Designation: D6750 – 15

StandardTest Methods for Evaluation of Engine Oils in a High-Speed, Single-Cylinder Diesel Engine—1K Procedure (0.4 % Fuel Sulfur) and 1N Procedure (0.04 % Fuel Sulfur)[1]

This standard is issued under the fixed designation D6750; 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

The test methods described in this standard can be used by any properly equipped laboratory without outside assistance. However, the ASTM Test Monitoring Center (TMC)[2] provides reference oils and an assessment of the test results obtained on those oils by the laboratory (see Annex A15). By this means, the laboratory will know whether its use of the test methods gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory uses the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army has such a requirement in some of its engine oil specifications.

Accordingly, these test methods are written for those laboratories that use the TMC services. Laboratories that choose not to use these services may ignore those portions of the test methods that refer to the TMC.

These test methods may be modified by Information Letters issued periodically by the TMC after the publication of this edition of the standard to become part of it. These letters are obtainable from the TMC. In addition, the TMC may issue supplementary memoranda related to the test methods, also obtainable from the TMC.

1. Scope*

1.1 These test methods cover the performance of engine oils intended for use in certain diesel engines. They are performed in a standardized high-speed, single-cylinder diesel engine by either the 1K (0.4 % mass fuel sulfur) or 1N (0.04 % mass fuel sulfur) procedure.[3] *The only difference in the two test methods is the fuel used*. Piston and ring groove deposit-forming tendency and oil consumption are measured. Also, the piston, the rings, and the liner are examined for distress and the rings for mobility. These test methods are required to evaluate oils intended to satisfy API service categories CF-4 and CH-4 for 1K, and CG-4 for 1N of Specification D4485.

1.2 These test methods, although based on the original Caterpillar 1K/1N procedures,[3] also embody TMC information letters issued before these test methods were first published. These test methods are subject to frequent change. Until the next revision of these test methods, TMC will update changes in these test methods by the issuance of information letters which shall be obtained from TMC (see Annex A15).

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

1.3.1 *Exception*—Where there is no direct SI equivalent such as screw threads, national pipe threads/diameters, tubing size, or single source equipment specified. Also Brake Specific Fuel Consumption is measured in kilograms per kilowatthour.

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 and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements appear throughout the text. Being engine tests, these test methods do have definite hazards that shall be met by safe practices (see Annex A16 on Safety Precautions).

[1] These test methods are under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0.02 on Heavy Duty Engine Oils.

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[2] ASTM Test Monitoring Center (TMC), 6555 Penn Ave., Pittsburgh, PA 15206-4489. The TMC issues Information Letters that supplement this test method. This edition incorporates revisions contained in all information letters through No. 14–1.

[3] These 1K/1N test procedures were developed by Caterpillar Inc., P.O. Box 610, Mossville, IL 61552-0610.

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

1.5 The following is the Table of Contents:

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D97 Test Method for Pour Point of Petroleum Products

D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)

D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)

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

D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption

D1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)

D2425 Test Method for Hydrocarbon Types in Middle Distillates by Mass Spectrometry

D2500 Test Method for Cloud Point of Petroleum Products

D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry

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

D3117 Test Method for Wax Appearance Point of Distillate Fuels (Withdrawn 2010)[5]

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

D4485 Specification for Performance of Active API Service Category Engine Oils

D4737 Test Method for Calculated Cetane Index by Four Variable Equation

D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration

[4] 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.

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

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
D5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID) (Withdrawn 2003)[5]
D5862 Test Method for Evaluation of Engine Oils in Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine (Withdrawn 2009)[5]
D6202 Test Method for Automotive Engine Oils on the Fuel Economy of Passenger Cars and Light-Duty Trucks in the Sequence VIA Spark Ignition Engine (Withdrawn 2009)[5]
D6594 Test Method for Evaluation of Corrosiveness of Diesel Engine Oil at 135 °C
D7422 Test Method for Evaluation of Diesel Engine Oils in T-12 Exhaust Gas Recirculation Diesel Engine
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *SAE Standard:*
SAE J183 Engine Oil Performance and Engine Service Classification[6]

2.3 *API Standard:*
API 1509 Engine Service Classification and Guide to Crankcase Oil Selection[7]

2.4 *Other ASTM Document:*
ASTM Deposit Rating Manual 20 (Formerly CRC Manual 20)[8]

3. Terminology

3.1 *Definitions:*

3.1.1 *blind reference oil, n*—a reference oil, the indentity of which is unknown by the test facility.

3.1.1.1 *Discussion*—This is a coded reference oil that is submitted by a source independent from the test facility. **D5844**

3.1.2 *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.

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

3.1.3 *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.

3.1.3.1 *Discussion*—In several automotive lubricant standard test methods, the TMC provides testing guidance and determines acceptability. **Sub. B Glossary**[2]

3.1.4 *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. **D5844**

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

3.1.6 *double-blind test, n*—a standard test performed on a double-blind reference oil.

3.1.7 *double-blind reference oil, n*—a reference oil, the identity of which is unknown by either the submitting source or the test facility and is not known to be a reference oil by the test facility.

3.1.7.1 *Discussion*—This is a coded reference oil that is supplied by an independent source to a second party, who applies their own coded designation to the oil (and if necessary, repackages it to preserve its anonymity), and submits it to a third party for testing. **Sub. B Glossary**

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

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

3.1.9 *erosion, n*—wearing away gradually, especially by rubbing or corroding.

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

3.1.11 *lubricating oil, n*—a liquid lubricant, usually comprising several ingredients, including a major portion of base oil and minor portions of various additives. **Sub. B Glossary**

3.1.12 *non-reference oil, n*—any oil other than a reference oil; such as a research formulation, commercial oil, or candidate oil. **D5844**

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

3.1.13.1 *Discussion*—The preferred term is *purchaser*. Deprecated terms that have been used are *client*, *requestor*, *sponsor*, and *customer*. **D6202**

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

3.1.14.1 *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. **D5844**

3.1.15 *soot, n—in internal combustion engines*, submicron size particles, primarily carbon, created in the combustion chamber as products of incomplete combustion. **D5862**

[6] Available from the Society of Automotive Engineers Inc., 400 Commonwealth Dr., Warrendale, PA 15096. Order *SAE Handbook*, Vol 3; the standard is not available separately.

[7] Available from the American Petroleum Institute, 1220 L St., NW, Washington, DC 20005.

[8] For Stock #TMCMNL20, visit the ASTM website, www.astm.org, or contact ASTM International Customer Service at service@astm.org.

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

3.1.16.1 *Discussion*—In some instances, such as a test method for chemical analysis, an ASTM working group can be the *sponsor* of a test method. In other instances, a company with a self-interest may or may not be the *developer* of the test procedure used within the test method, but is the *sponsor*, of the test method **D6594**

3.1.17 *standard test, n*—a test on a calibrated test stand using the prescribed equipment that is assembled according to the requirements in the test method, and conducted according to the specified operating conditions.

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *heavy land carbon, n*—see ASTM Deposit Rating Manual 20.

3.2.2 *Keystone ring, n*—a compression ring with both sides tapered.

3.2.3 *liner bore polishing, n*—see ASTM Deposit Rating Manual 20.

3.2.4 *new laboratory, n*—a laboratory that has not had two acceptable reference oil test results on approved reference oils (see special circumstances in 3.2.5.1).

3.2.4.1 *Discussion*—A laboratory not running either a 1K or 1N test for 24 months from the start of the last test is considered a new laboratory. Under special circumstances (such as extended downtime due to industry-wide parts shortage or fuel outages), the TMC may extend the lapsed time requirement. Non-reference oil tests conducted during an extended time allowance shall be annotated on the comment form.

3.2.5 *new test stand, n*—a test engine and support hardware that has never been calibrated under this test procedure.

3.2.6 *scratching, n*—see ASTM Deposit Rating Manual 20.

3.2.7 *scuffing, n—in lubrication*, see ASTM Deposit Rating Manual 20.

3.2.8 *test time, n—in this test method*, all engine test time accumulated when carrying out this test procedure.

3.2.9 *varnish, n—in internal combustion engines*, see ASTM Deposit Rating Manual 20.

3.3 *Abbreviations:*

3.3.1 *BDC*—bottom dead center.

3.3.2 *BSOC*—break specific oil comsumption.

3.3.3 *EOT*—end of test.

3.3.4 *EOTOC*—end of test oil consumption.

