Designation: D8047 − 16

Standard Test Method for Evaluation of Engine Oil Aeration Resistance in a Caterpillar C13 Direct-Injected Turbocharged Automotive Diesel Engine[1]

This standard is issued under the fixed designation D8047; 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

Portions of this test method are written for use by laboratories that make use of ASTM Test Monitoring Center (TMC)[2] services (see Annex A1).

The TMC provides reference oils, and engineering and statistical services to laboratories that desire to produce test results that are statistically similar to those produced by laboratories previously calibrated by the TMC.

In general, the Test Purchaser decides if a calibrated test stand is to be used. Organizations such as the American Chemistry Council require that a laboratory utilize the TMC services as part of their test registration process. In addition, the American Petroleum Institute and the Gear Lubricant Review Committee of the Lubricant Review Institute (SAE International) require that a laboratory use the TMC services in seeking qualification of oils against their specifications.

The advantage of using the TMC services to calibrate test stands is that the test laboratory (and hence the Test Purchaser) has an assurance that the test stand was operating at the proper level of test severity. It should also be borne in mind that results obtained in a non-calibrated test stand may not be the same as those obtained in a test stand participating in the ASTM TMC services process.

1. Scope

1.1 This test method evaluates an engine oil's resistance to aeration in automotive diesel engine service. It is commonly referred to as the Caterpillar-C13 Engine-Oil Aeration Test (COAT). The test is conducted under high-engine-speed (1800 r/min), zero-load conditions using a specified Caterpillar 320 kW, direct-injection, turbocharged, after-cooled, six-cylinder diesel engine designed for heavy-duty, on-highway truck use. This test method was developed as a replacement for Test Method D6894.

NOTE 1—Companion test methods used to evaluate engine oil performance for specification requirements are discussed in the latest revision of Specification D4485.

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 *Exception*—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.* See Annex A2 for general safety precautions.

1.4 This test method is arranged as follows:

[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 on Automotive Lubricants.

Current edition approved June 1, 2016. Published July 2016. DOI: 10.1520/D8047-16.

[2] ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489. http://www.astmtmc.cmu.edu.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels 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

D975 Specification for Diesel Fuel Oils

D976 Test Method for Calculated Cetane Index of Distillate Fuels

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)

D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge

D3524 Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography

D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter

D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants

D4485 Specification for Performance of Active API Service Category Engine Oils

D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

D5186 Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography

D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence

D6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)

D6894 Test Method for Evaluation of Aeration Resistance of Engine Oils in Direct-Injected Turbocharged Automotive Diesel Engine

D7549 Test Method for Evaluation of Heavy-Duty Engine Oils under High Output Conditions—Caterpillar C13 Test Procedure

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

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. **D4175**

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

3.1.3 *break-in, v—in internal combustion engines*, the running of a new engine under prescribed conditions to help stabilize engine response and help remove initial friction characteristics associated with new engine parts. **D4175**

3.1.4 *calibrate, v*—to determine the indication or output of a measuring device or a given engine with respect to a standard. **D4175**

3.1.5 *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.

3.1.5.1 *Discussion*—In several automotive lubricant standard test methods, the ASTM Test Monitoring Center provides testing guidance and determines acceptability. **D4175**

3.1.6 *calibration oil, , n*—an oil that is used to determine the indication or output of a measuring device or a given engine with respect to a standard. **D4175**

3.1.7 *calibration test, n*—an engine test conducted on a reference oil under carefully prescribed conditions, the results of which are used to determine the suitability of the engine stand/laboratory for such tests on non-reference oils.

3.1.7.1 *Discussion*—A calibration test also includes tests conducted on parts to ensure their suitability for use in reference and non-reference tests. **D4175**

3.1.8 *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.

3.1.8.1 *Discussion*—These oils are mainly submitted for testing as candidates to satisfy a specified performance; hence the designation of the term. **D4175**

[3] 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.

3.1.9 *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.

3.1.9.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples. **D4175**

3.1.10 *foam, n—in liquids*, a collection of bubbles formed in the liquid or on (at) its surface in which the air (or gas) is the major component on a volumetric basis. **D4175**

3.1.11 *heavy-duty engine, n—in internal combustion engine types*, one that is designed to allow operation continuous at or close to its peak output.

3.1.11.1 *Discussion*—This type of engine is typically installed in large trucks and buses as well as farm, industrial, and construction equipment. **D4175**

3.1.12 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D4175**

3.1.13 *lubricant test monitoring system (LTMS), n*—an analytical system in which ASTM calibration test data are used to manage lubricant test precision and severity (bias). **D4175**

3.1.14 *mass fraction of B, w_B, n*—mass of a component B in a mixture divided by the total mass of all the constituents of the mixture.

3.1.14.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of mass (for example, mass fraction of lead is $w_B = 1.3 \times 10^{-6}$ = 1.3 mg/kg).

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 *quality index (QI), n*—a mathematical formula that uses data from controlled properties to calculate a value indicative of control performance. **D4175**

3.1.17 *quantity, n—in the SI*, a measurable property of a body or substance where the property has a magnitude expressed as the product of a number and a unit; there are seven, well-defined base quantities (length, time, mass, temperature, amount of substance, electric current, and luminous intensity) from which all other quantities are derived (for example, volume, whose SI unit is the cubic metre).

3.1.17.1 *Discussion*—Symbols for quantities must be carefully defined; are written in italic font, can be upper or lower case, and can be qualified by adding further information in subscripts, or superscripts, or in parentheses (for example, T_{fuel} = 40 °C, where T is used as the symbol for the quantity temperature and T_{fuel} is the symbol for the specific quantity fuel temperature).

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

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

3.1.19 *test oil, n*—any oil subjected to evaluation in an established procedure.

3.1.19.1 *Discussion*—It can be any oil selected by the laboratory conducting the test. It could be an experimental product or a commercially available oil. Often it is an oil that is a candidate for approval against engine oil specifications (such as manufacturers' or military specifications, and so forth). **D4175**

3.1.20 *volume fraction of B, φ_B, n*—volume of component B divided by the total volume of the all the constituents of the mixture prior to mixing.

3.1.20.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of volume (for example, φ_B = 0.012 = 1.2 % = 1.2 cL/L).

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.

3.3 *Abbreviations and Acronyms:*

3.3.1 *ACERT*—Advanced Combustion Emission Reduction Technology

3.3.2 *ACM*—Alkyl Acrylate Copolymer

3.3.3 *BL*—Baseline (refers to density of fresh, un-aerated oil at 90 °C)

3.3.4 *BOT*—Beginning of Test

3.3.5 *CARB*—California Air Resources Board

3.3.6 *Cat*[4]—abbreviation for Caterpillar

3.3.7 *COAT*—Caterpillar-C13 Oil-Aeration Test

3.3.8 *ELC*[5]—Extended-Life Coolant

3.3.9 *EOAT*—Engine-Oil Aeration Test

3.3.10 *ET*—Engine Technician

3.3.11 *EOT*—End of Test

3.3.12 *FDM*—Flow and Density Meter

3.3.13 *ICP-AES*—Inductively Coupled Plasma Atomic Emission Spectrometry

3.3.14 *ID*—Internal Diameter

3.3.15 *LTMS*—Lubricant Test Monitoring System

3.3.16 *NPT*—National Pipe Thread

3.3.17 *OA*—Oil Aeration

3.3.18 *P/N*—Part Number (applies only to parts sourced from Caterpillar)

3.3.19 *QI*—Quality Index

3.3.20 *SLBOCLE*—Scuffing Load Ball-on-Cylinder Lubricity Evaluator

3.3.21 *TMC*—Test Monitoring Center of ASTM

3.3.22 *ULSD fuel*—Ultra-Low-Sulfur Diesel fuel

3.4 *Quantity Symbols:*

3.4.1 *OA*—Oil Aeration, %, (see 11.1.1.3)

[4] Registered trademark of Caterpillar Inc., 100 North East Adams St., Peoria, IL 61629.

