



**Designation: D6838 – 04**

# Standard Test Method for Cummins M11 High Soot Test<sup>1</sup>

This standard is issued under the fixed designation D6838; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method is commonly referred to as the Cummins M11 High Soot Test (HST). The test method defines a heavy-duty diesel engine test procedure conducted under high soot conditions to evaluate oil performance with regard to valve train wear, sludge deposits, and oil filter plugging.<sup>2</sup>

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See Annex A1 for general safety precautions.*

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<sup>1</sup> 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 on Automotive Lubricants.

Current edition approved May 1, 2004. Published June 2004. Originally approved in 2002. Last previous edition approved in 2002 as D6838-02. DOI: 10.1520/D6838-04.

<sup>2</sup> The ASTM Test Monitoring Center (TMC) will update changes in this test method by means of Information Letters. This edition incorporates revisions in all Information Letters through No. 03-1. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489, Attention: Administrator.

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## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

- D86** Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D92** Test Method for Flash and Fire Points by Cleveland Open Cup Tester
- D97** Test Method for Pour Point of Petroleum Products
- D129** Test Method for Sulfur in Petroleum Products (General Bomb Method)
- D130** Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
- 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
- D1319** Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- 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
- D2896** Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration
- D4485** Specification for Performance of 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 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)
- D5302** Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions<sup>4</sup>
- D5844** Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)<sup>4</sup>
- D5967** Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine
- D6557** Test Method for Evaluation of Rust Preventive Characteristics of Automotive Engine Oils
- E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E344** Terminology Relating to Thermometry and Hydrometry

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>4</sup> Withdrawn. The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

2.2 *Coordinating Research Council*.<sup>5</sup>  
**CRC Manual No. 12**  
**CRC Manual No. 18 (Revised May, 1994)**

### 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. **D5844**

3.1.2 *blowby*, *n*—in *internal combustion engines*, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D5302**

3.1.3 *calibrate*, *v*—to determine the indication or output of a measuring device with respect to that of a standard. **E344**

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 maximum. **D4485**

3.1.5 *heavy-duty engine*, *adj*—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. **D5844**

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 uncalibrated test stand using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D5844**

3.1.8 *reference oil*, *n*—an oil of known performance characteristics, used as a basis for comparison. **D5844**

3.1.9 *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. **D5302**

3.1.10 *test oil*, *n*—any oil subjected to evaluation in an established procedure. **D6557**

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

3.1.11.1 *Discussion*—Wear generally occurs between two surfaces moving relative to each other, and is the result of mechanical or chemical action or by a combination of mechanical and chemical actions. **D5844**

#### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *crosshead*, *n*—an overhead component, located between the rocker arm and each intake valve and exhaust valve pair, that transfers rocker arm travel to the opening and closing of each valve pair.

3.2.1.1 *Discussion*—Each cylinder has two crossheads, one for each pair of intake valves and exhaust valves.

3.2.2 *overhead*, *n*—in *internal combustion engines*, the components of the valve train located in or above the cylinder head.

3.2.3 *overfuel*, *v*—an operating condition in which the fuel flow exceeds the standard production setting.

3.2.4 *valve train*, *n*—in *internal combustion engines*, the series of components such as valves, crossheads, rocker arms, push rods, and camshaft, that open and close the intake and exhaust valves.

### 4. Summary of Test Method

4.1 This test method uses a Cummins M11 330 E diesel engine. Test operation includes a 25-min. warm-up, a 2-h break-in, and 200 h in four 50-h stages. During stages A and C, the engine is operated with retarded fuel injection timing and is overfueled to generate excess soot. During stages B and D, the engine is operated at higher load conditions to induce valve train wear.

4.2 Prior to each test, the engine is cleaned and assembled with new cylinder liners, pistons, piston rings, and overhead valve train components. All aspects of the assembly are specified.

4.3 A forced oil drain, oil sample, and oil addition, equivalent to an oil consumption of 0.21 g/kW-h, is performed at the end of each 25-h period.

4.4 The test stand is equipped with the appropriate instrumentation to control engine speed, fuel flow, and other operating parameters.

4.5 Oil performance is determined by assessing valve cross-head wear, sludge deposits, and oil filter plugging.

### 5. Significance and Use

5.1 This test method was developed to assess the performance of an engine oil to control engine wear and deposits under heavy duty operating conditions selected to accelerate soot production, valve train wear, and deposit formation in a turbocharged, aftercooled four-stroke-cycle diesel engine.

5.2 This test method may be used for engine oil specification acceptance when all details of this test method are in compliance. Applicable engine oil service categories are included in Specification **D4485**.

5.3 The test method was correlated with field service data, determined from side-by-side comparisons of two or more oils in on-highway service. These data are contained in a research report.<sup>6</sup> These same field service oils were used to develop the operating conditions of this test method.

5.4 The design of the engine used in this test method is representative of many, but not all, modern diesel engines. This factor, along with the accelerated operating conditions should be considered when extrapolating test results.