3.3.5 *EWMA*—exponentially weighted moving average.

3.3.6 *LTMS*—TMC Lubrication Test Monitoring System.

3.3.7 *SA*—severity adjustment.

3.3.8 *TDC*—top dead center.

3.3.9 *TGF*—top groove fill.

3.3.10 *TLHC*—top land heavy carbon.

3.3.11 *WDK*—weighted demerits (1K).

3.3.12 *WDN*—weighted demerits (1N).

4. Summary of Test Method

4.1 A Caterpillar 1Y540 diesel engine, or a 1Y73 diesel engine with a 1Y541 conversion arrangement (see 6.2), is built up prior to test (either 1K or 1N test procedure) in accordance with the accompanied directions using a special parts kit. These include disassembly, solvent cleaning, measurement, and rebuild of the power section in strict accordance with specifications. The parts comprise a new piston, ring assembly, and cylinder liner which are measured and installed prior to test. The engine crankcase is solvent cleaned and worn or defective parts replaced. The test stand is equipped with appropriate accessories for controlling speed, torque, and various other engine operating conditions. Suitable systems are provided for treating the inlet air and controlling the exhaust gases. Using the test oil as the engine lubricating oil, the single cylinder, calibrated diesel engine is run under the prescribed test conditions for a total of 252 h. A specified break-in procedure precedes each test and whenever the engine needs to be restarted. During the test, engine oil consumption is periodically measured. At the end of the test (either 1K or 1N), the engine is disassembled and the piston, liner, and rings photographed, inspected, and measured. Average oil consumption and used oil condition data are also recorded.

5. Significance and Use

5.1 These are accelerated engine oil tests (known as the 1K and 1N test procedures), performed in a standardized, calibrated, stationary single-cylinder diesel engine using either mass fraction 0.4 % sulfur fuel (1K test) or mass fraction 0.04 % sulfur fuel (1N test), that give a measure of (*1*) piston and ring groove deposit forming tendency, (*2*) piston, ring and liner scuffing and (*3*) oil consumption.

5.2 The 1K test was correlated with vehicles equipped with certain multi-cylinder direct injection engines used in heavy duty and high speed service prior to 1989, particularly with respect to aluminum piston deposits, and oil consumption, when fuel sulfur was nominally mass fraction 0.4 %. These data are given in Research Report RR:D02-1273.[9]

5.3 The 1N test has been used to predict piston deposit formation in four-stroke cycle, direct injection, diesel engines that have been calibrated to meet 1994 U.S. federal exhaust emission requirements for heavy-duty engines operated on fuel containing less than mass fraction 0.05 % sulfur. See Research Report RR:D02-1321.[9]

5.4 These test methods are used in the establishment of diesel engine oil specification requirements as cited in Specification D4485 for appropriate API Performance Category oils (API 1509).

5.5 These test methods are also used in diesel engine oil development.

[9] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Reports RR:D02:1273 and RR:D02-1321.

6. Apparatus

6.1 *General Laboratory Requirements:*

6.1.1 *Engine Operation and Buildup Area*—Keep the ambient air free from gross dirt, dust, and other contamination, especially in the build-up area, following accepted engine test laboratory practice.

6.1.2 *Measurement Area*—As good practice, maintain this area at about (10 to 25) °C. The actual air temperature is not critical within this range, but maintain it within ± 3 °C to achieve acceptable repeatability in the measurement of dimensions of parts. Filter the air supply to the area to remove particles larger than about 10 µm and maintain at (45 to 65) % relative humidity. If unable to do this, keep the air free from gross particulate contamination as indicated in 6.1.1.

6.1.3 *Parts Rating Area*—Maintain as specified in ASTM Deposit Rating Manual 20.

6.1.4 *Parts Cleaning Area*—(**Warning**—Provide adequate ventilation and fire protection in areas where solvents are used (see Annex A16).

6.2 *Test Engine*—The test engine for these 1K and 1N test procedures is either (*1*) a Caterpillar 1Y540 engine[10] or (*2*) a Caterpillar 1Y73 engine with a 1Y541 conversion arrangement[10]. Details are given in the Caterpillar Service Manual.[10] Each test engine (*1*) is a direct injection, single-cylinder diesel engine with a four-valve arrangement, (*2*) has a cylinder bore of 137.2 mm bore and a piston stroke of 165.1 mm resulting in a displacement of 2.4 L and (*3*) is equipped with a number of modified and unmodified accessories that are described in 6.3. See Annex A1 for specifications for engine build.

6.3 *Test Engine Accessories and Parts*—Many of the accessories of the assembled Caterpillar engines (see 6.2) require modifications for these test methods. These modifications are described herewith.

6.3.1 *Intake Air System*—The system comprises an air heater chamber, isolation hose and appropriate piping. Construction details are given in Annex A2. To ensure good precision, the system shall be uniform within a laboratory and among laboratories. The system shall be capable of filtering, heating, compressing, and humidifying the inlet air in accordance with the specified engine operating conditions in Annex A10.

6.3.1.1 *Filtering*—Use an air filter capable of 10 µm (or smaller) filtration.

6.3.1.2 *Heating*—Provide heating to heat the intake air to the specified temperature. Locate the air temperature measurement tap at the P/N 1Y632 adapter (see Annex A2). For air barrels mounted horizontally, the location of the pressure tap and air outlet pipe can be interchanged (see Annex A2).

6.3.1.3 *Compressing*—Provide air compression capability. Locate the intake air pressure measurement tap at the air barrel (see Annex A2). When air barrels are mounted horizontally, the locations of the pressure tap and air outlet pipe can be interchanged (see 6.3.1.2).

6.3.1.4 *Humidifying*—The equipment shall be capable of humidifying compressed air to a water content in dry air of 17.8 g/kg and maintaining the humidified inlet air at a specified temperature. See Annex A2 for location of humidity measurement tap.

6.3.1.5 *Inspection of Air Intake Barrel*—Prior to each stand calibration test, inspect the intake air barrel for rust and debris. Perform the inspection through either of the pipe flanges using a borescope or other optical means.

6.3.2 *Exhaust System*—The exhaust system comprises an exhaust elbow, a welded 45° pipe nipple, a bellows assembly, an exhaust barrel, and exhaust piping downstream of the barrel that contains a restriction valve to maintain the exhaust gases at back pressures up to (216 ± 1) kPa. Drawings of the component parts, dimensions, and instrument locations are given in Annex A3. The exhaust system shall also provide for exhaust gas temperature measurement and exhaust gas sampling, the exhaust gas temperature range being (550 ± 30) °C.

6.3.2.1 *Exhaust Barrel*—The exhaust barrel may be insulated or water-cooled. Place the new exhaust elbow P/N 1Y631-2 (see Annex A3) at the rear side or front of the engine. The volume of the exhaust barrel and the dimensions and distance of the exhaust piping from the exhaust elbow to the barrel are specified in Figs. A3.1-A3.4. The downstream distance of the restriction valve from the exhaust barrel is not specified.

6.3.2.2 *Exhaust Probe*—Use an exhaust probe to sample exhaust gases for air/fuel ratio determinations. Install the probe using a suitable reducer and compression fitting downstream of the exhaust restriction valve and within 1.2 m. Locate the probe in mid-stream and parallel to the exhaust flow as shown in Fig. A3.5.

6.3.2.3 *Exhaust Temperature*—Measure the exhaust temperature with thermocouple P/N 1Y467 or equivalent located as shown in Fig. A3.4.

6.3.2.4 *Exhaust Pressure*—Measure the exhaust pressure in the exhaust barrel as shown in Fig. A3.2. Set the pressure at the conditions specified in Table A10.1 by adjusting the restriction valve.

6.3.3 *Cooling System*—Provide a closed circulating cooling system with an engine-driven centrifugal water pump. System details given in Fig. A4.1 show cooling system modifications; Fig. A4.2 shows coolant temperature, flow, and pressure measurement locations; and Fig. A4.3 shows a water pump bypass arrangement. See 6.3.3.5 regarding system cleaning.

6.3.3.1 *Cooling System Modification*—Modify the cooling system as shown in Fig. A4.4.

