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Standard Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine¹

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1. Scope

1.1 This test method covers an engine test procedure for evaluating diesel engine oils for performance characteristics, including viscosity increase and soot concentrations (loading).² This test method is commonly referred to as the Mack T-8.

1.2 This test method also provides the procedure for running an extended length T-8 test, which is commonly referred to as the T-8E and an abbreviated length test, which is commonly referred to as T-8A. The procedures for the T-8E and the T-8A are identical to the T-8 with the exception of the items specifically listed in [Annex A8](#) and [Annex A9](#) respectively. Additionally, the procedure modifications listed in [Annex A8](#) and [Annex A9](#) refer to the corresponding section of the T-8 procedure.

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 *Exceptions*—Where there is no direct SI equivalent such as the units for screw threads, National Pipe Threads/diameters, tubing size, sole source equipment suppliers, and oil consumption in grams per kilowatt-hour.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See [Annex A6](#) for specific safety precautions.

1.5 A Table of Contents follows:

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.02 on Heavy Duty Engine Oils.

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² The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. This edition incorporates revisions contained in all information letters through 07-2. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

| | |
|---|-------|
| Scope | 1 |
| Referenced Documents | 2 |
| Terminology | 3 |
| Summary of Test Method | 4 |
| Significance and Use | 5 |
| Apparatus | 6 |
| General Description | 6.1 |
| The Test Engine | 6.2 |
| Mack Test Engine | 6.2.1 |
| Engine Cooling System | 6.2.2 |
| Engine Oil System | 6.2.3 |
| Auxiliary Oil System | 6.2.4 |
| Crankcase Aspiration | 6.2.5 |
| Blowby Meter | 6.2.6 |
| Air Supply and Filtration | 6.2.7 |
| Fuel Supply | 6.2.8 |
| Intake Manifold Temperature Control | 6.2.9 |
| Engine Fluids | 7 |
| Test Oil | 7.1 |
| Test Fuel | 7.2 |
| Engine Coolant | 7.3 |
| Cleaning Materials | 7.4 |
| Preparation of Apparatus at Rebuild | 8 |
| Cleaning of Parts | 8.1 |
| Valves, Seats, Guides, and Springs | 8.2 |
| Cylinder Liner, Piston, and Piston Ring Assembly | 8.3 |
| Injectors and Injection Pump | 8.4 |
| Assembly Instructions | 8.5 |
| Measurements | 8.6 |
| Laboratory and Engine Test Stand Calibration/Non-Reference Requirements | 9 |
| Calibration Frequency | 9.1 |
| Calibration Reference Oils | 9.2 |
| Test Numbering | 9.3 |
| New Laboratories and New Test Stands | 9.4 |
| Calibrated Laboratories and Test Stands | 9.5 |
| Calibration Test Acceptance | 9.6 |
| Failing Calibration Tests | 9.7 |
| Non-Reference Oil Test Requirements | 9.8 |
| Procedure | 10 |
| Pretest Procedure | 10.1 |
| Engine Start-Up | 10.2 |
| Engine Shutdown | 10.3 |
| Test Cycle | 10.4 |
| Oil Addition/Drain | 10.5 |
| Oil Samples | 10.6 |
| Oil Consumption Calculations | 10.7 |
| Fuel Samples | 10.8 |
| Periodic Measurements | 10.9 |
| Blowby | 10.10 |
| Centrifugal Oil Filter Mass Gain | 10.11 |

| | |
|--|----------|
| Oil Filter ΔP Calculation | 10.12 |
| Post Test | 10.13 |
| Inspection of Fuel and Oil During Test | 11 |
| Oil Inspection | 11.1 |
| Fuel Inspections | 11.2 |
| Oil Consumption | 11.3 |
| Report | 12 |
| Reporting Test Results | 12.1 |
| Deviations from Test Operational Limits | 12.2 |
| Electronic Transmission of Test Results | 12.3 |
| Plots of Operational Data | 12.4 |
| Precision and Bias | 13 |
| Precision | 13.1 |
| Bias | 13.2 |
| Keywords | 14 |
| Annexes | |
| Report Forms | Annex A1 |
| Sensor Locations | Annex A2 |
| Kinematic Viscosity At 100°C For Test Method D5967 Samples | Annex A3 |
| Enhanced Thermal Gravimetric Analysis (TGA) Procedure | Annex A4 |
| Procurement of Test Materials | Annex A5 |
| Safety Precautions | Annex A6 |
| Data Dictionary | Annex A7 |
| T-8E Extended Length Test Requirements | Annex A8 |
| T-8A Abbreviated Length Test Requirements | Annex A9 |

2. Referenced Documents

2.1 ASTM Standards:³

- [D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure](#)
- [D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester](#)
- [D97 Test Method for Pour Point of Petroleum Products](#)
- [D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test](#)
- [D235 Specification for Mineral Spirits \(Petroleum Spirits\) \(Hydrocarbon Dry Cleaning Solvent\)](#)
- [D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products \(Hydrometer Method\)](#)
- [D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids \(and Calculation of Dynamic Viscosity\)](#)
- [D446 Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers](#)
- [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](#)
- [D976 Test Method for Calculated Cetane Index of Distillate Fuels](#)
- [D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption](#)
- [D2274 Test Method for Oxidation Stability of Distillate Fuel Oil \(Accelerated Method\)](#)
- [D2500 Test Method for Cloud Point of Petroleum Products](#)
- [D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry](#)

- [D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge](#)
- [D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter](#)
- [D4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants](#)
- [D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry](#)
- [D4485 Specification for Performance of Engine Oils](#)
- [D4737 Test Method for Calculated Cetane Index by Four Variable Equation](#)
- [D5185 Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry \(ICP-AES\)](#)
- [D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence](#)
- [D6278 Test Method for Shear Stability of Polymer Containing Fluids Using a European Diesel Injector Apparatus](#)
- [E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications](#)