[5] Trademark of Caterpillar Inc., 100 North East Adams St., Peoria, IL 61629.

3.4.2 P_{SAMPLE}—Pressure of the aerated oil sampled during the 50 h test determined as the average of the FDM inlet- and outlet-pressures (see 10.5.6.3)

3.4.3 T—Temperature (see 10.4.2.3)

3.4.4 T_{SAMPLE}—Temperature of the aerated oil sampled during the 50 h test determined as the average of the FDM inlet- and outlet-temperatures (see 10.5.6.4)

3.4.5 ρ—density (see 10.4.2.3)

3.4.6 ρ_{AIR}—air density calculated at the temperature and pressure of the aerated oil sample during the 50 h test (see 11.1.1.2)

3.4.7 $\rho_{BL,\ 90}$—baseline density of the unaerated fresh oil at 90 °C determined as the intercept of the D4052 density versus temperature regression (see 10.4.2.3)

3.4.8 ρ_{SAMPLE}—the measured FDM density of the aerated oil sampled during the 50 h test at the temperature T_{SAMPLE} (see 10.5.6.4)

3.4.9 $\rho_{SAMPLE,\ 90}$—the calculated FDM density of the aerated oil sampled during the 50 h test at 90 °C (see 11.1.1.1)

3.4.10 $\frac{d}{dT}\rho_{BL}$—temperature dependence of the baseline density of fresh, un-aerated oil determined as the slope of the density vs. temperature regression of fresh, un-aerated oil (see 10.4.2.3)

4. Summary of Test Method

4.1 This test method uses a production Caterpillar C13 diesel engine. It is installed on a stand equipped with appropriate instrumentation to record and control various operating quantities. This test is run on an engine that is built with new components and then used for multiple oil evaluations until operational conditions or aeration performance are impacted by the engine condition.

4.2 The test operation involves two test oil flushes of 40 min duration for each test, a test warmup for 40 min and then a test length of 50 h at high-engine-speed (1800 r/min), zero-load conditions.

4.3 The percent aeration of the engine oil is determined using a flow and density meter to continuously monitor the density of a small portion of diverted gallery oil flow that has controlled pressure, temperature, and flow rate. The density of this oil is used to calculate the percentage of total sample volume that is entrained air.

5. Significance and Use

5.1 *Background*—Prior to this test method, the ability of an engine lubricant to resist aeration was measured by the engine-oil aeration test (EOAT) described in Test Method D6894. The continued availability of engine parts coupled with field service aeration problems led to concerns about the relevance of this test method to newer oil and engine technologies. These concerns prompted the development of this new engine-oil aeration test method, based on the Caterpillar C13 engine and termed COAT. This test method aims to provide a more reliable measurement of the ability of a lubricant to resist aeration during engine operation in field service. The engine used is of current technology and the aeration measurement is operator independent.

5.2 *Test Method*—This test method evaluates aeration performance under high-engine-speed, zero-load operation in a turbocharged, heavy-duty, four-stroke diesel engine.

5.3 *Use:*

5.3.1 The tendency of engine oils to aerate in direct-injection, turbocharged diesel engines is influenced by a variety of factors, including engine oil formulation, 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 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 hydraulically activated components, adversely affecting the engine timing characteristics and engine operation.

5.3.2 The results from this test method may be compared against specification requirements such as Specification D4485 to ascertain acceptance.

5.3.3 The design of the test engine used in this test method is representative of many, but not all, diesel engines. This factor, along with the unique operating conditions, needs to be considered when comparing the test results against specification requirements.

6. Apparatus

6.1 *Test Stand*—The test stand consists of the test engine and the aeration measurement system.

6.1.1 *Test Engine*—The test engine is a production 2004 Caterpillar 320 kW C13 engine,[6,7] designed for heavy-duty, on-highway truck use. It is an electronically controlled, turbocharged, after-cooled, direct-injected, six-cylinder diesel engine with an in-block camshaft and a four-valve per cylinder arrangement. The engine uses Caterpillar's ACERT technology featuring multiple injections per cycle and inlet-valve actuation control. It features a 2004 US EPA emissions configuration with electronic control for metering of the fuel and timing the fuel injection and inlet-valve actuation. See Annex A3 for the source of the test engine and critical and non-critical parts.

6.1.2 *Aeration-Measurement System*—The aeration measurement system uses the density measurement to calculate the percent entrained air volume within the engine oil at a given pressure and temperature. The system utilizes a Micro Motion Elite, Model CMF 025,[8,7] coriolis-based, flow and density meter (FDM) capable of measuring density to less than 1 kg/m^3. The calculation of the percent aeration is based on the difference in density between an un-aerated oil sample (measured by Test Method D4052) and the density of the aerated oil during the test measured by the FDM. The aeration measurement system comprises a heated line, a pressure-control valve, the FDM, a variable-speed pump, and pressure transducers and thermocouples. Assemble the system with the indicated line

[6] The sole source of supply of the apparatus known to the committee at this time is Caterpillar Inc., 100 North East Adams St., Peoria, IL 61629.

[7] 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.

[8] The sole source of supply of the apparatus known to the Committee at this time is Emerson Process Management Micro Motion Americas, 7070 Winchester Circle, Boulder, CO 80301. www.emersonprocess.com.

lengths, fittings and components as shown in Annex A7. The aeration measurement system is enclosed in a cabinet capable of maintaining the internal temperature at 50 °C regardless of ambient temperatures. This temperature is typically maintained by an internal heater and insulation within the cabinet. Include the FDM, FDM-inlet and -outlet thermocouples and pressure transducers in the enclosure.

6.2 *Test-Engine Configuration:*

6.2.1 *Oil-Heat-Exchanger and Oil-Heat System*—Replace the standard Caterpillar oil-heat-exchanger core with a stainless steel core, Caterpillar P/N 1Y-4026.[6,7] Additionally, install a remotely mounted heat exchanger. Control the oil temperature with a dedicated cooling loop and control system which is separate from the engine coolant (see Annex A4). Ensure that the oil-cooler bypass valve is blocked closed.

NOTE 2—In subsequent text, P/N denotes the part number for parts sourced from Caterpillar. Footnotes 6 and 7 apply.

6.2.2 *Oil-Pan Modification*—Modify the oil pan as shown in Figs. A5.1-A5.4. Install the oil-pan jacket as shown in Fig. A5.5.