6.3.3.2 *Coolant Flow, Control and Measurement*—Modify the engine coolant lines from the cylinder head to the standpipe in accordance with Fig. A4.1. As shown, the coolant line

[10] Available from Caterpillar Inc., Engine System Technology Development, P.O. Box 610, Mossville, Il 61552-0610. Service and parts manuals available are (*1*) Caterpillar Service Manual for Single Cylinder Oil Test Engine for Diesel Lubricants, Form No. SENR2856 and (*2*) Caterpillar Parts Book, Form No. SEBP1408.

contains (*1*) a calibrated Barco flowmeter, P/N BR 12705-16-31[11,12], 25.4 mm in diameter to measure the coolant flow and (*2*) a P/N 1Y496 orifice, 15.797 mm in diameter before the flowmeter to develop cooling system pressure and thereby to eliminate coolant cavitation. Control coolant flow at (65 ± 2.0) L/min at Step 5 (see Table A10.1) by a bypass valve downstream of the water pump, 19 mm in diameter. Replace the production hose and the restrictive 90° elbows that connect the bypass valve to the cylinder block by a Gates 20777 hose[13,12] or equivalent (see Fig. A4.3). Measure the coolant pressure at the block to ensure that proper cooling system operation has been attained (see Fig. A4.2).

6.3.3.3 *Engine Temperature Differential*—As an indicator of coolant system performance, maintain the engine temperature differential (ΔT) (coolant temperature out of the cylinder head minus coolant temperature into the block) at (5.0 ± 1.0) °C. Also control the coolant temperature out at (93 ± 2.5) °C.

6.3.3.4 *Engine Coolant*—The engine coolant is a mixture of 50/50 volume ratio of coolant (Caterpillar brand P/N 8C3684 in a 3.8 L container or P/N 8C3686 in a 200 L drum)[14,12] to mineral-free water, the mineral content being ≤34.2 mg/kg of total solids in water. This coolant mixture may be used for up to six tests or three months, whichever comes first. Maintain the mixture at a 50/50 ratio of coolant to water and verify periodically with either a Caterpillar tester P/N 5P3514 or P/N 590957 or equivalent commercial tester. Keep the coolant mixture substantially free from solids contamination (total solids <5000 mg/kg) and at the correct additive level by checking with test kit P/N 8T5296.

6.3.3.5 *Cooling System Cleaning Procedure, General*—Clean the system when visual inspection shows the presence of (*1*) oil or grease (see 6.3.3.6), (*2*) mineral deposits or rust, or both (see 6.3.3.7). *When the cooling system is contaminated by both oil and scale, first remove the oil, then remove the scale.* Cylinder head coolant passages also may be cleaned after the head is removed.

6.3.3.6 *Removal of Oil and Grease from Cooling System*—Follow these steps:

(*1*) Operate the engine until the engine oil and coolant water reach operating temperatures and then shut down the engine and drain the coolant from the cooling system.

(*2*) Fill the cooling system with oil/grease cleaning solution comprising 454 g of trisodium phosphate (Na_3PO_4) dissolved in 38 L of water. Run the engine for 5 min to ensure complete solution with any engine coolant left in the cooling system from (*1*).

(*3*) Shut down the engine, drain the oil/grease cleaning solution and flush the cooling system with fresh water. Drain the water from the system.

6.3.3.7 *Removal of Scale from Cooling System*—Follow these steps:

(*1*) Operate the engine until the engine oil and coolant water reach operating temperatures and then shut down the engine and drain the coolant from the cooling system.

(*2*) Fill the cooling system with scale cleaning solution comprising 454 g of commercial sodium bisulfate ($NaHSO_4$) dissolved in 38 L of water. Run the engine at operating temperatures for 30 min.

(*3*) Shut down the engine, drain the scale cleaning solution, and flush the cooling system with fresh water. Drain the water from the system.

(*4*) Fill the system with oil/grease cleaning solution comprising 454 g of trisodium phosphate (Na_3PO_4) dissolved in 38 L of water. Run the engine for 5 min to ensure complete solution with any water left in the cooling system from (*3*).

(*5*) Shut down the engine, drain the oil/grease cleaning solution and flush the cooling system with clear water. Drain the water from the system.

(*6*) Disassemble the engine and prepare for the next test.

6.3.4 *Dynamometer*—Use a dynamometer or other suitable loading device to maintain and control engine torque and speed.

6.3.5 *Engine Starting System*—Use an engine starting system capable of delivering to the engine breakaway torque of 136 N·m and a sustained torque of 102 N·m at 200 r/min.

6.3.6 *Engine Instrumentation*—Locations of the various measurement sensors and taps, and installation details and calibration requirements are given as follows: (*1*) for intake air system (see 6.3.1 and Annex A2); (*2*) for exhaust system (see 6.3.2 and Annex A3); (*3*) for cooling system (see 6.3.3 and Annex A4); (*4*) for oil system modifications, see Annex A5; and (*5*) for other locations, see Annex A6.

6.3.6.1 *Thermocouples*—Install the thermocouples or equivalents to a depth such that the sensor tip rests in the middle of the fluid stream at the following specified temperature measurement locations:

air-to-engine – P/N 1Y468 (see Annex A2)
engine exhaust – P/N 1Y467 (see Annex A3)
fluids, water, oil, fuel – P/N 1Y466 (see Annex A5 and Annex A6)

6.3.6.2 Locate the instruments for measuring fuel pressure and fuel temperature as shown in Fig. A6.1.

6.3.6.3 Locate the instrument for measuring crankcase pressure to the crankcase as shown in Fig. A6.2.

6.3.6.4 *Calibration of Instruments* —Calibrate all facility read-out instrumentation used for the test immediately prior to commencing a test stand calibration sequence. The test laboratory may, at its own discretion, carry out instrumentation calibrations prior to subsequent stand calibration tests, that is, those that follow a failed or invalid first attempt. Refer to Annex A12 for calibration tolerances and allowable time constants.

[11] The sole source of supply of the Barco flowmeter (Venturi Meter) known to the committee at this time is P/N No. BR12705-16-31 from Aeroquip Co., Maddock Mechanical Industries, 833 N. Orleans, Chicago, IL 60610.

[12] 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.

[13] The sole source of supply of the Gates hose known to the committee at this time is P/N 20777, available from The Gates Rubber Co., 900 S. Broadway, Denver, CO 80217-5887.

[14] The sole source of supply of the antifreeze known to the committee at this time is Caterpillar Brand, P/N 8C3684 (1-gal) or P/N 8C3686 (55-gal drum), from Caterpillar Inc., P.O. Box 610, Mossville, Il 61552-0610.

6.3.6.5 *Calibration of Instrument Measurement Standards*—Calibrate, annually, all temperature, pressure, and speed measurement standards themselves against *recognized national standards*. Maintain a record of these calibrations for at least two years.

6.3.7 *Standardized Fuel System and Fuels*—To ensure that fuel line pressure transients are held to acceptable conditions, install the fuel system components as specified in the service manual accompanying the diesel engine, taking especial care to use the high pressure fuel lines and fuel pump components described therein. In addition, the system shall have a fuel consumption measuring device (see 6.3.7.1), a fuel return line with a check valve (see 6.3.7.2) or shut-of solenoid (see 6.3.7.3). Install instruments for measuring fuel pressure and temperature in the locations shown in Fig. A6.1. Control fuel pressure and temperature in accordance with the requirements for engine operating conditions in Table A10.1. Change the fuel filter when the pressure deviates from specification requirements.

6.3.7.1 *Fuel Consumption Measuring Device*—Install a suitable fuel consumption measuring device to keep fuel consumption rates within required tolerances. Maintain the fuel flow transducer filter time constant at 73 s max. There shall be no variation in fuel transfer pump pressure or exhaust temperature when switching from the engine operating fuel system to the fuel rate measuring system.

6.3.7.2 *Fuel Return Line*—The fuel return line runs from the 1.19 mm D orificed tap, through the P/N 307946 elbow at the fuel pump, to the fuel scale. This line provides fuel temperature stabilization at the pump and also allows entrained air to be expelled from the system. Place a check valve or shut-off solenoid in the return line to prevent fuel from backing into the pump during engine shutdown.

6.3.7.3 *Shut-off Solenoid*—A P/N 9L8791 solenoid or equivalent should be placed at the pump housing fuel inlet to control the fuel flow. Location of the solenoid near the fuel pump decreases the fuel volume available to the pump and can reduce shut-down time if the solenoid is activated by the engine oil/water pressure safety circuit.