### 6. Apparatus

#### 6.1 Test Engine Configuration:

6.1.1 *Test Engine*—The Cummins M11 330 E is an 11 L in-line turbocharged six-cylinder heavy-duty diesel engine. The engine features a U.S. 1994 emissions configuration with electronic control of fuel metering and fuel injection timing. Obtain the test engine and the engine build parts kit from the supplier listed in **A2.2**. The components of the engine build parts kit are shown in **Table A3.1**.

<sup>5</sup> Available from the Coordinating Research Council, Inc., 219 Perimeter Parkway, Atlanta, GA 30346.

<sup>6</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report **RR:D02-140**.

**6.1.2 Oil Heat Exchanger, Adapter Blocks, and Block-off Plate**—The oil heat exchanger is relocated from the stock position with the use of adapter blocks as shown in Fig. A4.1. Install an oil cooler block-off plate on the back of the coolant thermostat housing as shown in Fig. A4.1. The adapter blocks may be obtained from the supplier listed in X1.3. Control the oil temperature by directing engine coolant through the oil heat exchanger (see Fig. A4.2).

**6.1.3 Oil Pan Modification**—Modify the oil pan as shown in Fig. A4.3. A modified oil pan may be obtained from the supplier listed in X1.3.

**6.1.4 Engine Control Module (ECM)**—Obtain the ECM from the supplier listed in A2.2. The ECM programming has been modified to provide overfueling and retarded injection timing to increase soot generation and overhead wear.

**6.1.5 Air Compressor and Fuel Pump**—The engine-mounted air compressor is not used for this test method. Remove the air compressor and install the fuel injection pump in its place (see Fig. A4.4). The fuel injection pump is driven with Cummins coupling P/N 208755. The coupling may be obtained from the supplier listed in X1.1.

## 6.2 Test Stand Configuration:

**6.2.1 Engine Mounting**—Install the engine with the crankshaft in a horizontal orientation. (**Warning**—The engine mounting hardware should be configured to minimize engine block distortion when the engine is secured to the mounts. Excessive block distortion may influence test results.)

**6.2.2 Intake Air System**—With the exception of the air filter and the intake air tube, the intake air system is not specified. A typical configuration is shown in Fig. X2.1. The air filter shall have a minimum initial efficiency rating of 99.2 % (specify micron size). Install the intake air tube (see Fig. A4.5) at the intake of the turbocharger compressor. Construct the system to minimize airflow restriction. A method to cool the intake air may be required. The intake air system shall allow control of the parameters within the ranges listed in Table 5.

NOTE 1—Difficulty in achieving or maintaining intake manifold pressure or intake manifold temperature, or both, could be indicative of excessive restriction.

**6.2.3 Aftercooler**—An assembly comprised of two Cummins aftercoolers, P/N 3801547, is used to control the intake manifold temperature. The two aftercoolers assembled with the air inlet and outlet flanges at opposite ends are as shown in Fig. A4.9. The aftercoolers may be obtained from the supplier listed in X1.1.

**6.2.4 Exhaust System**—Install the exhaust tube (see Fig. A4.6) at the discharge flange of the turbocharger turbine housing. The piping downstream of the exhaust tube is not specified. A method to control exhaust pressure is required.

**6.2.5 Fuel Supply**—The fuel supply and filtration system is not specified. A typical configuration is shown in Fig. X2.2.

TABLE 1 Maximum Allowable System Time Responses

| Measurement Type | Time Response (s) |
|------------------|-------------------|
| Speed            | 2.0               |
| Temperature      | 3.0               |
| Pressure         | 3.0               |
| Flow             | TBD               |

TABLE 2 Warm-up Conditions

| Parameter                                | Unit  | Stage |      |      |      |      |
|------------------------------------------|-------|-------|------|------|------|------|
|                                          |       | A     | B    | C    | D    | E    |
| Stage Length                             | min   | 5     | 5    | 5    | 5    | 5    |
| Speed                                    | r/min | 700   | 1200 | 1600 | 1600 | 1600 |
| Torque                                   | Nom   | 135   | 270  | 540  | 1085 | 1470 |
| Coolant Out Temperature <sup>A</sup>     | °C    | 105   | 105  | 105  | 105  | 105  |
| Oil Gallery Temperature <sup>A</sup>     | °C    | 130   | 130  | 130  | 130  | 130  |
| Intake Manifold Temperature <sup>A</sup> | °C    | 70    | 70   | 70   | 70   | 70   |

<sup>A</sup> Maximum.

TABLE 3 Break-in Conditions

| Parameter                        | Unit     | Specification  |
|----------------------------------|----------|----------------|
| Stage Length                     | min      | 120            |
| Speed                            | r/min    | 1600 ± 5       |
| Torque <sup>A</sup>              | Nom      | 1470 (target)  |
| Fuel Flow                        | kg/h     | 46-50 (target) |
| Coolant Out Temperature          | °C       | 88 ± 2         |
| Fuel In Temperature              | °C       | 40 ± 2         |
| Oil Gallery Temperature (target) | °C       | 115 ± 2        |
| Intake Air Temperature           | °C       | 30 ± 2         |
| Intake Manifold Temperature      | °C       | record         |
| Oil Gallery Pressure             | kPa      | record         |
| Oil Filter Delta Pressure        | kPa      | record         |
| Intake Manifold Pressure         | kPa abs. | record         |
| Exhaust Pressure                 | kPa abs. | 107 ± 1        |
| Crankcase Pressure               | kPa      | record         |
| Inlet Air Pressure               | kPa abs. | record         |

<sup>A</sup> At standard atmospheric temperature and pressure.