2.2 SAE Standard:⁴

- [SAE J1995 Engine Power Test Code—Spark Ignition and Compression Ignition—Gross Power Rating](#)

3. Terminology

3.1 Definitions:

- 3.1.1 *blind reference oil, n*—a reference oil, the identity of which is unknown by the test facility. **D4175**
- 3.1.2 *blowby, n*—in internal combustion engines, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D4175**
- 3.1.3 *calibrate, v*—to determine the indication or output of a measuring device with respect to that of a standard. **D4175**
- 3.1.4 *heavy-duty, adj*—in internal combustion engine operation, characterized by average speeds, power output, and internal temperatures that are close to the potential maximums. **D4485**
- 3.1.5 *heavy-duty engine, n*—in internal combustion engines, one that is designed to allow operation continuously at or close to its peak output. **D4485**
- 3.1.6 *non-reference oil, n*—any oil other than a reference oil; such as a research formulation, commercial oil, or candidate oil. **D4175**
- 3.1.7 *non-standard test, n*—a test that is not conducted in conformance with the requirements in the standard test method, such as running on an uncalibrated test stand, using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D4175**
- 3.1.8 *oxidation, n*—of engine oil, the reaction of the oil with an electron acceptor, generally oxygen, which can produce

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁴ Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or a combination thereof. **D4175**

3.1.9 *reference oil, n*—an oil of known performance characteristics, used as a basis for comparison. **D4175**

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

3.1.10 *sludge, n—in internal combustion engines*, a deposit, principally composed of insoluble resins and oxidation products from fuel combustion and the lubricant, that does not drain from engine parts but can be removed by wiping with a cloth. **D4175**

3.1.11 *standard test, n*—a test on a calibrated test stand, using the prescribed equipment in accordance with the requirements in the test method, and conducted in accordance with the specified operating conditions. **D4175**

3.1.11.1 *Discussion*—The specified operating conditions in some test methods include requirements for determining a test’s operational validity. These requirements are applied after a test is completed, and can include (1) mid-limit ranges for the *average* values of primary and secondary parameters that are narrower than the specified control ranges for the *individual* values, (2) allowable *deviations* for *individual* primary and secondary parameters from the specified control ranges, (3) downtime limitations, and (4) *special* parameter limitations.

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

3.1.13 *wear, n*—the loss of material from, or relocation of material on, a surface. **D4175**

4. Summary of Test Method

4.1 The test operation involves use of a Mack E7-350 diesel engine with a warm-up, a 2 h flush for each test, and then a

constant speed and load conditions that are held for the remainder of the test. Reference oil test length is 300 h. Non-reference oil test length is 250 h.

4.2 Oil samples are taken periodically and analyzed for viscosity increase.

4.3 Engine rebuild frequency is based on the degradation of test parameters and is left to the discretion of the test laboratory. At rebuild, the power section of the engine is disassembled, solvent-cleaned, measured, and rebuilt, using all new pistons, rings, cylinder liners, and valve guides, in strict accordance with furnished specifications.

4.4 The engine crankcase is solvent-cleaned, and worn or defective parts are replaced.

4.5 The test stand is equipped with appropriate accessories for controlling speed, load, and various engine operating conditions.

5. Significance and Use

5.1 This test method was developed to evaluate the viscometric performance of engine oils in turbocharged and inter-cooled four-cycle diesel engines. Results are obtained from used oil analysis.

5.2 The test method is used for engine oil specification acceptance when all details of the procedure are followed.

6. Apparatus

6.1 *General Description:*

6.1.1 The test engine is a Mack E7-350 mechanically governed engine, P/N 11GBA77623 (see **Annex A5**). It is an open-chamber, in-line, six-cylinder, four-stroke, turbocharged, charge air-cooled, compression ignition engine. The bore and stroke are (124 by 165) mm, and the displacement is 12 L. The engine is rated at 261 kW at 1800 r/min governed speed (see **SAE J1995**).

6.1.2 The ambient laboratory atmosphere should be relatively free of dirt, dust, and other contaminants as required by

TABLE 1 PC-9 Reference Diesel Fuel

| Property | Test Method | Min ^A | Max ^A |
|---|---------------------|------------------|------------------|
| Sulfur, mass % | D2622 | 0.04 | 0.05 |
| Gravity, °API | D287 or D4052 | 34.5 | 36.5 (37) |
| Hydrocarbon composition, % vol | | | |
| Aromatics | D1319 (FIA) | (27) 28 | 33 |
| Olefin | D1319 (FIA) | | Report |
| Cetane number | D613 | 40 (42) | 48 |
| Cetane index | D976 and D4737 | | Report |
| Copper strip corrosion | D130 | | 1 |
| Flash point, °C | D93 | 54 | |
| Pour point, °C | D97 | | -18 |
| Cloud point, °C | D2500 | | Report |
| Carbon residue on 10 % residuum, mass % | D524 (10 % bottoms) | | 0.35 |
| Water and sediment, vol % | D2709 | | 0.05 |
| Viscosity, mm ² /s at 40 °C | D445 | 2.4 | 3.0 |
| Ash, mass % | D482 | | 0.005 |
| Acid number | D664 | | 0.05 |
| Strong acid number | D664 | | 0.00 |
| Accelerated stability | D2274 | | Report |
| Distillation, °C | D86 | | |
| IBP | | | Report |
| 10 % vol | | | Report |
| 50 % vol | | | Report |
| 90 % vol | | 282 | 338 |
| EP | | | Report |

^A Min and max numbers in parentheses are EPA Certification Fuel Specifications.

good laboratory standards. Additionally, it is recommended that the atmosphere in the engine buildup area be filtered and controlled for temperature and humidity to prevent accumulation of dirt or dust on engine parts. Uniform temperature control will also aid in measuring and selecting parts for assembly.

6.1.3 Use the low sulfur reference diesel fuel shown in [Table 1](#).

6.2 *The Test Engine:*

6.2.1 *Mack Test Engine*—The engine is available from Mack Trucks, Inc. A complete parts list is shown in [Table A5.1](#).