6.3.7.4 *Fuels*—The required test fuels are obtainable from Haltermann Solutions[15,12] as LLC diesel test fuel containing mass fraction 0.4 % sulfur (see 7.2.1) for the 1K test, and from Chevron Phillips,[16,12] as PC-9-HS fuel containing mass fraction 0.04 % sulfur (see 7.2.2) for the 1N test. Except for the marked differences in sulfur contents, the fuels are essentially the same in properties (although specification limits show minor variations (compare Table A8.1 and Table A8.2).

(1) Use the high heating value to calculate the fuel rate as specified in Annex A10 and Table A12.2.

(2) A fuel analysis form is provided for each batch of fuel by the supplier. Include this analysis as the Fuel Batch Analysis form of the test report.

(3) If more than one batch is used, note that on the Unscheduled Downtime & Maintenance Summary form of the test report. List appropriate percentage of run time for each batch.

(4) For stands calibrated for both 1K and 1N tests simultaneously, take a sample of the fuel at the stand prior to each test and have it analyzed for sulfur. Report the results of this analysis in the Unscheduled Downtime & Maintenance Summary form of the test report.

6.3.8 *Engine Lubrication System*—Use the lubrication system of the engine (see 6.2), but make modifications as shown in Annex A5 to the (*1*) remote mount oil pump relief valve (see Fig. A5.1), (*2*) oil pump relief valve plug (see Fig. A5.2), (*3*) oil pump accessory drive drain (see Fig. A5.3) and (*4*) oil filter housing assembly (see Fig. A5.4). The engine lubrication system itself is shown in Fig. A9.1.

6.3.8.1 *Engine Oil Temperature and Pressure Measurement Locations, and Operating Conditions*—Locations of the measurement points are shown in Figs. A5.5-A5.7. The oil cooling jet pressure and the oil to manifold temperature limits are given in Table A10.1. Record other oil pressure and temperature readings, as necessary, to monitor the operational conditions of the engine and its lubrication system.

6.3.8.2 *Engine Oil Scale System*—Install an engine oil scale system to measure accurately engine oil consumption (see Fig. A5.8). The system shall have a capacity to measure about 5 kg of engine oil to within 4.5 g. The hoses[17,12] to and from the oil scale reservoir shall be of sufficient flexibility to eliminate measurement errors. Hose length to and from the oil scale cart shall be 2.7 m max.

6.3.8.3 *Oil Filter Replacement*—Replace the P/N 1Y636 factory oil/filter group by the new P/N 1Y0699 filter group. Fit the original oil lines directly into the mounting bracket as on the P/N 1Y7277 bracket. Attach the oil line from the oil cooler, to the lower oil hole, and the line to the oil manifold to the upper hole. The base assembly includes a pressure sensitive bypass around the filter. Install the last chance screen P/N 1Y3549. Disassemble and clean the oil filter bypass valve before each test.

6.3.8.4 *Oil Pump Modifications*—Modify the oil pump (see Fig. A5.1) by (*1*) adding an external oil pump bypass to safely and conveniently adjust oil pressure on engine break-in and warm-up; (*2*) routing directly the oil pump drive housing drain line to the oil pan to ensure proper drainage of the housing; and (*3*) tapping deeper the oil bypass port and installing a bolt to fill the dead oil space (see Fig. A5.2).

6.3.9 *Gas Meter for Measuring Engine Blowby*—Measure the engine blowby with a displacement type gas meter or equivalent fitted with an oil separator and surge chamber. Attach the meter to the engine in two steps. First, attach the fitting on the P/N 1Y479 valve (see Table A14.1) to the crankcase breather; then attach the meter by way of this fitting to the engine by using appropriate length of hose and pipe. When switching from a normal operating system to the blowby measuring system, allow no more than a minimal increase in crankcase pressure for a period not exceeding 4 min.

[15] The sole source of supply for 1K fuel known to the committee at this time is Haltermann Solutions, Ten Lamar, Ste. 1800, Houston, TX 77002.

[16] The sole source for 1N fuel known to the committee at this time is Chevron Phillips Chemical Co., Chevron Tower, 1301 McKinney Street, Houston, TX 77010-3030.

[17] The sole source of supply of the hoses known to the committee at this time is Gould/Imperial Eastman flexible hoses, P/N C405-100, or equivalent are suitable.

6.3.10 *Procurement of Parts and Warranty*—Obtain information concerning the test engine, new engine parts, replacement parts and permissible substitution of replacement parts from Caterpillar, Inc. (see Annex A14). Table A14.1 shows a listing of parts by part numbers (P/N) referenced in these 1K/1N standard methods, while A14.2 provides information on parts warranty.

7. Reagents and Materials

7.1 *Engine Coolant*—A mixture of equal volumes of mineral-free [total dissolved solids, ≤ (34.2 mg/kg) (0.03 g/L) max.] water and Caterpillar brand antifreeze, P/N 8C3684 (see Table A14.1) in a 3.8 L container, or P/N 8C3686 (see Table A14.1) in a 200 L drum. (**Warning**—Combustible. Health hazard.)

7.2 *Test Fuels:*

7.2.1 *Test Fuel for 1K Test*—Diesel test fuel containing mass fraction 0.4 % natural sulfur known as 0.4 % sulfur diesel test fuel (SDTF).[15,12] The specification for this fuel is given in Table A8.1. (**Warning**—Combustible. Health hazard.)

7.2.2 *Test Fuel for 1N Test*—Diesel test fuel containing mass fraction 0.04 % natural sulfur known as PC-9-HS.[15,12] The specification for this fuel is given in Table A8.2. (**Warning**—Combustible. Health hazard.)

7.3 *Solvent*—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0 to 2 vol) %, Flash Point (61 °C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning**—Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

7.4 *Dispersant Engine Cleaner*—[18,12] (**Warning**—Use with adequate safety precautions.)

7.5 *Aqueous Detergent Solution* , prepared from a commercial laundry detergent.

7.6 *Sodium Bisulfate* ($NaHSO_4$), commercial grade.

7.7 *Trisodium Phosphate* (Na_3PO_4), commercial grade.

7.8 *Pentane*—Any mixture of branched and normal aliphatic hydrocarbons containing, by volume, at least 95 % of pentanes and not more than a total, by volume, of 0.5 % hydrocarbons < C_4 and > C_6. (**Warning**—Flammable. Health hazard.)

7.9 *Reference Oil,* as supplied by TMC for calibration of the test stand.

7.10 *Test Oil*—See test oil sample requirements (see Section 8).

7.11 *Engine Oil,* for shakedown run, use TMC 809.

7.11.1 *Engine Oil, Substitute,* for oiling cylinder liner and when test oil unavailable at assembly, use Exxon-Mobil EF-411 oil.[19,12]

7.12 *Lead Shot,* [20,12] approximately 5 mm in diameter.

7.13 *Light Grease.* [21,12]

7.14 *Diesel Piston Rating Equipment.*

7.14.1 *Diesel Piston Rating Lamp*—See A11.5.

7.14.2 *Diesel Piston Rating Booth,* of plywood, 1200 mm by 775 mm by 648 mm (see A11.6).

7.15 *Valve Guide Honing Equipment*—see A1.2.

7.15.1 *Sunnen P-300 Dial Bore Gage.*[22,12]

7.15.2 *Sunnen P-375 Probe.*

7.15.3 *Ralmike's Ringmaster Set,* to set P-300 gage.[23,12]

7.15.4 *Stanley Model D-30LR-4 Air Drill,* 400 r/min.[24,12]

7.15.5 *Sunnen Honall P-180 Hone Head and Driver Group.*

7.15.6 *JK-12-370AS Mandrell.* [22,12]

7.15.7 *PK-12A Adapter.* [22,12]

7.15.8 *LN-3702A Stone Retainer.* [22,12]

7.15.9 *K-12-J68 Stones.* [22,12]

7.15.10 *S-370 Truing Sleeve.* [22,12]

7.15.11 *MAN-845-5 Sunnen Hone Oil,* 19 L.

7.15.12 *LBN-700 Stone Dresser.* [22,12]

7.15.13 *VST-2012 Perfect Circle Seal Groove Tool.* [10]

7.15.14 *Sunnen P-180 Head and Driver.*

7.15.15 *Sunnen B-L-12-370AS Mandrell.*

7.15.16 *L-12-J68 Stones.* [22,12]

7.15.17 *LN-3167A Stone Retainer.* [22,12]

7.16 *Gages*—One Ring, Four Feelers and One Taper (optional, see 9.3.3).[24,12]

8. Test Oil Sample Requirements

8.1 *Selection*—The sample of test oil shall be representative of the lubricant formulation being evaluated and shall be uncontaminated.

