Designation: D6750 – 17

Standard Test 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

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 – Annex A4).

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.

Laboratories that choose not to use the TMC services may simply disregard these portions.

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 A1 – Annex A4).

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 The following is the Table of Contents:

[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.

Current edition approved May 1, 2017. Published May 2017. Originally approved in 2002. Last previous edition approved in 2016 as D6750 – 16. DOI: 10.1520/D6750-17.

[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, 6555 Penn Ave., Pittsburgh, PA 15206-4489. Attention: Administrator. This edition incorporates revisions in all information Letters through No. 16-2.

[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 *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 A19 on Safety Precautions).

1.6 *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:*[4]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
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 and Liquid Fuels
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

[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.

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

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

[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.

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**

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 3.2.4.1).

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]

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

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.

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 °C 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 A19).

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 A5 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 A6. 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 A14.

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 A6). For air barrels mounted horizontally, the location of the pressure tap and air outlet pipe can be interchanged (see Annex A6).

6.3.1.3 *Compressing*—Provide air compression capability. Locate the intake air pressure measurement tap at the air barrel (see Annex A6). 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 A6 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 kPa ± 1 kPa. Drawings of the component parts, dimensions, and instrument locations are given in Annex A7. The exhaust system shall also provide for exhaust gas temperature measurement and exhaust gas sampling, the exhaust gas temperature range being 550 °C ± 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 A7) 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. A7.1-A7.4. 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. A7.5.

6.3.2.3 *Exhaust Temperature*—Measure the exhaust temperature with thermocouple P/N 1Y467 or equivalent located as shown in Fig. A7.4.

6.3.2.4 *Exhaust Pressure*—Measure the exhaust pressure in the exhaust barrel as shown in Fig. A7.2. Set the pressure at the conditions specified in Table A14.1 by adjusting the restriction valve.

6.3.3 *Cooling System*—Provide a closed circulating cooling system with an engine-driven centrifugal water pump or

[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.

equivalent electric motor-driven water pump.[11,12] System details given in Fig. A8.1 show cooling system modifications; Fig. A8.2 shows coolant temperature, flow, and pressure measurement locations; and Fig. A8.3 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. A8.4.

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. A8.1. As shown, the coolant line contains (*1*) a calibrated Barco flowmeter, P/N BR 12705-16-31[13,12], 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 L/min ± 2.0 L/min at Step 5 (see Table A14.1) 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[14,12] or equivalent (see Fig. A8.3). Measure the coolant pressure at the block to ensure that proper cooling system operation has been attained (see Fig. A8.2).

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 °C ± 1.0 °C. Also control the coolant temperature out at 93 °C ± 2.5 °C. If original Caterpillar coolant heat exchanger (from 1Y0581 – Lines and Heat Exchanger Group) is replaced, an equivalent replacement heat exchanger must be used to meet all temperature and pressure specifications (coolant outlet temperature: 93 °C ± 2.5 °C; coolant delta temperature: 5 °C ± 1 °C; coolant inlet temperature: 88 °C; coolant flow: 65 L/min ± 2 L/min; pressure drop across heat exchanger: 1.5 kPa maximum; coolant at jug pressure: 50 kPa).

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)[15,12] 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 A6); (*2*) for exhaust system (see 6.3.2 and Annex A7); (*3*) for cooling system (see 6.3.3 and Annex A8); (*4*) for oil system modifications, see Annex A9; and (*5*) for other locations, see Annex A10.

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[11] A suitable electric motor-driven water pump from MP Pumps is recommended by Caterpillar. MP part number 30885, CF1PMP SS 3-3 56C 6.0 T-2100, stainless steel pump, 3 hp e phase, 230/460 Vac motor. The sole source of supply of the apparatus known to the committee at this time is MP Pumps, 34800 Bennett Dr., Fraser MI 48026.

[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 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.

[14] 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.

[15] 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.

6.3.6.1 *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 A6)
engine exhaust – P/N 1Y467 (see Annex A7)
fluids, water, oil, fuel – P/N 1Y466 (see Annex A9 and Annex A10)

6.3.6.2 Locate the instruments for measuring fuel pressure and fuel temperature as shown in Fig. A10.1.

6.3.6.3 Locate the instrument for measuring crankcase pressure to the crankcase as shown in Fig. A10.2.

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 A16 for calibration tolerances and allowable time constants.

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. A10.1. Control fuel pressure and temperature in accordance with the requirements for engine operating conditions in Table A14.1. 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[16,12] as LLC diesel test fuel containing mass fraction 0.4 % sulfur (see 7.2.1) for the 1K test, and from Chevron Phillips,[17,12] 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 A12.1 and Table A12.2).

(1) Use the high heating value to calculate the fuel rate as specified in Annex A14 and Table A16.2.

(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 A9 to the (*1*) remote mount oil pump relief valve (see Fig. A9.1), (*2*) oil pump relief valve plug (see Fig. A9.2), (*3*) oil pump accessory drive drain (see Fig. A9.3) and (*4*) oil filter housing assembly (see Fig. A9.4). The engine lubrication system itself is shown in Fig. A13.1.

6.3.8.1 *Engine Oil Temperature and Pressure Measurement Locations, and Operating Conditions*—Locations of the measurement points are shown in Figs. A9.5-A9.7. The oil cooling jet pressure and the oil to manifold temperature limits are given in Table A14.1. 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. A9.8). The system shall have a capacity to measure about 5 kg of engine oil to within 4.5 g. The hoses[18,12] 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

[16] 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.

[17] 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.

[18] 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.

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. A9.1) 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. A9.2).

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 A18.1) 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.

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 A18). Table A18.1 shows a listing of parts by part numbers (P/N) referenced in these 1K/1N standard methods, while A18.2 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 A18.1) in a 3.8 L container, or P/N 8C3686 (see Table A18.1) 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).[16,12] The specification for this fuel is given in Table A12.1. (**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.[16,12] The specification for this fuel is given in Table A12.2. (**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*—[19,12] (**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.[20,12]

7.12 *Lead Shot,* [21,12] approximately 5 mm in diameter.

7.13 *Light Grease.* [22,12]

7.14 *Diesel Piston Rating Equipment.*

7.14.1 *Diesel Piston Rating Lamp*—See A15.5.

7.14.2 *Diesel Piston Rating Booth,* of plywood, 1200 mm by 775 mm by 648 mm (see A15.6).

7.15 *Valve Guide Honing Equipment*—see A5.2.

7.15.1 *Sunnen P-300 Dial Bore Gage.*[23,12]

7.15.2 *Sunnen P-375 Probe.*

7.15.3 *Ralmike's Ringmaster Set,* to set P-300 gage.[24,12]

7.15.4 *Stanley Model D-30LR-4 Air Drill,* 400 r/min.[25,12]

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

7.15.6 *JK-12-370AS Mandrell.* [23,12]

7.15.7 *PK-12A Adapter.* [23,12]

7.15.8 *LN-3702A Stone Retainer.* [23,12]

7.15.9 *K-12-J68 Stones.* [23,12]

7.15.10 *S-370 Truing Sleeve.* [23,12]

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

7.15.12 *LBN-700 Stone Dresser.* [23,12]

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.* [23,12]

7.15.17 *LN-3167A Stone Retainer.* [23,12]

7.16 *Gages*—One Ring, Four Feelers and One Taper (optional, see 9.3.3).[25,12]

[19] 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.

[20] 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.

[21] 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.

[22] 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.

[23] 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.

[24] 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.

[25] 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.

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 A17).

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:*

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.[26,12]

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. A9.3).

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. A13.2).

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. A13.2, 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. A13.2) 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. A13.10-A13.12).

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[27,12] 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. A13.3-A13.12 to conduct the engine flushing procedure. (See Fig. A13.8 (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. A13.2):

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. A13.3) on the top surface of the crankcase as shown in Fig. A13.8 (View A).

9.2.7.3 Install a new P/N 8N9586 (see Annex A18) engine oil filter and a clean P/N 1Y5700 (see Annex A18) 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 A18) (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 A18) rocker shaft oil line in the center opening of the clear plastic cover (see Fig. A13.3).

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,

[26] 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.

[27] 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.

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. 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. A13.5).

9.2.7.11 Remove the P/N 1Y653 (see Annex A18) 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. A13.8, 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. A13.6). Insert the crankcase sprayer (see Fig. A13.5) 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. A13.7) as shown in Fig. A13.8.

9.2.7.14 Connect the flushing pump outlet to the 8.5 mm 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. A13.9) 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. A13.10 and A13.11. Re-install the oil filler spout and 12.7 mm pipe plug in the modified governor housing cover (see Fig. A13.6).

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 A18). Re-install crankcase breather assembly P/N 1Y2592 (see Annex A18).

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. A5.1. 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 A5.2 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 A18) 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 A18) 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 A18) 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 A18) 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 A18 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. A5.2. For Keystone ring side clearance measurements, confine the ring in a dedicated slotted liner (see Fig. A5.2) or a ring gage 137.16 mm in size (see Fig. A5.2). 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. A5.5.

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. A5.3 and Fig. A5.5.

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. A5.6.

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[21,12] 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 mm ± 0.076 mm. Use multiple block gaskets (P/N 1Y3698) (see Annex A18) 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 A5.6) 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 A5.8.

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 A18), 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 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.

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

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 A14.1), 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 A14.1 are strictly followed, and the rated speed and power conditions observed as shown under Step No. 5 of Table A14.1.

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 A14.1.

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 A14.1, 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 kg ± 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 A14.1. Turn on the oil scale pumps when the engine reaches operating temperatures at the start of Step No. 5 in Table A14.1. 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 A14.1. *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 A16). 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 A11).

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 A11). 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 h to 24 h and 0 h 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 h, 72 h, 156 h, 204 h, and 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 h 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. A7.5. Tables and formulae for deriving air-fuel ratios are shown in Table A14.2.

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 A14.2.

11.9.1.3 Date and test hours observed.

11.10 *Recording of Engine Conditions*—Note the engine conditions listed in Table A14.1 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.

11.11 *Humidity Requirements/Calibration/Measurement :*

11.11.1 *Humidity Measurement*—Record humidity readings each test hour using the laboratory's primary humidity measuring system. This system shall be accurate to within ± 0.648 g of the humidity measuring chilled mirror dew point hygrometer (see 11.11.2). Make corrections to each hourly reading for non-standard barometric conditions using factors derived from the perfect gas law equation in X1.2.

11.11.2 *Calibration of Primary Humidity Measuring System*—Calibrate the primary humidity measuring system during the stand calibration or within 48 h of the start of a stand calibration test with a chilled mirror dew point hygrometer or equivalent having an accuracy of ±0.55 °C at 24 °C dew point and moisture content in dry air of ± 0.6 g/kg. Perform additional stand calibrations when ambient temperature and ambient humidity conditions differ from the last semi-annual ambient test condition to ensure that the stand humidity remains within test requirements.

11.11.2.1 The humidity (hygrometer) tap is located on the air inlet tube leading to the air heater chamber (see Fig. A6.1). The sample line shall not be hygroscopic and might require insulation to prevent a temperature decrease to below the dew point.

11.11.2.2 *Calibration Procedure*—Make a series of paired comparison measurements between the primary system and the chilled mirror dew point hygrometer. The comparison period lasts for 20 min to 2 h, measurements being taken at 1 min to 6 min intervals, for a total of 20 paired measurements. The measurement interval should be appropriate for the time constant of the humidity measuring instruments. Check the flow rate to ensure that it is within the equipment manufacturer's requirements.

11.11.2.3 *Calibration Measurements and Calculations*—Take all measurements with the dew point hygrometer at atmospheric pressure and correct to standard conditions (101.12 kPa) using the perfect gas law equation (see X1.2) or from humidity correction factors taken from Tables X1.1-X1.4. From the differences between the results of each pairs of measurements, calculate the mean and standard deviation (see Appendix X2). The absolute value of the mean difference of humidity shall not exceed 0.648 g and the standard deviation shall be ≤0.324 g. Both requirements shall be met when calibrating the primary humidity measurement. If one or both requirements are not met, investigate the cause, make repairs, and recalibrate. Maintain calibration records for two years.

11.11.3 *Combustion Air System Drain Taps*—Drain taps may be installed at low points of the combustion air system. Keep them open during shut-down and warm-up.

12. Engine and Parts Inspections, Photographs and Measurements

12.1 Refer to the appropriate report forms before doing the inspections and recording the data. Standard report forms are available from the TMC website (http://www.astmtmc.cmu.edu).

12.2 *Pre-Test Measurements of Engine Parts*—See 9.3.

12.3 *Post-Test Information*—At the completion of the engine test inspect for deposits and measure the wear of piston, rings, and liner as described herewith. Photograph the piston and rings and section the cylinder liner (see Fig. X3.2).

12.3.1 *Deposit Ratings, Photographs, Measurements*—Remove the piston and ring assembly from the engine. Examine the assembly and measure the components in accordance with the ASTM Deposit Rating Manual 20 that uses the varnish scale (see A15.1). Photograph the pistons and rings, and perform deposit ratings as follows:

12.3.1.1 Photograph the piston and rings with the rings placed on top of the piston to show the ring gaps (thrust view) and 180° from the gaps (anti-thrust view). Ensure that the photographs of the pistons show the piston from the crown down to at least the bottom of the pin bore.

12.3.1.2 When rating second groove and land deposits, categorize all deposits as either heavy or light. For this test method, any deposits not meeting the definition of heavy are categorized as light.

12.3.1.3 Define and break down the undercrown rating area as shown in Fig. A15.1.

12.3.1.4 Use a piston deposit demerit rating as specified in ASTM Deposit Rating Manual 20.

12.3.1.5 Rate the top land heavy carbon piston deposits within 15 min after the power unit or piston assembly is removed from the engine.

12.3.1.6 After the crownland (topland) heavy deposits are rated, wash the crownland in solvent and wipe dry before continuing with the rating.

12.3.1.7 *Training of Piston Deposit Rating Specialist (Rater)*—The ASTM Heavy Duty Rating Workshop trains piston deposit raters. They shall maintain rating expertise by attending rating workshops annually. The rater shall attend the ASTM Heavy Duty Rating Workshop held each fall. The rater shall rate a minimum of six diesel pistons at the workshop. If the rater is unable to attend the workshop, the rater shall make alternative arrangements at the earliest opportunity. In applying these workshop attendance requirements to a laboratory having more than one rater, the laboratory shall send at least one heavy duty diesel piston rater annually.

12.3.1.8 *Referee Ratings*—To detect quickly and correct any shifts in rater severity, obtain referee ratings for all operationally valid calibration tests. Referee ratings are also required for tests reviewed by the test procedure developer. Provide the rating breakdown for land 1 to the referee laboratory so that the referee rater can use those figures in computing weighted piston deposits (WD). Do not provide any other rating information to the referee laboratory. For shipping to the referee laboratory, wrap pistons in paper and seal them in a plastic bag along with dessicant chips. Report referee results to the TMC within ten working days of test completion.

12.3.2 *Piston/Ring Side Clearances*—Determine the level of deposit formation in the piston/ring area by measuring the piston/ring side clearance. Follow the procedure as shown in Fig. A5.2 for pre-treatment measurement. Insert the feeler gage between the ring and groove carefully so as not to disturb or remove the deposit. Do *not* force the gage as this could dislodge the deposit. Record clearances on all rings on the Test Report Summary and Ring Measurements forms of the test report.

12.3.3 *Ring End Gap Increase*—Measure the ring gap according to Fig. A5.2. Post-test, clean the rings to remove carbon. If scraping the rings is required, use an instrument made from soft material, such as, wood. Measure and record the end gap in accordance with 9.3.3 and record on the Ring Measurements form of the test report.

12.3.4 *Liner Wear/Bore Polishing Measurements and Photographs*—Carry out liner preparation and measurements in accordance with the linear rating procedure (see A15.3).

12.3.4.1 First remove the deposits on the liner above the piston ring travel.

12.3.4.2 Then, to determine the liner wear step, measure the surface profile at the wear step location transversely and longitudinally relative to the crankshaft at four locations about 15 mm from the top of the liner.

12.3.4.3 Record the measurements as liner wear on the Liner Measurements form of the test report.

12.3.4.4 Section the cylinder liner for measurement of the amount of bore polishing and for photographing. Photograph the sectioned liner so as to show the thrust and anti-thrust sides (see Annex A15 and Fig. X3.2). Use the linear rating procedure (see A15.3).

12.4 *Oil Inspections:*

12.4.1 *New Oil Inspections*—Perform the following tests on the new oil (see the Oil Analysis And Results Summary of the test report):

12.4.1.1 Kinematic Viscosity at 100 °C by Test Method D445.

12.4.1.2 Base number by Test Method D4739.

12.4.1.3 For reference against used oil tests, wear metals, that is, iron, aluminum, copper, chromium, and lead, and air-borne particle contamination element, silicon by Test Method D5185.

12.4.2 *Used Oil Inspections*—Perform the following tests on the used oil at 24 h, 204 h, and 252 h:

12.4.2.1 Same tests as for new oil (see 12.4.1).

12.4.2.2 Fuel dilution by Test Method D3524.

13. Report

REPORT FORMS

13.1 For reference oil tests, the standardized report forms and data dictionary for reporting test results and for summarizing the operational data are required. All report forms making up the 1K/1N final report are available at the TMC website (http://www.astmtmc.cmu.edu).

13.1.1 Report all deposits, wear and engine operational data as required by the report forms.

13.1.2 Report a summary of the overall test results on the Test Report Summary form of the test report.

REPORTING TOP GROOVE FILL (TGF)—1K TESTS ONLY

13.2 Add the appropriate industry correction factor from Table 2.

13.2.1 Add any lab severity adjustment.

13.2.2 Report result as TGFFNL.

REPORTING TOP GROOVE FILL (TGF)—1N TESTS ONLY

13.3 Convert TGF percent to transformed units:

$$TTGF = \ln(TGF+1) \tag{2}$$

13.3.1 Add the appropriate industry correction factor from Table 2 to TTGF and report as TTGFCOR.

13.3.2 Add any lab severity adjustment to TTGFCOR and report as TTGFFNL.

13.3.3 Convert the final transformed value back to TGF percent.

$$TGFFNL = \exp(TTGFFNL) - 1 \tag{3}$$

13.3.4 If TGFFNL from 13.3.3 is greater than 100, report TGFFNL as 100.

REPORTING WEIGHTED DEMERITS (WD)

13.4 Add the appropriate industry correction factor from Table 2.

13.4.1 Add any lab severity adjustment.

13.4.2 Report result as WDFNL.

REPORTING TOP LAND HEAVY CARBON (TLHC)—1K TEST ONLY

13.5 Add the appropriate industry correction factor from Table 2.

13.5.1 Add any lab severity adjustment.

13.5.2 Report result as TLHCFNL.

TABLE 2 Test Parameter Correction Factors

NOTE 1—For tests not meeting any of the tabulated conditions the correction factor for all parameters is 0.

	TGF	WD	TTLHC	BSOC	ETOC
Conditions:					
1N, 1Y3998 cylinder liner, Tests starting before April 20th, 2015	0	0	–0.451	0	0
1N, 1Y3998 cylinder liner, Tests starting on or after April 20th, 2015	0.419954	0	0	0	0
1K, currently there are no correction factors for 1K parameters	0	0	0	0	0

REPORTING TOP LAND HEAVY CARBON (TLHC)—1N TEST ONLY

13.6 Convert TLHC percent to transformed units:

$$TTLHC = \ln(TLHC + 1) \quad (4)$$

13.6.1 Add the appropriate industry correction factor from Table 2 to TTLHC and report as TTLHCCOR.

13.6.2 Add any lab severity adjustment to TTLHCCOR and report as TTLHCFNL.

13.6.3 Convert TTLHCFNL back to TLHC percent:

$$TTHCFNL = \exp(TTLHCFNL) - 1 \quad (5)$$

REPORTING BRAKE SPECIFIC OIL CONSUMPTION (BSOC)

13.7 Add the appropriate industry correction factor from Table 2.

13.7.1 Add any lab severity adjustment.

13.7.2 Report the result as BSOCFNL.

REPORTING END OF TEST OIL CONSUMPTION (ETOC)

13.8 Add the appropriate industry correction factor from Table 2.

13.8.1 Add any lab severity adjustment.

13.8.2 Report resul as ETOCFNL.

13.9 *Oil Consumption:*

13.9.1 Calculate average oil consumption for each 12 h period and record on the Oil Consumption Plot.

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

13.10 *Ring and Liner Wear Measurements*—Report the ring and liner measurements on the Ring Measurements and Liner Measurements forms, respectively.

13.10.1 *Reporting of Unusual Conditions*—Report any unusual conditions on the Unscheduled Downtime & Maintenance Summary form of the test report.

13.10.2 Record instances of missing or mis-recorded test data.

13.10.3 If a test has more than 4 h without data acquisition on any controlled parameter, report it as operationally invalid.

13.10.4 Note in the Comments section of the Unscheduled Downtime & Maintenance Summary form if any alternative, backup data acquisition method is used to record data.

13.10.5 Record the test hours and time and date of all occasions where the engine is shut down or operated out of test limits on the Unscheduled Downtime & Maintenance Summary form of the test report.

13.10.6 Report all prior reference test events that were deemed operationally and statistically invalid or aborted. Account for all runs during the calibration sequence.

13.11 *Photographs*—Include in the report photographs of the pistons, rings and sectioned liner showing the thrust and anti-thrust sides (see Fig. X3.2 for an example).

13.12 *Electronic Transmission of Test Results (Optional):*

13.12.1 Transmit test results electronically using the ASTM Data Communications Committee Electronic Test Report Transmission Model (see Section 2 – Flat File Transmission Format) available from TMC.

13.13 *Reporting Calibration Test Results:*

13.13.1 Transmit calibration test results to the TMC immediately after completion of the test. For the test to be considered valid, the laboratories shall transmit data to the TMC within seven days of end of test (EOT).

13.13.2 Only laboratories approved by the TMC for doing so may transmit test results electronically (see 13.12).

13.13.3 The TMC shall review all calibration test results to determine test acceptability.

13.13.3.1 If the calibration test results are judged acceptable, the TMC discloses the reference oil code and the industry average results for the reference oil.

13.13.3.2 If the calibration test results are judged not acceptable, make every effort to determine the cause of the anomalous result. If an explanation is not readily available, check all test-related equipment. If a fault is still not identifed, consider the problem to be laboratory-related and contact the TMC to schedule another reference oil assignment.

14. Precision and Bias

14.1 Test precision is established on the basis of reference oil test results (for operationally valid tests) monitored by the ASTM Test Monitoring Center. The data are reviewed semiannually by the Single-Cylinder Diesel Surveillance Panel. Contact the ASTM TMC for current industry data.

14.1.1 Table 3 and Table 4 summarize reference oil intermediate precision and reproducibility of the test. The tabulated values are current as of July 9, 2015. The Surveillance Panel updates these values as necessary.

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

NOTE 3—Intermediate precision is the appropriate term for this test method rather than repeatability which defines more rigorous within-laboratory conditions.

