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Standard Test Method for Evaluation of Diesel Engine Oils in T-9 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 lead corrosion and wear of piston rings and cylinder liners.² This test method is commonly referred to as the Mack T-9.

1.2

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 A5** for specific safety precautions.*

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2. Referenced Documents

2.1 ASTM Standards:³

D86 Test Method for Distillation of Petroleum Products at

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 on Automotive Lubricants.

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² The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. This edition includes all Information Letters through 03-1. Information Letters may be obtained from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

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.

Atmospheric Pressure

D93 Test Methods for Flash Point by Pensky-Martens Closed 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

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

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

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D482 Test Method for Ash from Petroleum Products

D524 Test Method for Ramsbottom Carbon Residue of Petroleum Products

D613 Test Method for Cetane Number of Diesel Fuel Oil

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

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

D4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter

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)⁴

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^{5 4}

D5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)⁵

D5967 Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E178 Practice for Dealing With Outlying Observations

E344 Terminology Relating to Thermometry and Hydrometry

2.2 SAE Standards.⁶

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. **D5844**

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

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 *candidate oil, n*—an oil that is intended to have the performance characteristics necessary to satisfy a specification and is intended to be tested against that specification. **D5844**

3.1.5 *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**

3.1.6 *heavy-duty engine, n*—in internal combustion engines, one that is designed to allow operation continuously at or close to its peak output. **D4485**

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

3.1.8 *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. **D5844**

3.1.9 *oxidation, n*—of engine oil, the reaction of the oil with an electron acceptor, generally oxygen, that can produce deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or combination thereof. **Sub. B Glossary⁷**

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

3.1.10.1 *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.

3.1.11 *sludge, n*—in internal combustion engines, a deposit, principally composed of insoluble resins and oxidation products from fuel combustion and lubricant, that does not drain from engine parts but can be removed by wiping with a cloth. **D5302**

3.1.12 *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

⁴ Withdrawn.

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

⁶ Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

⁷ Available from the secretary of the ASTM D02B Subcommittee.

TABLE 1 Low Sulfur Reference Diesel Fuel for Heavy Duty Engine Oil Tests

Property	Test Method	Minimum ^A	Maximum ^A
Sulfur, % weight	D2622	0.03	0.05
Gravity, ° API	D287 or D4052	32	36 (37)
Hydrocarbon Composition, % Vol.			
Aromatics	D1319 (FIA)	(27) 28	35
Olefin	D1319 (FIA)	Report	
Saturates	D1319 (FIA)	Report	
Cetane number	D613	(40) 42	48
Copper strip corrosion	D130		3
Flash point, °C	D93	54	
Cloud point, °C	D2500		–12
Pour point, °C	D97		–18
Carbon residue on 10 % residuum, %	D524 (10 % bottoms)		0.35
Water & sediment, % Vol.	D2709		0.05
Ash, % weight	D482		0.01
Viscosity, cSt @ 40°C	D445	2.0	3.2
Distillation, °C	D86		
IBP		(171) 177	199 (204)
10 %		(204) 210	232 (238)
50 %		(243) 249	277 (282)
90 %		(293) 299	327 (332)
EP		(321) 327	360 (366)

^A Minimum/maximum numbers in parentheses are EPA Certification Fuel Specifications.

specified operating conditions.

D5844

3.1.12.1 *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 for the specified control ranges, (3) downtime limitations, and (4) *special* parameter limitations.

3.1.13 *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.

D5302

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

D5302

3.1.14.1 *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 action.

4. Summary of Test Method

4.1 The test operation involves use of a Mack E7-350 V-MAC II diesel engine with a warm-up and a 1 h break-in, followed by a two-phase test consisting of 75 h at 1800 r/min and 425 h at 1250 r/min, both at constant speed and load.