6.2.3 *Engine-Control Module (ECM)*—The ECM defines the desired engine fuel timing and quantity. It also limits maximum engine speed and power. Caterpillar electronic governors are designed to maintain a speed indicated by the throttle position signal. Speed variation drives fuel demand (rack). Rack and engine speed are input to the injection duration and timing maps to determine duration and timing commands for the fuel injectors. Obtain special oil-test, engine-control software (module P/N 250-6775-03) for correct maps. Contact the Caterpillar oil-test representative through TMC for installation of this software. Use the Caterpillar engine technician (ET) service software package, version 2004B or later, to monitor engine parameters, flash software, and to change power and injector trim values. Use the full dealer version purchased from a Caterpillar dealer with a yearly subscription.

6.2.4 *Crankshaft-Position Sensor*—Sense the crankshaft position using a primary sensor at the crankshaft gear and a secondary sensor at the camshaft gear. The secondary sensor provides position information during cranking and in the event of a primary sensor position failure. *Calibrate the engine control software before starting the timed test operation*.

6.2.5 *Air Compressor—Do not use the engine-mounted air compressor for this test method*. Remove the air compressor and in its place install block-off plates, as shown in Fig. A5.6. P/N 227-2574 (cover group) and P/N 223-3873 (plug group) have been found satisfactory for this purpose.

6.2.6 *Turbocharger*—Modify the turbocharger wastegate for manual control by replacing the supplied pressure control with a manual linkage. See Figs. A5.21-A5.23.

6.3 *Test-Stand Configuration:*

6.3.1 *For Full-Load Break-in*—Configure the stand with a drive-line and dynamometer capable of meeting the conditions described in the break-in and on-test subsections in Section 10, Procedure, of Test Method D7549.

6.3.2 *Engine Mounting*—Install the engine so that it is upright and the crankshaft is horizontal.

6.3.2.1 Configure the engine-mounting hardware to minimize block distortion when the engine is fastened to the mounts. Excessive block distortion may influence test results.

6.3.3 *Intake-Air System*—With the exception of the air filter and intake-air tube, the intake-air system is not specified. See Fig. X1.1 for a typical configuration. Use a suitable air filter. Install the intake-air tube (Fig. A5.7) at the intake of the turbocharger compressor. The intake-air tube is a minimum 305 mm of straight, nominal 102 mm diameter tubing. The system configuration upstream of the air tube is not specified.

NOTE 3—Difficulty in achieving or maintaining intake-manifold pressure or intake-manifold temperature, or both, may be indicative of insufficient or excessive restriction.

6.3.4 *Charge-Air Cooler*—In addition to the Caterpillar-supplied, charge-air cooler which is engine mounted, use another cooler to simulate the air-to-air charge air cooler used in most field applications. A Modine[9,7] cooler (part number 1A012865) has been found suitable for this use.[10] Alternatively, other charge air coolers may be used that provide sufficient cooling capacity to control inlet-manifold temperatures in the range specified elsewhere in this test method. Equip all coolers with a drain system to remove condensate continuously from the boost air cooler outlet side. Remove the coolant-diverter-valve diaphragm for the Caterpillar-supplied, charge-air cooler.

6.3.5 *Exhaust System*—Install the exhaust tube, see Fig. A5.8, at the discharge flange of the turbocharger-turbine housing. Downstream exhaust piping is required but is left to the discretion of the laboratory to fabricate. Include a method to control exhaust back pressure.

6.3.6 *Fuel System*—The fuel-supply and filtration system is not specified. See Fig. X1.2 for a typical configuration. Determine the fuel-consumption rate by measuring the rate of fresh fuel flowing into the day tank. Provide a method to control fuel temperature. Return the excess fuel from the engine into the day tank.

6.3.7 *Coolant System*—The system configuration is not specified. See Fig. X1.3 showing a typical configuration consisting of a non-ferrous core heat exchanger, a reservoir (expansion tank), and a temperature-control valve. Pressurize the system by regulating air pressure at the top of the expansion tank. Ensure the system has a sight glass to detect air entrapment.

6.3.7.1 System volume is not specified. Avoid a very large volume as it may increase the time required for the engine coolant to reach operating temperatures.

6.3.8 *Pressurized Oil-Fill System*—The oil-fill system is not specified. A typical system includes an electric pump, a 50 L reservoir, and a transfer hose. Fig. A5.24 shows the location of the pressurized oil-fill system.

[9] The sole source of supply of this cooler known to the committee at this time is Modine Manufacturing Company. www.modine.com.

[10] Obtain the Modine cooler from a Mack Truck dealer. Order the aftercooler using part number 5424 03 928 031. This is a non-stocked part in the Mack Parts Distribution System and appears as an invalid part number. Instruct the dealer to expedite the aftercooler on a Ship Direct purchase order. The aftercooler will be shipped directly from Modine, bypassing the normal Mack Parts Distribution System.

6.3.9 *External Oil System for Full-Load Break-in:*

6.3.9.1 Configure the oil system as shown in Fig. A6.1 for full-load break-in of new or rebuilt engines only. *Do not use* this system during the oil aeration test cycle. The capacity of the oil reservoir is 10 L to 13 L. Ensure that the oil return is drawn from the bottom of the oil reservoir—see Fig. A5.10. Use Viking Pump Model No. SG053514.[11,7] Locate the external oil pumps at a depth that is below the pump supply fitting on the oil pan. The nominal speed for the oil-pump motor is 1725 r/min. Figs. A5.1-A5.5 show the pump supply and return port locations. This system is removed for testing after the break-in and during the aeration tests. The locations for the pump supply and return port of the oil pan are capped when this system is not in use.

6.3.9.2 *Oil-Sample Valve Location*—Locate the oil-sample valve on the oil-sump drain port.

6.3.9.3 *Unacceptable Oil-System Materials*—Do not use brass or copper fittings because they can adversely influence the analyses for oil-wear metals in the external oil system.

6.3.10 *Crankcase Aspiration*—Vent the blowby gas at the blowby filter housing located at the left-front side of the cylinder head cover (Fig. A5.11). Use crankcase breather P/N 9Y-4357. Use breather spacer P/N 221-3934 or equivalent plate 20 mm thick with a fully-open center. Use gasket P/N 9Y-1758 on each side of the spacer.

6.3.11 *Blowby Rate*—See the general configuration of this system in Fig. A5.11. The minimum internal volume of the blowby canister is 26.5 L. The inside diameter of the pipe connecting the breather outlet to the blowby canister is 32 mm. Incline the pipe downward to the canister. The hose connecting the blowby canister to the device for measuring the flow rate is not specified but it shall match closely to the inlet of the device. The device for measurement of flow rate is not specified, but shall be capable of measuring approximately 70 L/min. The J-TEC Associates, Inc. Model No. YF563A or YF563B[12,7] have been found to give satisfactory results under the conditions specified in this test method.

6.4 *System-Time Responses*—The maximum allowable system-time responses are shown in Table 1. Determine system-time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report.[13]

[11] The sole source of supply of the apparatus known to the committee at this time is Viking Pumps, Inc., 406 State Street, Cedar Falls, IA 50613. www.vikingpump-.com.