8.2 *Inspection*—New oil baseline inspection requirements are described in Form 6 (Annex A13).

8.3 *Quantity*—A total of approximately 38 L of test oil are required to run the test.

9. Preparation of Apparatus

9.1 *Engine Inspection:*

[18] The sole source of supply of the dispersant engine cleaner known to the committee at this time is The Lubrizol Corp., 29400 Lakeland Blvd., Cleveland, OH 44092.

[19] The sole source of supply of a suitable engine oil known to the committee at this time is Exxon-Mobil EF411. It is available from Exxon-Mobil Oil Corp., Att: Illinois Order Board, P.O. Box 66940, AMF-O'Hare, IL 60666. Request P/N 47503-8.

[20] The sole source of supply of the lead shot known to the committee at this time is 375 DIABOLO, 22 cal (5.5 mm) 14.3 gr. pellets from Benjamin Sheridan, Racine WI 53403.

[21] The sole source of supply of the light grease known to the committee at this time is AMOCO, RYKON Premium Grease from Eddins-Walcher Co., 9421 Andrews Highway, Odessa, TX 79765.

[22] The sole source of supply of the apparatus known to the committee at this time is Sunnen Products Co., 7910 Manchester Road, St. Louis, MO 63143.

[23] The sole source of supply of the apparatus known to the committee at this time is Ralmike Tool-A-Rama, 4505 S. Clinton Ave., South Plainfield, NJ 07080.

[24] The sole source of supply of the apparatus known to the committee at this time is Stanley Tool Div., 700 Beta Dr., Cleveland, OH 44143.

9.1.1 *General*—Completely inspect the engine at an interval of every second test stand calibration run or 18 months, whichever comes first, the aim being to ensure that wearing surfaces, such as, main bearings and journals, rod bearings and journals, camshaft bearings, valve train components, fuel system components, and so forth, are within manufacturer's specifications. Refer to the 1Y540 Service Manual for engine disassembly, assembly, inspections, and specifications requirements.[10] This inspection shall terminate the stand's current calibration (see Section 10), if any. Re-calibrate whenever the crankshaft is removed for any purpose other than bearing replacement.

9.1.2 *Engine Instrumentation*—Inspect and recalibrate periodically instruments (with their accompanying probes or sensors) of the engine, including those of the fuel and cooling systems (see 6.3.3, 6.3.6 and 6.3.7).

9.1.3 *New and Converted Engine Crankcases*—Inspect new and converted engine crankcases to ensure the presence of a proper paint coating. Coat crankcases, as needed, with either of the two approved paints.[25,12]

9.1.4 *Cooling Jets*—Measure the internal diameters of cooling jet tubes. Reject tubes that do not meet specification requirements.

9.1.5 *Shakedown Run After Rebuild*—Perform a shakedown run after rebuild using TMC 809 engine oil (see 7.11). Continue with the run until two consecutive 12 h periods show a stable copper level in the engine oil. Ensure that the valve opening and closing tolerance on the camshaft is ±4 crankshaft degrees.

9.2 *Engine Pre-Test Lubrication System Flush:*

9.2.1 *Preparation*—To ensure proper flushing and draining, drill a hole in the oil pump accessory drive housing and install a plug (see Fig. A5.3).

9.2.2 *Flushing/Cleaning Summary*—Flush and clean the lubrication system before each test so as to remove deposits from surfaces of all engine cavities. To achieve this, flush the crankcase of used oil by a series of liquid flushes in eleven steps as follows (see Fig. A9.2).

9.2.2.1 Flush with mineral spirits.

9.2.2.2 Flush with a mixture of mineral spirits and a dispersant engine cleaner.

9.2.2.3 Flush with additional repeated flushes with mineral spirits until the solvent remains clean.

9.2.2.4 Flush the lubrication system and crankcase with the test oil to remove the solvent before it is drained (see 9.2.3 on cooling jet alignment). This test oil flush is also used to check alignment of the piston cooling jet (see 9.2.3).

9.2.2.5 Finally, double flush the engine crankcase with test oil before starting the test (see Fig. A9.2, Steps 9 to 11). If the test oil is not available at engine assembly use Exxon-Mobil EF411 engine oil.

9.2.3 *Cooling Jet Alignment*—Use the final test oil flush (see Fig. A9.2) that removes the remaining solvent to check alignment of the piston cooling jet by using a poly(methyl methacrylate) top piston. Alignment may be done with either the jug assembly or the alignment fixture (see Figs. A9.10-A9.12).

9.2.4 *Cleaning of Some Other Components*—Before each test clean the oil weigh system. Also disassemble and clean the engine oil bypass valve. On occasion extra cleaning might be required.

9.2.5 *Additional Oil Filter*—Install a full-flow paper element filter in the flushing unit to remove engine wear particles during the engine flush. TEI CLR engine oil filter housing No. 2418 and filter element No. 3105[26,12] have been found satisfactory for this purpose. These particles have been known to cause piston scuffing during subsequent tests.

9.2.6 *Flushing Procedure Components*—Use the components shown in Figs. A9.3-A9.12 to conduct the engine flushing procedure. (See Fig. A9.8 (Views A and B) of flushing component location). A dummy engine oil filter may be used during the flush sequence.

9.2.7 *Flushing Procedures*—(See also Fig. A9.2):

9.2.7.1 With the crankcase breather secured to the side of the crankcase and the connecting rod assembled on the crankshaft, rotate the crankshaft until the top end of the connecting rod is below the cylinder block bore in the top of the crankcase.

9.2.7.2 Install the poly(methyl methacrylate) or clear plastic cover (see Fig. A9.3) on the top surface of the crankcase as shown in Fig. A9.8 (View A).

9.2.7.3 Install a new P/N 8N9586 (see Annex A14) engine oil filter and a clean P/N 1Y5700 (see Annex A14) element in the flushing pump oil filter housings. Change both oil flush cart filters after each engine flush.

9.2.7.4 Connect the flushing pump outlet hose to the engine oil cooler drain location.

9.2.7.5 Remove breather assembly P/N 1Y2592 (see Annex A14) (top portion of the side assembly) and clean separately by soaking in mineral spirits. Allow to air dry.

9.2.7.6 Insert the P/N 1Y653 (Annex A14) rocker shaft oil line in the center opening of the clear plastic cover (see Fig. A9.3).

9.2.7.7 Place the flushing pump inlet in a clean supply tank containing 7.6 L of mineral spirits. Open the crankcase drain, start the flushing pump and oil scale pumps and run this material once through the engine into a drain pan. Do not recirculate. Drain oil scale reservoir.

9.2.7.8 Close the crankcase drain and connect the flushing pump inlet line to the crankcase drain. Add to the crankcase 7.6 L of a flushing mixture comprising 1.9 L of dispersant engine cleaner and 5.7 L of mineral spirits.

9.2.7.9 Connect the flushing pump outlet line to the engine oil cooler drain location. Open the crankcase drain valve, start the flushing pump and oil scale pumps and circulate the flushing mixture through the engine for approximately 15 min.

[25] Either of the following two paints is acceptable: (*1*) In one gallon cans, Yellow Primer Paint Cat Part No. IE2083A, Primer No. A123590, Serial No. BIMO115877, B.A.S.F. Part No. U27YD005, obtainable from B.A.S.F. Coating and Colorant Div., P.O. Box 1297, Morganton, NC 28655 and (*2*) Glyptal 1201 Red Enamel, obtainable from Brownell Outlet, 84 Executive Avenue, Edison, NJ 08817.

[26] The sole source of supply of the oil filter, P/N 2418 and filter element, P/N 3105 known to the committee at this time is Test Engineering, Inc., 12718 Cimarron Path, San Antonio, TX 78249.

Turn off the pumps, but do not drain the flushing mixture from the crankcase. Open completely the oil pressure regulator during flushing.

9.2.7.10 Close the oil cooler drain valve, disconnect the flushing pump outlet hose from the oil cooler drain location and connect to the crankcase sprayer (see Fig. A9.5).

9.2.7.11 Remove the P/N 1Y653 (see Annex A14) oil line from the poly(methyl methacrylate) coverhole and insert the crankcase sprayer through the opening in the poly(methyl methacrylate) cover. Start the flushing pump and oil scale pumps and spray the interior of the crankcase by slowly moving the sprayer around and into all accessible areas of the crankcase (see Fig. A9.8, View A) for approximately 10 min. Turn off the pumps, but do not drain the flushing mixture from the crankcase. Insert the crankcase sprayer into the oil scale reservoir and start the flush pump and oil scale pumps. Spray the reservoir for 10 min. Turn off the pumps, but do not drain the flushing solution from the crankcase.