TABLE 4 Normal Shutdown Conditions

| Parameter                   | unit  | Stage   |         |         |
|-----------------------------|-------|---------|---------|---------|
|                             |       | B       | A       | Idle    |
| Stage Length                | min   | 5       | 5       | 5       |
| Speed                       | r/min | 1200    | 700     | 700     |
| Torque                      | Nom   | 270     | 135     | <40     |
| Coolant Out Temperature     | °C    | 105 max | 105 max | 105 max |
| Intake Manifold Temperature | °C    | 70 max  | 70 max  | 70 max  |
| Oil Gallery Temperature     | °C    | 130 max | 130 max | 130 max |

The fuel consumption rate is determined by measuring the rate of fuel flowing into the day tank. A method to control the fuel temperature is required.

**6.2.6 Coolant System**—The coolant system configuration is not specified. A typical configuration consists of a non-ferrous core heat exchanger, a reservoir (expansion tank), and a temperature control valve as shown in Fig. X2.3. Pressurize the system by regulating air pressure at the top of the expansion tank. The system should have a sight glass to detect air entrapment. (**Warning**—Although the system volume is not specified, an excessively large volume may increase the time required for the engine fluid temperatures to attain specification. A system volume of 45 L or less (including engine) has proven satisfactory.)

**6.2.7 Pressurized Oil Fill System**—The oil fill system is not specified. A typical configuration includes an electric pump, a 50-L reservoir, and transfer hose.

**6.2.8 External Oil System**—Configure the external oil system according to Fig. A5.1. The external reservoir shall be a Moroso P/N 22660, which may be obtained from the supplier listed in X1.4.

**TABLE 5 200-h Test Sequence**

| Parameter                            | Unit     | Stage     |           |           |           |
|--------------------------------------|----------|-----------|-----------|-----------|-----------|
|                                      |          | A         | B         | C         | D         |
| Stage Length                         | h        | 50        | 50        | 50        | 50        |
| Speed                                | r/min    | 1800 ± 5  | 1600 ± 5  | 1800 ± 5  | 1600 ± 5  |
| Power                                | kW       | record    | record    | record    | record    |
| Torque (typical) <sup>A</sup>        | Nom      | 1340-1360 | 1640-1660 | 1340-1360 | 1640-1660 |
| Fuel Flow                            | kg/h     | 53 ± 1    | 53 ± 1    | 53 ± 1    | 53 ± 1    |
| Blowby Flow                          | L/min    | record    | record    | record    | record    |
| Coolant Out Temperature              | °C       | 88 ± 2    | 88 ± 2    | 88 ± 2    | 88 ± 2    |
| Coolant In Temperature               | °C       | record    | record    | record    | record    |
| Coolant Delta Temperature            | °C       | 7 max     | 7 max     | 7 max     | 7 max     |
| Fuel In Temperature                  | °C       | 40 ± 2    | 40 ± 2    | 40 ± 2    | 40 ± 2    |
| Oil Gallery Temperature              | °C       | 115 ± 2   | 115 ± 2   | 115 ± 2   | 115 ± 2   |
| Intake Air Temperature               | °C       | record    | record    | record    | record    |
| Intake Manifold Temperature          | °C       | 46 ± 2    | 46 ± 2    | 46 ± 2    | 46 ± 2    |
| Exhaust Temperature                  | °C       | record    | record    | record    | record    |
| Fuel Pressure                        | kPa      | record    | record    | record    | record    |
| Oil Gallery Pressure                 | kPa      | record    | record    | record    | record    |
| Oil Filter Delta Pressure            | kPa      | record    | record    | record    | record    |
| Coolant System Pressure <sup>B</sup> | kPa      | 99 to 107 | 99 to 107 | 99 to 107 | 99 to 107 |
| Intake Manifold Pressure             | kPa abs. | record    | record    | record    | record    |
| Exhaust Pressure                     | kPa abs. | 107 ± 1   | 107 ± 1   | 107 ± 1   | 107 ± 1   |
| Crankcase Pressure                   | kPa      | record    | record    | record    | record    |
| Inlet Air Pressure                   | kPa abs. | record    | record    | record    | record    |

<sup>A</sup> At standard atmospheric temperature and pressure.

<sup>B</sup> Measure the coolant pressure on the top of the expansion tank.

6.2.8.1 *Oil Sample Valve Location*—Locate the oil sample valve on the return line from the external oil system to the engine. Locate the valve as close to the return pump as possible (see Fig. A5.1).

6.2.8.2 Brass or copper fittings may influence used oil wear metals analyses and shall not be used in the external oil system.

6.2.9 *Crankcase Ventilation*—Vent the blowby gas at the port located on the left side of the valve cover.