[12] The sole source of supply of the apparatus known to the committee at this time is J-TEC Associates, Inc., 5005 Blairs Forest Lane NE, Suite L, Cedar Rapids, IA 52402. www.j-tecassociates.co.

[13] Available at: http://ftp.astmtmc.cmu.edu/docs/TechnicalGuidanceCommittee/minutes/BestPractices/DACA_II_Data%20Acquisiti on%20and%20Control%20Automation.pdf.

TABLE 1 Maximum Allowable System-Time Responses

Quantity	Time Response
Speed	2.0 s
Temperature	3.0 s
Pressure	3.0 s
Fuel Flow	40.0 s
Oil-Sample Flow	4.0 s

TABLE 2 Part Numbers for Cat[A] ELC[B] Coolant Concentrate and Premixes

Container Size	3.8 L	19 L	208 L	Tote,[C] 275 g
Concentrate P/N	238-8647	...	...	...
Premix[D] P/N	238-8648	238-8649	238-8650	361-1024

[A] Registered Trademark of Caterpillar Inc., 100 North East Adams St., Peoria, IL 61629.

[B] Trademark of Caterpillar Inc., 100 North East Adams St., Peoria, IL 61629.

[C] A small container.

[D] Equal parts by volume of mineral-free water and coolant concentrate.

6.5 *Oil-Sample Containers*—Preferably use high-density polyethylene containers for oil samples. (**Warning—**Avoid using glass containers which may break and cause injury or exposure to hazardous materials.)

7. Engine Liquids and Cleaning Solvent

7.1 *Test Oil*—Approximately 115 L of test oil is required to complete the test.

7.2 *Test Fuel*—Approximately 490 L of Chevron Philips PC-10 ultra-low-sulfur diesel (ULSD) fuel,[14,7] is required to complete the test. Fuel property tolerances are shown in Annex A15.

7.3 *Engine Coolant:*

7.3.1 Use a mixture of equal parts by volume of mineral-free water and Caterpillar-brand, coolant concentrate P/N 238-86476.[6,7]

7.3.2 As an option, premixed coolant is available and may be used directly.

7.3.2.1 Table 2 shows Caterpillar part numbers for several container sizes for concentrate and premixed coolant.

7.3.3 Replace the coolant mixture after 5000 h. The mixture shall remain at equal parts by volume of water and concentrate during the course of the test. Keep the coolant mixture free from contamination.

7.3.4 Maintain a correct additive concentration.

7.4 *Cleaning Solvent*—Use a solvent meeting the requirements of Specification D235, Type II, Class C for volume fraction of aromatics 0 % to 2 %, flash point (61 °C, min), and color (not darker that +25 Saybolt or 25 Pt-Co). Obtain a certificate of analysis for each batch of solvent from the supplier. (**Warning—**Combustible. Health Hazard. Use adequate safety precautions.)

7.5 *Sealant*—Because leached silicon from engine gaskets and sealants can cause elevated aeration levels (see A12.1), use silicon-free sealants such as alkyl acrylate copolymer (ACM). Loctite[15,7] 5810A (item 39210 or 39211) has been found suitable for this purpose.

8. Preparation of Apparatus

8.1 *Cleaning of Parts During Rebuild:*

[14] The sole source of supply of the fuel known to the committee at this time is Chevron Philips Chevron Phillips Chemical Company LP, 10001 Six Pines Drive, Suite 4036B, The Woodlands, TX 77387-4910, www.cpchem.com.

[15] Loctite is a registered trademark of Henkel Corp., 26235 First Street, Westlake, OH 44145.

8.1.1 *General*—Preparation of test engine components specific to the Caterpillar C13 engine rebuild are indicated in this section. Use the Caterpillar Service Manual Form SEN R 9700[16] for the preparation of other components (except for the piston second ring—see 8.2.7.1). Take precautions to prevent rusting of iron components. Use of an engine-parts washer followed by a solvent wash is permitted.

8.1.2 *Engine Block*—Disassemble the engine, including removal of the crankshaft, camshaft, piston-cooling tubes, oil pump, and oil-gallery plugs. Thoroughly clean the surfaces and oil passages (galleries). Use a nylon brush to clean the oil passages. Removal of camshaft bearings is optional.

8.1.3 *Cylinder Head, Intake System, and Duct*—Disassemble and clean these components during engine rebuild. Scrub with a nylon brush and solvent. Use of an engine-parts washer followed by a solvent wash is permitted.

8.1.4 *Rocker Cover and Oil Pan*—Clean the rocker cover and oil pan. Use a nylon brush, as necessary, to remove deposits.

8.1.5 *External Oil Mass System*—Flush the internal surfaces of the oil lines and the external reservoir with solvent. Repeat until the solvent drains cleanly. Flush the solvent through the oil pumps until the solvent drains cleanly, then air dry.

8.1.6 *High-Pressure Turbocharger*—Carefully remove the turbine housing from the turbocharger and clean the wastegate valve with solvent and a soft-wire brush.

8.1.7 *Cam-Follower Assembly*—Take the cam-follower assembly apart and inspect the bushings and pins. Replace the parts as necessary.

8.2 *Engine Assembly:*

8.2.1 *General:*

8.2.1.1 Perform an engine assembly at the laboratory's discretion. Instances when an engine rebuild should be considered include not meeting operational conditions, or when reference limits cannot be met.

8.2.1.2 Except as noted in this section, use the procedures described in the Caterpillar Service Manual Form SEN R 9700.[16] Assemble the engine with the components shown in the Engine Build Parts List (Annex A3).

8.2.2 *Parts Reuse and Replacement*—Reuse engine components, except as noted in 8.2.7, provided they meet production tolerances as described in the Caterpillar Service Manual.

8.2.3 *Build-up Oils*—For the head, main caps, and rod bolts, use CAT DEO-ULS engine oil[16] as the build-up oil. If test oil is used, the engine build is valid only for the respective test oil.

8.2.4 *Coolant Thermostat*—Lock the engine-coolant thermostat open.

8.2.5 *Fuel Injectors*—Use P/N 239-4908 fuel injectors. If fuel injectors are reused, exercise caution to avoid mechanical damage to or contamination of the nozzles. Dedicate the injectors to a particular cylinder. Install the injectors according to the method described in Caterpillar Service Manual Form SENR9700.[16] Use Mobil EF-411[17,7] engine oil as the build-up oil for the injector o-rings.

8.2.6 *Piston-Cooling Tubes*—Aim the piston-cooling tubes at the underside of the pistons according to the specifications on the TMC website. Contact the TMC for details.

8.2.7 *New Parts:*

8.2.7.1 *General*—The following new parts are included in the Engine Build Parts List. They are not reusable. Clean the parts prior to use. A full rebuild parts list is available from the TMC.[2] For piston second rings, follow the D7549 Piston Second Ring Pre-Test Cleaning Procedure, available from the TMC. During a test, a replacement of any of the new parts listed below will invalidate the test:

8.2.7.2 *List of (Non-Reusable) New Parts:*

(1) Pistons

(2) Piston rings (top, second, and oil)

(3) Cylinder liners

(4) Valves (intake, exhaust)

(5) Valve guides

(6) Valve seats

(7) Connecting-rod bearings, main bearings, and thrust plate

(8) Turbochargers

(9) Oil pump

(10) Oil-pressure regulator springs located inside of the oil-filter block

8.3 *Operational Measurements:*

8.3.1 *Specified Units and Formats*—See Annex A8.