14.1.2.1 *Intermediate Precision Limit* (i.p.)—The difference between two results obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Tables 3 and 4 in only one case in twenty. When only a single

TABLE 3 1K Reference Oil Precision Data

NOTE 1—These statistics are based on results obtained on Test Monitoring Center reference oils between Sept. 8, 1995 and July 9, 2015.

Variable	$S_{i.p.}$	i.p.	S_R	R
Top groove fill, %	12.0	33.6	12.2	34.2
Weighted total deposits, demerits	55.6	155.7	66.3	185.6
Top land heavy carbon, ln(TLHC + 1)[A]	0.751	2.103	0.907	2.540
Average oil consumption, g/MJ	0.024	0.067	0.025	0.069

[A] This parameter is transformed using ln(TLHC + 1). When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate precision, or reproducibility) precision limit.

TABLE 4 1N Reference Oil Precision Data

NOTE 1—These statistics are based on results obtained on Test Monitoring Center reference oils between April 3, 1995 and July 9, 2015.

Variable	$S_{i.p.}$	i.p.	S_R	R
Top groove fill, %	16.6	46.5	16.8	47.1
Weighted total deposits, demerits	29.1	81.5	30.8	86.2
Top land heavy carbon, ln(TLHC + 1)[A]	0.825	2.310	0.829	2.321
Average oil consumption, g/MJ	0.022	0.062	0.022	0.062

[A] This parameter is transformed using ln(TLHC + 1). When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate precision, or reproducibility) precision limit.

Legend:

$S_{i.p.}$ = intermediate precision standard deviation.
i.p. = intermediate precision.
S_R = reproducibility standard deviation.
R = reproducibility.

test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

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

14.1.3.1 *Reproducibility Limit* (R)—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Tables 3 and 4 in only one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result ± Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

14.1.4 Bias is determined by applying an acceptable statistical technique to reference oil test results and when a significant bias is determined, a severity adjustment is permitted for non-reference oil test results (see TMC Memo 94-200, Lubricant Test Monitoring System document for details).

15. Keywords

15.1 deposits; engine oil; engine wear; 1K test; 1N test; piston-ring-liner scuffing; piston ring sticking; top land heavy carbon

ANNEXES

(Mandatory Information)

A1. ASTM TEST MONITORING CENTER ORGANIZATION

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

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

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

A1.3 *Management of the ASTM TMC*—The management of the Test Monitoring System is vested in the Executive Committee elected by Subcommittee D02.B0. The Executive Committee selects the TMC Director who is responsible for directing the activities of the TMC.

A1.4 *Operating Income of the ASTM TMC*—The TMC operating income is obtained from fees levied on the reference oils supplied and on the calibration tests conducted. Fee schedules are established by the Executive Committee and reviewed by Subcommittee D02.B0.

A2. ASTM TEST MONITORING CENTER: CALIBRATION PROCEDURES

A2.1 *Reference Oils*—These oils are formulated or selected to represent specific chemical, or performance levels, or both. They are usually supplied directly to a testing laboratory under code numbers to ensure that the laboratory is not influenced by prior knowledge of acceptable results in assessing test results. The TMC determines the specific reference oil the laboratory shall test.

A2.1.1 *Reference Oil Data Reporting*—Test laboratories that receive reference oils for stand calibration shall submit data to the TMC on every sample of reference oil they receive. If a shipment contains any missing or damaged samples, the laboratory shall notify the TMC immediately.

A2.2 *Calibration Testing*:

A2.2.1 Full-scale calibration testing shall be conducted at regular intervals. These full-scale tests are conducted using coded reference oils supplied by the TMC. It is a laboratory's responsibility to keep the on-site reference oil inventory at or above the minimum level specified by the TMC test engineers.

A2.2.2 *Test Stands Used for Non-Standard Tests*—If a non-standard test is conducted on a previously calibrated test stand, the laboratory shall conduct a reference oil test on that stand to demonstrate that it continues to be calibrated, prior to running standard tests.

A2.3 *Reference Oil Storage*—Store reference oils under cover in locations where the ambient temperature is between -10 °C and +50 °C.

A2.4 *Analysis of Reference Oil*—Unless specifically authorized by the TMC, do not analyze TMCreference oils, either physically or chemically. Do not resell ASTM reference oils or supply them to other laboratories without the approval of the TMC. The reference oils are supplied only for the intended purpose of obtaining calibration under the ASTM Test Monitoring System. Any unauthorized use is strictly forbidden. The testing laboratory tacitly agrees to use the TMC reference oils exclusively in accordance with the TMC's published Policies for Use and Analysis of ASTM Reference Oils, and to run and report the reference oil test results according to TMC guidelines. Additional policies for the use and analysis of ASTM Reference Oils are available from the TMC.

A2.5 *Conducting a Reference Oil Test*—When laboratory personnel are ready to run a reference calibration test, they shall request an oil code via the TMC website.

A2.6 *Reporting Reference Oil Test Results*—Upon completion of the reference oil test, the test laboratory transmits the data electronically to the TMC, as described in Section 13. The TMC reviews the data and contacts the laboratory engineer to report the laboratory's calibration status. All reference oil test results, whether aborted, invalidated, or successfully completed, shall be reported to the TMC.

A2.6.1 All deviations from the specified test method shall be reported.

A3. ASTM TEST MONITORING CENTER: MAINTENANCE ACTIVITIES

A3.1 *Special Reference Oil Tests*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. Occasionally, the majority or even all of the industry's test stands will conduct calibration tests at roughly the same 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.

A3.2 *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 status is left pending for an excessive length of time. 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 may 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. To ensure accurate stand, or laboratory, or both severity assessments, conduct non-reference oil tests the same as reference oil tests.

A3.3 *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 may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may 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.

A3.4 *Intervals Between Reference Oil Tests*—Under special circumstances, such as extended downtime caused by industry-wide parts or fuel shortages, the TMC may extend the intervals between reference oil tests.

A3.5 *Introducing New Reference Oils*—Reference oils produce various results. When new reference oils are selected, participating laboratories will be requested to conduct their share of tests to enable the TMC to recommend industry test targets. ASTM surveillance panels require a minimum number of tests to establish the industry test targets for new reference oils.

A3.6 *TMC Information Letters*—Occasionally it is necessary to revise the test method, and notify the test laboratories of the change, prior to consideration of the revision by Subcommittee D02.B0. In such a case, the TMC issues an Information Letter. Information Letters are balloted semi-annually by Subcommittee D02.B0, and subsequently by D02. By this means, the Society due process procedures are applied to these Information Letters.

A3.6.1 *Issuing Authority*—The authority to issue an Information Letter differs according to its nature. In the case of an Information Letter concerning a part number change which does not affect test results, the TMC is authorized to issue such a letter. Long-term studies by the surveillance panel to improve the test procedure through improved operation and hardware control may result in the issuance of an Information Letter. If obvious procedural items affecting test results need immediate attention, the test sponsor and the TMC issue an Information Letter and present the background and data supporting that action to the surveillance panel for approval prior to the semiannual Subcommittee D02.B0 meeting.

A3.7 *TMC Memoranda*—In addition to the Information Letters, supplementary memoranda are issued. These are developed by the TMC and distributed to the appropriate surveillance panel and participating laboratories. They convey such information as batch approvals for test parts or materials, clarification of the test procedure, notes and suggestions of the collection and analysis of special data that the TMC may request, or for any other pertinent matters having no direct effect on the test performance, results, or precision and bias.

A4. ASTM TEST MONITORING CENTER: RELATED INFORMATION

A4.1 *New Laboratories*—Laboratories wishing to become part of the ASTM Test Monitoring System will be requested to conduct reference oil tests to ensure that the laboratory is using the proper testing techniques. Information concerning fees, laboratory inspection, reagents, testing practices, appropriate committee membership, and rater training can be obtained by contacting the TMC Director.

A4.2 *Information Letters: COTCO Approval*—Authority for the issuance of Information Letters was given by the committee on Technical Committee Operations in 1984, as follows: "COTCO recognizes that D02 has a unique and complex situation. The use of Information Letters is approved providing each letter contains a disclaimer to the affect that such has not obtained ASTM consensus. These Information Letters should be moved to such consensus as rapidly as possible."

A4.3 *Precision Data*—The TMC determines the precision of test methods by analyzing results of calibration tests conducted on reference oils. Precision data are updated regularly. Current precision data can be obtained from the TMC.

A5. SPECIFICATIONS FOR TEST ENGINE AND ENGINE BUILD

A5.1 See Fig. A5.1 for the specification for valves.

A5.2 *Procedure for Honing Valve Guides*:

A5.2.1 Use equipment shown in parts list (see 7.15).

A5.2.2 Clean valves with a clean cloth and mineral spirits.

A5.2.3 Measure valve stems with a micrometer, having a range of 25.4 mm.

A5.2.4 If required, install new valve guides into the cylinder head. Either press or drive the valve guides into the head using the tool specified in the service manual.

A5.2.5 Before honing, cut a groove in the top of the intake guides for the P.C. seals using the Perfect Circle tool VST-2012.

A5.2.6 Hone the guides with a P-180 Honal. Measure the guides with a Sunnen P-300 bore gage and a P-375 probe. Hone the intake valves to a clearance of 0.0254 mm and the exhaust valves to 0.0508 mm, the tolerance of the clearance being + 0.005 mm.

A5.2.7 After honing, clean the guides with a nylon tooth brush.

VALVES

.... Height of valve guides from top of cylinder
.... head....... (32.3 ± 0.8) mm

.... Diameter of valve stems (new)
.... (9.441 ± 0.008) mm

.... Maximum bore in valve guide after assembled in the head and reamed to fit valve. (See valve fit procedure at the end of the section)... 9.472 mm

.... Diameter of valve head:
.... Exhaust valve...........(41.81 ± 0.13) mm
.... Intake valve.............(44.96 ± 0.13) mm

.... Angle of intake valve face......... .... 29 1/4° ± 1/4°
.... Angle of exhaust valve face....... .... 44 1/4° ± 1/4°

.... Depth of bore in head for valve seat inserts, exhaust and
.... Intake...... .... (13.01 ± 0.35) mm

.... Diameter of valve seat insert for exhaust valve
.... (42.850 ± 0.013) mm
.... Bore in head for valve seat insert for exhaust valve
.... (2.774 ± 0.025) mm

.... Diameter of valve seat insert for intake valve
.... (46.025 ± 0.013) mm

.... Bore in head for valve seat insert for intake valve
.... (45.949 ± 0.025) mm

.... Outside diameter of the face of the valve seat insert:
.... Exhaust seat .... (40.41 ± 0.13) mm
.... Intake seat (44.04 ± 0.13) mm

.... Valve seat width:
.... Exhaust seat .... (1.524 ± 0.508) mm
.... Intake seat (2.286 ± 0.635) mm

.... Angle of face of intake valve seat insert:
.... 30 1/4° ± 1/4°
.... Angle of face of exhaust valve seat insert:
.... 45 1/4° ± 1/2°

)......... "Use again" thickness of valve lip:
.... Exhaust valve .... 2.03 mm
.... Intake valve .... 2.51 mm

)......... Dimension from top of closed valve to face of head:
.... Maximum permissible dimension for intake and exhaust: 1.07 mm

.... Minimum permissible dimension for intake and exhaust: 0.05 mm

)........ Umbrella 6N7174

)........ Perfect Circle Seal VS-4
.... Perfect Circle Tool VST2012

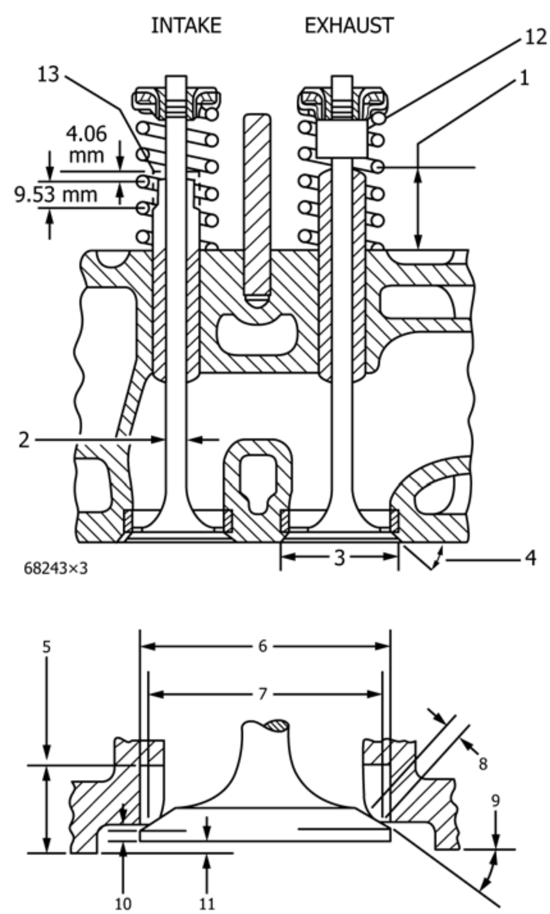


FIG. A5.1 Specification for Valves

A5.2.8 Machine the intake valve seat inserts into the head as specified to 30.25° + 0.25° and the exhaust valves to 45.25° +0.25°.

A5.2.9 Clean the head and guides with mineral spirits and blow dry.

A5.2.10 Lubricate the valves and guides with engine oil (Mobil EF-411) and assemble into the head.

A5.2.11 Additional valve clearance (0.0127 mm) is allowed after test, giving a maximum for the intake valve of 0.038 mm and for the exhaust valve of 0.0635 mm.

A5.2.12 Reuse, provided the requirements in A5.2.11 are met.

A5.2.13 The intake valves guides may be pre-cut for the valve guide seals before insertion into the head. A go-no-go gage may be used for valve depth measurements.

A5.3 *Piston Specifications*—See Fig. A5.2.

A5.4 *Details of Cylinder Liner*:

A5.4.1 *Liner Specifications 1Y3555 Cylinder Liner*—Surface finish shall be 0.4 µm to 0.8 µm (R_a). See Figs. A5.3-A5.6.

A5.5 *Cylinder Head Torquing Procedure*:

A5.5.1 Disassemble the rocker box and inspect before each test. (See Fig. A5.7).

A5.5.2 Put clean engine oil on all stud threads and tighten the nuts to the correct torque in the following sequence.

A5.5.3 Rocker arm shaft group is not assembled for initial head torque. Use separate 1Y609 pedestal under No. 6 nut.

A5.5.4 *Step 1*—Tighten nuts 1 to 6 in number sequence to 270 N·m ± 25 N·m.

A5.5.5 *Step 2*—Tighten nuts 1 to 6 in number sequence to 450 N·m ± 20 N·m.

A5.5.6 *Step 3*—Tighten nuts 1 to 6 in number sequence, again 450 N·m ± 20 N·m *Cylinder liner inside diameter is measured at end of Step No. 3*.

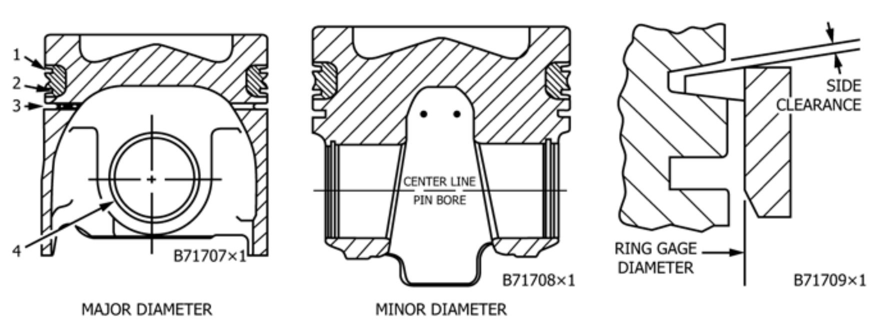
A5.5.7 *Step 4*—Loosen No. 6 nut and install the rocker arm shaft group.

A5.5.8 *Step 5*—Tighten nut 6 to a torque of 270 N·m ± 25 N·m.

A5.5.9 *Step 6*—Tighten nut 6 to a torque of 450 N·m ± 20 N·m.

A5.5.10 *Step 7*—Tighten nut 6 again to a torque of 450 N·m ± 20 N·m.

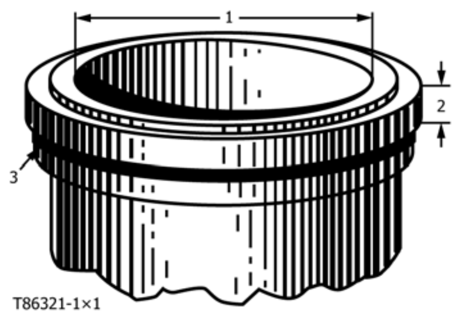
1Y0727 Piston And 1Y0728 Rings



	TOP RING[A]	INTERMEDIATE RING[A]	OIL CONTROL RING[A]
Width of groove in piston for piston ring (new)	—	2.455 mm ± 0.01 mm	3.21 mm ± 0.01 mm
Thickness of piston ring (new)	—	2.365 mm ± 0.01 mm	3.137 mm ± 0.006 mm
Side Clearance between groove and piston ring (new)	0.193 mm ± 0.032 mm	0.090 mm ± 0.02 mm	0.073 mm ± 0.016 mm
End gap clearance between end of ring (new) installed in 137.160 mm diameter gauge	0.724 mm ± 0.076 mm	0.673 mm ± 0.076 mm	0.572 mm ± 0.190 mm

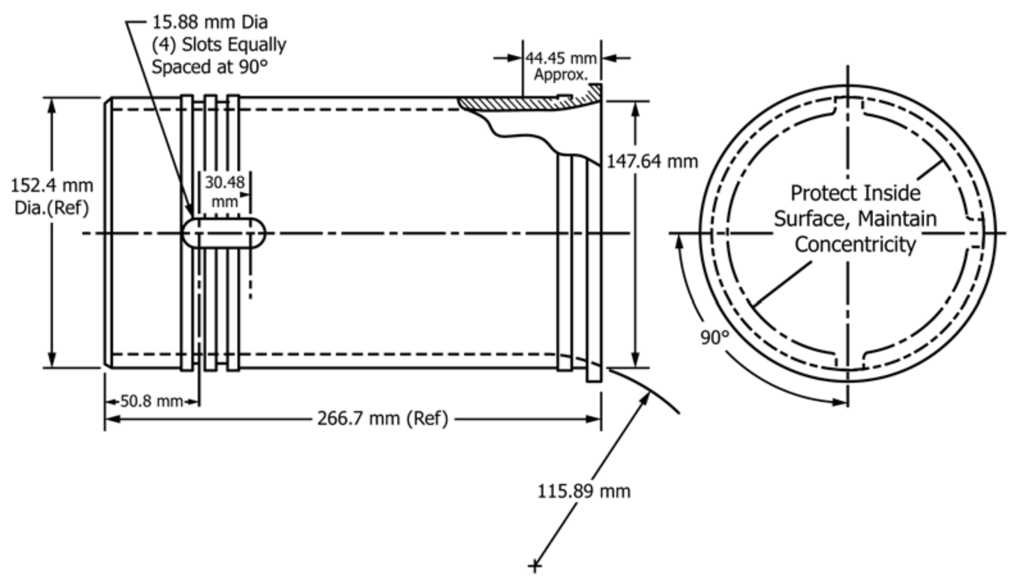
[A] This engine uses Keystone style piston rings and grooves in the piston for top rings. The piston ring lands are also elliptically ground. therefore measure top and ringside clearance as follows:
(*1*) Assemble piston ring on the piston with UP side toward the top of the piston.
(*2*) Install piston and ring in a 137.160 mm diameter ring gage.
(*3*) Push piston and ring until ring to be measured is at the top of the gage as shown. Keep the piston in the center of the gage.
(*4*) Measure the side clearance with a feeler gage at both major diameter (90° from the centerline of the pin bore) and minor diameter. Either measurement should be within specifications shown.
Install the oil control ring with gap in the sprint 180° away from the gap in the ring.
(*a*) Top ring groove.
(*b*) Intermediate ring groove.
(*c*) Oil control ring groove.
(*d*) Bore in piston for pin. . . . . 50.815 mm ± 0.008 mm
Piston pin diameter 50.795 mm ± 0.005 mm
Clearance between pin and bore in piston . . . . . 0.020 mm ± 0.013 mm

FIG. A5.2 Piston Specifications



NOTE 1—Legend:
(*1*) Bore in liner (new) 137.185 mm ± 0.025 mm. With head torqued to block, assembled liner diameter is measured at 15 mm, 25.4 mm, 50.8 mm, 130 mm, and 230 mm from top of liner. Out of round (difference of transverse and longitudinal diameters at each vertical height level) max 0.038 mm, taper (Difference of all vertical height diameters in either the transverse or longitudinal direction). max 0.050 mm. Minimum assembled liner diameter–137.154 mm.
(*2*) Thickness of flange on liner 8.89 mm ± 0.02mm.
(*3*) Filler band.

FIG. A5.3 Details of Cylinder Liner



NOTE 1—Retrofit not to distort inside diameter or surface.

FIG. A5.4 Front and Side Views of Cylinder Liner

A5.5.11 Height of dowel for the rocker arm pedestal from the cylinder head is 3.25 N·m ± 0.25) mm.

A5.5.12 Torque for exhaust manifold studs is 27 N·m ± 4 N·m.

A5.6 *Fuel Flow Timing Dimension Check (Bubble Method)*:

A5.6.1 *Procedure for Checking Timing:*

A5.6.1.1 Check flywheel point setting (see SENR2856 Sevice Manual, p 147).

A5.6.1.2 Pressurize air into the fuel system at 7 kPa ± 1.2 kPa. Remove the fuel rack pin and rotate the fuel rack clockwise to the full *on* position.

A5.6.1.3 Turn the crankshaft by hand in normal rotation (counter-clockwise rotation from the flywheel end) starting at 90° BTC on the compression stroke.

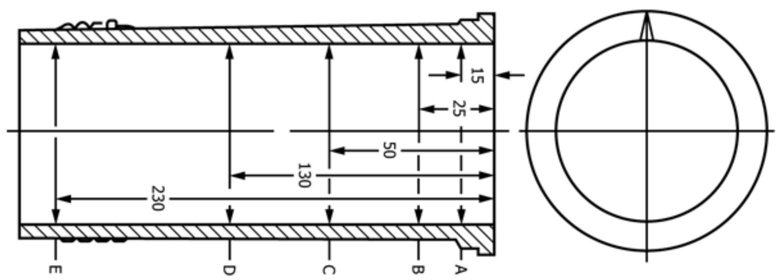
A5.6.1.4 The air at 90° BTC should flow from the adapter bleed line.

A5.6.1.5 Bleed the fuel using air pressure until a constant stream of bubbles is achieved.

A5.6.1.6 Slowly rotate the crankshaft (counter-clockwise from the flywheel end) until the bubbles stop, *stopping rotation immediately after the bubbles stop flowing*. This step is known as bypass closing. Failure to observe it by continued crank rotation will cause incorrect timing values.

(1) Place the Vernier on top of the flywheel. Put the 32.0° line of the Vernier at the flywheel pointer. Ensure that the 30° line of the Vernier is in the direction of the 30° mark of the flywheel. See Fig. A5.8.

