piston Deposit Raters	10.15
Procedure	11
Engine Break-in Procedure	11.1
Cool-down Procedure	11.2
Warm-up Procedure	11.3
Shutdowns and Lost Time	11.4
Periodic Measurements	11.5
Engine Control Systems	11.6
Engine Coolant	11.6.1
Engine Fuel System	11.6.2
Engine Oil Temperature	11.6.3
Exhaust Pressure	11.6.4
Intake Air	11.6.5
Post-Test Procedures	11.7
Piston Ring Side Clearances	11.7.1
Piston Ratings	11.7.2
Referee Ratings	11.7.3
Ring End Gap Increase	11.7.4
Cylinder Liner Wear	11.7.5
Cylinder Liner Bore Polish	11.7.6
Photographs	11.7.7
Calculation and Interpretation of Results	12
Test Validity	12.1
Calculations	12.2
Quality Index	12.2.1
Oil Consumption	12.2.2
Report	13
Forms and Data Dictionary	13.1
Test Validity	13.2
Report Specifics	13.3
Precision and Bias	14
Precision	14.1
Bias	14.1.4
Keywords	15
Annexes	
Engine and Parts Warranty	Annex A1
Instrument Locations, Measurements, and Calculations	Annex A2
Cooling System Arrangement	Annex A3
Intake Air Mass Flow Sensor Installation	Annex A4
Fuel System Design and Required Components	Annex A5
Oil System	Annex A6
Exhaust and Intake Barrel Piping	Annex A7
Humidity Probe Installation (Location)	Annex A8
Return Goods Authorization (Claim Form)	Annex A9
Engine Assembly Information	Annex A10
Flushing Instructions and Apparatus	Annex A11
Warm-up, Cool-down and Testing Conditions	Annex A12
Piston and Liner Rating Modifications	Annex A13
Additional Report Forms	Annex A14
Test Report Forms	Annex A15
Appendixes	
Various Examples for Reference Purposes	Appendix X1
Safety	Appendix X2

2. Referenced Documents

2.1 ASTM Standards:⁵

- D86** Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D93** Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
- D97** Test Method for Pour Point of Petroleum Products
- D130** Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
- D235** Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
- D445** Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
- D482** Test Method for Ash from Petroleum Products
- D524** Test Method for Ramsbottom Carbon Residue of Petroleum Products
- D613** Test Method for Cetane Number of Diesel Fuel Oil
- D664** Test Method for Acid Number of Petroleum Products by Potentiometric Titration
- D1319** Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- D2274** Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
- D2425** Test Method for Hydrocarbon Types in Middle Distillates by Mass Spectrometry
- D2500** Test Method for Cloud Point of Petroleum Products
- D2622** Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
- D2709** Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
- D3227** Test Method for (Thiol Mercaptan) Sulfur in Gasoline, Kerosine, Aviation Turbine, and Distillate Fuels (Potentiometric Method)
- D3524** Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography
- D4175** Terminology Relating to Petroleum, Petroleum Products, and Lubricants
- D4052** Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
- D4485** Specification for Performance of Active API Service Category Engine Oils
- D4739** Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
- D5185** Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

⁵ 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.

D5862 Test Method for Evaluation of Engine Oils in Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine (Withdrawn 2009)⁶

D6202 Test Method for Automotive Engine Oils on the Fuel Economy of Passenger Cars and Light-Duty Trucks in the Sequence VIA Spark Ignition Engine (Withdrawn 2009)⁶

D6593 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions

D7422 Test Method for Evaluation of Diesel Engine Oils in T-12 Exhaust Gas Recirculation Diesel Engine

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

G40 Terminology Relating to Wear and Erosion

2.2 SAE Standard:

SAE J183 Engine Oil Performance and Engine Service Classification⁷

2.3 API Standard:

API 1509 Engine Service Classification and Guide to Crankcase Oil Selection⁸

2.4 Other ASTM Document:

ASTM Deposit Rating Manual 20 (formerly CRC Manual 20)⁹

3. Terminology

3.1 Definitions:

3.1.1 *additive*, *n*—a material added to another, usually in a small amount, to impart or enhance desirable properties or to suppress undesirable properties. **D4175**

3.1.2 *automotive*, *adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines. **D4485**

3.1.3 *blind reference oil*, *n*—a reference oil, the identity of which is unknown by the test facility. **D4175**

3.1.3.1 *Discussion*—This is a coded reference oil which is submitted by a source independent from the test facility.