8.3.1.1 *Measurement of Fuel-Consumption Rate*—Calibrate the system for measuring the fuel-consumption rate before each sequence of reference-oil tests and within six months after completion of the last successful calibration test. Compensate volumetric systems for temperature, and calibrate them against a standard mass-flow device. The flowmeter on the test stand shall agree within 0.2 % of the calibration standard, that standard itself being calibrated against a national standard.

8.3.1.2 *Calibration of Temperature-Measurement System*—Calibrate the temperature-measurement systems before each reference-oil test sequence and within six months after completion of the last successful calibration test. Each temperature-measurement system shall agree within ±0.5 °C of the laboratory calibration standard, that standard itself being calibrated against a national standard.

8.3.1.3 *Calibration of Pressure-Measurement System*—Calibrate the pressure-measurement systems before each reference-oil test sequence and within six months after completion of the last successful calibration test. Confirm the calibration standard against a national standard.

8.3.1.4 *Calibration of FDM:*

(1) Calibrate the Micro Motion FDM at least once a year. Emerson's Flow Calibration and Service Centers[18] have been found satisfactory for this purpose.

(2) For all reference- and non-reference-oil tests to be considered valid, the FDM shall have a current calibration.

(3) Calibrate the FDM if there are concerns with the accuracy of the density or flow measurements.

[16] Available from a Caterpillar parts distributor.

[17] The sole source of this oil known to the committee at this time is Exxon-Mobil Oil Corp., P.O. Box 66940, AMF O'Hare, IL 60666, Attention Illinois Order Board.

[18] Emerson Process Management Micro Motion Americas, 7070 Winchester Circle, Boulder, CO 80301. www.flowsupport@emerson.com.

(4) A procedure for checking the accuracy of the FDM-determined densities is described in 10.4.

8.3.2 *Locations for Temperature-Measurement Sensors:*

8.3.2.1 *General*—The measurement equipment is not specified. Install the sensors such that the tip is located midstream of the flow unless otherwise indicated. The accuracy and measurement of the temperature-measurement sensors and the complete measurement system shall follow the guidelines in ASTM Research Report RR:D02-1218.[13, 19]

8.3.2.2 *Coolant-Out Temperature*—Install the sensor in the fitting on the thermostat housing (Fig. A5.13).

8.3.2.3 *Coolant-In Temperature*—Install the sensor on the right side of the coolant-pump intake housing at the 1 in. NPT port (Fig. A5.14).

8.3.2.4 *Fuel-In Temperature*—Install the sensor in the fuel-pump inlet fitting (Fig. A5.16).

8.3.2.5 *Oil-Gallery Temperature*—Install a ⅛ in. thermocouple at the sensor at the ⅜ in. NPT female boss on the right-rear of the engine (Fig. A5.15) extending from the cross fitting described in A7.2.1 to the center of the oil gallery flow.

8.3.2.6 *Intake-Air Temperature*—Install the sensor in the inlet air tube 127 mm upstream of the compressor connection (Fig. A5.7).

8.3.2.7 *Intake-Manifold Temperature*—Install the sensor at the ⅛ in. NPT female boss on the outside radius of the inlet-manifold elbow (Fig. A5.17).

8.3.2.8 *Exhaust Temperature*—Install the sensor in the exhaust tube (Fig. A5.8).

8.3.2.9 *Aeration-System-Enclosure Temperature*—Insert the sensor 75 mm directly above the vertical centerline of the Micro Motion FDM and extending into the enclosure to the vertical plane of the FDM face.

8.3.2.10 *Oil-Sump Temperature*—Insert a thermocouple to a depth of 50 mm into the drain-plug port on the right-front pan pictured in Fig. A5.5.

8.3.2.11 *Additional Temperatures*—It is permissible to measure any additional temperatures that may be useful for test operation or engine diagnostics.

NOTE 4—Additional exhaust-sensor locations, at the exhaust ports and pre-turbine (front and rear), are recommended. The detection of changes in exhaust temperatures is an important diagnostic feature.

8.3.3 *Locations for Pressure-Measurement Sensors:*

8.3.3.1 *General*—The measurement equipment is not specified. Follow the guidelines in ASTM Research Report RR:D02-1218[13, 19] for the accuracy and resolution of the pressure-measurement sensors and the complete measurement system. If the laboratory has problems with condensation forming in the pressure lines, install a condensation trap at the lowest elevation of the tubing between the pressure-measurement location and the final pressure sensor for crankcase pressure, intake-air pressure, and exhaust pressure. Route the tubing to avoid intermediate loops or low spots before and after the condensation trap.

8.3.3.2 *Oil-Gallery Pressure*—Measure the pressure from the upper vertical port of the ⅜ in. 4-way cross fitting on the right rear of the engine (Fig. A5.15).

8.3.3.3 *Oil-Filter-Inlet Pressure*—Measure the pressure at the plug located on the inlet side of the oil filter assembly (Fig. A5.9).

8.3.3.4 *Inlet-Manifold Pressure*—Measure the pressure at the ¼ in. NPT port on the outside radius of the inlet-manifold elbow (Fig. A5.17).

8.3.3.5 *Crankcase Pressure*—Measure the pressure by installing a bulkhead fitting in the top of the valve cover. (Fig. A5.12).

8.3.3.6 *Intake-Air Pressure*—Measure the pressure at a wall tap on the intake-air tube 153 mm upstream of the compressor connection (Fig. A5.7).

8.3.3.7 *Exhaust Pressure*—Measure the pressure on the exhaust tube (Fig. A5.8).

8.3.3.8 *Fuel Pressure*—Measure the pressure at the fuel-filter head (Fig. A5.25).

8.3.3.9 *Coolant Pressure*—Measure the pressure on top of the expansion tank (Fig. X1.3).

8.3.3.10 *Intercooler Delta Pressure*—Measure the pressure drop across the intercooler. Measure the intercooler inlet pressure at the elbow outlet of the CAT charge air cooler (Fig. A5.19). Use the intake-manifold pressure (8.3.3.4) as the intercooler outlet pressure. The intercooler delta pressure is the difference between the intercooler outlet pressure and the intercooler inlet pressure.

8.3.3.11 *Additional Pressures*—It is permissible to measure any additional pressures that may be useful for test operation or engine diagnostics.

NOTE 5—See Figs. A5.19 and A5.20 for additional instrument placement information.

8.3.4 *Locations for Flow-Rate Measurement:*

8.3.4.1 *General*—The equipment for fuel-rate measurements is not specified. Follow the guidelines in ASTM Research Report RR:D02-1218[13] for the accuracy and resolution of the flow-rate-measurement system.

8.3.4.2 *Blowby*—Measure the blowby flow rate using a JTEC model VF563A or VF563B. See 6.3.11 for blowby measurement system configuration.

8.3.4.3 *Fuel Flow*—Determine the fuel consumption rate by measuring the fuel flowing to the day tank (Fig. X1.2).