Cyl. No.	Serial No.	VERTICAL LOCATION OF MEASUREMENT									
		A		B		C		D		E	
		LONG.	TRANS.	LONG.	TRANS.	LONG.	TRANS.	LONG.	TRANS.	LONG.	TRANS.
1											
2											
3											
4											
5											
6											



NOTE 1—Measurements are in millimetres.

FIG. A5.5 Measurements of Cylinder Liner

(2) Read down on the Vernier to the location where a line on the Vernier directly matches up with a timing line on the flywheel. Read the Vernier value at the location where the lines match up. This is the fuel timing °BTDC.

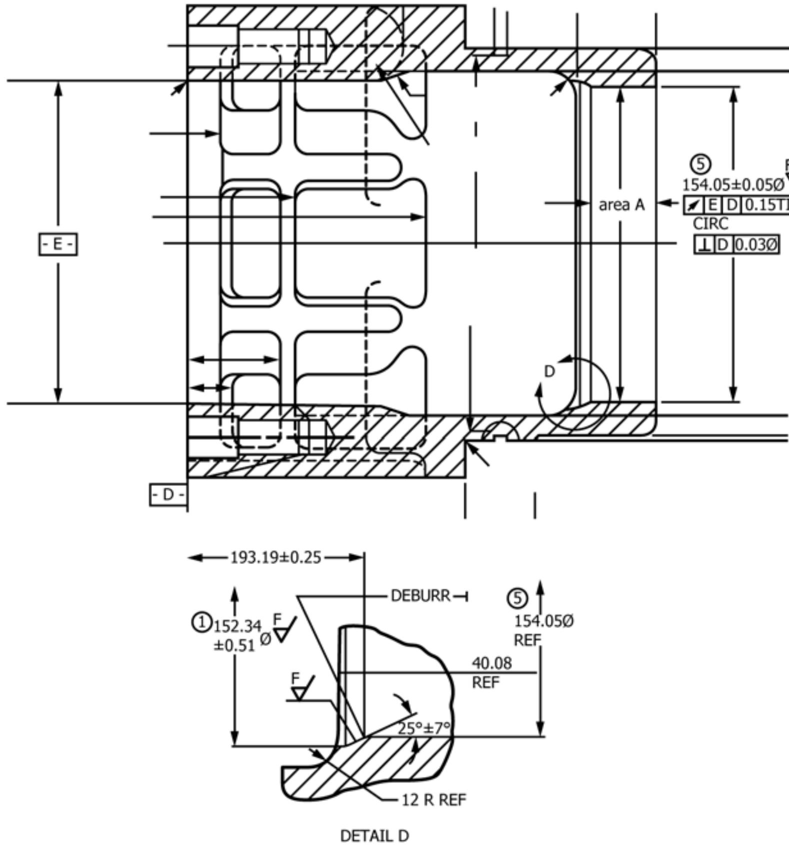
A5.6.1.7 The air flow at the timing setting (bypass closing and start of fuel injection) should stop and occur at 31.5° ± 0.5° BTC. Measure the position by the Vernier.

A5.6.1.8 Continue rotation with the crankshaft past the timing setting and air flow should return.

A5.6.1.9 Further crankshaft rotation within 180° of the timing setting should approach another point where the air does not flow. This step ensures that the fuel timing is set on the correct side of the fuel cam. Fig. A5.9 is a diagram of the bubble method apparatus.

A5.7 *1Y615 Cooling Jet I.D. Verification and Alignment*—See Fig. A5.10.

A5.8 *Fuel Pump Plunger Erosion*—See Fig. A5.11.



NOTE 1—1Y544 Cylinder Block (modifications required for product type cylinder liners)

NOTE 2—Machine o-ring area bore to 154.05 mm and tolerance shown.

NOTE 3—During assembly the cyl. liner o-ring flange must not touch the block in area A (liner distortion may occur). Use feeler gage to check clearances.

NOTE 4—Measurements are in millimetres.

FIG. A5.6 Cylinder Block Modifications

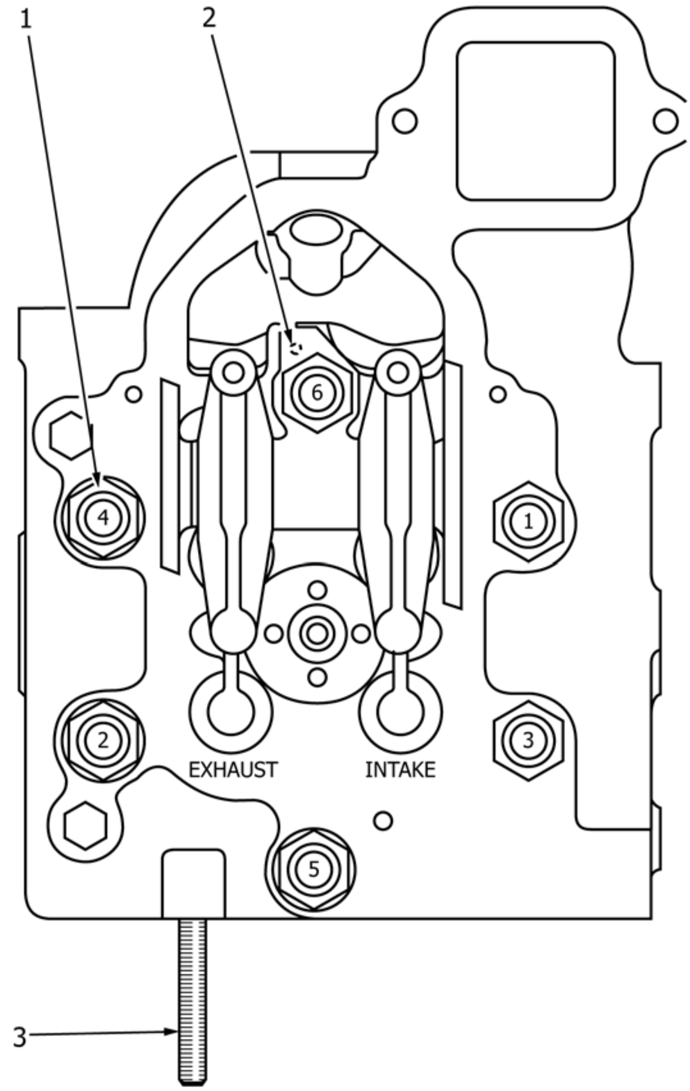
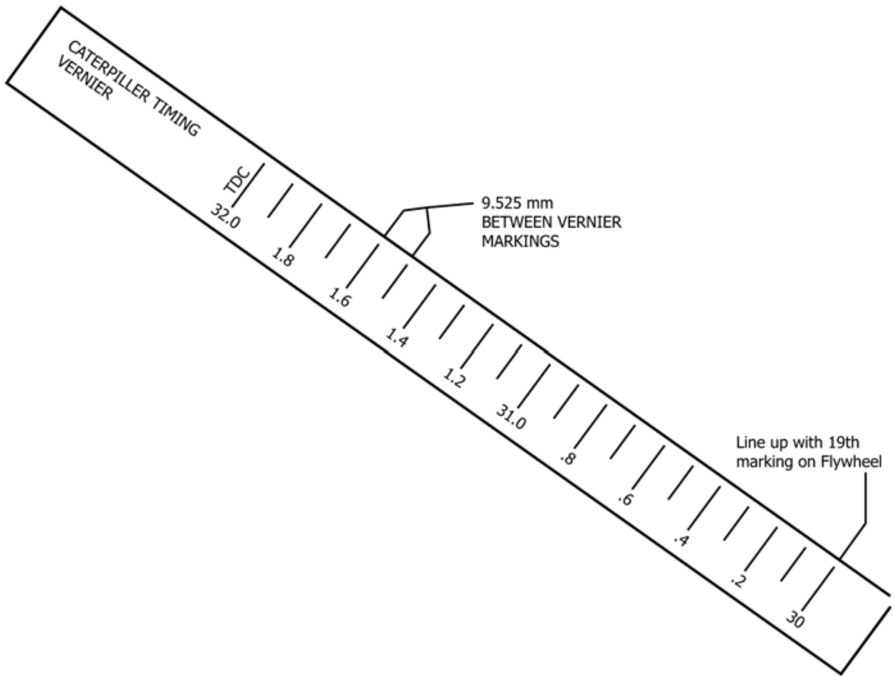


FIG. A5.7 Cylinder Head



NOTE 1—Vernier Information
(*1*) Make certain distance between the lines of the Vernier are 9.525 mm.
(*2*) Slowly rotate crankshaft (CCW from flywheel end) until bubbles stop. **STOP ROTATION IMMEDIATELY AFTER THE BUBBLES STOP FLOWING**. This is by-pass closing. Continued crank rotation will cause incorrect timing values.
(*3*) Place the Vernier on top of the flywheel. Put the 32.0° line of the Vernier at the flywheel pointer with 30° line in the direction of 30° mark of the flywheel.
(*4*) Read down on the Vernier to the location where a line on the Vernier directly matches up with a timing line on the flywheel. Read the Vernier °TDC value at the location where the lines match up.
(*5*) Method to determine Vernier length:

20 flywheel division (40°) = 195 mm

Length of Vernier scale $= \frac{195 \times 19}{20}$

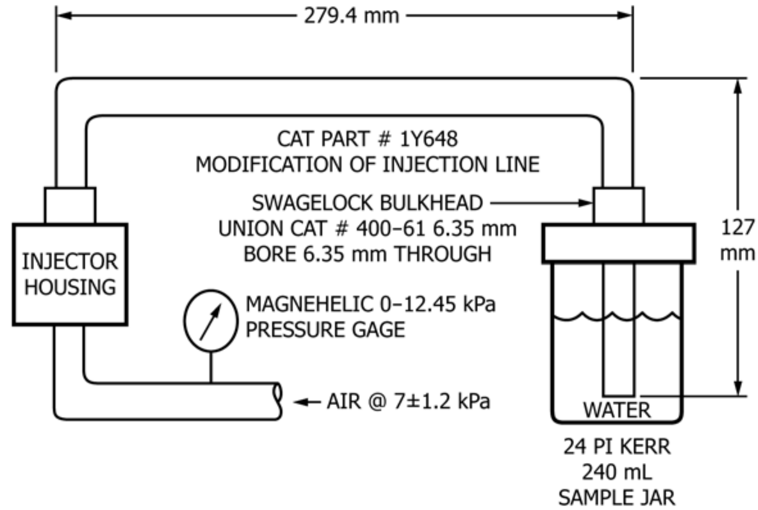
$= 185.25$ mm

Length of 0.1° on vernier = 185.25

20

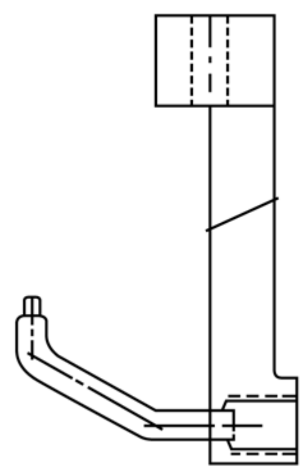
$= 9.2625$ mm

FIG. A5.8 Vernier for Measuring Flywheel Position



NOTE 1—Use Vernier to measure flywheel position.

FIG. A5.9 Diagram of Bubble Method Apparatus



NOTE 1—Ensure jet tube I.D. at threaded end (opposite end of orifice) is 3.43 mm ± 0.127 mm diameter.

NOTE 2—Tube can be inspected with:

ANSI No. 29 drill, 0.1360 in.— nominal size.

ANSI No. 28 drill, 0.1405 in.—drill should not fit in tube.

ISO No. 3.3 drill—drill should fit in tube.

NOTE 3—Replace 1Y615 cooling jet if not within specifications.

NOTE 4—When aligning the P tube (piston cooling jet tube), use an oil pressure of 358 kPa (system pressure).

FIG. A5.10 1Y615 Cooling, Jet I.D. Verification and Alignment

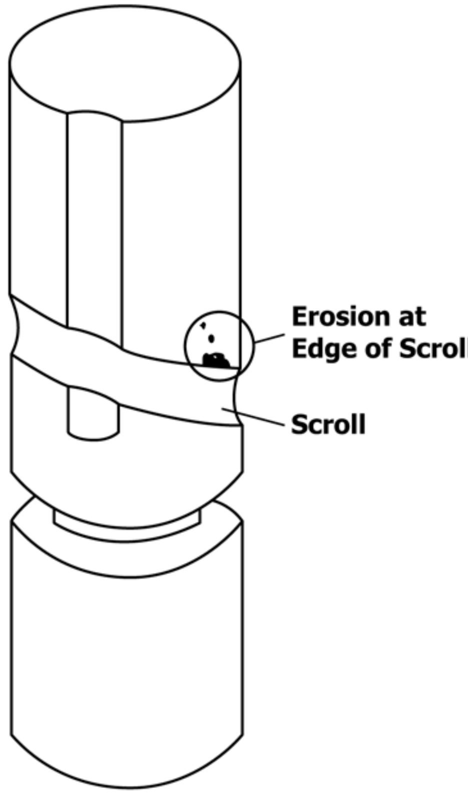


FIG. A5.11 Fuel Pump Plunger Erosion

A6. INTAKE AIR SYSTEM DETAILS

A6.1 See Fig. A6.1 and Fig. A6.2.

A6.2 *1Y38 Surge Chamber and Heater Assembly*:

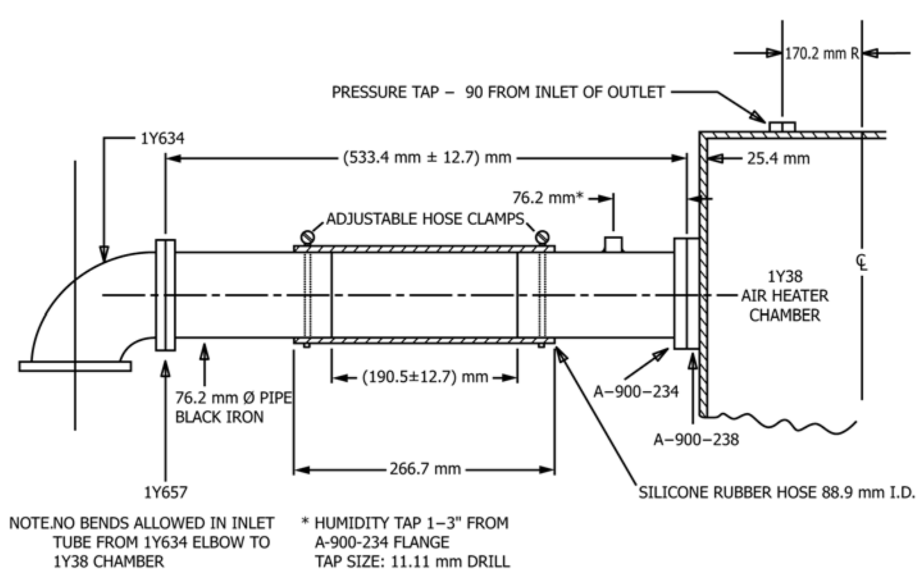


FIG. A6.1 Inlet Air Piping Arrangement

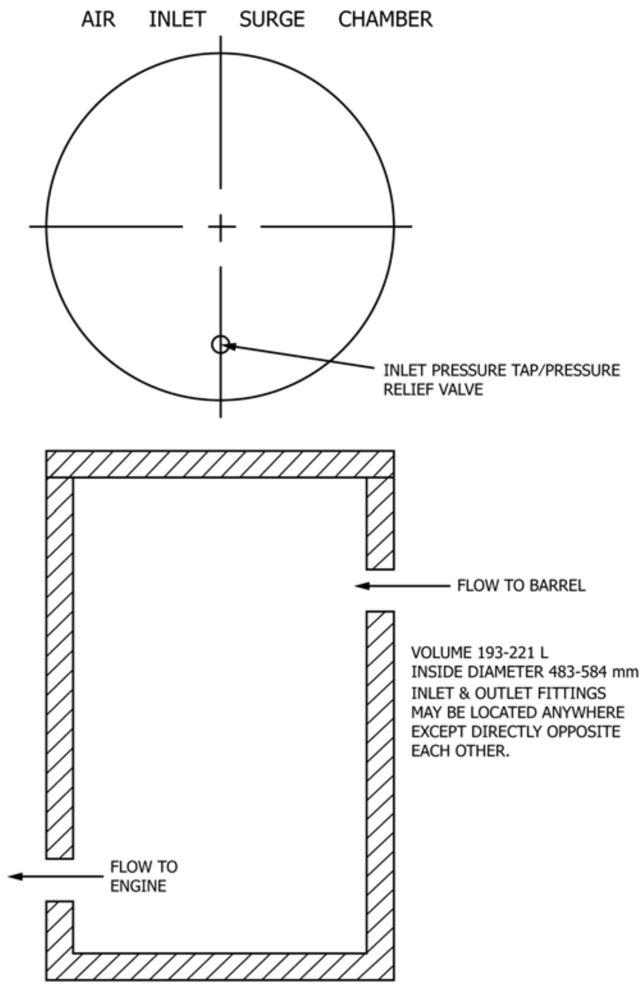


FIG. A6.2 Air Inlet Surge Chamber

A6.2.1 *General Dimensions*—This assembly is essentially a pressure vessel with internal electrical heating elements. The general dimensions of the surge chamber are: (*1*) volume, 204 L; (*2*) inside diameter, 533 mm; and (*3*) inside height, 933 mm. See Table A6.1.

A6.2.2 *Permissible Changes in Design*—If individual requirements or local building codes necessitate changes in the design, the following modifications are permissible:

A6.2.2.1 Volume may vary from 193 L to 221 L.

A6.2.2.2 Inside diameter may vary from 483 mm to 584 mm.

A6.2.2.3 Inside height is a function of the volume and inside diameter.

A6.2.2.4 Inlet and outlet fittings may be anywhere except opposite one another.

A6.2.2.5 The type and arrangement of heating controls may be determined by local conditions.

A6.2.2.6 The chamber may be located in any position relative to the engine so long as (*1*) the length of the air transfer pipe is 533.4 mm ± 12.7 mm from the face of the surge chamber mounting pad to the face of the 1Y634 elbow; and (*2*) the air transfer pipe contains no bends between the surge chamber and the 1Y634 elbow.

A6.2.2.7 A stand may be constructed to raise the chamber to the proper height to fit the engine arrangement and mounting.

A6.3 See Fig. A6.3 for intake air temperature location and Fig. A6.4 for horizontal air barrel pressure tap location.

TABLE A6.1 Bill of Material, Surge Chamber and Heater Assembly

NOTE 1—Drawings are available from Caterpillar.

Item No.	Name	Caterpillar Part No.	Description	No. Required
1-1	Surge chamber and Heater Assembly			1
1-2	Bolt	L1648	9.53 mm–24thd 63.5 mm long[A]	1
1-4	Thermostatic switch			2
1-5	Lockwasher	3B4506	Std. for 9.53 mm diameter bolt	20
1-6	Bolt	2A4996	9.53 mm–24thd 34.93 mm long	20
1-7	Pressure relief valve		[B]	1
1-8	Gasket		0.792 mm thick[C]	1
1-9	Mounting plate		508 mm by 305 mm by 1.59 mm thick SAE 1020 steel	1
1-10	Spacer	8B7430	19.1 mm OD 9.12 mm ID 13.51 mm thick SAE 1020 steel	4
1-11	Bolt	L1590	6.35 mm–28thd 28.58 mm long	4
1-12	Lockwasher	3B4504	Std. for 6.35 mm diameter bolt	4
1-13	Nut	1B4201	6.35 mm-28thd	4
1-14	Electrical junction box		305 mm by 457 mm by 102 mm std pull box w/ hinged cover	1
1-15	Strip heater		[D]	24
1-16	Gasket		0.792 mm thick[C]	1
2-1	Assembly			1
2-2	Top ring			1
2-3	Bottom plate			1
2-4	Strap-surge chamber			1
2-5	Hook			1
2-6	Pad			1
3-1	Assembly			1
3-2	Top cover			1
3-3	Inner bracket			1
3-4	Outer bracket			1
4-1	Terminal assembly			5
4-2	Nut		11.11 mm–14thd SAE 73 brass	29
4-3	Washer		Std. for 11.1 mm dia. bolt	10
4-4	Insulator		31.75 mm OD, 11.51 mm ID, 4.75 mm thick Synthane	5
4-5	Stud		11.11 mm -14thd 76.2 mm long brass	5
4-6	Collar			5
4-7	Insulator assembly			48
4-8	Washer		19.05 mm OD, 6.73 mm ID, 3.18 mm thick Mica	48
4-9	Insulator		12.7 mm OD, .6.73 mm ID	48
4-10	Insulator		42.85 mm by 1.59 mm w/ 6.73 mm hole Mica	
4-11	Bolt		6.35 mm-20thd 25.4 mm long	48
4-12	Washer		Std. for 6.35 mm diameter bolt	48
4-13	Nut		Std. for 6.35 mm 20thd	48
4-14	Electric cable cover			1
4-15	Terminal connector			[E]
4-16	Lower bracket assembly			1

[A] 4.44 °C per turn-normally closed-contacts open with increase of temperature. Turning screw counter-clockwise causes contacts to open at a higher temperature.
[B] Set to pop off at 137.9 kPa ± 3.4 kPa.
[C] Make gaskets to fit top ring (2-2) and pad (2-6).
[D] Terminal on element goes to inside of barrel on inner rings and to outside of barrel on outer rings.
[E] As required.

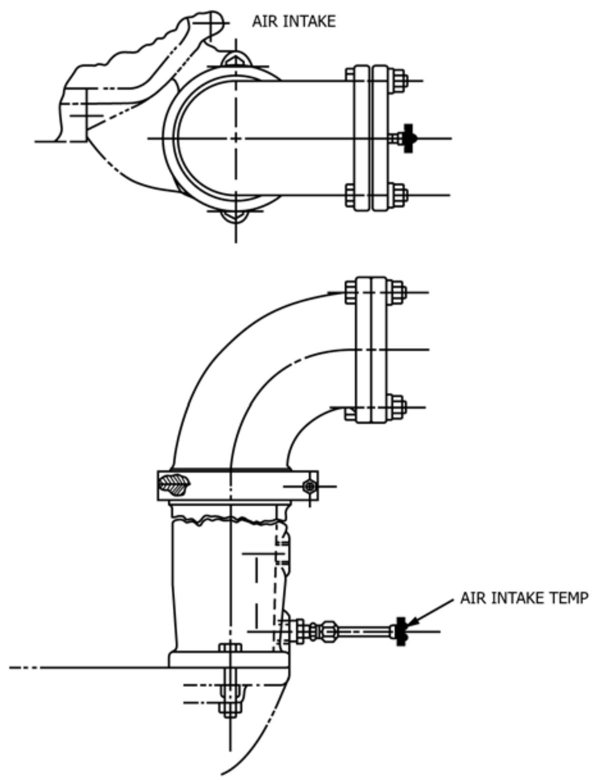
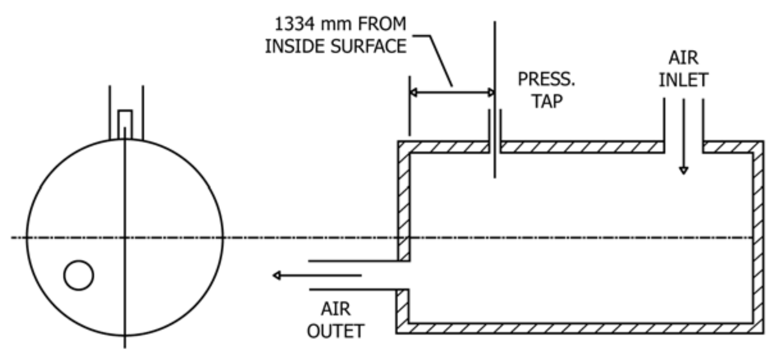


FIG. A6.3 Intake Air Temperature Location



NOTE 1—Air outlet should be 90° or greater from the air pressure tap.

