Designation: ~~D8047 – 19ε1~~ D8047 – 23

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.

~~ε1 NOTE—Editorially updated TMC governance information in June 2022.~~

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.

ASTM International policy is to encourage the development of test procedures based on generic equipment. It is recognized that there are occasions where critical/sole-source equipment has been approved by the technical committee (surveillance panel/task force) and is required by the test procedure. The technical committee that oversees the test procedure is encouraged to clearly identify if the part is considered critical in the test procedure. If a part is deemed to be critical, ASTM encourages alternative suppliers to be given the opportunity for consideration of supplying the critical part/component providing they meet the approval process set forth by the technical committee.

An alternative supplier can start the process by initiating contact with the technical committee (current chairs shown on ASTM TMC website). The supplier should advise on the details of the part that is intended to be supplied. The technical committee will review the request and determine feasibility of an alternative supplier for the requested replacement critical part. In the event that a replacement critical part has been identified and proven equivalent the sole-source supplier footnote shall be removed from the test procedure.

[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.

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[2] Until the next revision of this test method, the ASTM Test Monitoring Center will update changes in the test method by means of information letters. Information letters may be obtained from the ASTM Test Monitoring Center, 203 Armstrong Drive, Freeport, PA 16229, Attention: Director. This edition incorporates revisions in all information letters through No. ~~19-1.~~22-1. http://www.astmtmc.org.

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 test method is arranged as follows:

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* See Annex A2 for general safety precautions.

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

2. Referenced Documents

2.1 *ASTM Standards:*[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~~

[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.

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
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 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) (Withdrawn 2021)[4]
D6894 Test Method for Evaluation of Aeration Resistance of Engine Oils in Direct-Injected Turbocharged Automotive Diesel Engine (Withdrawn 2022)[4]
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.

[4] The last approved version of this historical standard is referenced on www.astm.org.

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**

3.1.9 *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; they 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,~~ = 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 lubricants*, the action of impregnating with air that forms foam bubbles in or on the surface of a lubricant or is entrained as a dispersion in that lubricant.

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)~~90 °C)

3.3.4 *BOT*—Beginning of Test

3.3.5 *CARB*—California Air Resources Board

3.3.6 *Cat*[5]—abbreviation for Caterpillar

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

3.3.8 *CPD*—Central Parts Distributor

3.3.9 *ELC*[6]—Extended-Life Coolant

3.3.10 *EOAT*—Engine-Oil Aeration Test

3.3.11 *ET*—Engine Technician

3.3.12 *EOT*—End of Test

3.3.13 *FDM*—Flow and Density Meter

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

3.3.15 *ID*—Internal Diameter

3.3.16 *LTMS*—Lubricant Test Monitoring System

3.3.17 *NPT*—National Pipe Thread

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

3.3.18 *OA*—Oil Aeration

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

3.3.20 *QI*—Quality Index

3.3.21 *RCV*—Research Control Valve

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

3.3.23 *SS*—Stainless Steel

3.3.24 *TMC*—Test Monitoring Center of ASTM

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

3.4 *Quantity Symbols:*

3.4.1 *OA*—Oil Aeration, %, (see ~~11.1.1.3~~11.2.1.3)

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~~11.2.1.2)

3.4.7 $\rho_{BL,\ 90}$—baseline density of the ~~unaerated~~un-aerated 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~~ 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~~11.2.1.1)

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 except where specified in this document 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~~ 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,[7,8] 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~~ shall utilize a Micro Motion Elite, Model CMF ~~025,~~025: coriolis-based, flow and density meter (FDM) with a remote core processor in a 5700R transmitter,[9] 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 lengths, fittings and components as shown in ~~Annex A7. The aeration measurement~~the schematic described in A7.1~~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.~~.

[7] 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.

[8] 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.

[9] 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.

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.[7,8] Additionally, install a remotely mounted heat exchanger. exchanger vertically with a drain valve on the outlet. See Figs. A4.1 and A4.2. 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 77 and 8 apply.

6.2.2 *Oil Pan Modification*—Modify the oil pan as shown in Figs. A5.1-A5.4Figs. A4.1-A4.4 of Annex A4 of Test Method D7549. Install the oil pan jacket as shown in Fig. A5.5A5.1.

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 plates. 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-A5.23Fig. A5.3.

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. Remove all break-in specific systems once break-in is complete. The modified oil pan may be used for the aeration test provided that all unused ports are plugged. The location for the pump supply of the oil pan is capped when this system is not in use.

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. A5.7A5.4) 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[10,8] cooler (part number 1A012865) has been

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

found suitable for this use.[11] 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~~<u>A5.5</u>, 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.~~

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~~ <u>The</u> Fig. A5.10. ~~Use Viking Pump Model No. SG053514.~~ ~~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.<u> See Fig. A5.2.</u>

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~~<u>A5.6</u>). 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~~<u>A5.6</u>. 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[12,13,8] have been found to give satisfactory results under the conditions specified in this test method.

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[11] 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.