6.2.10 *Blowby Rate*—The flowrate device and system configuration is not specified. Install the system using good engineering practices and operate the flowrate device according to the manufacturer's guidelines.

6.3 *System Time Responses*—The maximum allowable system time responses are shown in Table 1. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report.<sup>7</sup>

6.4 *Oil Sample Containers*—High-density polyethylene containers are recommended for oil samples. (**Warning**—Glass containers may break and may cause injury or exposure to hazardous materials, or both.)

6.5 *Mass Balance*—A balance is required to measure the mass of the crossheads and rod bearings. An electronic or mechanical balance may be utilized. The balance shall have a minimum display resolution of 0.1 mg.

## 7. Engine and Cleaning Fluids

7.1 *Test Oil*—Approximately 75 L of test oil is required to complete the test.

7.2 *Test Fuel*—Approximately 13 200 L of diesel fuel is required to complete the test. Purchase the fuel from the supplier listed in A2.1. The fuel shall be within the tolerances shown for all properties listed in Annex A6.

7.3 *Engine Coolant*—Use pre-mixed Fleetguard Compleat PG. The coolant may be obtained from the supplier listed in X1.1.

7.4 *Solvent*—Aliphatic naphtha or equivalent. (**Warning**—Use adequate safety precautions with all solvents and cleaners.)

## 8. Preparation of Apparatus

### 8.1 Cleaning of Parts:

8.1.1 *General*—The preparation of test engine components specific to the Cummins M11 test are indicated in this section. Use the Cummins service publications<sup>8</sup> listed in Annex A7 for the preparation of other engine components. Take precautions to prevent rusting of iron components.

8.1.2 *Engine Block*—Disassemble the engine, including removal of the crankshaft, camshaft, piston cooling tubes, oil pump, and oil gallery plugs. Thoroughly clean the surfaces and oil passageways. It is recommended that the oil passageways be cleaned with a brush. Removal of camshaft bearings is at the discretion of the laboratory.

8.1.3 *Cylinder Head*—Disassemble and clean the cylinder head. Use a brush as necessary to remove deposits.

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

8.1.5 *External Oil System*—Flush the internal surfaces of the oil lines and the external reservoir with solvent. Repeat until the solvent drains clean. Flush solvent through the oil pumps until the solvent drains clean.

8.1.6 *Crosshead Cleaning and Measurement*—(**Warning**—Avoid handling the crossheads with bare hands, use gloves or plastic covered tongs.)

8.1.6.1 Clean the crossheads with solvent. Use a non-metallic soft bristle brush if necessary.

<sup>7</sup> Available from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

<sup>8</sup> Available from a Cummins parts distributor.

- 8.1.6.2 Spray the crossheads with air until dry.
- 8.1.6.3 Rinse the crossheads in pentane and dry with air.
- 8.1.6.4 Measure the mass of each crosshead to a tenth of a milligram (xxx.x mg).

8.1.6.5 If an electronic scale is used for mass measurement, use the following procedure.

- (1) Demagnetize each crosshead prior to measurement.
- (2) Measure the crosshead two times. Make the second measurement with the crosshead in an orientation that is 90° from the original orientation. If the difference between the two mass measurements is greater than 0.2 mg, demagnetize the crosshead and repeat the measurement process.

8.1.6.6 Report the crosshead measurements on Form 3 listed in [Table A9.1](#).

8.1.7 *Rod Bearing Cleaning and Measurement*—**(Warning)**—Avoid handling the rod bearings with bare hands, use gloves or plastic covered tongs.)

8.1.7.1 Clean the rod bearings with solvent; use a non-metallic soft bristle brush, if necessary.

8.1.7.2 Spray the rod bearings with air until dry.

8.1.7.3 Rinse the rod bearings in pentane and dry with air.

8.1.7.4 Measure the mass of each bearing half to a tenth of a milligram (xxx.x mg).

8.1.7.5 Report the rod bearing measurements on Form 6 listed in [Table A9.1](#).

## 8.2 *Engine Assembly:*

8.2.1 *General*—Except as noted in this section, use the procedures indicated in the Cummins service publications (see [Annex A7](#)). Assemble the engine with the components from the Engine Build Parts Kit (see [Annex A3](#)). Other non-kit components are available from the suppliers listed in [X1.1](#) and [X1.2](#).

8.2.2 *Parts Reuse and Replacement*—Engine components may be reused or replaced at the discretion of the laboratory except as noted in [8.2.7](#).

8.2.3 *Build-Up Oil*—Use Cummins Premium Blue (see [X1.1](#)) or test oil to lubricate parts for engine build. If test oil is used, then the engine build is valid only for the respective test oil.

8.2.4 *Coolant Thermostat*—Lock the engine coolant thermostat open or allow it to function normally. The locked-open position is recommended.

8.2.5 *Oil Thermostat*—Remove the oil thermostat and plug the coolant passage. This shall cause all of the oil to flow through the oil cooler.

8.2.6 *Fuel Injectors*—The fuel injectors may be reused. Dedicate the injectors to a particular cylinder. Install the injectors according to the torque wrench method as noted in the Cummins service publications (see [Annex A7](#)).