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

4.3 Engine rebuild is required prior to each test. The engine power section is disassembled, solvent-cleaned, measured, and rebuilt, using all new pistons, rings, cylinder liners, and connecting rod bearings, 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 wear performance of engine oils in turbocharged and intercooled four-cycle diesel engines. Obtain results from used oil analysis and component measurements before and after test.

5.2 The test method may be 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 electronically governed engine, P/N 11GBA78786 (see **Annex A3**). 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 (4 $\frac{7}{8}$ by 6 $\frac{1}{2}$ in.), and the displacement is 12 L (728 in.³). The engine is rated at 261 kW (350 bhp) at 1800 r/min governed speed (see **SAE J1995**).

6.1.2 The ambient laboratory atmosphere should be relatively free of dirt and other contaminants as required by 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 and other contaminants on engine parts. Uniform temperature control aids in measuring and selecting parts for assembly.

6.1.3 Use the low sulfur reference diesel fuel shown in **Table 1**.

6.2 Test Engine:

6.2.1 *Mack T-9 Test Engine*—The engine is available from Mack Trucks, Inc. A complete parts list is shown in **Table A3.1**. Use test parts on a first-in/first-out basis.

6.2.2 Engine Cooling System:

6.2.2.1 Use a new Mack coolant conditioner shown in **Table A3.1**, every test, to limit scaling in the cooling system. Pressurize the system to 103 kPa (15 psi) at the expansion tank.

6.2.2.2 Use a closed-loop, pressurized external engine cooling system composed of a nonferrous condenser, radiator,

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. A2.8, Annex A2](#).

6.2.4 Auxiliary Oil System—To maintain a constant oil level in the pan, provide an additional 9.5 L (10 qt) sump by using a separate closed tank connected to the sump. Circulate oil through the tank at a rate of 5.7 ± 1.9 L/min (1.5 ± 0.5 gal/min) with an auxiliary pump. Typical oil rig plumbing is shown in [Fig. A2.7](#). The No. 6 and No. 8 lines are to have inside diameters of 10 mm ($\frac{3}{8}$ in.) and 13 mm ($\frac{1}{2}$ in.), respectively. Use a minimum No. 8 size vent line. Equivalent lines may be substituted for Aeroquip lines,⁸ provided they have the proper inside diameters.

6.2.5 Blowby Meter—Use a displacement type gas meter, or equivalent, to measure blowby. To prevent blowby condensate from draining back into the engine, the blowby line shall have a downward slope to a collection bucket. The collection bucket shall have a minimum volume of 18.9 L (5 gal). Locate the blowby meter downstream of the collection bucket. The slope of the blowby line downstream of the collection bucket is unspecified.

6.2.6 Air Supply and Filtration—Use the Mack air filter element and the Mack filter housing shown in [A3.3](#). Replace filter cartridge when 2.5 kPa (10 in. H₂O) 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.

6.2.7 Fuel Supply—Heating, cooling, or both, of the fuel supply may be required, and a recommended system is shown in [Fig. A2.9](#).

6.2.8 Intake Manifold Temperature Control—Use a Modine intercooler to control intake manifold temperature (refer to [A3.4](#)). A typical intercooler arrangement is shown in [Fig. A2.10](#).

7. Engine Fluids

7.1 Test Oil—Approximately 151 L (40 gal) 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](#). Test fuel may be obtained from the supplier shown in [A3.8](#).

7.3 Engine Coolant—Use demineralized water with less than 0.03 g/L (2 grains/gal) of salts or distilled water (do not use antifreeze solutions). It is permissible to use Pencool 3000^{9,10} coolant additive at the manufacturer's recommended rate.

⁸ Available from local industrial hose suppliers.

⁹ The sole source of supply of the apparatus known to the committee at this time is The Penray Companies, Inc., 100 Crescent Center Pkwy., Suite 104, Tucker, GA 30084.

¹⁰ If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

7.4 Cleaning Materials—Use a solvent meeting Specification [D235](#), Type II, Class C for cleaning parts. Other materials, such as diesel fuel, may be required by some labs to ensure parts cleanliness. (**Warning**—Use adequate safety precautions with all solvents and cleaners.)