FIG. A6.4 Horizontal Air Barrel Pressure Tap Location

A7. EXHAUST SYSTEM DETAILS

A7.1 See Figs. A7.1-A7.5.

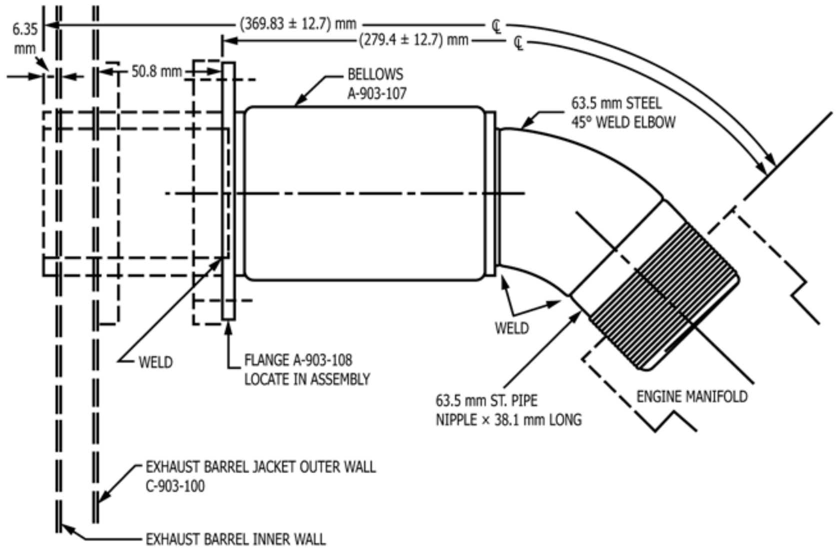


FIG. A7.1 Exhaust Piping Arrangement

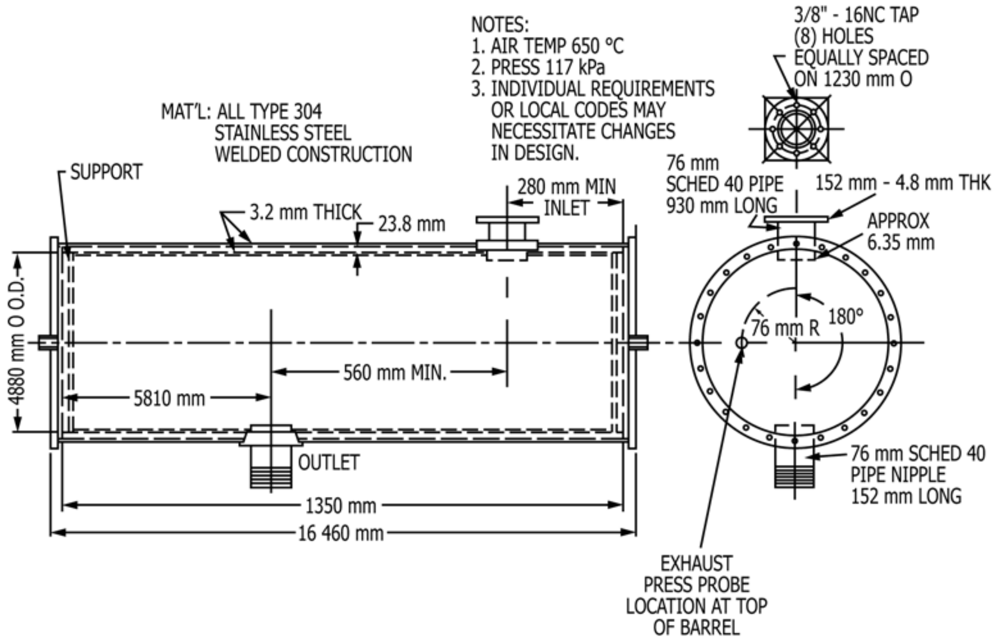


FIG. A7.2 Exhaust Barrel Diagram

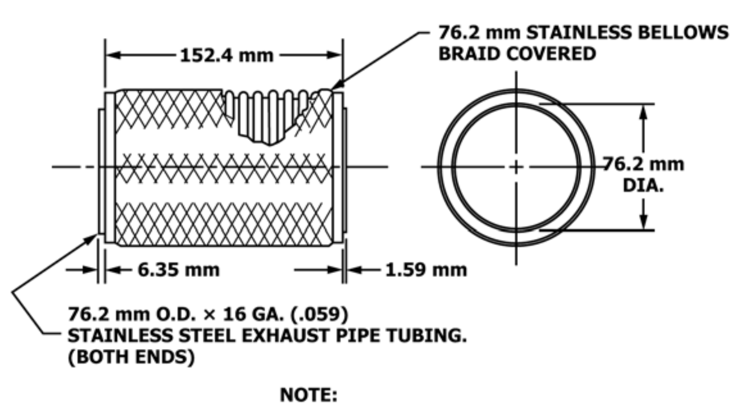
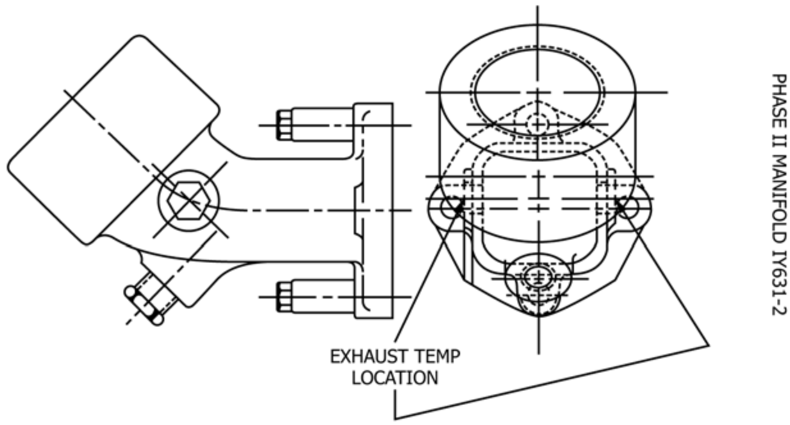
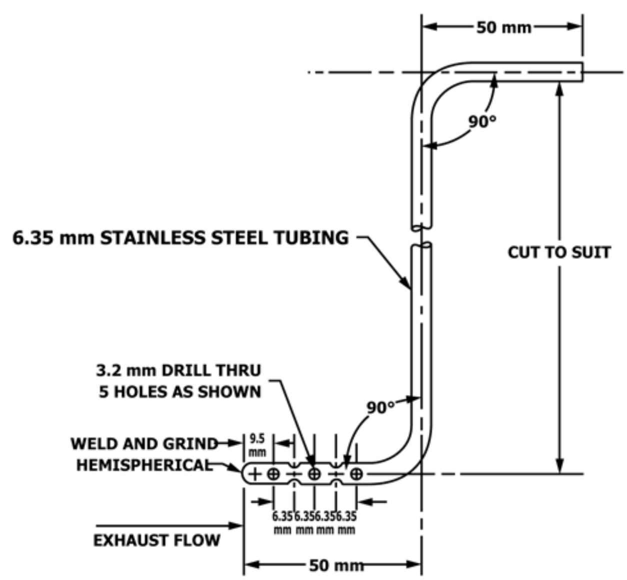


FIG. A7.3 Exhaust Bellows



Either location is acceptable.

FIG. A7.4 Thermocouple Location in Exhaust Manifold



NOTE. WALL THICKNESS 0.76 mm

FIG. A7.5 Exhaust Gas Sample Probe

A8. COOLING SYSTEM DETAILS

A8.1 See Figs. A8.1-A8.4.

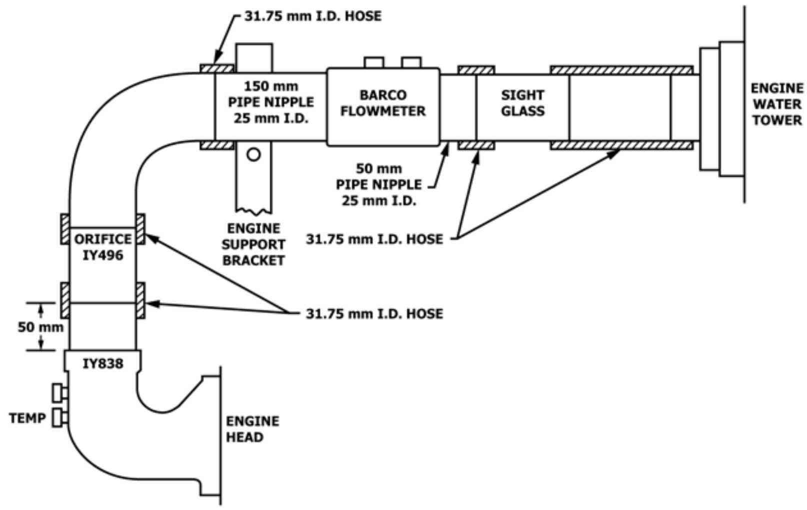


FIG. A8.1 Piping Arrangement and Instrument Locations

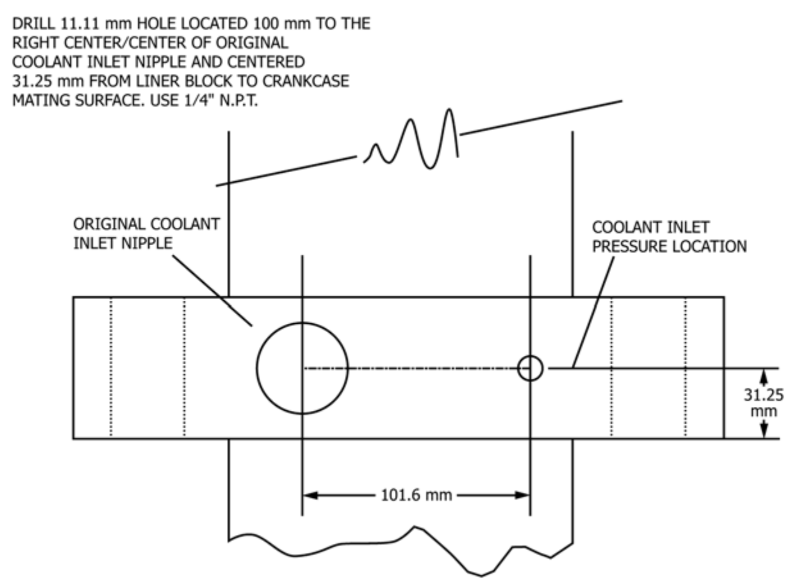
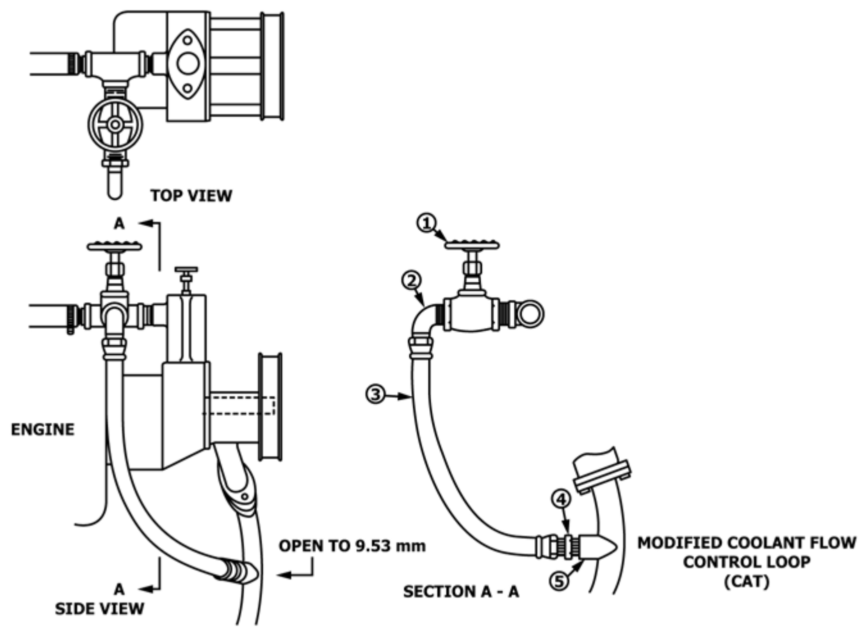


FIG. A8.2 Block Coolant Pressure Tap Location



NOTE 1—19.1 mm valve.

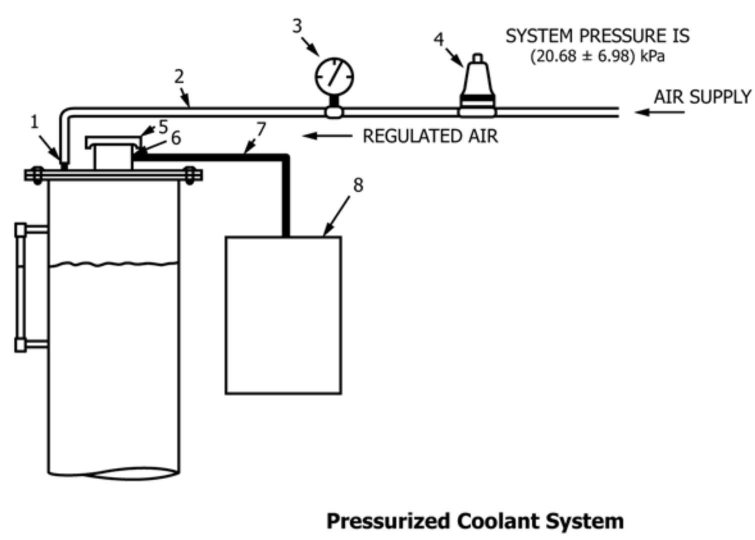
NOTE 2—90° elbow ¾ in. MNPT - TO No. 10AN.

NOTE 3—No. 10 hose with swivels.

NOTE 4—Connector ⅜ in. MNPT - TO No. 10AN. Drill to 11.1 mm inside diameter.

NOTE 5—Modify existing boss on the water pump intake. Drill and tap to ⅜ in. NPT.

FIG. A8.3 Water Pump Bypass Arrangement



NOTE 1—Legend:

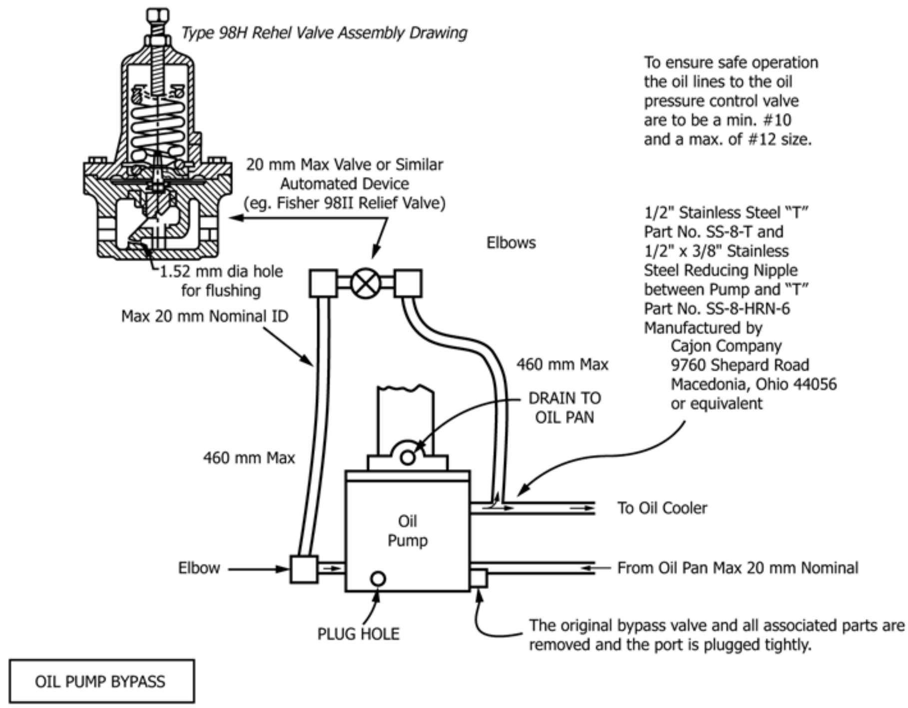
1. ¼ in. NPT-to No. 4AN (male connector)
2. No. 4 hose
3. Pressure gage 0 to 103 kPa
4. Pressure regulator (self bleeding)
5. Radiator cap 103 to 110 kPa
6. Radiator filler neck
7. Overflow tube
8. Overflow tank

NOTE 2—If the system builds to greater than regulator setting, then condensate will back-flow through regulator.

FIG. A8.4 Cooling System Modification

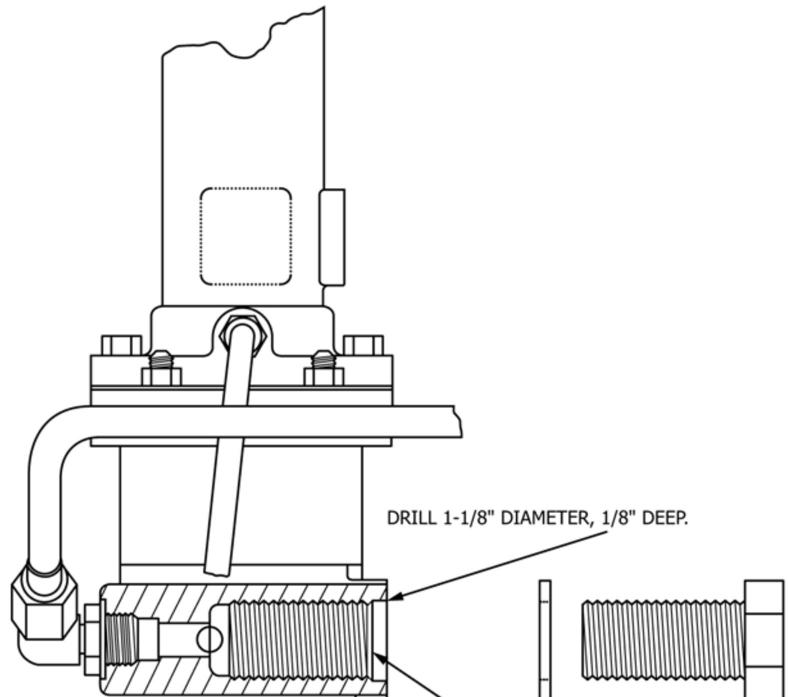
A9. OIL SYSTEM MODIFICATIONS AND INSTRUMENT LOCATIONS

A9.1 See Figs. A9.1-A9.8.



NOTE 1—Available from General Meters and Controls, 1776 Commerce Drive, Bos 625, Elk Grove, Village, IL 60007 as Oil Pressure External Relief Valve Fisher 98H-17 ½ in. Cast Iron Body, S.S. Diaphragm.

FIG. A9.1 Remote Mount Oil Pump Relief Valve



NOTE 1—Install: 1-2H3751 bolt (1-1/8-12 × 2-1/2"); 1–5B3265 gasket. If desired, bolt thread may be sealed with 7M7456 bearing mount.