6.2.2 *Engine Cooling System:*

6.2.2.1 A new Mack coolant conditioner shown in [Table A5.1](#) is required every test to limit scaling in the cooling system. Pressurize the system at the expansion tank to 103 kPa.

6.2.2.2 Use a closed-loop, pressurized external engine cooling system composed of a nonferrous core heat exchanger, reservoir, and water-out temperature control valve. The system should prevent air entrainment and control jacket temperatures within the specified limit. Install a sight glass between the engine and the cooling tower to check for air entrainment and uniform flow in an effort to prevent localized boiling. Block the thermostat wide open.

6.2.3 *Engine Oil System*—A schematic of the engine oil system is shown in [Fig. A2.9](#).

6.2.4 *Auxiliary Oil System*—To maintain a constant oil level in the pan, a separate closed tank is connected to the sump that provides an additional 9.5 L sump. Circulate oil through the tank with an auxiliary pump at a rate of (5.7 ± 1.9) L/min. A typical auxiliary oil system is shown in [Fig. A2.9](#). The No. 6 and No. 8 Aeroquip⁵ lines should have inside diameters of 10 mm and 13 mm, respectively. The vent line size is specified as a minimum No. 8 line size. Equivalent lines may be substituted for Aeroquip lines provided they have the proper inside diameters.

6.2.5 *Crankcase Aspiration*—A simple squirrel cage blower will suffice to control crankcase pressure within the test limits.

6.2.6 *Blowby Meter*—Use a displacement type gas meter, or equivalent, to measure blowby.

6.2.7 *Air Supply and Filtration*—Use an intake air filter with an initial efficiency of 99.2%. Replace filter cartridge when 2.5 kPa ΔP is reached. Install an adjustable valve (flapper) in the inlet air system at least two pipe diameters before any temperature, pressure, and humidity measurement devices. Use the valve to maintain inlet air restriction within required specifications.

6.2.8 *Fuel Supply*—Heating or cooling, or both, of the fuel supply may be required and a recommended system is shown in [Fig. A2.11](#).

6.2.9 *Intake Manifold Temperature Control*—Control intake manifold temperature with the use of a slave intercooler.

7. Engine Fluids

7.1 *Test Oil*—Approximately 151 L of test oil are required for the test.

7.2 *Test Fuel*—The recommended fuel with the properties and tolerances are shown in [Table 1](#).

7.3 *Engine Coolant*—Use demineralized water with less than 0.03 g/L of salts or distilled water (do not use antifreeze solutions or other coolant additives).

7.4 *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.

8. Preparation of Apparatus at Rebuild

8.1 *Cleaning of Parts:*

8.1.1 *Engine Block*—Thoroughly spray the engine with solvent (see [7.4](#)) to remove any oil remaining from the previous test, and air dry.

8.1.2 *Rocker Covers and Oil Pan*—Remove all sludge, varnish, and oil deposits. Rinse with solvent, and air dry.

8.1.3 *Auxiliary Oil System*—Flush all oil lines, galleries, and external oil reservoirs with solvent to remove any previous test oil, and air dry.

8.1.4 *Oil Cooler and Oil Filter*—If heavy deposits are present or suspected, flush the oil cooler and filter lines with solvent to remove any previous test oil, and air dry.

8.1.5 *Cylinder Head*—Clean the cylinder heads using a wire brush to remove deposits and rinse with solvent to remove any sludge and oil, and air dry.

8.2 *Valves, Seats, Guides, and Springs*—Visually inspect valves, seats, and springs for defects and replace, if defective.

8.2.1 Replace and ream guides to (0.9525 ± 0.0013) cm.

8.3 *Cylinder Liner, Piston, and Piston Ring Assembly:*

8.3.1 *Cylinder Liner Fitting*—To ensure proper heat transfer, fit cylinder liners to the block in accordance with the procedure outlined in the Mack Service Manual (see [Annex A5](#)).

8.3.2 *Piston and Rings*—Cylinder liners, pistons, and rings are provided as a set and should be used as a set. Examine piston rings for any handling damage. Measure piston ring end gaps for conformance with Mack specifications and record.

8.4 *Injectors and Injection Pump:*

8.4.1 *Injectors*—Servicing of injectors is recommended every 1000 h. Resetting of injector opening pressure is allowed if pressure is below specification.

8.4.2 *Injection Pump*—The removal of the injection pump is not recommended unless a problem is noted during a test. Removing the injection pump invalidates the test stand calibration. Replacing injection pumps at each calibration is recommended. Only new injection pumps, which have never been serviced or rebuilt, are permitted. High pressure flow calibration equipment, such as a Bacharach No. 72-7010 standard injector tester, is available from Mack approved dealers. Kent-Moore^{6,7} tool numbers J29539 top dead center

⁶ The sole source of supply of the tools known to the committee at this time is Kent-Moore Corp., 29784 Little Mack, Roseville, MI 48066.

⁷ If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

⁵ Aeroquip lines are available at local industrial hose suppliers.

indicator and J37077 position sensor are recommended for setting the injection timing.

8.5 *Assembly Instructions:*

8.5.1 *General*—The test parts specified for this test method are intended to be used without material or dimensional modification. Exceptions, for example, a temporary parts supply problem, shall be approved by the Test Monitoring Center (TMC), and noted in the test report. All replacement test engine parts shall be genuine Mack Trucks, Inc. parts. Assemble all parts as illustrated in the Mack Service Manual (see A5.2), except where otherwise noted. Target all dimensions for the means of the specifications. Use the buildup oil (see **Annex A5**) for lubricating parts during assembly.

8.5.1.1 *Thermostat*—Block the thermostat wide open using an all thread rod.

8.5.1.2 *Rod Bearings*—Check the condition of the connecting rod bearings. Replacement of the connecting rod bearings is at the laboratory's discretion.

8.5.1.3 *Main Bearings*—Check the condition of the main bearings. Replacement of the main bearings is at the laboratory's discretion.