8.3.5 *Controller Outputs and Indications of Malfunction in the Aeration-Measurement System*—Record the controller output as % for the sample pressure control regulator. If this value is above 50 % for 15W-40 or lower viscosity oils (that is, for oils with kinematic viscosity at 100 °C less than 12.5 mm^2/s) the test is invalid. Oils of higher viscosity need a statement of validity in the comments section of the report if the controller output exceeds 50 %.

8.3.6 *Quantities for Aerated-Oil Samples*—Measure temperature, pressure, flow rate, and density using the aeration system shown in Annex A7.

8.3.6.1 Record the oil sample temperature as the average of the inlet- and outlet-thermocouple temperatures of the FDM. (This temperature is a theoretical temperature at the midpoint of the FDM.)

[19] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1218. Contact ASTM Customer Service at service@astm.org.

8.3.6.2 Record the oil sample pressure as the average of the inlet- and outlet-pressure transducers of the FDM. (This pressure is a theoretical pressure at the midpoint of the FDM.)

9. Engine/Stand Calibration and Non-Reference-Oil Tests

9.1 Annex A9 describes calibration procedures using the TMC reference oils, including their storage and conditions of use, the conducting of tests, and the reporting of results.

9.2 Annex A10 describes maintenance activities involving TMC reference oils, including special reference-oil tests, special use of the reference-oil calibration system, donated reference-oil test programs, introducing new reference oils, and TMC information letters and memoranda.

9.3 Annex A11 provides information regarding new laboratories, the role of the TMC regarding precision data, and the calibration of test stands used for non-standard tests.

9.4 *Stand Calibration:*

9.4.1 Calibrate the test stand by conducting a test with a blind reference oil (see A9.2). Submit the results to the TMC as described in A9.6. Determine the acceptability of a reference-oil test according to the LTMS.

9.4.2 *New Test Stand*—A new test stand is one that has never been calibrated or has not completed an acceptable reference-oil test within 24 months of the end of test (EOT) date of the last acceptable reference-oil test. Perform a calibration as described in 9.4.1 to introduce a new test stand.

9.4.3 *Stand-Calibration Period*—The calibration period is 6 months and a certain number of operationally valid non-reference-oil tests, whichever comes first, from the EOT date of the last acceptable reference-oil test. The number of non-reference-oil tests allowed during a calibration period is determined by the number of reference-oil tests that have been completed on a test stand. The first calibration period on a new stand is six months or two non-reference-oil tests, whichever comes first. The second calibration period on a stand is six months or four non-reference-oil tests. The third calibration period on a stand is six months or six tests. The fourth and all subsequent calibration periods on a test stand is six months or nine tests.

9.4.4 *Stand Modification and Calibration Status*—Stand-calibration status will be invalidated by conducting any non-standard test or modification of the test and control systems, or both. A non-standard test is any test conducted under a modified procedure, or using non-procedural hardware, or using controller-set-point modifications, or any combination thereof. Any such changes terminate the current calibration period. A reference test is required before restarting the current calibration period (see A9.2.2). If changes are contemplated, contact the TMC beforehand to ascertain the effect on the calibration status.

9.5 *Test-Numbering System:*

9.5.1 The test number for both reference and non-reference oils has three parts: X, Y, and Z, where X represents the test-stand number, Y the sequential test-stand-run number, and Z the number of hours run on the stand since the last reference-oil test. For example 27-15-150 indicates run number 15 on test-stand number 27, the test stand having been run for 150 h since the last reference-oil test. The test stand run number, Y, will increase sequentially by one for each test start (reference oil or non-reference oil). A letter suffix may also be necessary (see 9.5.2).

9.5.2 A reference-oil test conducted subsequent to an unacceptable reference-oil test shall include a letter suffix after Y. The letter suffix shall begin with A and incremented alphabetically until acceptable reference-oil test is completed. For example, if two consecutive unacceptable reference-oil tests were conducted and the first number was 27-15-150, the second test number would be 27-16A-150. A third calibration attempt would have the test number 27-17B-150. If the third test were acceptable, then 27-17B-150 would identify the reference-oil test in the test report.

9.5.3 *Non-Reference-Oil Tests*—Add no letter suffix to Y for aborted or operationally invalid non-reference-oil tests.

9.6 *Reference-Oil Tests*—Carry out reference-oil tests as described in A9.5 and report the results to the TMC as described in A9.6. Determine the acceptability of a reference-oil test according to the LTMS.

9.7 *Non-Reference-Oil Tests: Last Start Date*—When running non-reference-oil tests during the calibration period, crank the engine prior to the expiration of the calibration period (9.4.3).

10. Procedure

10.1 *Engine Break-in and Silicon Passivation:*

10.1.1 Following the engine assembly, install the engine on the stand and connect the engine to the stand support system.

10.1.2 Carry out the engine break-in as described in Annex A12.

10.1.2.1 *Shutdown During Break-in*—If a shutdown occurs during the break-in, resume the break-in from the point at which the shutdown occurred. Record such an occurrence in "Other Comments" on the appropriate report form.

NOTE 6—Use the break-in as an opportunity to confirm engine performance and to make repairs prior to the start of the 50 h test procedure.

10.1.3 After completion of the engine break-in, shut the engine down, using the normal shutdown procedure described in 10.3.1.

10.1.4 Drain the oil and remove the oil filter.

NOTE 7—After the engine has performed the break-in, it can be transferred to the stand equipped with the aeration measurement system and instrumented according to this procedure. Alternatively, both the break-in and the aeration testing can be carried out on the same stand provided as it can meet the break-in procedure conditions and can also maintain the operation conditions defined in this procedure for aeration testing.

10.2 *Aeration Pretest Procedure:*

10.2.1 Install a new Caterpillar 1R-1808 oil filter.[16]

10.2.2 Charge the engine with 32.2 L ± 0.2 L of test oil.

10.2.2.1 Use the pressurized, oil-fill system described in 6.3.8 or charge manually through the engine-oil, add-tube.

10.2.3 *Warmup*—Start the engine and perform the warmup described by Steps 1 and 2 of Table 3. After completion of Step 2, perform a 2 min cool-down at Step 1 conditions before shutting down the engine.

TABLE 3 Warmup Conditions

Quantity, units	Step 1	Step 2
Stage Length, min	5	35
Speed, r/min	900	1800
Load, N·m	0	0
Coolant Out Temperature,[A] °C	90	90
Intake Air Temperature,[A] °C	25	25
Manifold Temperature,[A] °C	40	40
Fuel Temperature,[A] °C	40	40
Gallery Oil Temperature,[A] °C	90	90
Sample Oil Temperature,[A] °C	90	90
Sample Oil Flow Rate,[A] L/min	1.5	1.5
Sample Oil Pressure,[A] kPa (absolute)	150	150
Intake Air Pressure,[A] kPa (absolute)	96	96
Fuel Flow Rate, g/min	Record	Record
Blowby Flow Rate, L/min	Record	Record
Intake Manifold Pressure,[B] kPa (gauge)	Record	Record
Exhaust After Turbo Temperature, °C	Record	Record
Fuel Pressure, kPa (gauge)	Record	Record
Oil Gallery Pressure, kPa (gauge)	Record	Record
Coolant System Pressure, kPa (gauge)	100	100
Exhaust Restriction Pressure, kPa (absolute)	104	104
Crankcase Pressure, kPa (absolute)	103	103
Aeration Enclosure Temperature, °C	50	50

[A] This is the control set-point. It can require up to 30 min of operation to achieve.
[B] With turbocharger waste-gate fully closed.