9.2.7.12 Remove the one-half in. pipe plug from the modified 1Y1990 governor housing cover (see Fig. A9.6). Insert the crankcase sprayer (see Fig. A9.5) through the opening in the governor housing cover. Start the pumps and spray the interior governor housing for about 10 min. Turn off the pumps, but do not drain the flushing solution from the crankcase.

9.2.7.13 Remove the oil spout assembly from the front of the crankcase and install the front cover sprayer (see Fig. A9.7) as shown in Fig. A9.8.

9.2.7.14 Connect the flushing pump outlet to the (8.5 by 127) mm fitting. Start the flushing pump and oil scale pumps and spray the interior of the front cover for about 10 min. Drain the crankcase, governor housing, engine and flushing pump unit filters, oil cooler and oil pump accessory drive housing, and oil scale reservoir. Discard the drained flushing mixture.

9.2.7.15 Using mineral spirits, repeat steps 9.2.7.9 – 9.2.7.14 until the discharge is clean. Three-to-four flushes with mineral spirits are usually sufficient to remove all traces of the flushing mixture from the engine.

9.2.7.16 Drain the mineral spirits from the crankcase, governor housing, engine and flushing pump unit filters, oil cooler, oil pump accessory drive housing, and oil scale reservoir.

9.2.7.17 Prepare the flush with test oil by blocking off the 1Y653 oil line to the rocker arm shaft and installing the 6.35 mm fitting (see Fig. A9.9) on the open end of the line. Close all drain openings.

9.2.7.18 Using the flushing pump, add 4.7 L of test oil to the engine crankcase through the engine oil cooler.

9.2.7.19 Connect the flushing pump outlet to the engine oil cooler drain location. Start the flushing pump and oil scale pumps and force any mineral spirits left in the system out through the crankcase drain. After the mineral spirits have been forced out of the system, connect the inlet line of the flushing pump to the crankcase drain. Install the dummy piston and the assembled cylinder block and liner. The dummy piston with a poly(methyl methacrylate) top is shown in Figs. A9.10 and A9.11. Re-install the oil filler spout and 12.7 mm pipe plug in the modified governor housing cover (see Fig. A9.6).

9.2.7.20 Open the crankcase drain and start the flushing pump and oil scale pumps. Set and maintain the oil pressure at 359 kPa. With the starter or dynamometer, turn the engine over at a speed of 200 r/min for 1 min. Turn off the pumps and drain all of the oil from the engine crankcase, governor housing, engine and flushing pump unit filters, oil cooler, oil pump accessory drive housing, and oil scale reservoir. Discard the drained oil.

9.2.7.21 Again add 4.7 L of test oil to the engine crankcase through the engine oil cooler. Repeat the flushing procedure in 9.2.7.20. During this flush, check the alignment of the piston cooling nozzle and adjust, if necessary, being certain that oil condition has stabilized before adjustment. Drain the oil and install a new P/N 8N9586 oil filter (see Annex A14). Re-install crankcase breather assembly P/N 1Y2592 (see Annex A14).

9.3 *Engine Pre-Test Measurements and Inspections*—Measure and inspect the engine components prior to each test. Information on component reusability and assembly is found, herein, and in the P/N 1Y540 Service Manual[10]. Part numbers for replacement parts are also given in this manual.

9.3.1 *Crankshaft Angles*—Record the crankshaft angles at the specified exhaust and intake cam lift before each test and show a full lift profile before each reference test. See 1Y540 Service Manual.

9.3.2 *Cylinder Head and Specification for Valves*—Use a new or reconditioned head for each test. Ensure that measurements after reconditioning are within specification requirements as shown in Fig. A1.1. Also measure valve head projection and ensure that it meets specification requirements. Record the measurement. Conduct non-reference tests using cylinder head/jug assemblies that, during their laboratory histories, had been subjected to at least one complete and acceptable calibration test.

9.3.2.1 *Valve Guide Bushings*—The valve guide bushings have threaded bores and are machined to close fit tolerances to the valve stem. See A1.2 for the reconditioning method. Use a short arbor and a long stone for valve guide honing, the final valve guide sizing operation.

9.3.2.2 *Fuel Nozzle*—Remove the fuel nozzle from the cylinder head before commencing reconditioning. Use either Service Kit P/N 6V7020 (see Annex A14) to pull the nozzle or a suitable adapter that is threaded on the nozzle head. Replace the P/N 9L9098 seal and P/N 2W6163 (see Annex A14) fiber washer as needed. Inspect the nozzle tip for carbon build-up and deformed surfaces. Replace questionable nozzles. Check the valve opening pressure (V.O.P.) before each test using any commercially available nozzle testing tool or a P/N 5P4150 (see Annex A14) nozzle tester group. A V.O.P. equal to or greater than 10.34 MPa is satisfactory. Remove the P/N 2W1230 screw (see Annex A14) only during this check. See the Caterpillar Service Manual for additional information. Fuel injection housing bolts may be standardized to the hex head type of Grade 8 quality.

9.3.3 *Piston and Rings*—Use a new piston (P/N 1Y0727) and new rings (P/N 1Y0728) for each test, and record measurements before and after each test (see Annex A14 for all P/Ns). The measurements before the test ensure that good parts are evaluated and are compared to measurements after the test to determine the amount of wear.

9.3.3.1 Before the test clean all three rings using pentane and a lint-free cotton cloth.

9.3.3.2 Measure the ring side clearances and ring end gaps of all three rings in accordance with the procedure in Fig. A1.2. For Keystone ring side clearance measurements, confine the ring in a dedicated slotted liner (see Fig. A1.2) or a ring gage 137.16 mm in size (see Fig. A1.2). Obtain the average side clearances with four feeler gages of equal width and thickness increments of 0.01 mm at 90° spacing around the piston. Similarly, measure the rectangular side clearance.

9.3.3.3 Measure minimum side clearance in accordance with directions in ASTM Deposit Rating Manual 20. Measurement may also be made using taper gages.

9.3.4 *Cylinder Liner*—Use a 1Y3998 liner for 1K and 1N testing. No surface finish measurement is required for 1Y3998 liners. Remove the protective grease with mineral spirits, then clean the liner bore with a hot water/detergent solution (see 7.5) and rinse with hot water.

9.3.4.1 Measure the surface finish and record the results on the Liner Measurements form of the test report. Oil the liner bore with Exxon-Mobil EF-411 oil.

9.3.4.2 Assemble the cylinder liner, block and head, torquing the stud nuts as shown in Fig. A1.5.

9.3.4.3 Measure the liner with a dial bore gage to ensure that the out-of-round and taper conditions are within specified tolerances measured at five intervals as shown in Fig. A1.3 and Fig. A1.5.

9.3.4.4 Torquing increases the cylinder liner outside diameter at the o-flange necessitating machining of the 1Y544 cylinder block. Machine the block inside diameter as shown in Fig. A1.6.

9.3.5 *Compression Ratio*—Before starting each test, ensure that the engine has the specified compression ratio of 14.5 to 1 by measuring the piston-to-head clearance. For this measurement use lead shot[20,12] approximately 5 mm in diameter. Place four lead shots on top of the piston at 90° intervals on the major and minor piston diameters, holding them in position with light grease. With the piston near the top of the stroke, install and torque to specifications the head and block assembly. Then in succession, turn the engine over top center by hand, remove the head and block assembly and measure the thickness of the lead shot to obtain the average piston-to-head clearance. The piston-to-head clearance shall measure (3.556 ± 0.076) mm. Use multiple block gaskets (P/N 1Y3698) (see Annex A14) to adjust the clearance. If the piston-to-head clearance still exceeds the requirement, check the crankshaft main and rod journals, connecting rod main bearings and piston pin and rod bushings for excessive wear. Also, check the piston cooling jet-to-piston skirt clearance to ensure that no contact is made.