8.5.1.4 *Piston Undercrown Cooling Nozzles*—Take particular care in assembling the piston undercrown cooling nozzles to ensure proper piston cooling (as outlined in the Mack Service Manual).

NOTE 1—Proper oil pressure is also important to ensure sufficient oil volume for proper cooling.

8.5.2 *New Parts*—Install the following new parts for each rebuild (see **Table A5.1**, **Annex A5**, for part numbers):

- 8.5.2.1 Cylinder liners,
- 8.5.2.2 Pistons,
- 8.5.2.3 Piston rings,
- 8.5.2.4 Overhaul gasket set,
- 8.5.2.5 Oil filters (also after each test),
- 8.5.2.6 Engine coolant conditioner (also every test),
- 8.5.2.7 Primary fuel filter (also every test),
- 8.5.2.8 Secondary fuel filter (also every test),
- 8.5.2.9 Valve guides, and
- 8.5.2.10 Valve stem seals.

8.6 *Measurements:*

8.6.1 *Calibrations*—Calibrate thermocouples, pressure gages, speed, and fuel flow measuring equipment prior to each reference test or at any time readout data indicates a need. Conduct calibrations with at least two points that bracket the normal operating range. Make these calibrations part of the laboratory record. During calibration, connect leads, hoses, and read-out systems in the normally used manner and calibrate with necessary standards. Immerse thermocouples in calibration baths. Calibrate standards with instruments traceable to the National Institute of Standards and Technology on a yearly basis.

8.6.2 *Temperatures:*

8.6.2.1 *General*—Measure temperatures with thermocouples and conventional readout equipment or equivalent. For (0 to 150) °C range, calibrate temperature measuring systems to ± 0.5 °C at (100 \pm 1) °C and to ± 0.5 °C at (0 \pm 1) °C. Insert all thermocouples so that the tips are located midstream of the flow unless otherwise indicated.

8.6.2.2 *Ambient Air*—Locate thermocouple in a convenient, well-ventilated position between (2 and 3) m from the engine and hot accessories.

8.6.2.3 *Coolant*—Locate thermocouple in water manifold prior to thermostat housing. Locate in center of water stream (refer to **Fig. A2.5**).

8.6.2.4 *Oil*—Locate thermocouple on the right side of the engine on the top of the accessory drive, as shown in **Fig. A2.5**.

8.6.2.5 *Intake Air*—Locate sensors for dry bulb temperature measurement and humidity in center of air stream at the turbocharger inlet as shown in **Fig. A2.3**. It is not necessary to control intake air humidity, but measurements are recommended.

8.6.2.6 *Fuel In*—Locate thermocouple in center of fuel line between secondary filter and injection pump, as shown in **Fig. A2.4**.

8.6.2.7 *Pre-Turbine Temperatures*—Locate one thermocouple in each side of exhaust manifold tee section (see **Fig. A2.3**). The exhaust manifold (pre-turbine) thermocouples and pressure taps are located on the same tee.

8.6.2.8 *Exhaust (Tailpipe) Temperature*—Locate thermocouple in exhaust pipe downstream of turbine in accordance with **Fig. A2.7**.

8.6.2.9 *Intake Manifold*—Locate thermocouple at tapped fitting on intake air manifold, as shown in **Fig. A2.6**.

8.6.2.10 *Additional*—Monitor any additional temperatures the test lab regards as helpful in providing a consistent test procedure.

8.6.3 *Pressures:*

8.6.3.1 *Before Filter Oil Pressure*—Locate pickup at tapped hole on oil cooler fitting (see **Fig. A2.2**).

8.6.3.2 *After Filter/Main Gallery Oil Pressure*—Locate pickup at tapped hole on top of oil filter pad above centrifugal oil filter (see **Fig. A2.2**).

NOTE 2—The E7 engine has only one oil gallery, which serves as both a main gallery and a piston cooling gallery.

8.6.3.3 *Pre-Turbine Exhaust Pressure*—Locate pickup in each side of exhaust manifold tee section (same tap as pre-turbine pressure), **Fig. A2.3**.

8.6.3.4 *Intake Air Boost*—Take measurement at tapped fitting provided on intake manifold, as illustrated in **Fig. A2.6**.

8.6.3.5 *Intake Air Total Pressure*—Measure with a Keil Probe^{7,8} (p/n No. KDF-8-W recommended) located at the turbo inlet (see **Fig. A2.3**).

8.6.3.6 *Exhaust Back Pressure*—Locate pickup in exhaust pipe after turbocharger in center of exhaust stream. Measure exhaust back pressure in a straight section of pipe, (30.5 to 40.6) cm downstream of the turbo with a 1/16 NPT tread pressure tap hole, as shown in **Fig. A2.3**.

8.6.3.7 *Crankcase Pressure*—Locate pickup at dipstick tube fitting or other suitable opening direct to the crankcase.

8.6.3.8 *Barometric Pressure*—Locate barometer approximately 1.2 m above ground level in convenient location in the lab.

⁸ The sole source of supply of Keil Probes known to the committee at this time is United Sensor Corp., 3 Northern Blvd., Amherst, NH 03031.

8.6.4 *Engine Blowby*—Connect the metering instrument to the blowby line coming from the valve cover crossover tube (P/N 191GC418A).

8.6.5 *Fuel Consumption Measurements*—Place the measuring equipment in the fuel line before the primary fuel filter. Install the primary fuel filter before the fuel transfer pump and install the secondary filter before the injection pump. Accurate fuel consumption measurements require proper accounting of return fuel. (**Warning**—Fuel return lines should never be plugged.)

8.6.6 *Humidity*—Place the measurement equipment between the inlet air filter and compressor in such a manner so as not to affect temperature and pressure measurements. Measure humidity at 8 h intervals and report (see [Annex A1](#)).