FIG. A9.2 Oil Pump Relief Valve Plug

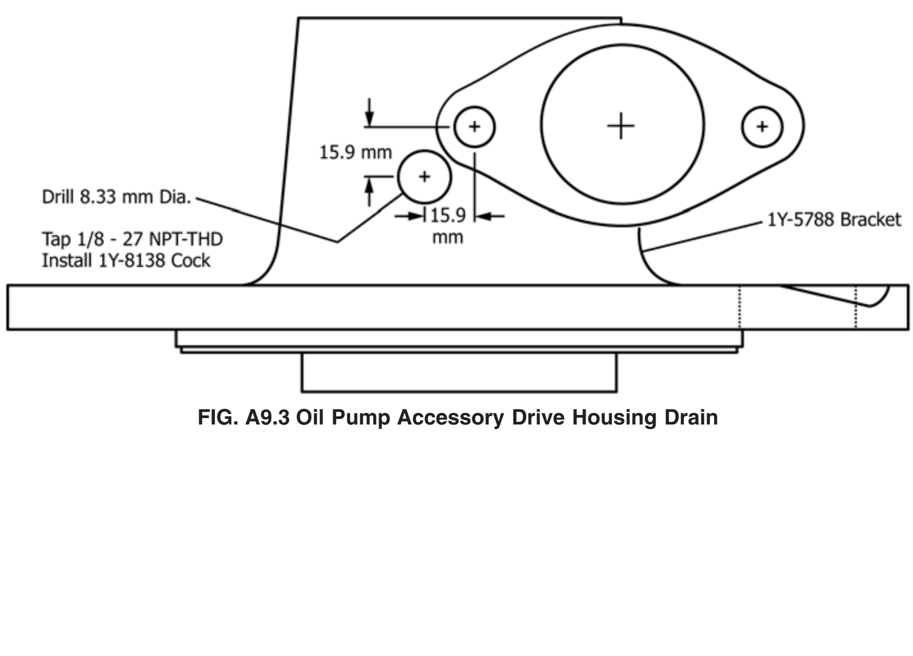
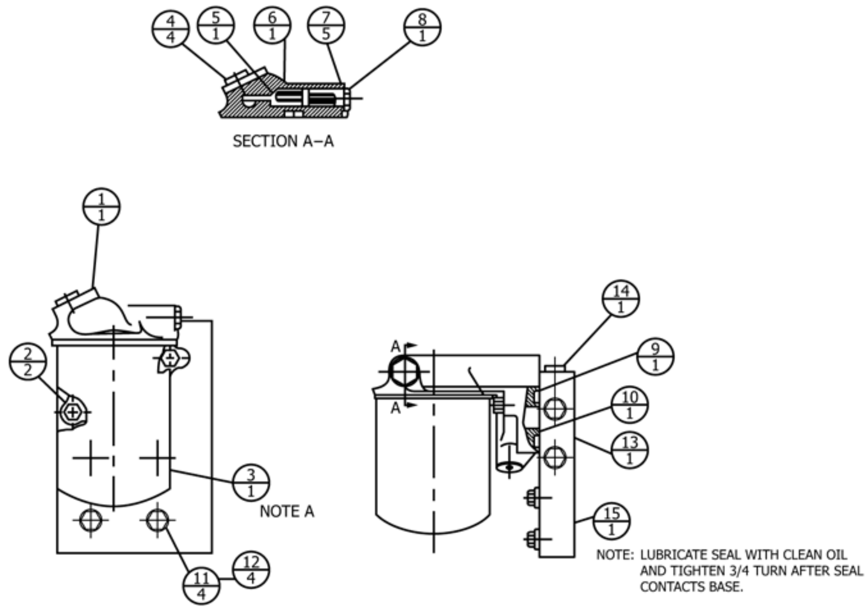


FIG. A9.3 Oil Pump Accessory Drive Housing Drain



NOTE 1—Legend:

Quantity	PART NO.	NAME
1	IN4426	Base AS.
2	OS1571	Bolt
1	8N9586	Filter AS.
4	9S8005	Plug
1	IN4424	Valve
1	IN4425	Spring
5	SK0360	Seal
1	IN4423	Plug
1	6J2244	Seal
1	5P7530	Seal
4	OS1590	Bolt
4	5M2894	Washer
1	7M7410	Plug
1	5B8994	Gasket
1	1Y0698	Bracket

FIG. A9.4 Oil Filter Housing Assembly

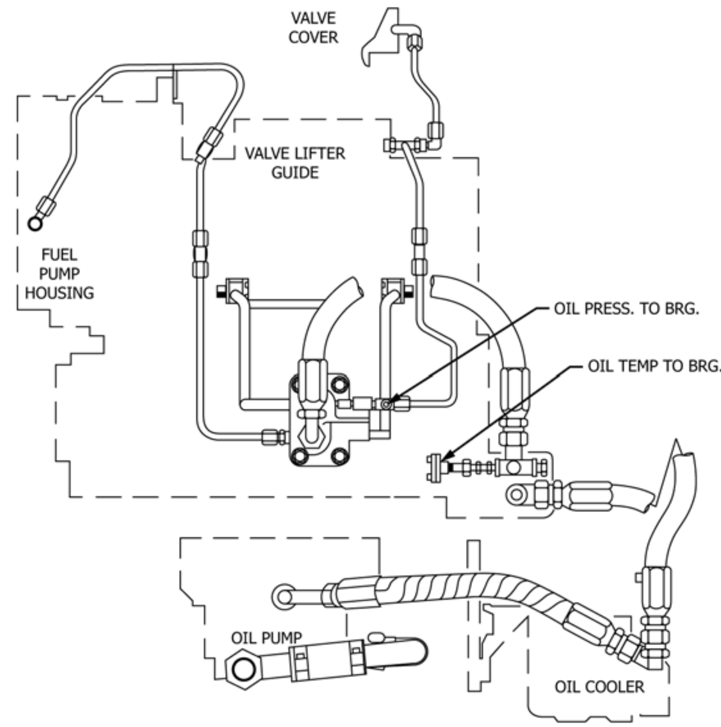


FIG. A9.5 1Y580 Engine Oil Lines Group – Part 1

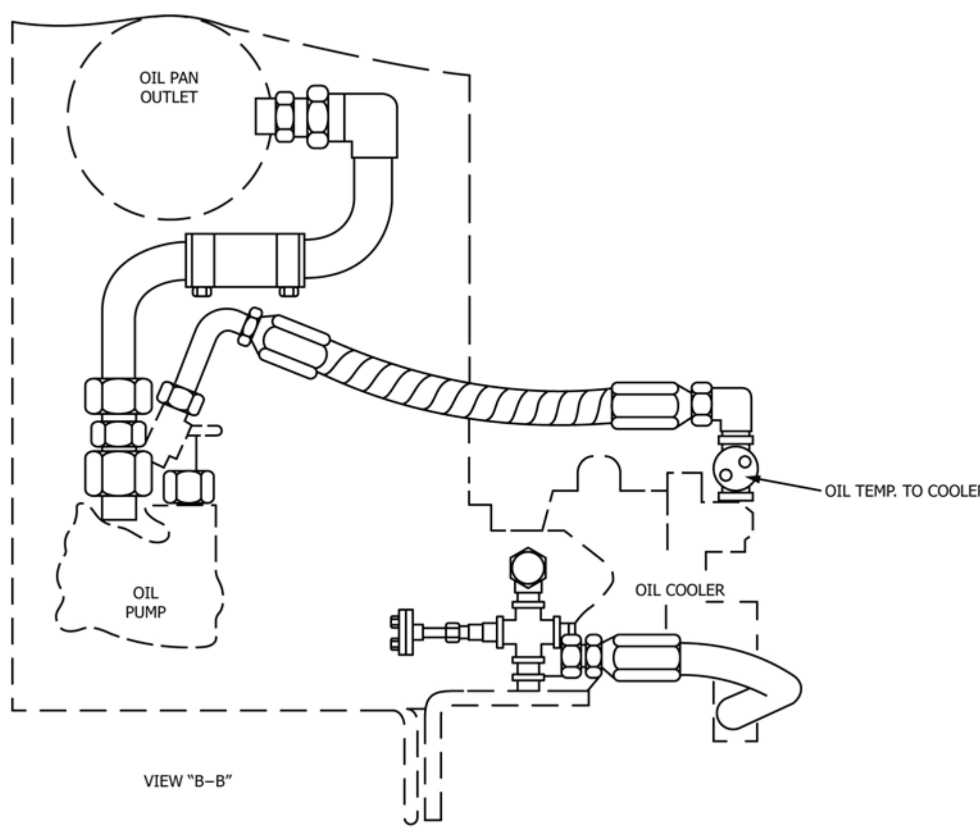


FIG. A9.6 1Y580 Engine Oil Lines Group – Part 2

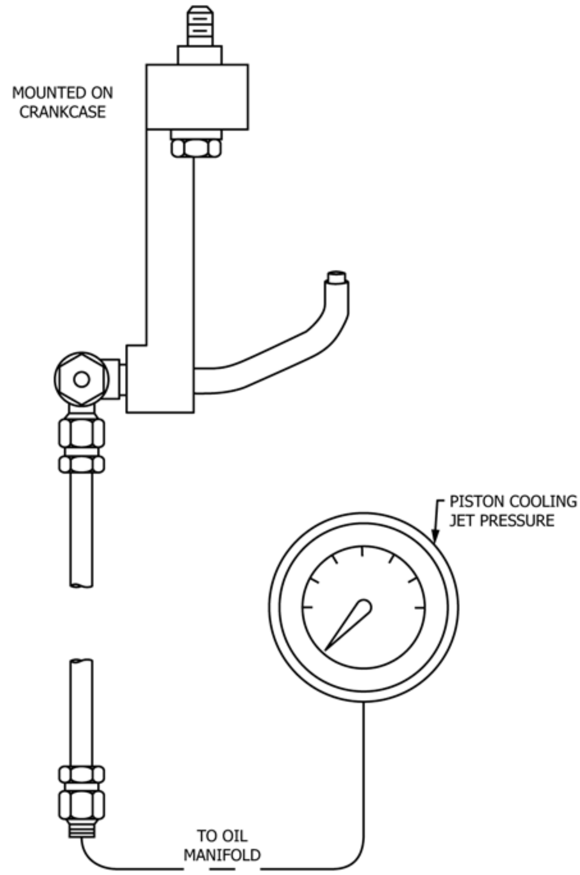
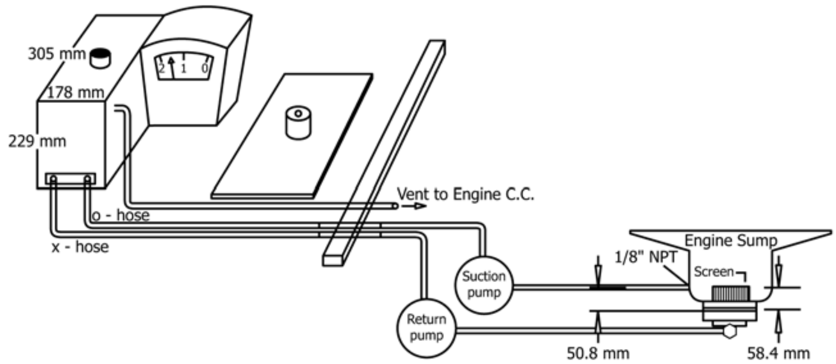


FIG. A9.7 1Y616 Piston Cooling Jet Group

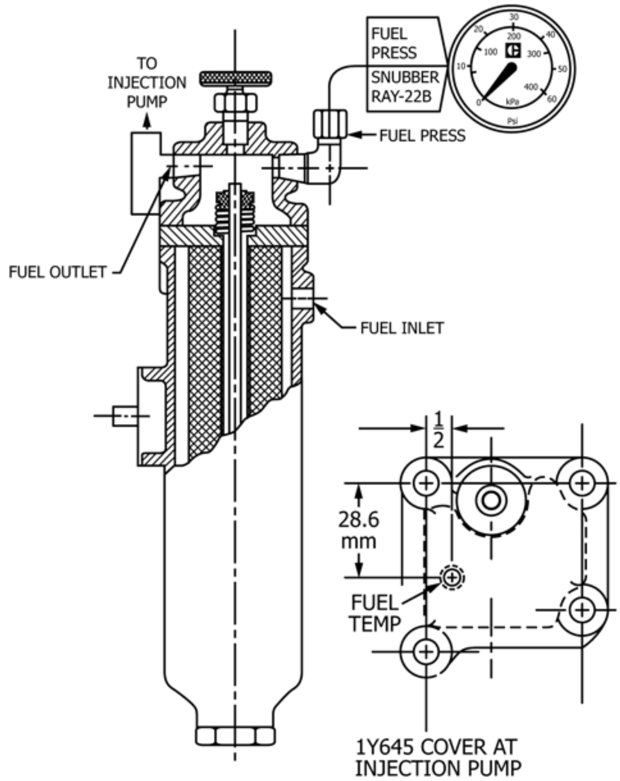


NOTE 1—Requirements:
(*1*) Suction pump and hose
Type – Viking C-90 pump or equivalent
Flow – 0.38 L/min to 0.095 L/min
Speed – 285 r/min
Hose – 6.35 mm ID; 2740 mm total length (max.)
Pulley – 125.75 mm OD
(*2*) Return pump and hose
Type – Viking C-92 pump or equivalent
Flow Differential – (0.19 L/min ± 0.063 L/min)
Speed – 163 r/min
Hose – 6.35 mm ID; 2740 mm total length (max.)
Pulley – 200 mm OD
(*3*) Pump motor (both pumps)
Type – 56 Nema Grainger 6K949 or equivalent
Speed – 1140 r/min
H.P. – 560 W
Pulley – 38.1 mm OD
Vent line – 6.35 mm OD hose
(*4*) Oil in reservoir – 1.9 L
(*5*) Scale precision – 0.01 (properly damped)
(*6*) Flexible hose – To/from reservoir from fixed cart support – Gould/Imperial catalog C405-100

FIG. A9.8 Low Flow Oil Scale System

A10. OTHER PRESSURE AND TEMPERATURE MEASUREMENT LOCATIONS

A10.1 See Figs. A10.1 and A10.2.



NOTE 1—Fuel gage snubber available from Operating and Maintenance Specialities, Charlotte, NC: As Ray Snubber, Model 22B.

FIG. A10.1 Fuel Pressure and Temperature Measurement Locations

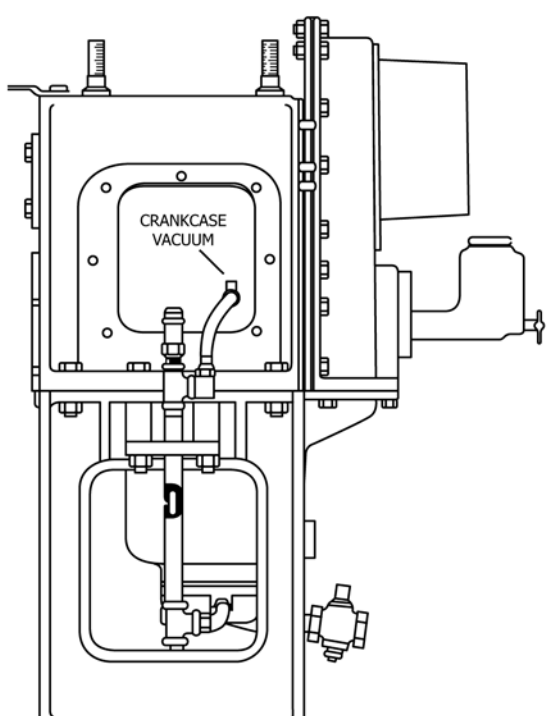


FIG. A10.2 Crankcase Pressure Measurement Location

A11. OIL CONSUMPTION LINEAR REGRESSION METHOD

A11.1 If there is good reason to assume that a variable *Y* is dependent upon another variable *X* and that the relationship is linear, the best-fit line describing this relationship can be plotted using: Eq A11.1 and A11.2. Also, see Figs. A11.1 and A11.2.

$$b = \frac{\sum x_i y_i - \frac{\sum x_i \sum y_i}{n}}{\sum x_i^2 - \frac{(\sum x_i)^2}{n}} \quad \text{(A11.1)}$$

$$a = \left[\frac{\sum y_i}{n} - b\frac{\sum x_i}{n}\right] \quad \text{(A11.2)}$$

$$r^2 = \frac{\left[\sum x_i y_i - \frac{\sum x_i \sum y_i}{n}\right]^2}{\left[\sum (x_i)^2 - \frac{(\sum x_i)^2}{n}\right]\left[\sum (y_i)^2 - \frac{(\sum y_i)^2}{n}\right]} \quad \text{(A11.3)}$$

where:

Y_i points = oil masses taken at time *X*,
X_i points = times at which oil mass observation *X* are made (that is, hours 1,2,....n),
b = slope of best-fit line = oil consumption,
a = *Y*–intercept, and
r^2 = goodness of fit (if 1, perfect; if 0, no fit at all).

A11.2 *Methods of Computation of Oil Consumption Using Linear Regression*:

A11.2.1 Oil consumption can be calculated during any period by performing a linear regression on Y_i and X_i data points where:

Y_i = oil mass taken at time *X* (from digital readout, strip chart, or as recorded by a computer), and
X_i = time at which oil observation *Y* is taken (from manual log or computer memory).

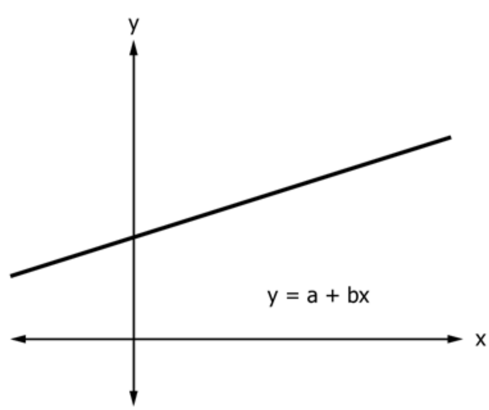


FIG. A11.1 Oil Consumption Linear Regression Graph

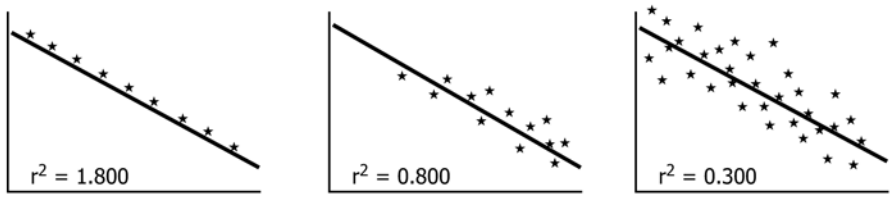


FIG. A11.2 Examples of Goodness of Fit

A12. TEST FUEL SPECIFICATIONS

A12.1 See Tables A12.1-A12.3.

TABLE A12.1 Specification for 1K Test Fuel

Test	ASTM Method	Requirement	
Flash point	D93	60.0 °C min. or legal	
Pour point	D97	–7 °C max.	
Cloud point	D2500 OR D3117	Report	
Water and sediment	D1796	0.05 volume % max.	
Ramsbottom carbon residue on 10% residuum	D524	0.20 mass % max.	
Ash	D482	0.01 mass % max.	
Distillation	D86	IBP Report	
		10 % Report	
		50 % 260-277 °C	
		90 % 310-327 °C	
		EP 343-366 °C	
Kinematic viscosity at 40.0 °C	D445	2.0-4.0 mm^2/s	
Total sulfur (must be natural)	D2622	0.380-0.420 mass %	
Copper corrosion (50 °C, 3 h)	D130		
Acid No. (an-E)	D664	0.15 mg KOH/g max.	
Cetane No.	D613	47.0-53.0	
Density	D287 OR D1298	report	
API gravity	D287 OR D1298	33-35°API	
Cracked stocks		none	
Hydrocarbon types	D1319	report	
Hydrocarbon Types	D2425	Component	Mass %
		Aliphatic paraffins	45.0-65.0
		Monocycloparaffins	report
		Dicycloparaffins	0.0-15.0
		Tricycloparaffins	report
		Alkybenzenes	5.0-10.0
		Indans/Tetralins	report
		Indenes	report
		Napthalene	report
		Napthalenes	5.0-15.0
		Acenaphthenes	report
		Acenaphthylenes	report
		Tricyclic aromatics	report

TABLE A12.2 Specification for 1N Test Fuel

Test	ASTM Method	Requirement	
Flash point	D93	54 °C min.	
Pour point	D97	–18 °C max.	
Cloud point	D2500	–12 °C max.	
Water and sediment	D2709	0.05 volume % max.	
Ramsbottom carbon residue on 10% residuum	D524	0.35 mass % max.	
Ash	D482	0.01 mass % max.	
Distillation	D86	IBP 177-199 °C 10 % 210-232 °C 50 % 249-277 °C 50 % 299-327 °C EP 327-360 °C	
Kinematic viscosity At 40°C	D445	2.0-3.2 mm^2/s	
Total sulfur (must be natural)	D2622	0.03-0.05 mass %	
Copper corrosion	D130	no. 3 max.	
Cetane index	D4737	42-48	
Cetane number	D613	42-48	
API gravity	D287	32-36°API	
Hydrocarbon Types		Component	
	D5186	Aromatics % volume	28-35
	D1319	Olefin	report
	D1319	Saturates	report

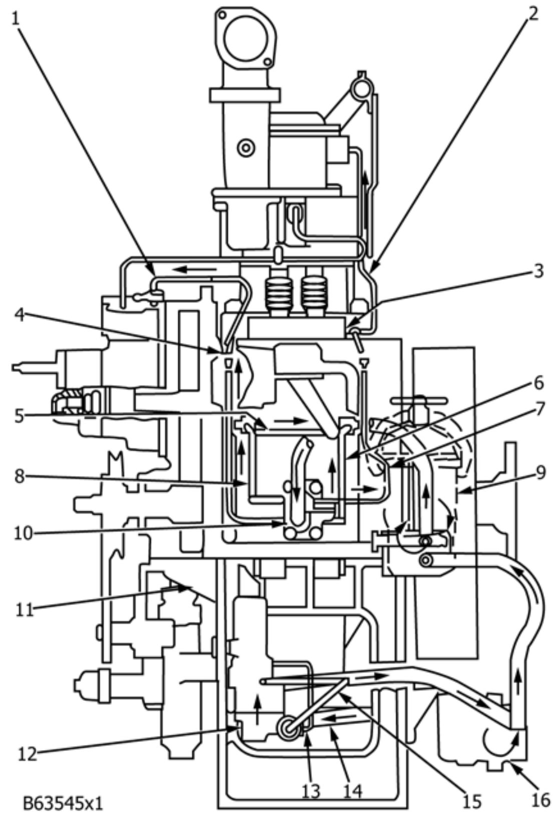
TABLE A12.3 Estimation of High Heating Value of Fuel from API Gravity

NOTE 1—For calculating heat input, use the high heating value (gross heat of combustion) estimated from the API gravity of the fuel. The relationship between gross heat of combustion and API gravity figures in this table was obtained from NIST Miscellaneous Publication No. 97.

Gravity	Gross Heat of Combustion
Degrees, A.P.I., 15.6 °C	kJ/kg
30	45 155
31	45 225
32	45 318
33	45 388
34	45 481
35	45 551

A13. LUBRICATION SYSTEM, FLUSH APPARATUS, AND PROCEDURE

A13.1 See Figs. A13.1-A13.12.



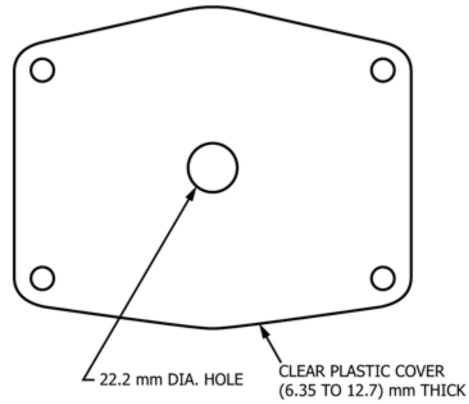
NOTE 1—B63545X1 Legend
1. Line to fuel cam
2. Line to rocker arm shaft.
3. Line to lifter.
4. Line to accessory shaft.
5. Line to piston cooling jet.
6. Line to rear main bearing.
7. Line to rear cam bearing.
8. Line to front main bearing.
9. Oil filter.
10. Manifold.
11. Oil pan.
12. Oil pump.
13. Drain line.
14. Oil pump supply line.
15. Bypass line.
16. Oil cooler assembly.

FIG. A13.1 Lubrication System

PROCEDURE	FLUSH FLUID	PUMP CONNECTION		FLUSHING TIME (min)			
		Inlet	Outlet	Engine Oil Line	Crank case	Governor Housing	Front Cover
1. Install a new 8N9586 oil filter and a clean 1Y5700 element in the flushing pump unit. Remove crankcase breather 1Y2592 from engine and wash in solvent until clean. Air dry.	7.6 L Stoddard solvent No recirculation; Crankase drain open.	Solvent tank	Oil cooler drain	5			
*2. Recirculate cleaning mixture. Turn on oil scale pumps.	Cleaning mixture: 1.9 L engine cleaner 5.7 L Stoddar solvent	Crankcase drain	Oil cooler drain	15			
		Crankcase drain	Crankcase sprayer		10	10	
		Crankcase drain	Front cover sprayer				10
*3. Drain mixture from crankcase,governor housing, drive housing, oil cooler, oil scale reservoir, and engine and flushing pump filters. Recirculate using C.	Solvent flush A 7.6 L Stoddard solvent	Crankcase drain	Oil cooler drain	15			
		Crankcase drain	Crankcase sprayer		10	10	
		Crankcase drain	Front cover sprayer				10
*4. Drain Stoddard solvent from crankcase, governor housing, oil cooler, oil scale reservoir, and engine and flushing pump filters. Recirculate using B.	Solvent flush B 7.6 L Stoddard solvent	Crankcase drain	Oil cooler drain	15			
		Crankcase drain	Crankcase sprayer		10	10	
		Crankcase drain	Front cover sprayer				10
*5. Drain Stoddard solvent from crankcase, governor housing, oil cooler, oil scale reservoir, and engine and flushing pump filters. Recirculate using C.	Solvent flush C 7.6 L Stoddard solvent	Crankcase drain	Oil cooler drain				
		Crankcase drain	Crankcase sprayer		10	10	
		Crankcase drain	Front cover sprayer				10
*6. Drain Stoddard solvent from crankcase, governor housing, oil cooler, oil scale reservoir, and engine and flushing pump filters. If solvent clean, go to step. Otherwise, recirculate with extra solvent.	Extra solvent flushes: 7.6 L Stoddard solvent	Crankcase drain	Oil cooler drain	15			
		Crankcase drain	Crankcase sprayer		10	10	
		Crankcase drain	Front cover sprayer				10
7. Repeat step 6							
*8. Drain Stoddard solvent from crankcase, governor housing, oil cooler, oil scale reservoir, and engine and flushing pump filters. Close drain & 1Y653 line. Install dummy piston, cylinder block, liner, oil filler spout, governor housing cover.	4.7 L test oil						
9. Add test oil. Recirculate at 359 kPa	4.7 L test oil	Crankcase drain	Oil cooler drain	5	Motor engine @ 400r/min at least 1 min		
*10. Drain test oil from crankcase, governor housing, accumulator drive housing, oil cooler, and oil scale reservoir, engine and flushing pump filters.							
11. Add test oil. Recirculate at 359 kPa. Align piston jet. Drain and build for test.	4.7 L test oil	Crankcase drain	Oil cooler drain	Recirculate 5 min			

* Low flow oil scale pumps should be turned on during each step.