9.3.6 *Fuel Timing*—Before each test, ensure that the engine fuel timing is set at (31.5 ± 0.5)° before top center (BTC) of the piston travel. Set the engine flywheel which has 2° marked intervals to coincide with the piston travel. Make a final check to ensure that the fuel timing is set correctly. The fuel flow timing method (described in A1.6) is the preferred method for assessing quickly timing settings. Alternatively, use an electronic fuel timing instrument before each test, provided that it is equivalent in accuracy to the Caterpillar or AVL device. Calibrate the electronic instrument to give the same timing values as the fuel flow timing method. Refer to Service Manual SENR2856[10] for instructions and fuel timing dimensions for major rebuilds or fuel pump disassemblies.

9.3.7 *Pre-Test Component Inspections*—For future reference, inspect all components and assemblies that are exposed when the engine is disassembled and record the observations. These include valve train components, bearings, journals, housings, seals, and gaskets as well as those items noted in 9.3.1 – 9.3.3. Replace those that fail to meet requirements.

9.3.7.1 Inspect the special fuel plunger for erosion as noted in A1.8.

9.3.7.2 Ensure that the valve camshaft timing meets the requirements as listed in Service Manual SENR2856 (that is, ±4° tolerance).

9.4 *Engine Assembly*—Assemble the engine with components and bolt torques as specified in Engine Service Manual P/N 1Y540 (see Annex A14), aiming for the mean of the specified values. In keeping with good assembly practices, ensure that (*1*) the components are clean and lubricated, (*2*) airborne dirt and debris are kept to a minimum in the assembly area (see 6.1), and (*3*) standard assembly techniques such as staggered piston ring gap positions are maintained.

9.5 *Pressure Testing of Fuel System Assembly*—Pressure test the fuel system assembly, notably the high pressure fuel line and components at 20.00 MPa, to ensure that it is leak-proof. Because the fuel line connections are routed under the valve cover, fuel leakage can lead to undesirable fuel dilution of the engine oil. A fuel dilution greater than 2.0 % by volume at or beyond 24 h will render the test operationally invalid. The pressure test will also show if the P/N 7W8629 line assembly needs to be replaced.

9.5.1 *Pressure Testing Procedure* —After engine assembly, connect a high pressure fuel line to the external rocker arm housing fitting where the P/N 1Y648 line assembly connects. Using a P/N 5P4150 CAT nozzle tester pump, pressurize the system to 20.00 MPa. Close the back bleed valve of the pump to check pressure leak-off rates. Hereafter, the fuel system should maintain pressure with little or no pressure leak-off.

10. Calibration of Engine Test Stand

10.1 *General Requirements and Frequency of Calibration:*

10.1.1 To maintain test consistency and severity levels, calibrate the engine test stand at regular intervals in accordance with the requirements of the TMC using TMC reference oils.

10.1.2 The TMC shall establish frequency of calibration testing.

10.1.3 For each test type (1K or 1N), conduct a calibration test on a reference oil assigned by the TMC either 12 months from the start of the last acceptable calibration test, or after 15 test starts, whichever occurs first. For each test type (1K or 1N), count only tests of the same type toward the allowable total of 15. Start non-reference tests before the end of the 12 month calibration period.

10.1.3.1 A test stand can be calibrated as both a 1K and 1N test stand, and failure to calibrate under one test type shall not invalidate an existing calibration of the other type.

10.1.4 Reference oil test frequency may be adjusted for the following reasons:

10.1.4.1 *Procedural Deviations*—On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

10.1.4.2 *Parts and Fuel Shortages*—Under special circumstances, such as industry-wide parts or fuel shortages, the surveillance panel might direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

10.1.4.3 *Reference Oil Test Data Flow*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There might be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

10.1.4.4 *Special Use of the Reference Oil Calibration System*—The surveillance panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel might direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

10.1.5 *Donated Reference Oil Test Programs*—The Surveillance Panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it might be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel might choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

10.2 *Runs:*

10.2.1 *Double Blind Runs*—TMC shall administer double blind tests on a maximum of every third engine in each laboratory annually.

10.3 *Specified Test Parameters*—The specified test parameters for determination of test acceptance are as follows:

10.3.1 Top groove fill (TGF), percent volume (critical parameter).

10.3.2 Weighted total deposits (WD), demerits (critical parameter).

10.3.3 Transformed top land heavy carbon (TTLHC), transformed units, percent area (non-critical parameter).

10.3.4 Brake specific oil consumption (BSOC), kg/kWh (non-critical parameter).

NOTE 1—The kWh unit is deprecated. The preferred SI unit is the joule (J); 1 kWh = 3.6 MJ.

10.4 *Calibration Test Acceptance Criteria*—See TMC Lubrication Test Monitoring System (LTMS) for calibration test targets and acceptance criteria.

10.5 *Failing Calibration Test:*

10.5.1 *Failure of a Reference Oil Test*—Failure of a calibration test to meet test acceptance criteria can indicate (*1*) a testing stand problem, (*2*) a testing laboratory problem, (*3*) an industry-wide problem or (*4*) a false alarm. When failure occurs, the laboratory in conjunction with the TMC shall attempt to determine the cause.

10.5.2 *Action to Determine Cause of Problem*—First, the TMC shall decide, with advice from industry specialists (testing laboratories, test procedure developer, ASTM Technical Guidance Committee, Surveillance Panel, and so forth), if the cause of any unacceptable blind reference oil test is isolated to one particular stand or is related to other stands as well. Second, if the problem is isolated to an individual stand, calibrated testing on other stands can continue throughout the laboratory. Third, if it is decided that more than one stand might be involved, the involved stands shall be considered not calibrated until the problem is identified, corrected, and an acceptable reference oil test completed in one of the involved stands.

10.5.3 *Non-standard Tests*—If non-standard tests are conducted on the calibrated test stand, at the discretion of TMC, the test stand may be required to be recalibrated prior to running standard tests.

10.6 *Test Numbering*—Each 1K/1N test shall be identified by a test stand number and test run number. All runs shall be numbered sequentially. All repeat calibration runs shall be appended with a letter (also sequentially). The letter suffix sequencing for each test type calibration shall be maintained until the calibration is accepted. Any test start, regardless of type, shall increment the run number. Test start is the start of accumulation of any engine test time by this test procedure.

10.6.1 *Example of Test Numbering*—See Table 1.

10.7 *Reference Oils*—The reference oils used to calibrate the 1K and 1N test stands are formulated or selected to represent specific chemical types or specific performance levels or both. The TMC assigns the reference oils for

TABLE 1 Example of Test Numbering

Test	1K	1N	Run No.
1st	Reference Fail		1
2nd	Reference Fail		2A
3rd	Reference Fail		3B
4th		Reference Fail	4
5th		Shakedown	5
6th		Reference Pass	6A
7th	Reference Pass		7C
8th	Non-reference		8
9th		Non-reference	9

calibration tests. The oils are available from the TMC and are supplied under code numbers (blind reference oils).

10.7.1 *Banning Extra Analysis/Testing of Reference Oils*—Do not identify reference oils by chemical analysis and laboratory bench testing of physical properties. Such analysis and testing would undermine the confidentiality required to operate an effective blind reference oil system. Perform only those chemical analyses and physical tests specified within this procedure. However, the TMC might authorize analyses and bench testing under special circumstances. When authorized, supply written confirmation of the circumstances involved, data obtained, and the name of the person authorizing such analyses and bench testing to the TMC.

10.8 *Severity Adjustments:*

10.8.1 *Non-Reference Oil*— Non-reference oil test results may be adjusted to maintain intended severity levels.

NOTE 2—See fixed candidate oil test pass criteria in Specification D4485.

10.8.2 *Severity Adjustments*—Use a method accepted by the Surveillance Panel for calculating a severity adjustment (SA) for non-reference test results. When a significant bias is identified according to the control chart technique (10.8.3), apply a severity adjustment (SA) to non-reference oil test results. The SA remains in effect until subsequent calibration test results indicate that the bias is no longer significant. SA's are calculated and applied on a laboratory basis.

10.8.3 *Control Chart Techniques for Severity Adjustment (SA)*—Include all operationally valid calibration test results on a laboratory control chart. Record the test results on the chart in order of completion. Record EOT date and time for all tests as hour and minutes according to the 24 h clock (1 a.m. = 1:00, 1 p.m. = 13:00). Reporting completion time allows proper ordering of tests completing on the same day. Report calibration test results to the TMC in order of test completion. Results from at least two tests are required to start a control chart. Compute the exponentially weighted moving average (EWMA) for all standardized calibration oil test results. To calculate EWMA, standardize the test results using the following ratio: Delta/SD ((result − target)/standard deviation). The target and standard deviation values are available from the TMC. Calculate EWMA values using the following equation:

$$Z_i = \text{Lambda} \times Y_i + (1 - \text{Lambda}) \times Z_{i-1} \quad (1)$$

where:

Z_0 = 0,
Y_i = standardized test result,
Z_i = EWMA of the standarized test result at test order i, and
Lambda = the appropriate lambda from the LTMS document.