9. Laboratory and Engine Test Stand Calibration/Non-Reference Requirements

9.1 Calibration Frequency:

9.1.1 To maintain test consistency and severity levels, engine test stand calibration is required at regular intervals. The frequency of calibration is dependent on the laboratories' previous calibration experience or at the discretion of the TMC.

9.1.2 Engine test stand calibration is required when the injection pump is removed from the engine, when cylinder heads are replaced, or when pistons, rings, and liner are changed. Cylinder heads can be rebuilt without re-calibrating. If a piston, piston rings, or cylinder liner are changed, then re-calibration is necessary.

9.2 Calibration Reference Oils:

9.2.1 The reference oils used to calibrate test stands have been formulated or selected to represent specific chemical types or performance levels, or both. They can be obtained from the TMC. The TMC will assign reference oils for calibration tests. These oils are supplied under code numbers (blind reference oils).

9.2.2 *Reference Oils Analysis*—Reference oils are not to be submitted to either physical or chemical analysis, for identification purposes. Identifying the oils by analysis could undermine the confidentiality required to operate an effective blind reference oil system. Therefore, reference oils are supplied with the explicit understanding that they will not be subjected to analysis other than those specified within this procedure unless specifically authorized by the TMC. In such cases in which analysis is authorized, written confirmation of the circumstances involved, the data obtained, and the name of the person authorizing the analysis shall be supplied to the TMC.

9.3 *Test Numbering*—Number each test to identify the test stand number, the test stand run number, engine serial number, and engine block hours at the start of the test. The sequential stand run number remains unchanged for reruns of aborted, invalid, or unacceptable calibration tests. However, the sequential stand run number shall be followed by the letter A for the first rerun, B for the second, and so forth. For calibration tests, engine block hours are the test hours since last engine rebuild. For non-reference tests, engine block hours are the test hours accumulated since last reference. For example, 58-12A-2H0380-500 defines a test on stand 58 and stand run 12 as a

calibration test that was run twice on engine 2H0380 (serial number), which has run 500 h since the last engine rebuild.

9.4 New Laboratories and New Test Stands:

9.4.1 A new stand is defined as an engine, dynamometer/cell and support hardware that has never been previously calibrated under this test procedure. On both new and existing stands the test engine is part of the stand calibration. A new engine in a existing test stand only requires one successful calibration test.

9.4.2 Calibrate a new test stand in accordance with the Lubricant Test Monitoring System (LTMS). Generally, new test stands require two successful calibration tests. However, provisions do exist within the LTMS to allow new stands to calibrate with one test, based upon previous test experience within the laboratory.

9.4.3 A laboratory not running a test for 12 months from the start of the last test is considered a new laboratory. Under special circumstances (that is, extended downtime due to industry-wide parts shortage or fuel outages) the TMC may extend the lapsed time requirement. Non-reference tests conducted during an extended time allowance shall be annotated (see [Annex A1](#)), Downtime and Comments Summary.

9.5 Calibrated Laboratories and Test Stands:

9.5.1 A calibration test on a reference oil assigned by the TMC is required after 3000 h of non-reference test time, ten operationally valid non-reference oil tests, or nine months, whichever comes first, have elapsed since the starting date of the last calibration test. A non-reference test may be started in a test stand provided at least 1 h remains in its calibration period.

9.6 Calibration Test Acceptance:

9.6.1 Use the TMC's Lubricant Test Monitoring System (LTMS)⁹ for calibration test targets and acceptance criteria.

9.6.2 The specified test parameter for determination of test acceptance is Viscosity Increase in mm²/s, at 100 °C and 3.8 % Thermal Gravimetric Analysis (TGA) soot, as shown in [Annex A3](#) and [Annex A4](#).

9.6.2.1 Calculate Viscosity Increase at 3.8 % TGA, using linear interpolation from the minimum viscosity that occurs during the test. Do not use the 25 h, 75 h, and 125 h oil sample results to calculate Viscosity Increase at 3.8 % TGA soot.

9.6.3 Soot Requirements:

9.6.3.1 All operationally valid calibration tests on TMC oil 1004-1 shall produce a TGA soot level between (4.0 to 4.6) % at 250 h.

9.6.3.2 All operationally valid calibration tests on TMC oil 1004-2 shall produce a TGA soot level between (4.0 to 4.8) % at 250 h.

9.6.3.3 All operationally valid calibration tests on TMC oil 1004-3 completed on or before Dec. 31, 2006 shall produce a TGA soot level between (4.0 to 4.8) % at 250 h.

9.6.3.4 All operationally valid calibration tests on TMC oil 1004-3 completed on or after Jan. 1, 2007 and all operationally valid calibration tests on TMC oil 1005-2 shall produce a TGA soot level between (4.0 to 5.0) % at 250 h.

⁹ The lubricant test monitoring system may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. Attention: Administrator.

9.6.3.5 A laboratory may terminate a calibration test that is projected to miss the 250 h test soot window. Calibration tests with soot levels outside the 250 h soot window are considered operationally invalid.

9.7 *Failing Calibration Tests:*

9.7.1 Failure of a reference oil test to meet test acceptance bands can be indicative of a false alarm, testing stand, testing laboratory, or industry-related problem. When this occurs, the laboratory, in conjunction with the TMC, shall attempt to determine the problem source.

9.7.2 The TMC will decide, with input as needed from industry expertise (testing laboratories, test developer, ASTM Technical Guidance Committee, Surveillance Panel, and so forth), if the reason for any unacceptable blind reference oil test is isolated to one particular stand or related to other stands. If it is decided that the problem is isolated to an individual stand, calibrated testing on other stands can continue throughout the laboratory. Alternatively, if it is decided that more than one stand may be involved, the involved stands will not be considered calibrated until the problem is identified, corrected, and an acceptable reference oil test completed in one of the involved stands.

9.7.3 If nonstandard tests are conducted on the referenced test stand, the stand may be required to be recalibrated prior to running standard tests at the discretion of the TMC.