FIG. A13.2 Flushing Instruction Sheet



NOTE 1—Use 1 Y3698 gasket as pattern for bolt hole locations.

FIG. A13.3 Clear Plastic Cover

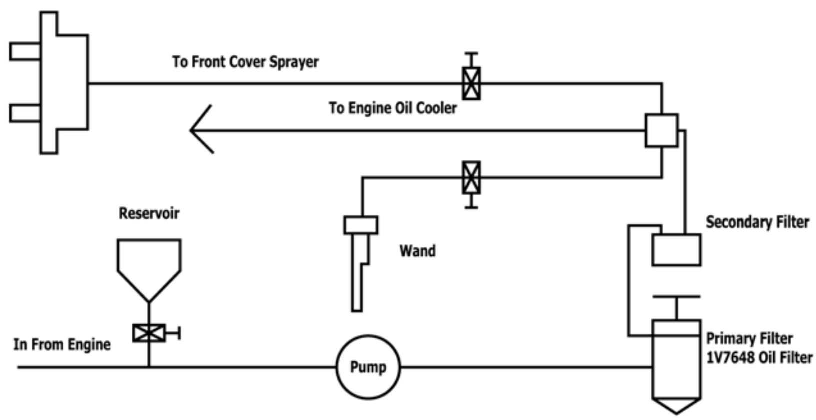


FIG. A13.4 Flushing Cart Flow Schematic

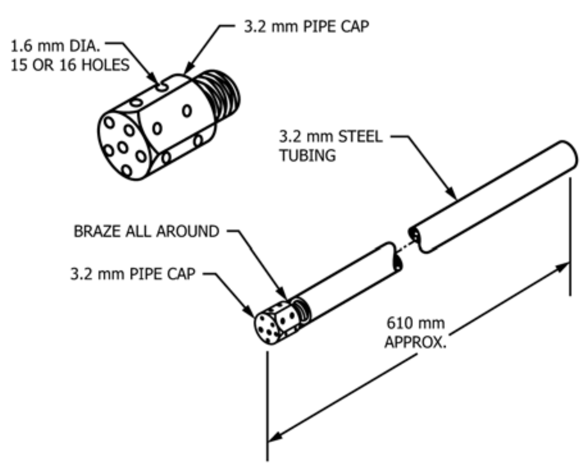


FIG. A13.5 Crankcase/Governor Housing Sprayer

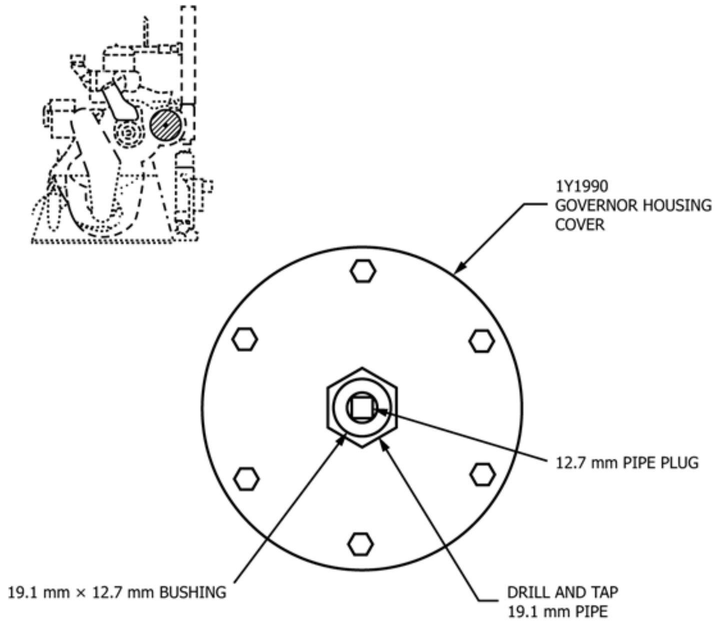


FIG. A13.6 Governor Housing Cover Modification

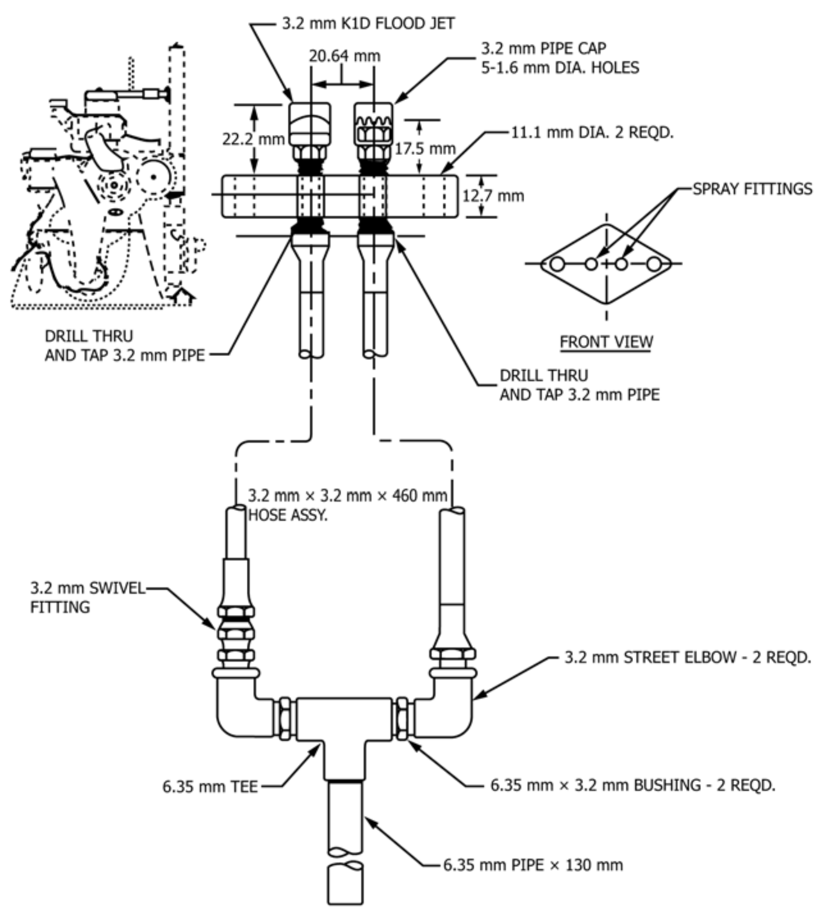


FIG. A13.7 Front Cover Sprayer

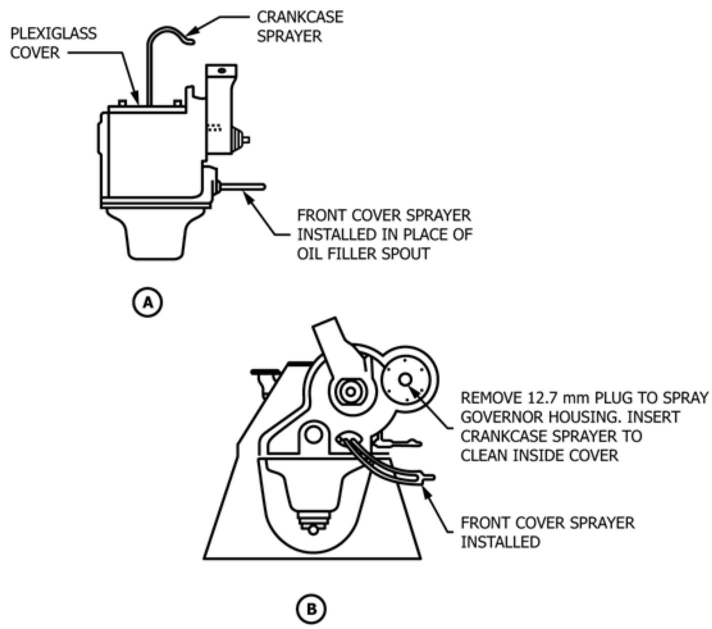
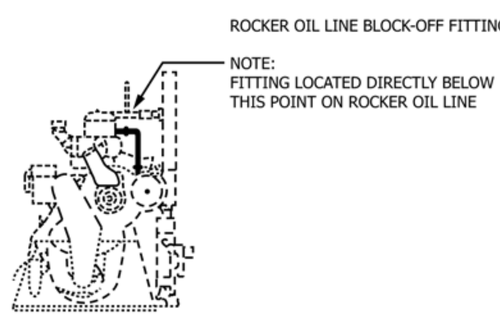


FIG. A13.8 Flushing Component Location



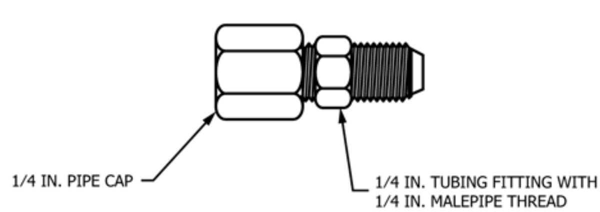


FIG. A13.9 Rocker Oil Line Block-off Fitting

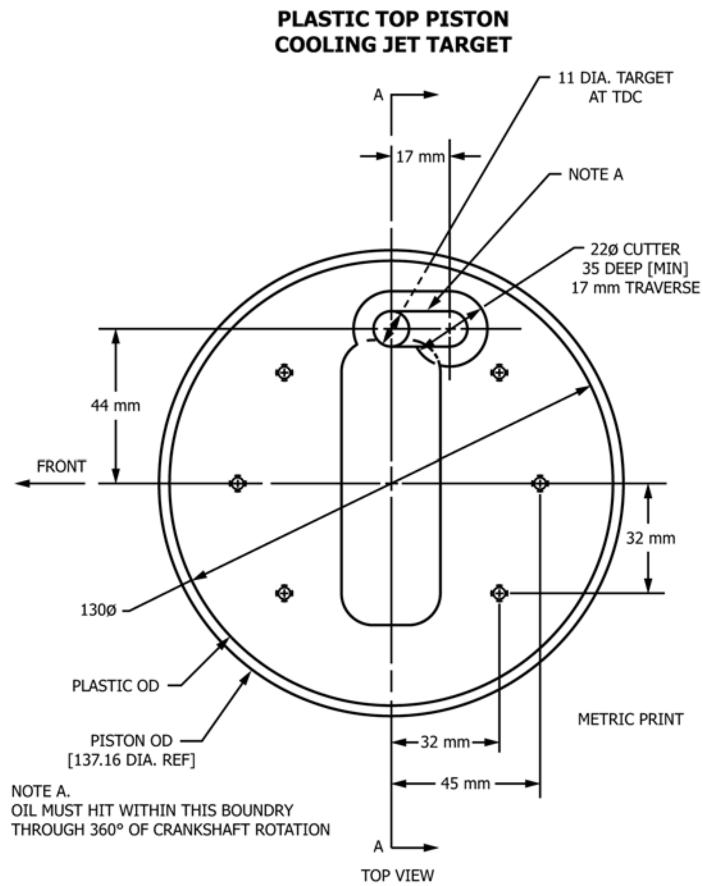


FIG. A13.10 Plastic Top Piston Cooling Jet Target

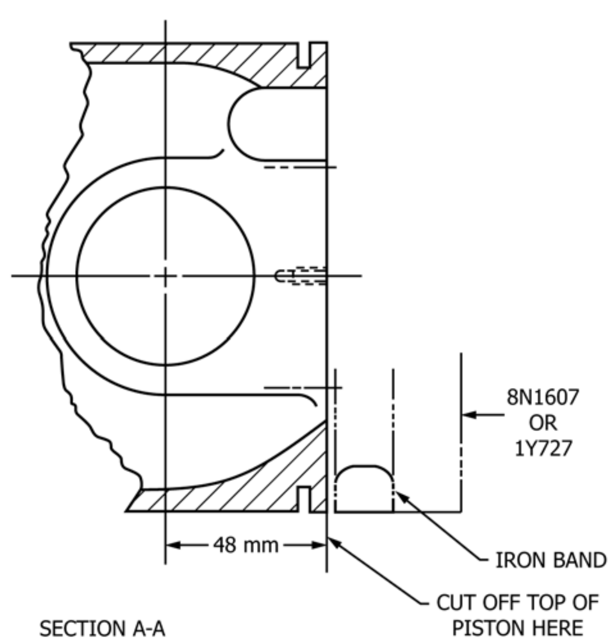


FIG. A13.11 Plastic Top Piston Cooling Jet Target, Section A-A

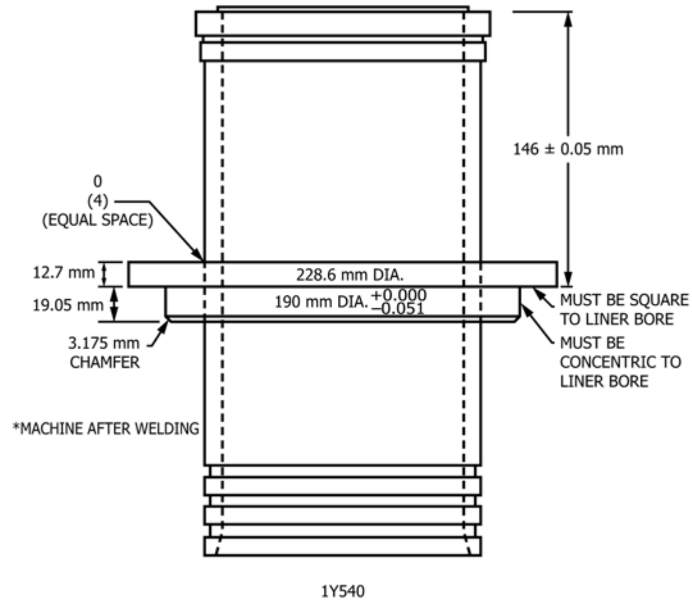


FIG. A13.12 Jet Alignment Fixture (2W6000 Liner)

A14. ENGINE OPERATING CONDITIONS

A14.1 See Tables A14.1 and A14.2.

TABLE A14.1 Engine Run-in, Warm-up, Cool-down, and Test Conditions

Step No.	Range	Unit	1	2	3	4	5
Test Time		min	5	5	10	20	20
Engine speed	± 10	r/min	1000	1000	1800	2100	2100
Engine power		kW	idle	12	26	38	52
BMEP		kPa		586	690	855	1240
Fuel Rate	± 53	kJ/min		2160	4250	6250	8430
Fuel flow		g/min		48	94	137	185
B.S.F.C.		kg/kWh				0.222	0.213
Humidity	± 1.7	g/kg				17.8	17.8
		Temperatures					
Coolant out	± 2.5	°C			84	90	93
Coolant in		°C				86	88
Coolant ΔT	± 1	°C				4	5
Oil to bearing	± 2.5	°C			76	93	107
Oil cooler in		°C				96	110
Inlet air	± 2.5	°C			93	93	127
Exhaust	± 30	°C				405	550
Fuel injector housing	± 3	°C				57	57
		Pressures					
Oil to bearing[A]		Max. kPa				440	482
Oil to jet[A]	± 13	kPa			410	370	360
Inlet air (ABS)	± 1	kPa	120	120	160	220	240
Exhaust (ABS)	±1	kPa		104	140	180	216
Fuel filter housing	± 20	kPa				210	210
Crankcase vacuum	± 0.1	kPa					0.7
Coolant jug		kPa					50
		Flows					
Blowby		L/min					23
Coolant flow	± 2.0	L/min					65
Air/Fuel ratio							29

[A] Oil pressure operating specifications apply only to 15W-40 oils. Attempt to maintain these limits for all oils. When oils other that 15W-40 oils fall outside these limits, explain these deviations from the limits in the comments section of the test report.

TABLE A14.2 Air-Fuel Ratios

NOTE 1—

$$A/F_{O_2} = 14.33786\left(\frac{100 - 0.064355(\%\ O_2)}{100 - 4.7619(\%\ O_2)}\right)$$

$$A/F_{CO_2} = \left(\frac{208.8367}{\%CO_2}\right) + 0.9227$$

% CO_2	A/F CO_2	% CO_2	A/F CO_2	% O_2	A/F O_2	% O_2	A/F O_2
6.5	33.05	10.5	20.81	6.5	20.68	10.5	28.48
6.6	32.56	10.6	20.62	6.6	20.82	10.6	28.75
6.7	32.09	10.7	20.44	6.7	20.96	10.7	29.03
6.8	31.63	10.8	20.26	6.8	21.11	10.8	29.31
6.9	31.19	10.9	20.08	6.9	21.26	10.9	29.60
7.0	30.76	11.0	19.91	7.0	21.41	11.0	29.90
7.1	30.34	11.1	19.74	7.1	21.56	11.1	30.20
7.2	29.93	11.2	19.57	7.2	21.72	11.2	30.50
7.3	29.53	11.3	19.40	7.3	21.87	11.3	30.81
7.4	29.14	11.4	19.24	7.4	22.03	11.4	31.13
7.5	28.77	11.5	19.08	7.5	22.20	11.5	31.46
7.6	28.40			7.6	22.36		
7.7	28.04			7.7	22.53		
7.8	27.70			7.8	22.70		
7.9	27.36			7.9	22.87		
8.0	27.03			8.0	23.04		
8.1	26.71			8.1	23.22		
8.2	26.39			8.2	23.40		
8.3	26.08			8.3	23.58		
8.4	25.78			8.4	23.77		
8.5	25.49			8.5	23.96		
8.6	25.21			8.6	24.15		
8.7	24.93			8.7	24.34		
8.8	24.65			8.8	24.54		
8.9	24.39			8.9	24.74		
9.0	24.13			9.0	24.95		
9.1	23.87			9.1	25.15		
9.2	23.62			9.2	25.37		
9.3	23.38			9.3	25.58		
9.4	23.14			9.4	25.80		
9.5	22.19			9.5	26.02		
9.6	22.68			9.6	26.25		
9.7	22.45			9.7	26.48		
9.8	22.23			9.8	26.71		
9.9	22.02			9.9	26.95		
10.0	21.81			10.0	27.20		
10.1	21.60			10.1	27.44		
10.2	21.40			10.2	27.20		
10.3	21.20			10.3	27.95		
10.4	21.00			10.4	28.22		

A15. PROCEDURE FOR RATING PISTON AND LINER

A15.1 *Manual for Rating Piston and Liner*—Rate piston and liner in accordance with ASTM Deposit Rating Manual 20. This includes rating the varnish deposit and using the varnish scale described in the manual. Carbon deposit factors range from 1.000 to 0.250 and varnish deposits range from 9.0 to 0.0. Convert varnish scale values to demerit values as described in ASTM Deposit Rating Manual 20.

A15.2 Fig. A15.1 is a diagram of the procedure for rating undercrown deposits.

A15.3 *Procedure for Rating Liner*—Carry out the rating of the liner in sequence as follows:

A15.3.1 Evaluate deposits above ring travel immediately upon the completion of the test or disassembly.

A15.3.2 *Liner Preparation:*

A15.3.2.1 *Marking*—Draw a straight line on the front and rear of the liner from the top to the bottom. Then mark the thrust and anti-thrust sides as *T* and *AT* respectively. See Fig. A15.2. Finally place on the liner appropriate test identification (for example, run number, and so forth).

A15.3.2.2 *Cutting*—Cut the liner on a vertical line *fore* and *aft*.

A15.3.2.3 *Liner Handling and Surface Preparation*—Handle the liner with care to avoid injury from the sharply cut

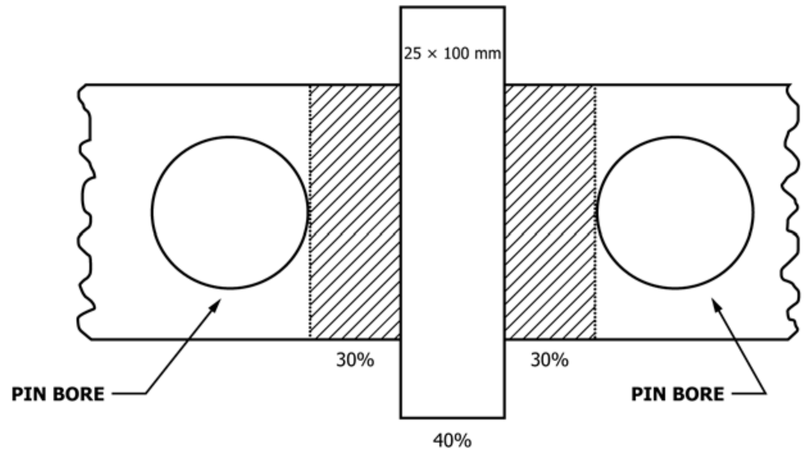


FIG. A15.1 Procedure for Rating Undercrown Deposits

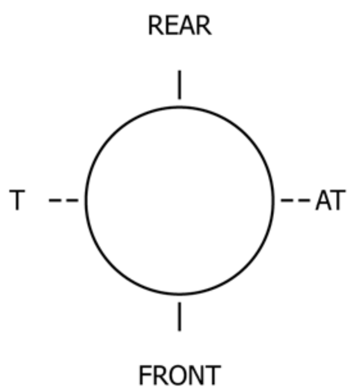
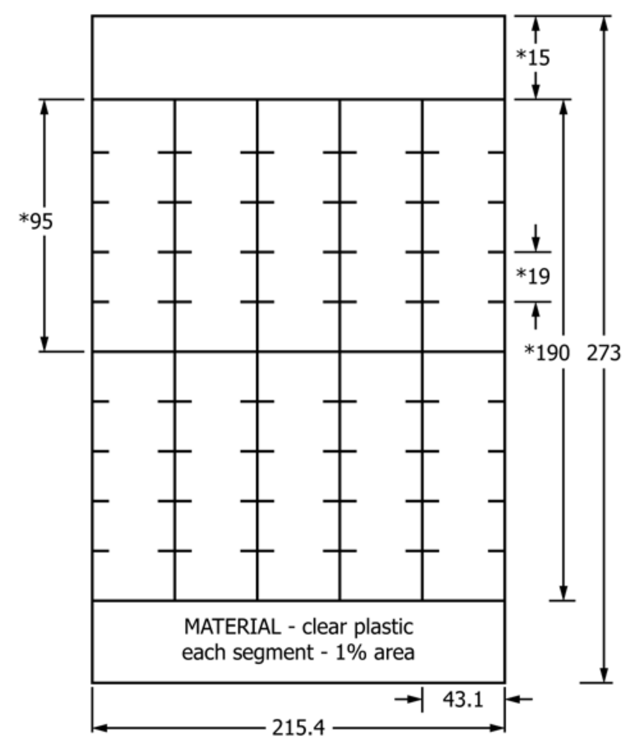


FIG. A15.2 Rating Liner Marking



NOTE 1—Measurements are in millimetres.