10.2.4 Drain the engine of the initial oil charge while allowing the oil sampling circuit pump to run and drain.

10.2.5 Repeat 10.2.2 to 10.2.4.

10.2.5.1 Install a new Caterpillar 1R-1808 oil filter.

10.2.5.2 Charge the engine with 36 L ± 0.2 L of test oil and perform the warmup as described in Table 3 before continuing to on-test conditions as described in 10.5.

10.3 *Shutdowns and Maintenance*—The test may be shutdown at the discretion of the laboratory to perform repairs. However, the intent of this test method is to conduct the 50 h test procedure without shutdowns. Shutdowns between 30 h and 50 h test time invalidate the test. This period is critical for accurate measurement of the aeration average from 40 h to 50 h.

10.3.1 *Normal Shutdown*—A normal shutdown is accomplished by ramping down to warmup Step 1 conditions (Table 3), running for 2 min, and then stopping the engine.

10.3.2 *Emergency Shutdown*—An emergency shutdown occurs when the normal shutdown cannot be completed, such as under an alarm condition. During an emergency shutdown ignition can be turned off immediately and the engine allowed to stop. Such an occurrence is described in "Other Comments" of the appropriate report form (see 12.1).

10.3.3 *Maintenance*—Engine components or stand support equipment or both may be repaired or replaced at the discretion of the laboratory and in accordance with this test method. It is recommended to monitor the condition of the oil pressure regulator springs within the oil filter housing. These springs may require replacement if the oil gallery pressures are not typical.

10.3.4 *Downtime*—The limit for total downtime is not specified. Record on the appropriate report form all shutdowns, pertinent actions, and total downtime during the 50 h test procedure. Downtime is calculated as the period between the engine leaving on-test and until it returns to on-test. Warmup periods are included in the downtime period.

10.3.5 *Engine Restarting*—Each time the engine is restarted, perform the warmup described in 10.2.3 before proceeding onto test.

10.4 *Determination of Baseline Densities:*

10.4.1 *General*—The percent aeration of the test oil is based on a comparison of the densities of the fresh, un-aerated oil and the aerated oil sampled during the engine operation (see 11.1). To eliminate the effects of temperature on the density results, all densities are calculated at a reference temperature of 90 °C. For this purpose, the temperature dependence of the density of the un-aerated fresh oil is determined by Test Method D4052 and is used to calculate the density at 90 °C of the both the un-aerated fresh oil and the aerated sample oil. The D4052 density of the un-aerated fresh oil and its temperature dependence are referred to as baseline (BL) values and are determined after completion of the pretest procedure described in 10.2 and before carrying out the 50 h test procedure described in 10.5.

10.4.2 *Baseline D4052 Density of Unaerated Fresh Oil and its Temperature Dependence:*

10.4.2.1 Measure the density of the fresh test oil between 30 °C to 90 °C at 10 °C increments using Test Method D4052.

10.4.2.2 Use these seven data points to calculate the first order, linear regression of density versus temperature using the least squares method. R^2 values shall be greater than 0.99990. Repeat the density measurements as necessary until the required value is obtained.

10.4.2.3 The slope of this line quantifies the effect of temperature on the D4052 density of the fresh, un-aerated oil and is denoted by $\frac{d}{dT}\rho_{BL}$; the intercept at 90 °C is the D4052 density of the un-aerated fresh oil at 90 °C and is denoted by $\rho_{BL,90}$. (Here ρ and *T* are used as the symbols for density and temperature, respectively, and BL denotes "baseline".)

NOTE 8—For convenience, a list of the quantity symbols and their definitions is given in 3.4.

10.5 *50 h Test Procedure:*

10.5.1 Following on from 10.2.5, measure out 36 L ± 0.2 L of test oil and determine the mass. Record the volume and mass of the oil. Charge the engine as described in 10.2.2.1.

10.5.2 Start the engine and carry out the warmup described in 10.2.3.

10.5.3 Immediately after completing the warmup and without shutting down the engine, start the 50 h test procedure described in Table 4.

10.5.3.1 *Test Timer*—The 50 h test timer starts immediately following the warmup. If a shutdown occurs, stop the test timer immediately at the initiation of the shutdown. The test timer shall resume after the warmup described in Table 3 and when the test has been returned to the test operation schedule and all controlled quantities are within specification requirements.

10.5.4 *Operational Data Acquisition*—Record all operational quantities shown in Table 4 with automated data acquisition at a minimum frequency of once every 30 s. Recorded values shall have a minimum resolution in accordance with Annex A8.

10.5.4.1 Record the operational data on the appropriate test report form.

TABLE 4 Schedule of Conditions for the 50 h Test

Quantity, units	Step 1
Stage Length, h	50
Speed, r/min	1800
Load, N·m	0
Coolant Out Temperature, °C	90
Air Intake Temperature, °C	25
Intake Manifold Temperature, °C	40
Fuel-in Temperature, °C	40
Oil Gallery Temperature, °C	90
Sample Oil Temperature,[A] °C	90
Sample Oil Flow Rate,[A] L/min	1.5
Sample Oil Pressure,[A] kPa (absolute),	84
Intake Air Pressure, kPa (absolute),	96 ± 1.5
Fuel Flow Rate, g/min	Record
Blowby Flow Rate, L/min	Record
Intake Manifold Pressure,[B] kPa (gauge)	Record
Crankcase Pressure, kPa (gauge)	103
Intercooler Delta Pressure, kPa (gauge)	15 max
Exhaust After Turbo Temperature, °C	Record
Fuel Pressure, kPa (gauge)	Record
Oil Gallery Pressure, kPa (gauge)	Record
Coolant System Pressure, kPa (gauge)	99 to 107
Exhaust Restriction Pressure, kPa (absolute)	104
Pressure Regulator Controller Output,[C,D] %	<50 %
Micropump Controller Output,[C,D] %	<50 %

[A] Micro Motion quantity.
[B] With turbocharger waste-gate fully closed.
[C] If this value is above 50 % output for 15W-40 or thinner viscosity oils, the test is invalid. Oils of higher viscosity need a statement of validity in the comments section of the report if they exceed 50 % output.
[D] Average value over the length of the test.

10.5.5 *Oil Sampling and Analyses:*

10.5.5.1 *New Oil Sample*—Take a 240 mL sample of the fresh test oil from the original oil container. Measure and report the quantities shown in A14.2.

10.5.5.2 Take oil samples and carry out analyses according to the schedule and methods shown in Annex A13.

10.5.5.3 Record the results on the appropriate test report form.

10.5.6 *Quantities for Aerated Oil Samples:*

10.5.6.1 *General*—Measure the sample oil temperature, pressure, flow rate, and FDM density using the aeration system shown in Fig. A7.1.