8.2.7 *New Parts*—The parts listed below are contained in the Engine Build Parts Kit and are not reusable (except as noted in [10.3.3](#)). Clean the parts prior to use. Replacement of any part listed in [8.2.7.1–8.2.7.11](#) during a test shall invalidate the test.

8.2.7.1 Pistons (crown, skirt).

8.2.7.2 Piston rings (top, second, oil).

8.2.7.3 Cylinder liners.

8.2.7.4 Rocker lever shafts

8.2.7.5 Rocker lever assemblies (exhaust, intake, injector).

8.2.7.6 Valves (intake, exhaust).

8.2.7.7 Valve stem guides.

8.2.7.8 Valve inserts.

8.2.7.9 Piston cooling nozzles.

8.2.7.10 Valve crossheads.

8.2.7.11 Connecting rod bearings.

## 8.3 *Operational Measurements:*

8.3.1 *Units and Formats*—See [Annex A8](#).

8.3.2 *Instrumentation Calibration:*

8.3.2.1 *Fuel Consumption Rate Measurement Calibration*—Calibrate the fuel consumption rate measurement system before each reference oil test. Temperature-compensate volumetric systems and calibrate them against a mass flow device. The flowmeter located on the test stand shall indicate within 0.2 % of the calibration standard. Trace the calibration standard to national standards.

8.3.2.2 *Temperature Measurement Calibration*—Calibrate the temperature measurement systems at least once every six months. Each temperature measurement system shall indicate within  $\pm 0.5^{\circ}\text{C}$  of the laboratory calibration standard. Trace the calibration standard to national standards.

8.3.2.3 *Pressure Measurement Calibration*—Calibrate the pressure measurement systems at least once every six months. Locate the pressure measurement transducers in a temperature-controlled environment to minimize calibration drift. The maximum temperature variation should not exceed  $63^{\circ}\text{C}$ . Trace the calibration standard to national standards.

## 8.3.3 *Temperatures:*

8.3.3.1 *Measurement Location*—The temperature measurement locations are specified in this section. The measurement equipment is not specified. Install the sensors such that the tip is located midstream of the flow unless otherwise indicated. The accuracy and resolution of the temperature measurement sensors and the complete measurement system shall follow the guidelines detailed in a research report.<sup>9</sup>

8.3.3.2 *Coolant Out Temperature*—Install the sensor at the  $\frac{1}{8}$ -in. NPT port on the thermostat housing as shown in [Fig. A4.7](#).

8.3.3.3 *Coolant In Temperature*—Install the sensor on the right side of the coolant pump intake housing at the 1-in. NPT port as shown in [Fig. A4.7](#).

8.3.3.4 *Fuel In Temperature*—Install the sensor in the fuel pump inlet fitting as shown in [Fig. A4.4](#).

8.3.3.5 *Oil Gallery Temperature*—Install the sensor at the  $\frac{1}{4}$ -in. NPT hole on the left-rear of the engine as shown in [Fig. A4.4](#).

8.3.3.6 *Intake Air Temperature*—Install the sensor as shown on [Fig. A4.5](#).

8.3.3.7 *Intake Manifold Temperature*—Install the sensor at the  $\frac{1}{8}$ -in. NPT hole on the intake manifold as shown in [Fig. A4.7](#).

8.3.3.8 *Exhaust Temperature*—Install the sensor as shown in [Fig. A4.6](#).

8.3.3.9 *Additional*—Monitor any additional temperatures that the laboratory considers beneficial.

<sup>9</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-126.

NOTE 2—Additional exhaust sensor locations are recommended, such as the exhaust ports and pre-turbine (front and rear). The detection of changes in exhaust temperature(s) is an important diagnostic tool.

### 8.3.4 Pressures:

**8.3.4.1 Measurement Location and Equipment**—The pressure measurement locations are specified in this section. The measurement equipment is not specified. The accuracy and resolution of the pressure measurement sensors and the complete measurement system shall follow the guidelines detailed in a research report.<sup>9</sup> (**Warning**—A condensation trap should be installed at the lowest elevation of the tubing between the pressure measurement location and the final pressure sensor for crankcase pressure, intake air pressure, and exhaust pressure. Route the tubing to avoid intermediate loops or low spots before and after the condensation trap.)

**8.3.4.2 Oil Gallery Pressure**—Measure the pressure at the  $\frac{1}{16}$  in.-18 Compucheck adapter at the left-front of the engine, as shown in Fig. A4.4.

**8.3.4.3 Oil Filter Inlet Pressure**—Measure the pressure at the  $\frac{7}{8}$  in.-14 O-ring plug located on the oil filter assembly as shown in Fig. A4.8.

**8.3.4.4 Oil Filter Outlet Pressure**—Measure the pressure at the  $\frac{1}{4}$ -in. NPT port located on the oil filter assembly as shown in Fig. A4.8.

**8.3.4.5 Intake Manifold Pressure**—Measure the pressure at the  $\frac{1}{2}$ -in. NPT port at the top-front of the intake manifold as shown in Fig. A4.7.