FIG. A15.3 Bore Polishing Grid

edges. Wipe both halves of the liner first with a soft cloth dampened with mineral spirits and then with a soft, clean, dry cloth.

A15.3.3 *Liner Rating:*

A15.3.3.1 *Rating Environment*—Rate the liners in the existing rating booth using the same light as specified for piston rating or a two-bulb fluorescent desk lamp.

A15.3.3.2 *Bore Polishing Rating*—Outline the bore polished area of the liner with a black magic marker. Insert the overlay in the liner half and use the 10 % segments with 1 % indicators as a guide in estimating the amount of polishing. Record the percent polish for each segment and then summarize the ten areas or equivalent for a permanent recording of the liner polishing. The rating area is defined as the area swept by the rings from the top of the first ring at TDC to the bottom of the ring at BDC. Occasionally, the rating area might include the area above top ring travel.

A15.3.3.3 *Liner Scuffing Rating*—Identical to bore polishing rating (see A15.3.3.2).

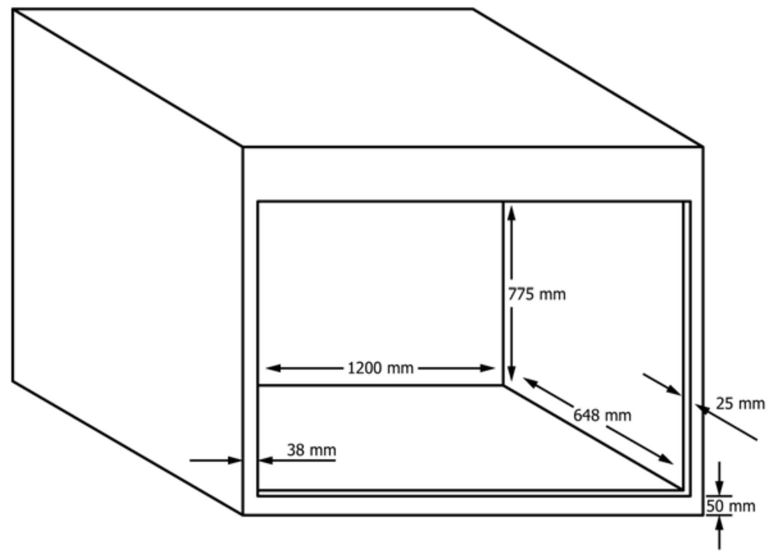
A15.3.3.4 *Above Top Ring Travel Conditions*—For multi-cylinder engines, check the above top ring travel conditions before piston removal. Use the 20-segmented template to determine area percentages in the liner. Rate carbon deposits in two levels. If required, report polishing and scratching/scuffing in the area covered.

A15.4 *Bore Polishing Grid*—See Fig. A15.3.

A15.5 *Rating Lamp*:

A15.5.1 *Source and Description*—A suitable lamp is the diesel piston rating lamp obtainable from Newark Electronics Corp.[28,12] described Model No., LFM-1; Stock No., 99F 1100; Mounting Bracket Stock No., 99F 1114; and bulb designation, cool white 20W.

[28] The sole source of supply of the lamp known to the committee at this time is Newark Electronics Corporation, 500 N Pulaski Road, Chicago, IL 60624.



NOTE 1—Materials–Plywood/13mm internal bracing can be made of strips of wood.

FIG. A15.4 Rating Booth

A15.5.2 *Mounting*—Mount the lamp in any convenient position such that the liner can be placed and manipulated in the rating booth (see A15.6) while being viewed through the lamp.

A15.5.3 *Bulb Replacement*—Replace the bulb annually or when burned out. After replacement, stabilize the bulb by turning it on for 24 h before using it for rating.

A15.5.4 Use the lamp without the accompanying magnifying lens.

A15.6 *Rating Booth*—See Fig. A15.4.

A16. CALCULATION OF PERCENT OFFSET AND PERCENT DEVIATION

A16.1 See Tables A16.1-A16.4.

A16.2 *Instructions for Calculation of Percent Out/Percent Off*:

A16.2.1 Calculate the percent out and percent off using the same units as in the recorded data.

A16.2.2 The logging frequency used for calculating the percentages shall be at the discretion of the laboratory and shall be at least hourly.

A16.2.3 Any data used in the calculation of the percentages that are edited should include an explanation. List the data before they are edited, the new value, and the explanation for the change in comments or outlier section of the test report.

A16.2.4 Record these percent calculations on the Operational Summary – Offset And Deviation form of the test report.

A16.2.5 Calculate each percent out to three significant digits using Practice E29, Rounding Off Method.

A16.2.6 Round off the calculated average used in the percent off calculation to 0.1 using the rounding off method of Practice E29.

A16.2.7 Round off the percent out summation and percent off results to 0.1 using the rounding off method of Practice E29.

A16.2.8 Use the following formula to calculate percent out:

$$\text{percent out} = \frac{\frac{|A - B|}{C} \times \frac{D}{60} \times 100}{252} \quad (A16.1)$$

where:

A = recorded test measurement of parameter that is beyond test limits prior to any corrective action,
B = upper test specification if the measured parameter is out on the high side or the lower test specification if it is out on the low side,
C = specification tolerance of the measured parameter,
D = length of deviation in minutes (it cannot be less than the logging frequency),
60 = conversion factor for minutes per hour, and
100 = conversion to percent.

A16.2.9 Calculate the percent out for each measured parameter based on its logging frequency. Sum the individual percent outs to arrive at the final percent out for judging test validity. See Table A16.4.

TABLE A16.1 Calibration Tolerance

Parameter	Tolerance
Speed, r/min	2
Power	Not applicable due to differences within industry. TMC to verify each laboratory during visits.
Fuel Flow	Not applicable due to differences within industry. TMC to verify each laboratory during visits.
Humidity	Not applicable. Already specified. Checked during running conditions as outlined in the test procedure (see form attached).
Oil Mass	Not applicable because relative difference is the only item that matters. Measurement resolution must be met as defined in the test procedure.
Temperatures	°C
Coolant out	0.25
Coolant in	0.25
Oil to bearing	0.5
Intake air	0.5
Exhaust	1.0
Fuel at injector housing	0.5
Pressures	
Oil to bearing	0.7 kPa
Oil to jet	0.7 kPa
Inlet air	0.3 kPa
Exhaust	0.3 kPa
Fuel at filter, housing	0.7 kPa
Crankcase vacuum	0.02 kPa

A16.2.10 Use the following formula to calculate the percent off (see Table A16.4):

$$\text{percent off} = \frac{|\text{X} - \text{Specification}| \times 100}{\text{specification range}} \quad (A16.2)$$

where:

X = average of all readings of the parameter for the entire test duration, and

specification range = the upper specification limit minus the lower specification limit, or two times the specification tolerance.

A16.3 *Allowable Limits for Percent Out and Percent Off*—Use the parameters in Table A16.5 to judge test validity based on their operational control. Consider any parameter for a given test with a percent out or percent off that is *greater than* the specifications listed in the table to be operated in an invalid manner.

TABLE A16.2 Operational Specifications, Measurement Resolution and Rounding

CAT-1K/IN		SI Specification		
Parameter	Units	Specified Range	Minimum Measurement Resolution	Round Values to the Nearest
Speed	r/min	2100 ± 10	1	whole number
Power	kW	52		
BMEP	kPa	1240		
Fuel rate	kJ/min	8430 ± 53		
Fuel flow[A]	g/min	185 ± 1	0.1	tenth
BSFC	kg/kWh	0.213		
Humidity	g/Kg	17.8 ± 1.7	0.1	tenth
Oil mass	g	N/A	1	whole number
		Temperatures		
Coolant out	°C	93 ± 2.5	0.1	tenth
Coolant in	°C	88	0.1	tenth
Coolant Δ	°C	5 ± 1	0.1	tenth
Oil to bearing	°C	107 ± 2.5	0.1	tenth
Oil cooler inlet	°C	110	0.1	tenth
Inlet air	°C	127 ± 2.5	0.1	tenth
Exhaust	°C	550 ± 30	1	whole number
Fuel at injector housing	°C	57 ± 3	0.1	tenth
		Pressures		
Oil to bearing	kPa	482 max.		
Oil to jet	kPa	360 ± 13	0.1	tenth
Inlet air (ABS)	kPa	240 ± 1	0.1	tenth
Exhaust (ABS)	kPa	216 ± 1	0.1	tenth
Fuel at filter	kPa	210 ± 20	0.1	tenth
Crankcase vacuum	kPa	0.7 ± 0.1	0.01	hundredth
Coolant at jug	kPa	50		
		Flows		
Blowby	L/min	23		
Coolant flow	L/min	65 ± 2	0.1	tenth
Air/fuel ratio		29		

[A] The fuel flow specified range is based on the high heating value of 45.567 MJ/kg at an API Gravity of 35. The fuel specification range is 33 to 35 API Gravity.

TABLE A16.3 System Time Constants, Maximum Allowable Caterpillar 1K/1N Industry Wide System Time Constant Survey (time, s)

Measurements	
Speed	3.0
Fuel flow	73.0
Temperatures	
Coolant out	3.0
Coolant in	3.0
Oil to bearings	3.0
Intake air	3.0
Exhaust	3.0
Fuel at injection	3.0
Pressures	
Oil to bearings	3.0
Oil to jet	3.0
Intake air	3.0
Exhaust	3.0
Fuel at filter	3.0
Crankcase vacuum	3.0

TABLE A16.4 Example of Calculation of Percent Out and Percent Off

NOTE 1—This example is for 21 test hours using humidity measured in g/kg.

NOTE 2—Percent out for test hour 11:

$$\% \text{ out} = \frac{\frac{|16.0 - 16.1|}{1.7} \bullet \frac{60}{60} \bullet 100}{252} = 0.023$$

NOTE 3—At 21 test hours:
Percent out summation = 1.1 (round to 0.1)
Average of the rounded values = 128.6 (round to 0.1)
Percent offset = 15.0 (round to 0.1)

Test Hours	Raw Value, g/kg	Rounded Value, g/kg	% Out for Each Value, Rounded to 0.001
1	18.65	18.7	
2	18.65	18.7	
3	18.55	18.6	
4	17.96	18.0	
5	18.28	18.3	
6	17.96	18.0	
7	18.00	18.0	
8	17.73	17.7	
9	17.59	17.6	
10	16.90	16.9	
11	15.99	16.0	0.023
12	15.21	15.2	0.210
13	18.28	18.3	
14	18.93	19.0	
15	19.27	19.3	
16	19.64	19.6	0.023
17	19.95	20.0	0.117
18	19.67	19.7	0.047
19	19.64	19.6	0.023
20	19.95	20.0	0.117
21	18.06	18.1	

TABLE A16.5 Allowable Limits for Percent Out and Percent Off

Controlled parameter	Allowable % Out	Allowable % Off
Speed	5	20
Fuel flow	10	25
Humidity	10	25
Coolant Flow	5	25
Temperatures		
Coolant Out	5	20
Oil to Bearing	5	20
Intake air	5	20
Fuel at injector housing	5	20
Pressures		
Oil jet	5	25
Intake air	10	25
Exhaust	10	25
Fuel at filter housing	5	20
Crankcase vacuum	10	20

A17. 1K/1N TEST REPORTING

A17.1 Download report forms and data dictionary from the ASTM Test Monitoring Center (TMC) Web Page at: http://www.astmtmc.cmu.edu/. TMC can also provide hardcopies on request.

Report Form Table of Contents

1. Final Report Cover Sheet	Cover
2. Test Report Summary	Form 1
3. Operational Summary	Form 2
4. Operational Summary–Offset and Deviation	Form 3
5. Piston Rating Summary	Form 4
6. Piston Rating Worksheet	Form 4a
7. Supplemental Piston Deposits (Groove Sides and Rings)	Form 5
8. Referee Rating	Form 5a
9. Oil Analysis And Results Summary	Form 6
10. Unscheduled Downtime & Maintenance Summary	Form 7
11. Ring Measurements	Form 8
12. Liner Measurements	Form 9
13. Characteristics of the Data Acquisition System	Form 10
14. Engine Operational Data Plots	Form 11
15. Engine Operational Data Plots (2)	Form 12
16. Oil Consumption Plot	Form 13
17. Piston, Ring, and Liner Photographs	Form 14
18. Severity Adjustment History	Form 15
19. TMC Control Chart Analysis	Form 16
20. Fuel Batch Analysis	Form 17

NOTE A17.1—If the test will be submitted to the registration organization as a candidate oil, then use the same forms used for reporting reference test results and add the ACC Conformance Statement, Form 18.

A18. TEST ENGINE/PARTS/ACCESSORIES

A18.1 Table A18.1 provides the test engine, parts, and accessories list.

A18.2 *Engine Parts Warranty*:

A18.2.1 All parts of the 1Y540 engine and the 1Y540 conversion kit that are nonconforming due to faulty manufacture shall be noted by the laboratory and brought to the attention of Engine System Technology Department (ESTD).

A18.2.2 ESTD shall determine whether the part is to be returned or warranty is to be provided without viewing the part.

A18.2.3 If ESTD determines that the part is nonconforming without viewing the part, the test laboratory shall be asked by ESTD to return the part to its Caterpillar dealer. ESTD shall contact the dealer and inform the dealer that the part is coming and to provide warranty for it.

A18.2.4 If ESTD wants to view the part, then ESTD shall issue a return goods authorization number (RGA) to the test laboratory. The laboratory shall fill out the return goods authorization claim form (RGA) (see Fig. A18.1) and shall send the completed claim form in a package with the part and separately by FAX as follows:

A18.2.4.1 Send claim form in a package with the part to Caterpillar, Inc., Tech Center TC-L, Wing 4-Rm 406, 14009 Old Galena Rd., Mossville, IL 61552.

A18.2.4.2 FAX a separate copy of the claim form to Caterpillar, Inc., Tech Services Div., Tech Center Bldg. L.

A18.2.5 If ESTD determines that the part is nonconforming, ESTD shall contact the dealer on behalf of the test laboratory and have the dealer provide warranty.

A18.2.6 The return goods authorization (RGA) claim form shall include a return goods authorization number; part name; hours on the part; part number; quantity; purchase order number; date purchased; test laboratory that purchase; the part and contact person's name, telephone number, FAX number and address; dealer's name that sold the part; measurements or photos, or both, to document the noncomformance.

A18.2.6.1 Fig. A18.1 is a sample of a blank RGA claim form.

TABLE A18.1 Test Engine/Parts/Accessories List

Part Number (P/N)	Engine/Part/Accessory Name
307946	elbow
BR 12705-16-31	Barco flowmeter
8C3684	coolant in 1-gal container
8C3686	Coolant in 55-Gal drum
9L8791	solenoid
9L9098	seal
8N9586	engine oil filter
5P0957	commercial tester
5P3514	commercial tester
5P4150	nozzle tester
6V7020	service kit
2W1230	screw
2W6163	fibre washer
7W8629	line assembly
1Y27	piston
1Y73	Cat diesel engine and service manual
1Y466	thermocouple (fluids)
1Y467	thermocouple (engine exhaust)
1Y468	thermocouple (air to engine)
1Y479	valve (to crankcase breather)
1Y496	orifice
1Y506	piston ring
1Y507	piston ring
1Y508	piston ring
1Y540	Cat diesel engine and service manual
1Y541	conversion arrangement for 1Y73
1Y544	cylinder block
1Y631-2	elbow
1Y632	adapter
1Y636	oil/filter group (factory)
1Y648	line assembly
1Y653	rocker shaft oil line
1Y702	cylinder liner
1Y0699	oil/filter group (new-replacement)
1Y1990	governor housing cover
1Y2592	crankcase breather assembly
1Y3549	screen (last chance)
1Y3698	multiple block gaskets
1Y5700	filter element
1Y7277	bracket

CATERPILLAR SCOTE 1K/1N TEST 4:3
2/98

RETURN GOODS AUTHORIZATION FORM

RETURN GOODS AUTHORIZATION NUMBER ______________

CLAIM DATE ______________

CONTACT: CATERPILLAR, INC.
ENGINE SYS TECH DEV
P.O. BOX 610
MOSSVILLE, IL 61552
PHONE: 309-578-2131
FAX: 309-578-6457
ATTN: R.A. RIVIERE

PART NUMBER/QUANTITY ______________

PART NAME/HOURS ON PART ______________

DATE PART PURCHASED ______________

PURCHASE ORDER NUMBER ______________

TEST LAB

NAME ______________

ADDRESS ______________

CONTACT PERSON'S NAME ______________

PHONE NUMBER ______________

FAX NUMBER ______________

NAME OF CAT DEALER/MORTON PARTS THAT SOLD PART ______________

INCLUDE DOCUMENTATION AND PHOTOS OF NON-CONFORMING PART

FIG. A18.1 Example of Return Goods Claim Form

A19. SAFETY PRECAUTIONS

A19.1 *General Considerations*:

A19.1.1 Performing engine tests on engine oils exposes personnel and facilities to many hazards. This includes all aspects associated with the test itself, preparations for the test, conclusion of the test, housekeeping, and, indeed, anything and everything else that could come to mind as possible hazards.

A19.1.2 Only personnel who are thoroughly trained and experienced in engine testing shall undertake the design, installation, and operation of engine test stands.

A19.1.3 The engine test installation shall be inspected and approved by a competent authority external to the laboratory, such as, a safety department or safety officer.

A19.2 *Personnel in the Work Area*:

A19.2.1 Provide personnel working on the engines with the proper tools, be alert to common safety practices, and avoid contact with hot surfaces and external moving parts.

A19.2.2 When working on the engines, personnel shall wear safety masks or safety glasses.

A19.2.3 In the vicinity of running engines, personnel shall not wear loose or flowing clothing (notably ties), nor transport bulky material that could topple on the running engines.

A19.2.4 Preferably personnel working on engines should not have long hair or long beards. If these hairy appendages are permitted, then they shall be firmly secured to the person possessing them so that they will not get caught in moving parts.

A19.3 *Guards and Barriers*:

A19.3.1 Provide barriers appropriately around the engine to protect personnel. In addition, heavy duty guards shall be placed alongside the engine and coupling shaft.

A19.4 *Fuel and Oil Lines, and Electrical Wiring*:

A19.4.1 All fuel and oil lines, and electrical wiring shall be properly routed, guarded, kept clean and dry and, generally, in good order.

A19.5 *Housekeeping* :

A19.5.1 The external parts of the engines and the floor area around the engines shall be kept clean and free from spills of fuel, oil, coolant and so forth.

A19.5.2 The working area shall be free from obstacles that could cause injury or falls.

A19.5.3 The testing area shall not be used for storage. Containers of fuel, oil, coolant, and so forth, shall not be allowed to accumulate there.

A19.6 *Toxic Fume and Fire Hazards*—Vent exhaust gases by way of appropriate leak free ductwork. Fuel containers shall not be left open. Correct fuel leaks, and immediately treat fuel and oil spills with absorbent and removed.

A19.7 *First Aid*—Good safety measures avoid both major injuries and minor ones such as scraped knuckles and minor burns. All injuries require first aid treatment and subsequent recording and reporting of the incident.

A19.8 *Automatic Shutdown, Remote Cut-off and Interlocks*:

A19.8.1 Equip the test installation with a fuel shut-off valve that shall automatically cut off the fuel supply when the engine is not running.

A19.8.2 There shall be a remote station for cutting off fuel from the test stand.

A19.8.3 There shall be an excessive vibration pickup interlock if the engine runs unattended.

A19.8.4 Provide suitable interlocks that shut down the engine automatically when any of the following occurs:

A19.8.4.1 The engine dynamometer loses field current,

A19.8.4.2 The engine overspeeds,

A19.8.4.3 Low oil pressure develops,

A19.8.4.4 High water temperature develops,

A19.8.4.5 The exhaust system fails,

A19.8.4.6 The room ventilation system fails, or

A19.8.4.7 The fire protection system is activated.

A19.9 *Fire Protection Equipment*:

A19.9.1 Provide fixed fire protection equipment.

A19.9.2 Place dry chemical fire extinguishers at a number of locations at the test stands.

APPENDIXES

(Nonmandatory Information)

X1. HUMIDITY DATA

X1.1 *Humidify Correction Factors for Non-Standard Barometric Conditions*—See Tables X1.1-X1.4.