9.8 *Non-Reference Oil Test Requirements*—Non-reference oil tests shall produce a minimum 3.8 % TGA soot level at 250 h. Tests shall run to 250 h regardless of meeting the 3.8 % soot level prior to 250 h. Tests that do not reach 3.8 % soot at 250 h are deemed not interpretable.

NOTE 3—Fixed non-reference oil pass criteria are published in Specification **D4485**.

9.8.1 *Non-Reference Oil Test Result Severity Adjustments*—This test method incorporates the use of a severity adjustment (SA) for non-reference oil test results. A control chart technique, described in the LTMS, has been selected for the purpose of identifying when a bias becomes significant for viscosity increase at 3.8 % TGA soot. When calibration test results identify a significant bias, a SA value is determined in accordance with the LTMS. Report the SA value (see **Annex A1**), Test Result Summary, under the non-reference oil test block in the space for SA. Add this SA value to non-reference oil test results, and enter the adjusted viscosity increase at 3.8 % TGA soot value in the appropriate space. The SA remains in effect until a new SA is determined from subsequent calibration tests, or the test results indicate the bias is no longer significant.

9.9 *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.

9.10 *Adjustments to Reference Oil Calibration Periods:*

9.10.1 *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.

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

9.10.3 *Reference Oil Test Data Flow*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may 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.

9.10.4 *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 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.

10. Procedure

10.1 *Pretest Procedure:*

10.1.1 *Initial Oil Fill for Flush*—The initial oil fill is 45.4 L of test oil: 26.5 L for the pan, 3.8 L for the filters, 1.9 L for the engine oil cooler, and 13.2 L for the auxiliary oil reservoir and lines. Add the first 3.8 L of fresh test oil to the oil filters (1.9 L per filter), then turn on the auxiliary oil pumps and add an additional 41.6 L of test oil to the engine. This oil can be added directly through the engine oil fill tube.

10.1.2 *Pretest Oil Flush and Break-In:*

10.1.2.1 Start the engine, as described in **11.2**. For a new or rebuilt engine, run the break-in sequence described in **Table 2**. For non-reference oil tests only a pretest oil flush procedure is

TABLE 2 Break-in and Flush Operating Conditions

| Conditions | New or Rebuild Break-in | | Pretest Flush |
|--|-------------------------|-------------|---------------|
| | 30 | 30 | 120 |
| Time, min | 30 | 30 | 120 |
| Speed, r/min | 1250 | 1800 | 1800 |
| Torque, N·m ^A ± 1 % ^B | 1731 (1277) | 1384 (1021) | 1384 (1021) |

^A At 98.2 kPa and 29.5 °C dry air.

^B When engine performance falls outside these limits, corrective action should be taken.

required. A post test flush should be done prior to a pretest, as described in 11.13.1 and 11.13.2.

10.1.2.2 Shutdown the engine (as shown in 11.3) and drain the test oil from the oil pan, external oil reservoir, and change the oil filters.

10.1.2.3 Install new oil filters and add 3.8 L of fresh test oil to the filters (1.9 L per filter). Start the auxiliary oil pumps and add an additional 41.6 L of new oil to the engine. This oil can be added directly through the engine oil fill tube.

10.2 *Engine Start-Up*—Each time the engine is started, work up to (20 to 30) % of full load at (1000 to 1400) r/min and hold until the oil sump temperature reaches approximately (66 to 77) °C. This takes about 10 min for a cold engine; then go to test conditions. Start-ups are not included as test time. Test time starts as soon as the engine returns to the test cycle. The start date and time of a test, is defined as when the test reaches test conditions (after a flush). (**Warning**—The engine should be cranked prior to start-up to fill the engine oil passages. This practice will enhance engine durability significantly.)

10.3 *Engine Shutdown*—The engine may be shut down for periods of time. Before each shutdown, operate the engine at (1000 to 1400) r/min no-load for 10 min, then close the fuel rack. The shutdown operation does not count as test time. Record the length and reason of each shutdown (see [Annex A1](#)).

10.4 *Test Cycle*—The test cycle includes a pretest oil flush at the conditions shown in [Table 2](#). For new and rebuilt engines, a break-in procedure is also required. Conduct the test at 1800 r/min full-load conditions as described in [Table 3](#). Reference oil test length is 300 h. Non-reference oil test length is 250 h.

10.4.1 At EOT (end of test), the average results for all controlled operational parameters shall be within the stated specifications for the test to be declared operationally valid. For calibration tests, investigate any uncontrolled operational parameters outside the stated specifications jointly by the laboratory and the TMC. Base a validity judgment on the joint agreement between the laboratory and the TMC.

10.5 *Oil Addition/Drain*—Establish the *full mark* as the oil mass in the first 1 h period of the test. At the end of every 25 h period, perform a forced drain that equates to an oil consumption of 0.243 g/kWh. If a sample is required, follow the guidelines set forth in 10.6. If a sample is not required, then drain a sufficient amount of oil to obtain an oil mass that is below the *full mark* by 1.59 kg. Then add 1.59 kg of new oil to the engine. After a shutdown, use the drain level of the previous period to determine the forced drain quantity.

NOTE 4—The kWh symbol is not an SI unit symbol. The equivalent SI

TABLE 3 Test Conditions

| Parameter | Limits |
|------------------------------------|--------------------------------|
| Time, h | 250 (300 for reference oils) |
| Controlled Parameters ^A | |
| Speed, r/min | 1800 ± 5 |
| Fuel flow, kg/h | 63.3 ± 1 % |
| Inlet manifold temperature, °C | 43 ± 3 |
| Coolant out, °C | 85 ± 3 |
| Fuel in, °C | 40 ± 1 |
| Intake air, °C | 25 ± 3 |
| Crankcase pressure, kPa | 0.50 ± 0.25 |
| Inlet air restriction, kPa | 2.50 ± 0.25 |
| Exhaust back pressure, kPa | 3.1 ± 0.4 |
| Uncontrolled Parameters | |
| Torque, N·m ^B | 1369/1398 ^C |
| Exhaust temperature, °C | |
| Pre-turbine | 602/632 |
| Tailpipe | 455/474 |
| Inlet manifold pressure, kPa | 186/199 ^C |
| Oil, °C | 100/107 |
| Main gallery oil pressure, kPa | 372/441 ^D |
| Intercooler ΔP, kPa | Not to exceed 13.6 |
| Oil filter ΔP, kPa | Not to exceed 138 ^E |

^A All control parameters are to be held at the mean indicated.