**8.3.4.6 Crankcase Pressure**—Measure the pressure at the top-rear of the rocker cover as shown in Fig. A4.2.

**8.3.4.7 Intake Air Pressure**—Measure the pressure on the intake air tube as shown in Fig. A4.5.

**8.3.4.8 Exhaust Pressure**—Measure the pressure on the exhaust tube as shown in Fig. A4.6.

**8.3.4.9 Fuel Pressure**—Measure the pressure at the  $\frac{1}{16}$ -18 Compucheck adapter on fuel pump body as shown in Fig. A4.4.

**8.3.4.10 Coolant Pressure**—Measure the pressure on top of the expansion tank as shown in Fig. X2.3.

**8.3.4.11 Additional**—Monitor any additional pressures considered to be beneficial.

### 8.3.5 Flow Rate:

**8.3.5.1 Flow Rate Location and Measurement Equipment**—The flow rate measurement locations are specified in this section. The equipment for the blowby rate and the fuel rate are not specified. The accuracy and resolution of the flow rate measurement system shall follow the guidelines detailed in a research report.<sup>9</sup>

**8.3.5.2 Blowby**—The device or type of system used to measure the blowby flow rate is not specified. Use engineering judgement and the manufacturer's guidelines concerning the installation and use of the blowby rate measurement device.

**8.3.5.3 Fuel Flow**—The fuel consumption rate is determined by measuring the fuel flowing to the day tank as shown in Fig. X2.2.

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

**9.1 General**—Calibrate the test engine and the test stand by conducting a test with a blind reference oil. Submit the results

to the ASTM Test Monitoring Center (TMC) for determination of acceptance according to the Lubricant Test Monitoring System (LTMS).<sup>7</sup>

**9.1.1** An engine shall not be calibrated for use in more than one test stand during the calibration period of the engine.

**9.2 Calibration Configuration**—To enhance test stand utilization, a maximum of two test engines may be calibrated for use on one test stand. Notify the TMC of the intent to calibrate as either a one-engine stand or a two-engine stand.

**9.3 New Test Stand**—A new test stand is defined as a test stand that has never been calibrated or has not completed an acceptable reference oil test within 12 months of the expiration of the last calibration period. Under special circumstances, such as industry-wide parts or fuel shortages, the TMC may extend the time period beyond 12 months. Perform the following to introduce a new test stand.

**9.3.1 One-engine Stand**—Conduct two acceptable reference oil tests with one engine.

**9.3.2 Two-engine Stand**—Conduct one acceptable reference oil test with each engine.

**9.3.2.1** After a two-engine stand has been calibrated, conduct subsequent reference oil tests by alternating the two engines.

**9.3.3 Special Calibration Acceptance Criteria**—A new stand may be calibrated with only one acceptable reference oil test as detailed in the LTMS.<sup>7</sup>

### 9.4 Engine/Stand Calibration Period:

**9.4.1 Engine**—The calibration period is 12 months from the EOT date of the last acceptable reference oil test.

**9.4.2 One-engine Stand**—The calibration period is 12 months from the EOT date of the last acceptable reference oil test.

**9.4.3 Two-engine Stand**—The calibration period is 6 months from the EOT date of the last acceptable reference oil test.

**9.4.4** The TMC may schedule more frequent reference oil tests or extend the calibration period.

**9.5 Change of Calibration Configuration**—The laboratory may change the calibration configuration of a test stand according to the following:

**9.5.1 One-engine to Two-engine Stand**—Notify the TMC and conduct one acceptable reference oil test on a second engine. The stand calibration period shall change to a two-engine stand. However, the calibration period of the first engine shall not exceed 12 months, therefore: (1) If the calibration period of the first engine expires prior to the two-engine stand calibration period, then conduct an acceptable reference oil test on the first engine at the end of its calibration period. (2) Any time remaining in the calibration period of the first engine beyond the calibration period of the two-engine stand is void.

**9.5.2 Two-engine to One-engine Stand**—Notify the TMC and conduct an acceptable reference oil test. The stand calibration period shall change to a one-engine stand. The time remaining on the calibration period of the other engine, if any, is void.

**9.5.3** If an engine from a two-engine stand is removed from service, then the stand shall revert to a one-engine stand until the engine is returned to service. The calibration period

remains that of a two-engine stand. (**Warning**—Replacement of test engine components may invalidate the calibration status of the engine.)

**9.6 Stand Modification and Calibration Status**—Modification of the test stand control systems or the conducting of any non-standard test, or both, may invalidate the calibration status. A non-standard test includes any test conducted under a modified procedure, non-procedural hardware, controller set-point modifications, or a combination thereof. The TMC should be contacted prior to any changes to determine the effect upon the calibration status.

#### **9.7 Test Numbering System:**

**9.7.1 General**—The test number has three parts, X-Y-Z. X represents the test stand number, Y represents the engine serial number, and Z represents the engine block run number. For example, test number 27-4B4607-2 indicates stand number 27, engine serial number 4B4607, and the second test on the engine block. Every test start (reference oil and non-reference oil) shall increment Z by one, with the exception stated in **9.7.2**.