3.1.4 *blowby*, *n*—in internal combustion engines, that portion of the the combustion products and unburned air/fuel mixture that leaks past piston rings into the engine crankcase during operation. **D4175**

3.1.5 *calibrate*, *v*—to determine the indication or output of a device (e.g., thermometer, manometer, engine) with respect to that of a standard.

3.1.6 *calibrated test stand*, *n*—a test stand on which the testing of reference material(s), conducted as specified in the standard, provided acceptable test results. **Sub. B Glossary**²

3.1.6.1 *Discussion*—In several automotive lubricant standard test methods, the ASTM Test Monitoring Center provides testing guidance and determines acceptability.

3.1.7 *candidate oil*, *n*—an oil which is intended to have the performance characteristics necessary to satisfy a specification and is to be tested against that specification. **D4175**

3.1.7.1 *Discussion*—These oils are mainly submitted for testing as *candidates* to satisfy a specified performance; hence the designation of the term.

3.1.8 *debris*, *n*—in internal combustion engines, solid contaminant materials unintentionally introduced into the engine or resulting from wear. **D5862**

3.1.9 *dispersant*, *n*—in engine oil, an additive that reduces deposits on oil-wetted engine surfaces primarily through suspension of particles. **D4175**

3.1.10 *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 a combustion gas sealant for the piston rings. **D5862**

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

3.1.11 *heavy-duty*, *adj*— in internal combustion engine operation, characterized by average speeds, power output, and internal temperatures that are generally close to the potential maximums. **D4485**

3.1.12 *lubricant*, *n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D5862**

3.1.13 *lubricating oil*, *n*—a liquid lubricant, usually comprising several ingredients, including a major portion of base oil and minor portions of various additives. **D4175**²

3.1.14 *oxidation*, *n*—of engine oil, the reaction of the oil with an electron acceptor, generally oxygen, that can produce deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or a combination thereof. **D4175**

3.1.15 *non-reference oil*, *n*—any oil other than a reference oil; such as a research formulation, commercial oil, or candidate oil. **D4175**

3.1.16 *purchaser*, *n*—of an ASTM test, person or organization that pays for the conduct of an ASTM test method on a specified product. **D6202**

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

3.1.17.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other material (such as seals) that interact with oils. **D4175**

3.1.18 *scoring*, *n*—in tribology, a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding. **G40**

3.1.19 *scuffing*, *n*—in lubrication, damage caused by instantaneous localized welding between surfaces in relative motion which does not result in immobilization of the parts. **D6593**

⁶ The last approved version of this historical standard is referenced on www.astm.org.

⁷ Available from the Society of Automotive Engineers Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

⁸ Available from the American Petroleum Institute, 1220 L Street NW, Washington DC, 20005.

⁹ For Stock #TMCML20, visit the ASTM website, www.astm.org, or contact ASTM International Customer Service at service@astm.org.

3.1.20 *sponsor, n*—of an ASTM test method, an organization that is responsible for ensuring supply of the apparatus used in the test procedure portion of the test method. **D4175**

3.1.20.1 *Discussion*—In some instances, such as a test method for chemical analysis, an ASTM working group can be the sponsor of the test method. In other instances, a company with a self-interest may or may not be the developer of the test procedure used within the method, but is the sponsor of the test method.

3.1.21 *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. **D4175**

3.1.22 *varnish, n*—in internal combustion engines, a hard, dry, generally lustrous deposit that can be removed by solvents but not by wiping with a cloth. **D4175**

3.1.23 *wear, n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action or a combination of both. **D7422**

4. Summary of Test Method

4.1 Prior to each test, the power section of the engine is disassembled, solvent-cleaned, measured, and rebuilt in strict accordance with the specifications. A new piston, ring assembly, and cylinder liner are measured and installed for each test. The engine crankcase is solvent-cleaned and worn or defective parts are replaced. The test stand is equipped with feedback control systems for fuel rate, engine speed, and other engine operating conditions. A suitable system for filtering, compressing, humidifying, and heating the inlet air is required along with a system for controlling the engine exhaust pressure. Test operations involve the control of the single-cylinder diesel test engine for a total of 360 h at specified speeds and fuel rate input using the test oil as a lubricant. A defined break-in precedes each test and is also used when restarting an engine. At the end of the test, the piston deposits are rated, the piston, rings and liners are photographed, inspected and measured, oil consumption is calculated and the oil is analyzed to determine the test results. Critical engine conditions are statistically analyzed to determine if the test was precisely operated. Test acceptability parameters for each calibration test are also statistically analyzed to determine if the engine/test stand produce the specified results.