^B At 98.2 kPa and 29.5 °C dry air.

^C When engine performance falls outside these limits, corrective action should be taken. Fuel flow is the primary control parameter.

^D Note pressures are typical of SAE 15W40 oils; other oil grades may show different results.

^E If oil filter ΔP exceeds 138 kPa, change the two full flow filters.

unit symbol is J (joule); 1 kWh = 3.6 MJ.

10.6 Oil Samples:

10.6.1 For reference oil tests, take oil samples of 118 mL at 25 h intervals. For non-reference oil tests, the 25 h, 75 h, and 125 h samples are optional. Obtain oil samples through a drain petcock located in the oil rig return line (oil pan to return pump) (see [Fig. A2.8](#)).

10.6.2 If oil consumption during a 25 h period is less than or equal to 1.02 kg, withdraw a 473 mL purge, then withdraw a 118 mL sample. Then drain enough oil to complete the forced drain of 1.59 kg (including mass of the 473 mL purge).

10.6.3 If the oil consumption is greater than 1.02 kg, withdraw a 473 mL purge and then a 118 mL sample. Then return the purge oil to the external oil reservoir. Then drain an amount of oil equal to the difference of the oil consumption of that period from 1.59 kg. Then follow with the forced oil addition of 1.59 kg of new oil.

10.7 Oil Consumption Calculations:

10.7.1 Record the oil mass hourly and compute the oil consumption from these readings.

10.7.2 Calculate the average oil consumption for the test as the average of the 25 h periods from 26 h to end of test. Do not use the first 25 h period to calculate oil consumption since this is a period of stabilization of the oil scale system. Do not include oil drains and samples as oil consumption.

10.7.3 Use the following formula to calculate the oil consumption for a 25 h period:

$$\text{Oil Consumption (g/kWh)} = (FW - W_n) / (P \times 25) \quad (1)$$

where:

FW = full mass, g,

W_n = oil scale mass at n test hours before additions, samples, or drains, g, and

P = brake power output of the engine, kW.

The reported oil consumption is the average of the 25 h period oil consumption calculations.

10.7.4 The full mass may need to be reestablished, depending on the rate of oil consumption of the engine for the 25 h period. If the oil consumption is greater than 0.225 g/kWh, recalculate the full mass by subtracting the mass of the oil sample and adding the mass of the oil addition (1.59 kg) to the previous 25 h period's mass.

10.8 *Fuel Samples*—Take fuel samples prior to the start of test (two 0.95 L samples) and at EOT (two 0.95 L samples).

10.9 *Periodic Measurements*—Make measurements at the end of each test hour or more frequently, if desired, on the parameters listed in 10.9.1 and record (see Annex A1). Record data before adjustments are made to control parameters to achieve operation at specification mean. Each measurement is to be an hourly snapshot. The TMC encourages automatic data acquisition and permits multiple measurements to be made within an hour. Characterize the procedure used to calculate the hourly average (see Annex A1).

10.9.1 *Parameters:*

- 10.9.1.1 Speed, r/min,
- 10.9.1.2 Torque, N·m,
- 10.9.1.3 Oil temperature, °C,
- 10.9.1.4 Water-out temperature, °C,
- 10.9.1.5 Water-in temperature, °C,
- 10.9.1.6 Intake air temperature, °C,
- 10.9.1.7 Intake manifold temperature, °C,
- 10.9.1.8 Intake air boost, kPa,
- 10.9.1.9 Fuel flow, s/kg or kg/h,
- 10.9.1.10 Fuel inlet temperature, °C,
- 10.9.1.11 Tailpipe exhaust back pressure, kPa,
- 10.9.1.12 Before filter oil pressure, kPa,
- 10.9.1.13 Main gallery oil pressure, kPa,
- 10.9.1.14 Crankcase pressure, kPa,
- 10.9.1.15 Pre-turbine exhaust temperature, front manifold, °C,
- 10.9.1.16 Pre-turbine exhaust temperature, rear manifold, °C,
- 10.9.1.17 Inlet restriction, kPa,
- 10.9.1.18 Tailpipe exhaust temperature, °C,
- 10.9.1.19 Crankcase blowby, L/min (see 10.9),
- 10.9.1.20 Pre-turbine exhaust pressure, front manifold, kPa,
- 10.9.1.21 Pre-turbine exhaust pressure, rear manifold, kPa, and
- 10.9.1.22 Inlet air humidity, g/kg.

10.10 *Blowby*—Record the total crankcase blowby at a minimum of 8 h intervals. Disconnect crankcase aspirating equipment during blowby measurements. Take care to prevent oil traps from occurring in the blowby line at any time during operation.

10.11 *Centrifugal Oil Filter Mass Gain*—Prior to the start of test, determine the mass of the centrifugal oil filter canister. At EOT, remove the centrifugal oil filter canister from the engine and drain upside down for 30 min. After draining, determine the mass of the canister and record (see Annex A1). Centrifugal oil filter mass gain determination is required for calibration tests and optional for non-reference oil tests.

10.12 *Oil Filter ΔP Calculation:*

10.12.1 The reported oil filter ΔP is the maximum oil filter ΔP that occurs from (0 to 250) h. Calculate the oil filter ΔP as follows:

$$\Delta P = \Delta P_{\max} - \Delta P_{\text{initial}} \quad (2)$$

where:

- ΔP_{\max} = the maximum ΔP across the oil filter, and
- $\Delta P_{\text{initial}}$ = the ΔP across the oil filter at the start of test conditions.