**9.7.2 Reference Oil Tests**—A reference oil test conducted subsequent to an unacceptable reference oil test shall include a letter suffix after Z. The letter suffix shall begin with A and increment alphabetically until an acceptable reference oil test is completed. For example, if two consecutive unacceptable reference oil tests were conducted and the first test number was 27-4B4607-10, then the second test number would be 27-4B4607-10A. A third calibration attempt would have the test number 27-4B4607-10B. If the third test was acceptable, then 27-4B4607-10B would identify the reference oil test in the test report.

**9.7.3 Non-Reference Oil Tests**—No letter suffix shall be added to Z for aborted or operationally invalid non-reference oil tests.

#### **9.8 Reference Oil Test Acceptance:**

**9.8.1** Reference oil test acceptance and laboratory severity adjustment (SA) are determined in accordance with the LTMS.<sup>7</sup>

#### **9.9 Unacceptable Reference Oil Test:**

**9.9.1** It is recognized that some reference oil test results may not fall within the LTMS acceptance limits. The laboratory, in conjunction with the TMC, shall attempt to determine the cause of the deviation. The TMC may solicit input from industry authorities to help determine the cause and extent of the problem.

**9.9.2** If the laboratory is not within the LTMS acceptance limits and the TMC has determined that probable cause is isolated to an individual stand, then non-reference oil testing on other calibrated stands may continue.

**9.9.3** If the laboratory is not within the LTMS acceptance limits and the TMC has determined that probable cause involves more than one stand, then the TMC may declare the particular stands non-calibrated. Non-reference oil tests in progress at the time of the calibration status change are not effected.

**9.9.3.1** The laboratory shall attempt to identify and correct the cause and conduct an acceptable reference oil test in at least one of the stands to demonstrate resolution of the problem.

**9.9.4** The TMC will assign reference oil when satisfied that no particular problems exist or the problem has been resolved. The laboratory shall provide adequate documentation or findings, or both, to support the conclusions reached during this process. The conclusions shall be documented in the acceptable reference oil test report.

#### **9.10 Reference Oil Accountability:**

**9.10.1** Laboratories shall provide a full accounting of the identification and quantities of all reference oils used. With the exception of the oil analyses required in **11.6**, perform no physical or chemical analyses of reference oils without written permission from the TMC. In such an event, include the written conformation and the data generated in the reference oil test report.

**9.10.2** Retain used reference oil samples for 90 days from the EOT date.

#### **9.11 Non-Reference Oil Tests:**

**9.11.1** 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 is used to determine if a significant bias exists for crosshead mass loss, average sludge, or oil filter plugging, or a combination thereof. When calibration results indicate a significant bias, an SA is determined according to the LTMS and applied to the non-reference oil test result. The SA and the adjusted result are reported on Form 1 listed in **Table A9.1**. The SA shall remain in effect until a new SA is determined from subsequent calibration tests.

**9.11.2** For a two-engine stand, the two engines shall be alternated between each non-reference oil test.

**9.11.3 Last Start Date**—A non-reference oil test shall commence engine warm-up (see **10.5**) prior to the expiration of the calibration period (see **9.4**).

## **10. Test Procedure**

**10.1 Engine Installation and Stand Connections**—Install the test engine on the stand and connect the engine to the stand support equipment.

**NOTE 3**—A final check of valve and injector settings is recommended at this time.

**10.2 Coolant System Fill**—Install a new coolant filter, Cummins WF-2071. Fill the cooling system with pre-mixed Fleetguard Compleat PG. The coolant for non-reference oil tests may be reused provided the level of inhibitors is within specification as determined by DCA Level Test Kit, Cummins P/N CC2602 (see **X1.1**). Use new coolant for each reference oil test.

**NOTE 4**—The coolant system should be pressurized to specification and checked for leaks prior to adding the test oil.

#### **10.3 Oil Fill for Break-in:**

**10.3.1** Install a new Cummins LF-3000 oil filter. The filter may be obtained from the supplier listed in **X1.1**.

**10.3.2** Use the pressurized oil fill system (see **6.2.7**) to charge the engine with 24.7 kg of test oil at the location shown in **Fig. A4.2**.

**10.3.3 Engine Build Committed**—Once the test oil has been introduced into the engine, the engine build and the test number are valid only for the respective engine build.

engine has not been cranked (whereby, the test parts have not been subjected to wear or injected fuel, or both), then the new parts may be used again. Disassemble and clean the engine according to Section 8.

10.4 *Fuel Samples*—Take a 1.0 L fuel sample at the start of the test and at EOT.

10.5 *Engine Warm-up*—The engine warm-up conditions are shown in [Table 2](#).

10.5.1 *Shutdown During Warm-up*—Stop the warm-up timer at the initiation of shutdown. When the laboratory is ready to resume warm-up, start the engine and continue the warm-up from the stage in which the shutdown occurred. The warm-up timer shall resume when the engine speed and the engine torque are within specification.

10.6 *Engine Break-in*—Perform a break-in on each new engine build prior to the start of the 200-h test procedure. The break-in conditions are shown in [Table 3](#).