X1.2 *Correcting Humidity by Applying the Perfect Gas Law Equation–With Examples*:

$$\text{corrected humidity} = 999.6\ g/kg(M_v/M_a)\ P_v\ (P_B - P_v) \quad (X1.1)$$

TABLE X1.1 Grams per kilogram; Range: 101.6 kPa to 104.6 kPa

		104.6	104.3	104.0	103.6	103.3	102.9	102.6	102.1	101.9	101.6
	18.3	–0.44	–0.40	–0.36	–0.32	–0.27	–0.23	–0.17	–0.13	–0.09	–0.04
D	18.9	–0.46	–0.41	–0.37	–0.32	–0.27	–0.23	–0.19	–0.14	–0.09	–0.04
E	19.4	–0.47	–0.43	–0.37	–0.33	–0.29	–0.24	–0.19	–0.14	–0.10	–0.04
W	20.0	–0.49	–0.44	–0.39	–0.34	–0.29	–0.24	–0.20	–0.14	–0.10	–0.04
	20.6	–0.50	–0.46	–0.40	–0.36	–0.30	–0.26	–0.20	–0.16	–0.10	–0.06
P	21.1	–0.53	–0.47	–0.43	–0.37	–0.32	–0.27	–0.21	–0.16	–0.10	–0.06
O	21.7	–0.54	–0.49	–0.43	–0.39	–0.33	–0.27	–0.21	–0.16	–0.11	–0.06
I	22.2	–0.56	–0.50	–0.44	–0.39	–0.33	–0.29	–0.23	–0.17	–0.11	–0.06
N	22.8	–0.59	–0.53	–0.47	–0.41	–0.36	–0.30	–0.23	–0.17	–0.11	–0.06
T	23.3	–0.60	–0.54	–0.49	–0.41	–0.36	–0.30	–0.24	–0.19	–0.11	–0.06
	23.9	–0.63	–0.57	–0.50	–0.44	–0.37	–0.31	–0.26	–0.19	–0.13	–0.06
T	24.4	–0.64	–0.59	–0.51	–0.46	–0.39	–0.33	–0.26	–0.20	–0.13	–0.07
E	25.0	–0.67	–0.60	–0.54	–0.47	–0.40	–0.34	–0.27	–0.20	–0.13	–0.07
M	25.6	–0.70	–0.63	–0.56	–0.49	–0.41	–0.36	–0.29	–0.21	–0.14	–0.07
P	26.1	–0.72	–0.64	–0.57	–0.50	–0.43	–0.36	–0.29	–0.21	–0.14	–0.07
°C	26.7	–0.74	–0.67	–0.60	–0.51	–0.44	–0.37	–0.30	–0.23	–0.14	–0.07

TABLE X1.2 Grams per kilogram; Range: 98.2 kPa to 101.2 kPa

		101.2	100.9	100.6	100.2	99.9	99.5	99.2	98.9	98.5	98.2
	18.3	0	0.04	0.10	0.14	0.19	0.24	0.29	0.33	0.37	0.43
D	18.9	0	0.04	0.10	0.14	0.20	0.24	0.29	0.34	0.39	0.44
E	19.4	0	0.06	0.10	0.16	0.20	0.26	0.30	0.36	0.40	0.46
W	20.0	0	0.06	0.10	0.16	0.21	0.27	0.32	0.37	0.43	0.47
	20.6	0	0.06	0.11	0.16	0.21	0.27	0.33	0.39	0.43	0.49
P	21.1	0	0.06	0.11	0.17	0.23	0.29	0.33	0.39	0.44	0.50
O	21.7	0	0.06	0.11	0.17	0.23	0.30	0.36	0.41	0.47	0.53
I	22.2	0	0.06	0.11	0.19	0.24	0.30	0.36	0.41	0.49	0.54
N	22.8	0	0.06	0.13	0.19	0.26	0.32	0.37	0.44	0.50	0.57
T	23.3	0	0.07	0.13	0.20	0.26	0.33	0.40	0.46	0.53	0.59
	23.9	0	0.07	0.13	0.20	0.27	0.34	0.40	0.47	0.54	0.60
T	24.4	0	0.07	0.14	0.21	0.29	0.36	0.41	0.49	0.56	0.63
E	25.0	0	0.07	0.14	0.21	0.29	0.37	0.44	0.51	0.59	0.66
M	25.6	0	0.07	0.14	0.23	0.30	0.37	0.44	0.51	0.60	0.67
P	26.1	0	0.07	0.16	0.23	0.32	0.39	0.46	0.54	0.61	0.70
°C	26.7	0	0.09	0.16	0.24	0.32	0.40	0.49	0.56	0.64	0.72

TABLE X1.3 Grams per kilogram; Range: 94.8 kPa to 97.9 kPa

		97.9	97.5	97.2	96.8	96.5	96.2	95.8	95.5	95.2	94.8
	18.3	0.47	0.53	0.57	0.63	0.67	0.73	0.77	0.83	0.87	0.93
D	18.9	0.49	0.54	0.59	0.65	0.70	0.76	0.80	0.86	0.92	0.96
E	19.4	0.50	0.56	0.61	0.66	0.72	0.77	0.83	0.89	0.93	0.99
W	20.0	0.53	0.59	0.64	0.70	0.76	0.82	0.86	0.92	0.97	1.03
	20.6	0.54	0.60	0.66	0.72	0.77	0.84	0.90	0.96	1.02	1.07
P	21.1	0.56	0.61	0.67	0.74	0.80	0.86	0.92	0.97	1.04	1.10
O	21.7	0.59	0.64	0.72	0.77	0.83	0.90	0.96	1.02	1.07	1.14
I	22.2	0.60	0.67	0.73	0.80	0.86	0.93	0.99	1.06	1.12	1.19
N	22.8	0.63	0.70	0.76	0.83	0.89	0.96	1.03	1.09	1.16	1.22
T	23.3	0.66	0.73	0.80	0.86	0.93	1.00	1.07	1.14	1.20	1.27
	23.9	0.67	0.74	0.82	0.89	0.96	1.03	1.10	1.17	1.24	1.32
T	24.4	0.70	0.77	0.84	0.92	0.99	1.07	1.14	1.22	1.29	1.36
E	25.0	0.73	0.80	0.89	0.96	1.03	1.12	1.19	1.26	1.33	1.42
M	25.6	0.74	0.83	0.90	0.99	1.06	1.14	1.23	1.30	1.39	1.46
P	26.1	0.77	0.86	0.94	1.02	1.10	1.19	1.27	1.36	1.43	1.52
°C	26.7	0.80	0.89	0.97	1.06	1.14	1.23	1.32	1.40	1.49	1.57

TABLE X1.4 Grams per kilogram; Range: 91.4 kPa to 94.5 kPa

		94.5	94.1	93.8	93.5	93.1	92.8	92.4	92.1	91.7	91.4
	18.3	0.97	1.03	1.07	1.13	1.17	1.23	1.27	1.33	1.37	1.43
D	18.9	1.02	1.07	1.13	1.19	1.24	1.30	1.34	1.40	1.46	1.52
E	19.4	1.04	1.10	1.16	1.22	1.27	1.34	1.40	1.46	1.52	1.57
W	20.0	1.09	1.14	1.20	1.27	1.33	1.39	1.44	1.50	1.57	1.63
	20.6	1.13	1.19	1.26	1.32	1.37	1.44	1.50	1.56	1.62	1.69
P	21.1	1.14	1.23	1.29	1.36	1.42	1.49	1.56	1.62	1.69	1.74
O	21.7	1.16	1.27	1.33	1.40	1.47	1.54	1.60	1.67	1.74	1.80
I	22.2	1.24	1.32	1.39	1.46	1.53	1.60	1.66	1.73	1.80	1.87
N	22.8	1.29	1.36	1.43	1.50	1.57	1.66	1.73	1.80	1.87	1.94
T	23.3	1.34	1.42	1.49	1.57	1.64	1.72	1.79	1.86	1.94	2.02
	23.9	1.39	1.46	1.54	1.62	1.70	1.77	1.84	1.93	2.00	2.09
T	24.4	1.43	1.52	1.59	1.67	1.76	1.84	1.92	2.00	2.09	2.16
E	25.0	1.49	1.57	1.66	1.74	1.83	1.92	1.99	2.07	2.16	2.25
M	25.6	1.54	1.63	1.72	1.80	1.89	1.99	2.07	2.16	2.25	2.33
P	26.1	1.60	1.69	1.79	1.87	1.96	2.06	2.15	2.23	2.32	2.42
°C	26.7	1.66	1.76	1.84	1.94	2.03	2.13	2.22	2.32	2.40	2.50

where:

999.6 = number of g/kg.
M_v = molecular weight of water vapor,
M_a = molecular weight of dry air,
P_v = partial pressure of water vapor at dew point, and
P_B = barometric pressure.

$$\text{or humidity} = 999.6(18.0152/28.96247)\frac{P_v}{(P_B - P_v)} \quad (X1.2)$$

$$\text{or humidity} = 621.77\, P_v/(P_B - P_v) \quad (X1.3)$$

X1.3 *Saturation Vapor Pressure Over Water*—See Table X1.5.

TABLE X1.5 Saturation Vapor Pressure Over Water

Dew Point Temperature, °C	Vapor Pressure, kPa	Dew Point Temperature, °C	Vapor Pressure, kPa
15.55	1.7670	23.89	2.9630
16.11	1.8302	24.44	3.0634
16.67	1.8961	25.00	3.1667
17.22	1.9641	25.56	3.2731
17.78	2.0342	26.11	3.3826
18.33	2.1064	26.67	3.4954
18.89	2.1811	27.22	3.6112
19.44	2.2578	27.78	3.7304
20.00	2.3373	28.33	3.8533
20.56	2.4187	28.89	3.9792
21.11	2.5028	29.44	4.1092
21.67	2.5892	30.00	4.2427
22.22	2.6788	30.56	4.3798
22.78	2.7707	31.11	4.5206
23.33	2.8654	31.67	4.6656

X2. STATISTICAL EQUATIONS FOR MEAN AND STANDARD DEVIATION

X2.1 See Eq X2.1 and X2.2 where:

$$\bar{x} = \text{mean} = \frac{1}{n}\sum_{i=1}^{n}\left[Y_i\,(\text{standard}) - Z_i\,(\text{reading})\right], \quad \text{(X2.1)}$$

$$s = \text{standard deviation} = \sqrt{\frac{\sum_{i=1}^{n}\left[(Y_i - Z_i) - \bar{x}\right]^2}{df}} \quad \text{(X2.2)}$$

n = total number of data pairs (Y_i, Z_i), and
df = degrees of freedom = n – 1.

X3. EXAMPLES OF FORMS FOR REPORTING

X3.1 *Examples of Reporting Test Results*—See Figs. X3.1-X3.4.

X3.2 When testing candidate oil against the limits of Specification D4485, report the results of multiple tests on the form shown as Fig. X3.5.

CATERPILLAR 1K/1N TEST REPORT

Form 4A (Example)

Rating Worksheet

METHOD: 1K

TEST NO: 72-112 OIL CODE: CMIR 19869 SR-0177 RATER : GC EOT DATE: 19971130

Grooves															
C	NO. 1			NO. 2			NO. 3			UNDERCROWN			UPPERSKIRT		
a	A%	FCT	DEM	A%	FCT	DEM	A%	FCT	DEM	A%	FCT	DEM	A%	FCT	DEM
r	19	1.0	10.00	57	1.0	57.00		1.0			1.0			1.0	
b	40	.50	20.00					.50							
o	41	.25	10.25	42	.25			.25			.25			.25	
n	100	Sub T	49.25	99	Sub T	67.50		Sub T			Sub T			Sub T	
V		1040.0		1	10-1.0	0.090	10	10-9.6	0.040	20	10-8.5	0.300	15	10-9.0	0.15
a		1040.0			10-10.0		20	10-9.9	0.020	15	10-9.0	0.150	45	10-9.5	0.225
r		1040.0			10-10.0		70	1040.0		65	1040.0		40	1040.0	
n		1040.0			10-10.0			1040.0			1040.0			1040.0	
i		1040.0			10-10.0			1040.0			1040.0			1040.0	
s		1040.0			10-10.0			1040.0			1040.0			1040.0	
h		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		Sub T	0.00	1	Sub T	0.090		Sub T	0.060	100	Sub T	0.45	100	Sub T	0.38
		TOTAL	49.25		TOTAL	67.59		TOTAL	0.060		TOTAL	0.45		TOTAL	0.38

LANDS										PINS					
C	NO. 1			NO. 2			NO. 3			FRONT			REAR		
a	A%	FCT	DEM	A%	FCT	DEM	A%	FCT	DEM	A%	FCT	DEM	A%	FCT	DEM
r	18	1.0	18.00	8	1.0	8.00		1.0			1.0			1.0	
b															
o	65	.25	16.25	87	.25	21.75		.25			.25			.25	
n	83	Sub T	34.25	95	Sub T	29.75		Sub T			Sub T			Sub T	
V	17	10-9.5	0.086	3	10-7.0	0.090	5	10-8.5	0.075	10	10-8.0	0.200	5	10-7.0	0.150
a		1040.0		2	10-5.5	0.090	15	10-9.0	0.150	90	1040.0		5	10-8.0	0.100
r		1040.0			10-10.0		20	10-9.5	0.100		1040.0		90	1040.0	
n		1040.0			10-10.0		25	10-9.9	0.025		1040.0			1040.0	
i		1040.0			10-10.0		35	1040.0			1040.0			1040.0	
s		1040.0			10-10.0			1040.0			1040.0			1040.0	
h		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
		1040.0			10-10.0			1040.0			1040.0			1040.0	
	17	Sub T	0.09	5	Sub T	0.180	100	Sub T	0.350	100	Sub T	0.20	100	Sub T	0.25
		TOTAL	34.34		TOTAL	29.93		TOTAL	0.350		TOTAL	0.20		TOTAL	0.25

	GROOVES			LANDS			UPPER	UNDER	PIN BORE	
	1	2	3	1	2	3	SKIRT	CROWN	FRONT	REAR
RATING	49.25	67.59	0.06	34.34	29.93	0.35	0.38	0.45	0.20	0.25
WDK LOC FCT	1.5	1.5	25	1	1	25	50	20	0	0
WT RATING	73.88	101.39	1.5	34.34	29.93	8.75	19.00	9.00	0.0	0
TGF 41	INT. GROOVE FILL 62			WDK/WDN 277.8			TOP LAND HVY CARBON 18			

FIG. X3.1 Example of Piston Rating Worksheet (Form 4A)

LAB: OK	**EOT DATE**: 19970214	**END TIME**: 15:05	**METHOD**: 1K
STAND: 3	**RUN NUMBER**: 34		
FORMULATION/STAND CODE:			
OILCODE/CMIR: 12345			

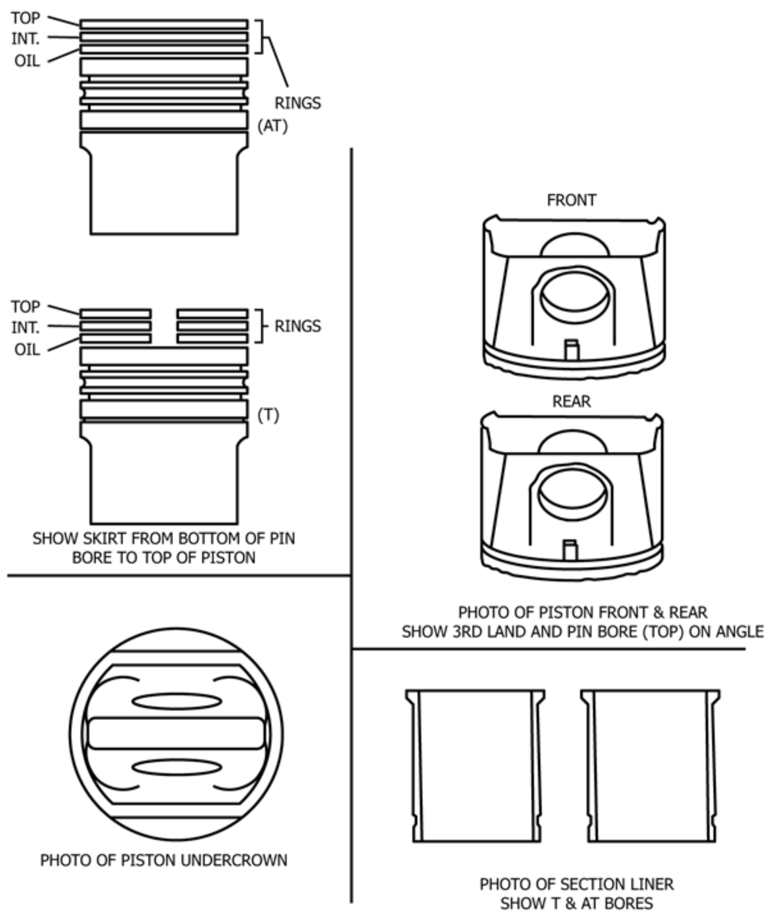


FIG. X3.2 Piston, Ring and Liner Photographs (Example of Form 14)

1K/1N

Form 16 (Example)

TMC CONTROL CHART ANALYSIS

LAB: OK	EOT DATE: 19970214	END TIME: 15:05	METHOD: 1K
STAND: 3	RUN NUMBER: 34		
FORMULATION/STAND CODE:			
OILCODE/CMIR: 12345			

Fax To: JOE ENGINEER
Company: OK OIL TEST LAB
Fax Number: 800-555-1212

*** ASTM TMC ***
*** CATERPILLAR 1K ***
** Control Chart Analysis **

Start = 19970202
EOT date = 19970214
EOT time = 15:05
LTMS date = 19970214
LTMS time = 15:05

Lab = OK
Stand = 3
Run = 34
Reported = 19970218

CMIR = 12345
Oil = 809-1

Analysis compiled: 30FEB97 13:37:09

Parameter	Measured Units	Transformed Units	Targets Mean	Targets S
WDK	175.6		216.4000	35.6000
TGF	19		17.5000	15.7000
TLHC	0	0.0000	0.6050	1.1000
BSOC	0.180		0.2680	0.1450
EOTOC	0.170		0.2750	

Note: When two Limits given, the upper is the Warning Limit and the lower is the Action Limit.

Key: A - Action alarm
W - Warning alarm

Stand Analysis

	N	EWMA Z(I)	Severity Limit	Alarm	Q(I)	Precision Limit	Alarm	SHEWHART Y(I)	Severity Limit	Alarm	R(I)	Precision Limit	Alarm
WDK	9	−0.444	±0.882		−0.611	+0.756		−1.146	±1.750		−0.940	+1.800	
TGF	9	−0.125	±0.882		−0.107	+0.756		0.096	±1.750		−0.228	+1.800	
TLHC	9	−0.348	±0.882		−1.015	+0.756		−0.550	±1.750		−2.329	+1.800	
BSOC	9	−0.632	±0.882		−0.981	+0.756		−0.607	±1.750		−1.437	+1.800	
EOTOC	9	−0.307	±0.882		−1.134	+0.756		−0.344	±1.750		−1.796	+1.800	

Laboratory Analysis

	N	EWMA Z(I)	Severity Limit	Alarm	Q(I)	Precision Limit	Alarm	SHEWHART Y(I)	Severity Limit	Alarm	R(I)	Precision Limit	Alarm
WDK	124	−1.007	±0.653	SA	−0.673	+0.600 +0.860		−1.146	±1.750		−1.489	+1.800	
TGF	124	−0.320	±0.653		−0.331	+0.600 +0.860		0.096	±1.750		0.302	+1.800	
TLHC	124	−0.503	±0.653		−1.043	+0.600 +0.860		−0.550	±1.750		−0.974	+1.800	
BSOC	124	−0.708	±0.653	SA	−0.990	+0.600 +0.860		−0.607	±1.750		−1.488	+1.800	
EOTOC	124	−0.380	±0.653		−1.331	+0.600 +0.860		−0.344	±1.750		−1.635	+1.800	

** SEVERITY ADJUSTMENTS **

WDN SA = 35.8 TGF SA = TLHC SA =

* TMC Validity Code:____

AC = Acceptable Calibration.
OC = Oper. Valid, Failed Acceptance Criteria.

Calibration Expires: ____________________
__ Stand Pulled From LTMS

* Based on review of call-in report of operational data and control chart analysis shown above.

		EWMA Lambda		EWMA K		SHEWHART K	
Chart Level	Limit Type	Precision	Severity	Precision	Severity	Precision	Severity
Stand	Action	0.3	0.3	1.8	2.1	1.8	1.75
Lab	Warning Action	0.2 0.2	0.2	1.8 2.58	1.96	1.8	1.75
Industry	Warning Action	0.15 0.15	0.15 0.15	1.74 2.58	2.05 2.81		

FIG. X3.3 TMC Control Chart Analysis (Example of Form 16)

1K/1N
Form 17 (Example)
FUEL BATCH ANALYSIS

LAB: OK	EOT DATE: 19970301	END TIME: 17:15	METHOD: 1K
STAND: 3	RUN NUMBER: 35		
FORMULATION/STAND CODE:			
OILCODE/CMIR: 12346			

Product: LSRD-4 Batch: 9701234
Date: 19970121 Tank: 84

SPECIFICATIONS

TEST	METHOD		MIN		MAX	RESULT
Distillation, °C	D86	IBP	177		199	91
		5 %				101
		10 %	210		232	104
		30 %				115
		50 %	249		277	128
		70 %				131
		90 %	299		327	158
		95 %				164
		EP	327		360	171
		Recovery, vol %		Report		98.4
		Residue, vol %		Report		1.6
		Loss, vol %		Report		0.0
Gravity, °API[A]	D287		32.0		36.0	34.5
Cetane Number[B]	D613		42.0		48.0	46.8
Cetane Index	D976			Report		45.3
Cetane Index	D4737		42.0		48.0	45.3
Flash Point, °C	D93		54			81
Cloud Point, °C	D2500				−12	17
Pour Point, °C	D97				−18	−21
Sulfur, mass	D2622		0.030		0.050	0.041
Acid Number, mg KOH/g	D664			Report		<0.05
Viscosity, mm^2/s @ 40 °C	D445		2		3.2	2.7
Hydrocarbon Composition, vol %						
Aromatics	D5186		28.0		35.0	29.6
Olefins	D1319			Report		1.4
Saturates	D1319			Report		69
Copper Corrosion, 3 h @ 100 °C	D130				3	1A
Ash, mass %	D482				0.01	.002
Ramsbottom Carbon, 10 % residuum	D524				0.35	0.08
Basic Sediment & Water, vol %	D2709				0.05	<0.01
Aliphatic paraffins	D2425			Report		46.78
Monocycloparaffins				Report		10.55
Dicycloparaffins				Report		8.08
Tricycloparaffins				Report		5.37
Alkylbenzenes				Report		9.16
Indanes/Tetralins				Report		5.32
Indenes				Report		4.12
Naphthalene				Report		0.77
Naphthalenes				Report		6.56
Acenaphthenes				Report		1.49
Acenaphthylenes				Report		1.13
Tricyclic aromatices				Report		0.67

[A]Alarm Spec 34.0 - 36.0 [B]Alarm Spec 45.0 - 48.0

Approved by: ____________________ ____________________

HHC Laboratory **Analyst**

FIG. X3.4 Fuel Batch Analysis (Example of Form 17)

OIL CODE NO. ________

CHECK ONE	
1K	1N

TEST NO.	DATE TEST COMP.	OIL CODE NO.	TEST LAB.	ENGINE NUMBER			FINAL LAB RATING			BSOC, g/kW-h	
				SERIAL	STAND	RUN	WDK	TGF	TLHC	0–252	0–24
1ST											
2											
3											
4											
TEST AVERAGE											
1ST											
2											
3											
4											
	2 TEST AVERAGE WITH OUTLIER REMOVED										
	3 TEST AVERAGE WITH OUTLIER REMOVED										

FIG. X3.5 1K/1N Multiple Test Data Summary Sheet

X4. OPTIONAL RECORDING OF RELEVANT CANDIDATE OIL PASS LIMIT INFORMATION

X4.1 If the non-reference oil test result is to be offered as a candidate oil test result against an engine oil specification, such as Specification D4485, then the relevant candidate oil pass limit information may be recorded on Form 2 (see Annex A17) using the mnemonics LDESC, DTCEFF, WPDL, TGFPL, TLHCPL, BSCOPL, and EPTOCPL.

SUMMARY OF CHANGES

Subcommittee D02.B0 has identified the location of selected changes to this standard since the last issue (D6750 – 16) that may impact the use of this standard. (Approved May 1, 2017.)

(1) Subsection 6.3.3, added an alternative electric moter-driven water pump for cooling system.
(2) Subsection 6.3.3.3, instructions provided for replacing original Caterpillar coolant heat exchanger and lines.
(3) Subsection 11.11.2, revised.

Subcommittee D02.B0 has identified the location of selected changes to this standard since the last issue (D6750 – 15a) that may impact the use of this standard. (Approved Oct. 1, 2016.)

(1) New Introduction section added.
(2) Subsection 13.3.4 added to allow a correction of TGFFNL to 100 if calculated value exceeds 100.
(3) Four new Annex sections (Annex A1 – Annex A4) added detailing services provided by the Test Monitoring System; deleted former Annex A15.