10.12.2 If an oil filter change is made, add the oil filter ΔP value obtained after the filter change to the oil filter ΔP obtained prior to the filter change. If a shutdown occurs, add the oil filter ΔP value obtained after the shutdown to the oil filter ΔP obtained prior to the shutdown.

10.13 *Post Test:*

10.13.1 *Post Test Flush*—As soon as possible after the EOT, perform a post test flush. Drain all oil from the oil pan, external oil reservoir, and filters. Perform an initial fill in accordance with 10.1, and use Bulldog Premium Oil⁷⁻¹⁰ as the flush oil. Start the engine as described in 10.2 and run the pretest flush conditions as described in Table 2. Shutdown the engine (see 10.3) and drain the post test flush oil from the oil pan, external oil reservoir, and remove filters.

10.13.2 *Post Test Solvent Wash*—After the post test flush is performed, wash the top of the cylinder heads (rocker area), rocker arms, and rocker covers with solvent until clean. The oil drain plug should be open for this procedure. Remove the oil pan and wash with solvent until clean. Also wash the external oil rig system and the external oil lines with solvent until clean.

11. Inspection of Fuel and Oil During Test

11.1 *Oil Inspection:*

11.1.1 Analyze oil samples for viscosity at 100 °C in accordance with Annex A3; poor test precision can result if the modified test method (see Annex A3) is not followed exactly. To maintain test accuracy and precision, conduct all viscosity and soot measurements at a TMC-calibrated laboratory. Take two samples at 250 h and analyze for viscosity and soot. In Annex A1, the viscosity reported is the average of the two samples taken at 250 h. Base viscosity increase on the minimum viscosity as reported in Annex A1. In addition to the viscosity measurements, conduct soot analysis in accordance with Annex A4. Determine wear metals content (Fe, Pb, Cu, Cr, Al); additive metals content, silicon, and sodium levels in accordance with Test Method D5185 from new, 150 h, 250 h, and 300 h (if applicable) oil samples. Conduct oil analysis as soon as possible after sampling.

11.2 *Fuel Inspections*—Use fuel purchase inspections to complete forms in Annex A1 for the last batch of fuel used during the test. If more than one batch is used for a test, list each fuel batch in the fuel batch identifier block in Annex A1. List the fuel batches in chronological order (initial to final batch). In addition, perform the following inspections on NEW and EOT fuel samples:

- (1) API Gravity at 15.6 °C, Test Method D287

¹⁰ The sole source of supply of Bulldog Premium Oil known to the committee at this time is Mack Truck suppliers or Mack Trucks, Inc., 13302 Pennsylvania Ave., Hagerstown, MD 21742.

(2) Total Sulfur, mass %, Test Method **D5453** (Test Methods **D2622** or **D4294** can be substituted)

(3) Use one 0.95 L sample for inspections

11.3 *Oil Consumption:*

11.3.1 Compute total oil consumption for the test and report in kilograms per kilowatt-hour for each test. A value of 0.182 g/kWh or lower is desirable. For calibration tests, if oil consumption exceeds 0.304 g/kWh, the test is considered operationally invalid. Oil consumption greater than 0.304 g/kWh requires further investigation of the test oil or the engine, or both, to determine the cause.

11.3.2 The recommended oil consumption rig plumbing is shown in **Fig. A2.8**.

12. Report

12.1 *Reporting Test Results*—For reference oil tests, the standardized report form and data dictionary for reporting the test results and for summarizing the operational data are required. The report forms and data dictionary are available on the ASTM Test Monitoring Center Web Page at <http://www.astmtmc.cmu.edu/> or can be obtained in hard copy format from the TMC.

12.1.1 During the test, if the engine is shut down or operated out of test limits, record the engine hours, time, and date (see **Annex A1**). In addition, note in the comment section all prior reference oil tests that were deemed operationally or statistically invalid or aborted.

12.1.2 When reporting reference oil test results to the TMC, transmit by facsimile the test Cover Sheet and Forms 1, 2, 4, 6, and 8 (see **Annex A1**) and any other supporting information to the ASTM TMC within five days of test completion. Mail a copy of the final test report within 30 days of test completion to the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206–4489. Electronic transfer of test results to the ASTM TMC is also permitted for approved laboratories (see **12.3**).

12.2 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits (see **Annex A1**), Other Comments.

12.3 *Electronic Transmission of Test Results*—Electronic transfer of the test report can be done utilizing the ASTM Data

Communications Committee Test Report Transmission Model (see Section 2—Flat File Transmission Format) available from the ASTM TMC.

12.4 *Plots of Operational Data*—Graphical representation of operational data is required. Place graphs on (216 by 219) mm portrait oriented paper. The x-axis (hours) shall be 127 mm in length and segmented into 10 h increments with hour labels at 50 h increments.

13. Precision and Bias¹¹

13.1 *Precision*—Test precision is established on the basis of operationally valid reference oil test results monitored by the ASTM TMC. The research report contains industry data developed prior to establishment of this test method. Practice **E29** was used as a guide to develop this data.

13.1.1 *Intermediate Precision (formerly called repeatability) 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.

13.1.1.1 *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 **Table 4** in only one case in twenty.

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

13.1.2.1 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values in **Table 4** in only one case in twenty.

13.1.3 The test precision, as of Dec. 1, 2004, is shown in **Table 4**.

13.1.4 The TMC can furnish current precision information.

13.2 *Bias*—Bias is determined by applying an accepted statistical technique to reference oil test results and when a significant bias is determined, a SA is permitted for non-reference oil test results (see **9.8.1**).

14. Keywords

14.1 diesel engine oil; lubricants; soot; T-8 diesel engine; viscosity

TABLE 4 T-8 Precision Data

| Parameter | Intermediate Precision (i.p.) | Reproducibility (R) |
|--------------------------------------|-------------------------------|---------------------|
| Viscosity increase at 3.8 % TGA soot | 2.80 | 2.83 |

¹¹ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report D02-1324.