[12] 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.~~<u>J-TEC Associates, Inc., 5005 Blairs Forest Lane NE, Suite L, Cedar Rapids, IA 52402. www.j-tecassociates.co.</u>

~~[13] 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: ~~https://www.astmtmc.org/ftp/docs/misc/QualityIndex/Minutes/DACA_II_Data%20Acquisition%20and%20Control%20Automation.pdf.~~<u>http://ftp.astmtmc.org/docs/TechnicalGuidanceCommittee/minutes/BestPractices/DACA_II_Data%20Acquisition%20and%20Control%20Automation.pdf.</u>

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.[13,14]

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

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,~~fuel[14,15,8] is required to complete the test. ~~Fuel property tolerances are~~ The fuel shall have the properties and tolerances shown in ~~Annex A15.~~the "PC-10 Fuel Specification" section of the "TMC-Monitored Test Fuel Specifications" document maintained on the TMC website at http://www.astmtmc.org/ftp/docs/fuel/tmc-monitored%20test%20fuel%20specifications.pdf.

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.[7,8]

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.)

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.

[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.

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[15,16,8] 5810A (item 39210 or 39211) has been found suitable for this purpose.

8. Preparation of Apparatus

8.1 *Cleaning of Parts During Rebuild:*

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[16,17] 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 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[17] 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.

[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.

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[17,18,8] 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 Test Method 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:~~test and terminate the current calibration period:

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, and
(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 flow meter 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~~ ±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 and Verification of FDM:*
(1) Calibration of FDM System is required for new installation of a COAT Aeration Measurement System or replacement of Micro Motion Assembly components found in Annex A7 Drawings_REV3_5_7_19. Calibrate the Newly Installed Box and Micro Motion FDM ~~at least once a year. Emerson's Flow~~ System using n-Decane (99+ %) and EF411 oil to determine potential gains and offsets for the FDM Density Data Acquisition (DAQ) measurement as compared with Test Method D4052 Density/Temperature sweeps of both fluids as outlined in Annex A6. Reference ~~*Calibration*~~ *Two Fluid EF411 nDecane Calibration Summary.xlsx*~~and Service Centers~~ file available on the TMC website to follow Gain and Slope determination. ~~have~~SeeA6.2 ~~been found satisfactory for this purpose.~~for Set Up procedure and methodology.

[18] 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.

(2) ~~For all reference and non-reference oil tests to be considered valid, the FDM shall have a current calibration.~~Verification of FDM System is required for each subsequent Reference period of the stand (6 months or test limit): Verify the Micro Motion FDM Apparatus using Reference Oils 832-1 or 833-1 along with the nDecane results from the original calibration to determine potential changes in gains and offsets for the FDM Density Data Acquisition (DAQ) measurement as compared with Test Method D4052 Density/Temperature sweeps of both fluids as outlined in Annex A6. Reference *Two Fluid Reference Oil nDecane Verification Summary.xlsx* file available on the TMC website to follow Gain and Slope determination. See A6.3 for setup procedure and methodology.

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

~~*(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.[14,18]

8.3.2.2 *Coolant-Out Temperature*—Install the sensor in the fitting on the thermostat housing (Fig. ~~A5.13~~A5.8).

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~~A5.9).

8.3.2.4 *Fuel-In Temperature*—Install the sensor in the fuel-pump inlet fitting (Fig. ~~A5.16~~A5.10).

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~~A5.11) 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~~A5.4).

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~~A5.12).

8.3.2.8 *Exhaust Temperature*—Install the sensor in the exhaust tube (Fig. ~~A5.8~~A5.5).

8.3.2.9 *Aeration System Enclosure Temperature*—Insert the sensor ~~75 mm~~ 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~~A5.2.

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[14] 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~~A5.11).

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. A5.9A5.13).

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. A5.17A5.12).

8.3.3.5 *Crankcase Pressure*—Measure the pressure by installing a bulkhead fitting in the top of the valve cover. (Fig. A5.12A5.7).

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. A5.7A5.4).

8.3.3.7 *Exhaust Pressure*—Measure the pressure on the exhaust tube (Fig. A5.8A5.5).

8.3.3.8 *Fuel Pressure*—Measure the pressure at the fuel-filter head (Fig. A5.25A5.14).

8.3.3.9 *Coolant Pressure*—Measure the pressure on top of the expansion tank (Fig. X1.3A5.16).

8.3.3.10 *Intercooler Delta Intake Valve Actuator Oil Pressure*—Measure the pressure drop across the intercooler. Measure the intercooler inlet pressure at the elbow outlet of the CAT charge air cooler (intake valve actuator rail pressure at the rear of the cylinder head (refer to Fig. A5.19A5.17). Use the intake-manifold pressure (an EL pressure snubber.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 *External Oil Heat Exchanger Outlet Pressure*—Measure the heat exchanger outlet pressure at the return port to the oil filter block assembly. See Fig. A5.15.

8.3.3.12 *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[14] 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 the test average 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%an engineering review should be peformed to determine if ^{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 %.valid.

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.)

8.3.6.2 Record the oil sample pressure as the average of the inlet and outletusing the inlet and delta 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 six 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 four parts: W, X, Y, and Z, where W represents the test-stand number, X the sequential test-stand-run number, Y the laboratory engine identification number, and Z the sequential engine run number. For example 27-15-25050-15 indicates run number 15 on test-stand number 27 and the 15th run on engine number 25050. The test stand run and engine run numbers, X and Z, 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 X. The letter suffix shall begin with A and incremented alphabetically until an acceptable reference oil test is completed. For example, if two consecutive unacceptable reference oil tests were conducted and the first number was 27-15-25050-15, the second test number would be 27-16A-25050-16. A third calibration attempt would have the test number 27-17B-25050-17. If the third test were acceptable, then 27-17B-25050-17 would identify the reference oil test in the test report.

9.5.3 *Non-Reference Oil Tests*—Add no letter suffix to X 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).