10.8.3.1 If the absolute value of EWMA, rounded to three decimal places, exceeds the alarm limit in the LTMS document, apply an SA to subsequent non-reference oil results.

10.8.4 *Example of Calculation of Severity Adjustment*—This example shows how to calculate and apply EWMA and SA values (test targets being examples only).

10.8.4.1 *TGF Severity Adjustment:*

(1) Applicable test targets: Mean, 40.8; standard deviation (SD), 15.9; TGF, 55; Z_i, 0.897.

(2) Standard test result: Y_2 = (TGF − Mean)/SD = (55 − 40.8)/15.9 = 0.893.

(3) Alarm limit: 0.653.

(4) EWMA: $Z_2 = 0.2 \times Y_2 + 0.8 \times Z_1 + 0.896$.

10.8.4.2 Since | 0.896 | > 0.653, apply an SA as follows: SA = –1 × EWMA × SD (in the example, SA = –14). For TGF, round the SA to a whole percent; for WD, round to one decimal place; and for TTLHC, round to three decimal places. Do not adjust BSOC and EOTOC for severity. Enter these SA numbers on the Test Report Summary of the test report and add them to the test results. Recalculate all SA's at the completion of every calibration test.

11. Engine Operating Procedure

11.1 *Engine Run-In*—After the engine components have been prepared and assembled as described in Section 9, perform the final engine preparations and the 60 min run-in itself as follows:

11.1.1 Fill the crankcase with 6 L of fresh test oil.

11.1.2 Install a new P/N 8N9586 oil filter.

11.1.3 Fill the cooling system with specified coolant and ensure that the facility coolant to the engine heat exchanger is operational.

11.1.4 Pressurize the fuel system to remove air, then return the system to a non-pressurized state before starting the engine.

11.1.5 Finally, ensure that all other systems and facilities are operational.

11.1.6 Obtain familiarity with the engine run-in operating conditions (see Table A10.1), and note the five time-related steps.

11.1.7 Start the engine run-in by turning the engine on and then ensuring that the operating conditions of Table A10.1 are strictly followed, and the rated speed and power conditions observed as shown under Step No. 5 of Table A10.1.

11.1.8 During the 5-step run-in period measured in minutes ((5 + 5 + 10 + 20 + 20) min = 60 min) check and correct for leakage, and make adjustments as necessary to meet the engine operating requirements in Table A10.1.

11.2 *Cool-Down Procedure*—Except for emergencies or uncontrolled stops, at the end of the 60 min run-in period start a 20 min cool-down period by following the run-in period in partial reverse order as follows: Step No. 3 (10 min), Step No.

2 (5 min) and Step No. 1 (5 min) and including the observance of the test parameters in Table A10.1, finally turning the engine off.

11.3 *Warm-Up Procedure*—For all subsequent starts throughout the test, warm up the engine in accordance with the run-in directions in 11.1.1 – 11.1.8.

11.4 *Operating Conditions and Oil Additions:*

11.4.1 After the run-in (60 min) and cool-down (20 min) periods of 11.1 and 11.2 and while the engine is hot, drain the oil for 30 min from the crankcase, governor housing, oil cooler, engine oil filter, oil pump accessory drive housing, and weigh scale.

11.4.2 Charge the engine with (4.95 ± 0.11) kg of test oil (reference or non-reference, as required).

11.4.3 Start and warm-up the engine for the 252 h test in accordance with 11.1.1 – 11.1.8, observing the test conditions in Table A10.1. Turn on the oil scale pumps when the engine reaches operating temperatures at the start of Step No. 5 in Table A10.1. Record the full oil scale pump mark at the end of this step.

11.4.4 Throughout the test, record the oil scale reading at least every hour. Add oil to the full mark (initial fill level) every 12 h, but *do not overfill*, recording the mass of oil added.

11.4.5 Measure oil consumption in accordance with 11.5 and take used oil samples for analysis in accordance with 11.6.

11.4.6 During the test hold all control parameters within the specified tolerance range in Table A10.1. *Failure to do so affects the validity of the test.*

11.4.7 *Test Duration*—The test duration is 252 h. It is counted from the moment that stabilized conditions are attained, a maximum of 30 min being allowed to attain stabilization.

11.4.8 *Calculation of Offset from Mean and of Deviation*—At the end of the test, calculate the offset from the mean (in percent) and deviation (in percent) outside of the specification tolerance (see Annex A12). Report these values on the Operational Summary – Offset And Deviation form of the test report.

11.5 *Measurement of Oil Consumption:*

11.5.1 Use linear regression to calculate oil consumption (see Annex A7).

11.5.2 Plot graphically the oil scale readings taken hourly over a 12 h period versus time at which the reading was taken (see Annex A7). Delete the first reading after the oil addition from the linear regression.

11.5.3 Derive oil consumption data every 12 h.

11.5.3.1 For a 12 h period, which includes a shutdown, calculate the BSOC from linear regression as follows:

(1) Excluding the first oil weigh reading after the shutdown, calculate the linear regression for the periods before and after the shutdown.

(2) Average the two linear regressions to obtain the oil consumption for the 12 h period. Base the BSOC calculations on actual average engine horsepower over the 12 h period.

11.5.4 Derive average values of oil consumption for recording on the Oil Analysis And Results Summary form of the test report. Also derive and record average oil consumptions between (0 to 24) h and (0 to 252) h.

11.5.4.1 Derive the end of test oil consumption (EOTOC) from the average of the last two 12 h (BSOC) figures. For a normal, completed test, this number is the same as the BSOC number at 252 h.

11.6 *Sampling Used Oil:*

11.6.1 Obtain samples of new oil and used oil after run-in and at (24, 72, 156, 204, 252) h. The quantity of each sample shall be 237 mL.

11.6.2 See 12.4.2 for tests required on the used oil.

11.6.2.1 Testing of the used oil samples taken at (72 and 156) h is optional.

11.6.3 After the used oil samples are taken, fill the oil system to the initial level.

11.7 *Shutdowns, Lost Time, and Off Tolerance Conditions*—Report the test hours, date, and length of off-test conditions for all occurrences on the Unscheduled Downtime & Maintenance Summary of the test report. Record the occurrence of off-test conditions, early inspections or early test termination with the reasons for the occurrences. If the cool down procedure is not used, identify the shutdown as an *emergency shutdown*. A maximum of 125 h of off-test conditions is allowed.

11.7.1 Always pump the oil from the scale cart to the engine crankcase to ensure an adequate oil volume for engine restarting. To limit the ingress of foreign matter into the combustion chamber and to protect the deposits, rotate the engine to top dead center of the compression stroke during downtime.

11.7.2 In the event of an emergency shutdown, allow the engine to cool for 2 h before restarting.

11.8 *Recording of Exhaust Temperature*—An exhaust temperature recorder can be used to track all regular starts, run-ins, and shut-downs and as well all exhaust temperature excursions that occur from speed and power changes during run-in, warm-up and cool-down procedures. Examine all exhaust temperature excursions for possible effects on test results. Operate the engine so as to minimize exhaust temperature excursions from speed, power, and air pressure variations or adjustments.

11.9 *Air-Fuel Ratio Measurement* —Calculate the air-to-fuel ratio within 24 h of test hour 24 and test hour 252. Use either an orifice air flow meter and fuel flow measuring device or exhaust gas analysis. Draw gas samples by way of the exhaust pressure probe, its location being shown in Fig. A3.5. Tables and formulae for deriving air-fuel ratios are shown in Table A10.2.

11.9.1 *Air-Fuel Ratio Report*—The report shall include the following three entries:

11.9.1.1 Observed measurement data comprising either *(1)* percent CO_2 and percent O_2 or *(2)* air flow and fuel flow.

11.9.1.2 Calculated air-fuel ratio from Table A10.2.

11.9.1.3 Date and test hours observed.

11.10 *Recording of Engine Conditions*—Note the engine conditions listed in Table A10.1 at least once per hour. Record data before adjustments are made. These data show the actual engine conditions at each hour of test; do not average data logged during the course of the test hour.