5. Significance and Use

5.1 This is an accelerated engine oil test, performed in a standardized, calibrated, stationary single-cylinder diesel engine that gives a measure of (1) piston and ring groove deposit forming tendency, (2) piston, ring and liner scuffing and (3) oil consumption. The test is used in the establishment of diesel engine oil specification requirements as cited in Specification **D4485** for appropriate API Performance Category C oils (API 1509). The test method can also be used in diesel engine oil development.

6. Apparatus and Installation

6.1 The test engine is an electronically controlled, direct injection, in-head camshaft, single-cylinder diesel engine with

a four-valve arrangement. The engine has a 137.2 mm bore and a 165.1 mm stroke resulting in a displacement of 2.4 L.

6.1.1 The electronic control module (ECM) defines the desired engine fuel timing, monitors and limits maximum engine speed, maximum engine power, minimum oil pressure, and, optionally, maximum engine crankcase pressure. The ECM also controls the fuel injection duration that defines the engine fuel rate based on set conditions from the test cell feedback control systems. The oil pressure is also set by the ECM with signals to the 1Y3867 engine air pressure controller (Mamac) to modulate the facility air supply to the 1Y3898 Johnson Controls relief valve.

6.1.2 The 1Y3700 engine arrangement also consists of inlet air piping and hoses from the cylinder head to the air barrel and exhaust piping and bellows from the cylinder head to the exhaust barrel that are specifically designed for oil testing. See the Caterpillar Service Manual.⁴

6.2 Equip the engine test stand with the following accessories or equipment:

6.2.1 *Intake Air System*—The intake air system components from the cylinder head to the air barrel are a part of the basic 1Y3700 engine arrangement. These components consisting of an adapter, elbow, hose, clamps, and flanged tube can be found in the 1Y3700 Parts Book.⁴

6.2.1.1 Purchase the 1Y3978 intake air barrel (which is almost identical to the exhaust barrel except for the top cover) that has been specifically designed from one of the three approved manufacturers.^{10,11} Install the intake air barrel at the location shown in **Annex A7**. Do not add insulation to the barrel.

6.2.1.2 Paint the inside of the intake air piping with Caterpillar yellow primer or red Glyptal prior to installation.^{11,12}

6.2.1.3 Install the air heater elements in the intake air barrel as specified in **Annex A7** (even if they will not be supplied with electricity).^{11,13}

6.2.1.4 Use an air filter capable of filtering particles 10 μ (or smaller).

6.2.1.5 Use a Sierra Model 780 airflow meter with Feature 1 = F6, Feature 2 = CG and calibration temperature = 60 °C to measure intake airflow for each calibration test.^{11,14} **Annex A4** shows the piping requirements for the installation of the Sierra Model 780 airflow meter.

6.2.1.6 Measure the inlet air temperature at the location shown in **Annex A2**. Measure the inlet air pressure at the air

¹⁰ The sole sources of supply of the intake air barrel known to the committee at this time are Cimino Machinery Corp., 5958 South Central Ave., Chicago, IL 60638; Gaspar Inc., 4106 Mahoning Rd. N.E., Canton, OH 44705; and M.L. Wyrick Welding, 2301 Zanderson Highway 16 N, Jourdan, TX 78026.

¹¹ 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 committee¹, which you may attend.

¹² The sole source of supply of the crankcase paint primer known to the committee at this time is BASF Coating and Colorant Div., P.O. Box 1297, Morganton, NC 28655. (Primer No.A123590 and BASF Part No.U27YD005, Yellow CAT Primer Part No.IE2083A.)

¹³ The sole source of supply of the air heater elements known to the committee at this time is Watlow Air Heaters, Chicago, IL 708-490-3900.

¹⁴ The sole source of supply of the airflow meter known to the committee at this time is Sierra Instruments, Inc., 5 Harris Ct., Monterey, CA 93940.