10.6.1 Start the engine, perform the warm-up (see [Table 2](#)) and proceed directly to the break-in (see [Table 3](#)).

10.6.1.1 *Shutdown During the Break-in*—Stop the break-in timer at the initiation of shutdown. When the laboratory is ready to resume break-in, start the engine, perform the warm-up, and proceed to the break-in conditions. The break-in timer shall resume when the engine speed and the engine torque are within specification. If a shutdown occurs within the last 10 min of the break-in, the break-in shall be considered complete. Note such an occurrence in Other Comments of Form 17 listed in [Table A9.1](#).

10.6.2 At the completion of break-in, perform a normal shutdown (see [Table 4](#)) and shut off the engine.

10.6.3 Drain the oil from the engine and the external oil system.

10.6.4 Remove the LF-3000 oil filter.

10.6.5 Properly dispose of the drain oil and oil filter.

10.6.6 Once completed, the break-in is not repeated for the respective test.

NOTE 5—Use the break-in as an opportunity to confirm engine performance and to make repairs prior to the start of the 200-h test procedure.

10.7 *Shutdown and Maintenance*—The test may be shut down at the discretion of the laboratory to perform repairs. However, the intent of this test method is to conduct the 200-h procedure uninterrupted.

10.7.1 *Normal Shutdown*—Proceed directly from the operating conditions to the shutdown schedule in [Table 4](#).

10.7.2 *Emergency Shutdown*—An emergency shutdown occurs when the normal shutdown was not performed, such as an alarm condition. Include Emergency Shutdown on the down-time report of Form 17 shown in [Table A9.1](#).

10.7.3 *Maintenance*—Engine components or stand support equipment, or both, may be repaired or replaced at the discretion of the laboratory and in accordance with this test method.

10.7.3.1 Removal of the crossheads prior to test completion shall invalidate the test.

10.7.4 *Downtime*—The limit for total downtime and number of shutdowns is not specified. Record all shutdowns, pertinent actions, and total downtime during the 200-h test procedure on Form 17 shown in [Table A9.1](#).

10.8 *200-h Test Procedure*:

10.8.1 Measure and record the mass of a new test oil filter, Cummins P/N 390383200 (see [Table A3.1](#)), and install the oil filter on the engine.

10.8.2 *Oil Fill for Test*—Using the pressurized oil fill system (see [6.2.7](#)), charge the engine with 24.7 kg of test oil at the location shown in [Fig. A4.2](#).

10.8.3 Start the engine and perform the warm-up (see [Table 2](#)).

10.8.3.1 *Zero-hour Oil Sample*—During Stage E of the warm-up, remove a 0.23 kg oil purge sample, and remove a 0.23 kg oil analysis sample. Return the purge sample to the external oil system.

10.8.4 *Operating Conditions*—After warm-up, proceed directly to the 200-h Test Sequence (see [Table 5](#)).

10.8.4.1 *Stage Transition Times*—1 min (r/min only).

10.8.5 *Injection Timing Change*—The fuel injection timing may be adjusted once between 50 and 100 h to meet the 150-h % soot target, provided the 50-h soot is at least 2.1 %.

10.8.6 *Mass % Soot Validity*:

10.8.6.1 *Reference Oil Test*—Mass % soot shall be  $5 \pm 0.5$  % at 150 h.

10.8.6.2 *Non-Reference Oil Test*—Mass % soot shall be a minimum of 4.5 % at 150 h.

10.8.7 *Test Timer*—The 200-h test sequence timer starts when all controlled parameters shown in Stage A of [Table 5](#) are within specification. If a shutdown(s) occurs, the test timer stops immediately at the initiation of the shutdown. The test timer resumes when the test has been returned to the appropriate stage and all controlled parameters are within specification.

10.8.7.1 The test timer continues incrementing through stage transitions.

10.8.8 *Operational Data Acquisition*—Record all operational parameters shown in [Table 5](#), except Blowby Flow, with automated data acquisition at a minimum frequency of once every 6 min. Record Blowby Flow a minimum of once every 8 h. Recorded values shall have minimum resolution in accordance with [Annex A8](#). Report the characteristics of the data acquisition system on Form 18 listed in [Table A9.1](#).

10.8.8.1 The operational data is reported on Form 2 listed in [Table A9.1](#).

10.8.9 *Oil Purge, Oil Sample, and Oil Addition*—Perform a forced oil drain, oil sample, and oil addition at the end of each 25-h period. Add the new oil and the purge sample to the external oil system reservoir.

10.8.9.1 Do not shut down the engine for oil sampling and oil addition. Purge oil samples are retained at the discretion of the laboratory.

10.8.9.2 *Full and Drain Weight*—Record the oil weight indicated by the external oil system at the completion of the first test hour, this value establishes the full weight. Subtract 1.4 kg (3.1 lb) from the full weight, this value establishes the drain weight. The full weight and the drain weight are fixed for the test.

10.8.9.3 At the end of each 25-h period, take a 0.23 kg (0.51 lb) oil purge sample followed by a 0.23 kg (0.51 lb) oil analysis