10.5.6.2 *Temperature of Sampled Oil*—Record the average of the inlet and outlet thermocouple temperatures of the FDM. This temperature is a theoretical temperature at the midpoint of the FDM; it is referred to as the sample oil temperature and is denoted by T_{SAMPLE}.

10.5.6.3 *Pressure of Sampled Oil*—Record the average of the inlet and outlet pressure transducers of the FDM. This pressure is a theoretical pressure at the midpoint of the FDM; it is referred to as the sample oil pressure and is denoted by P_{SAMPLE}.

10.5.6.4 *FDM Density of Sampled Oil*—Record the sample oil density. This is the density of the aerated oil at the temperature T_{SAMPLE} and the pressure P_{SAMPLE}; it is denoted by ρ_{SAMPLE}.

10.5.7 After completion of the 50 h test perform a normal shutdown as described in 10.3.1.

10.5.8 Drain the test oil charge from the engine with the oil sample circuit pump running, weigh the drained oil and calculate the total oil consumed during the test as the difference in mass between the initial charge (as recorded in 10.5.1) and the drained oil.

11. Calculation

11.1 *Oil Aeration Calculations:*

11.1.1 Calculate the percent oil aeration from the quantities recorded in 10.5.6 as follows:

11.1.1.1 First, using Eq 2, calculate ρ_{SAMPLE_90}, the FDM density of the aerated-oil sample at 90 °C:

$$\rho_{SAMPLE,\,90} = \rho_{SAMPLE} + (90 - T_{SAMPLE}) \times \frac{d}{dT}\rho_{BL} \quad (1)$$

where:

ρ_{SAMPLE} = the recorded density of the aerated oil sample at the temperature T_{SAMPLE} (see 10.5.6.4),
T_{SAMPLE} = the sample oil temperature (see 10.5.6.2), and
$\frac{d}{dT}\rho_{BL}$ = the temperature dependence of the baseline density (see 10.4.2.3).

11.1.1.2 Then, using Eq 3, calculate the air density, ρ_{AIR}, at the temperature and pressure, T_{SAMPLE} and pressure P_{SAMPLE}, respectively, of the oil sample:

$$\rho_{AIR} = \rho_{SAMPLE} / [287.003 \times (T_{SAMPLE} + 273.15)] \quad (2)$$

where:

ρ_{SAMPLE} = the pressure of the sampled oil determined as described in 10.5.6.3,
273.15 = the ice point in °C and,
287.003 = the specific gas constant for dry air with units $Jkg^{-1}K^{-1}$, where K is the symbol for kelvin.

11.1.1.3 Finally, using Eq 4, calculate the oil aeration:

$$OA = [(\rho_{BL,90} - \rho_{SAMPLE,90}) / (\rho_{SAMPLE,90} - \rho_{AIR})] \times 100\,\% \quad (3)$$

where:

OA = the symbol denoting oil aeration,
$\rho_{BL,90}$ = the D4052 baseline density of the unaerated fresh oil at 90 °C (see 10.4.2.3), and

$\rho_{SAMPLE,90}$ and ρ_{AIR} are given by Eq 2 and Eq 3, respectively.

11.1.2 Report on the appropriate test report form. Report the percent oil aeration to two decimal places.

12. Report

12.1 For reference-oil results, use the standardized report form set available from the ASTM TMC and data dictionary for reporting test results and for summarizing operational data.

NOTE 9—Report the non-reference-oil test results on these same forms if the results are intended to be submitted as candidate oil results against a specification.

12.1.1 Fill out the report forms according to the formats shown in the data dictionary.

12.1.2 Transmit results to the TMC within five working days of test completion.

12.1.3 Transmit the results electronically as described in the ASTM Data Communications Committee Test Report Transmission Model (Section 2—Flat File Transmission Format) available from the ASTM TMC. Upload files via the TMC's website.

12.2 Report all reference-oil test results, whether aborted, invalidated, or successfully completed, to the TMC.

12.3 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits.

12.4 *Precision of Reported Units*—Use the Practice E29 rounding-off method for critical pass/fail test result data. Report the data to the same precision as indicated in data dictionary.

12.5 In the space provided, note the time, date, test hour, and duration of any shutdown or off-test condition. Document the outcome of all prior reference-oil tests from the current calibration sequence that were operationally or statistically invalid.

12.6 If a calibration period is extended beyond the normal calibration period length, make a note in the comment section and attach a written confirmation of the granted extension from the TMC to the test report. List the outcomes of previous runs that may need to be considered as part of the extension in the comment section.

13. Precision and Bias

13.1 *Precision:*

13.1.1 Test precision is established on the basis of operationally valid reference-oil test results monitored by the TMC.

13.1.2 *Intermediate Precision Conditions*—Conditions where test results are obtained with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

NOTE 10—Intermediate Precision is the appropriate term for this test method, rather than repeatability, which defines more rigorous within-laboratory conditions.

13.1.2.1 *Intermediate Precision Limit (i.p.)*—The difference between two results obtained under intermediate precision conditions that in the long run, in the normal and correct conduct of the test method, exceed the value shown in Table 5 in only one case in twenty.

13.1.3 *Reproducibility Conditions*—Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

13.1.3.1 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values in Table 5 in only one case in twenty.

13.1.4 The test precision for the COAT as of February 10, 2016 is shown in Table 5. The TMC updates precision data frequently, and this information can be obtained by contacting the TMC.

13.2 *Bias*—Bias is determined by applying an accepted statistical technique to reference-oil test results and, when a significant bias is determined, a severity adjustment is permitted for non-reference-oil test results (refer to the TMC for details).

14. Keywords

14.1 automotive; Caterpillar C13; COAT; diesel engine oil; heavy-duty diesel engine; lubricants; oil aeration

TABLE 5 Test Precision for COAT[A]

Quantity	Intermediate Precision, *i.p.*	Reproducibility, *R*
Average Engine Oil Aeration from 40 h to 50 h, %	0.743	0.858

[A] These statistics are based on 33 tests conducted on three stands (one at each of three laboratories) on six ASTM TMC Reference Oils (832, PC11H, PC11I, PC11J, 833, PC11L) and were calculated on February 10, 2016.

ANNEXES

(Mandatory Information)

A1. ASTM TEST MONITORING CENTER ORGANIZATION

A1.1 *Nature and Functions of the ASTM Test Monitoring Center (TMC)*—The TMC is a non-profit organization located in Pittsburgh, Pennsylvania and is staffed to: administer engineering studies; conduct laboratory inspections; perform statistical analyses of reference-oil test data; blend, store, and ship reference oils; and provide the associated administrative functions to maintain the referencing calibration program for various lubricant tests as directed by ASTM Subcommittee D02.B0 and the TMC Executive Committee. The TMC coordinates its activities with the test sponsors, the test developers, the surveillance panels, and the testing laboratories. Contact TMC through the TMC Director at:

ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489
www.astmtmc.cmu.edu

A1.2 *Rules of Operation of the ASTM TMC*—The TMC operates in accordance with the ASTM Charter, the ASTM Bylaws, the Regulations Governing ASTM Technical Committees, the Bylaws Governing ASTM Committee D02, and the Rules and Regulations Governing the ASTM Test Monitoring System.