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 then air dry.

8.1.4 Oil Cooler and Oil Filter—Flush the oil cooler and filter lines with solvent to remove any previous test oil, and then 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 then air dry.

8.2 Valves, Seats, Guides, and Springs:

8.2.1 Visually inspect valves, seats, and springs for defects or heavy wear and replace if necessary. Replacement of the valves, guides, and seat inserts for each test is recommended, but not required.

8.2.2 Replace and ream guides to 0.9525 ± 0.0013 cm (0.3750 ± 0.0005 in.).

8.3 Cylinder Liner, Piston, and Piston Ring Assembly:

8.3.1 Cylinder Liner Fitting—For proper heat transfer, fit cylinder liners to the block in accordance with the procedure outlined in the Mack Service Manual.¹¹

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. Record pretest measurements, as detailed in [11.1](#).

8.4 Injectors and Injection Pump:

8.4.1 Injectors—Servicing of injectors is recommended every 500 h. Resetting of injector opening pressure is recommended 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. Should a problem occur, replacement with a new injection pump that has never been serviced or rebuilt is recommended. High pressure flow calibration equipment such as a Bacharach No. 72-7010 standard injector tester is available from Mack approved dealers. Kent-Moore^{10,12} tool numbers J29539 (top dead center 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

¹¹ Available from local Mack Trucks, Inc. distributors.

¹² The sole source of supply of Kent-Moore tools known to the committee at this time is Kent-Moore Corp., 29784 Little Mack, Roseville, MI 48061.

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 Truck Inc. parts. Assemble all parts as illustrated in the Mack Service Manual except where otherwise noted. Target all dimensions for the means of the specifications. Use EF-411 (see [Annex A3](#)) for lubricating parts during assembly.

8.5.1.1 *Thermostat*—Block the thermostat wide open.

8.5.1.2 *Rod Bearings*—Install new rod bearings for each test. See [11.1](#) for pretest measurements to be recorded.

8.5.1.3 *Main Bearings*—Install new main bearings for each test.

8.5.1.4 *Piston Undercrown Cooling Nozzles*—Particular care shall be taken 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*—Use test parts on a first-in/first-out basis. Install the following new parts for each rebuild (see [Table A3.1](#) 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.

8.5.2.6 Engine coolant conditioner.

8.5.2.7 Primary fuel filter.

8.5.2.8 Secondary fuel filter.

8.5.2.9 Valve stem seals.

8.5.2.10 Connecting rod bearings.

8.5.2.11 Main bearings.

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 (NIST) 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 (32 to 300°F) range, calibrate temperature measuring systems to $\pm 0.5^\circ\text{C}$ ($\pm 1^\circ\text{F}$) at $100 \pm 1^\circ\text{C}$ ($210 \pm 2^\circ\text{F}$) and to $\pm 0.5^\circ\text{C}$ ($\pm 1^\circ\text{F}$) at $0 \pm 1^\circ\text{C}$ ($32 \pm 2^\circ\text{F}$). 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 (approximately 6 and 10 ft) from the engine and hot accessories.

8.6.2.3 *Coolant*—Locate the coolant-out thermocouple in the water manifold prior to the thermostat housing. Locate in center of water stream (refer to [Fig. A2.1](#)). Locate the

coolant-in thermocouple within 30.5 cm (12 in.) of the elbow upstream of the oil cooler (refer to [Fig. A2.2](#)).

8.6.2.4 *Oil*—Locate thermocouple on the right side of the engine on the top of the accessory drive, as shown on [Fig. A2.5](#).

8.6.2.5 *Intake Air*—Locate sensors for dry bulb 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. A2.3](#).

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 that 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, that serves as both a main gallery and 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 temperature), see [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^{10,13} (p/n # 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 (12 to 16 in.) downstream of the turbo with a 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 (4 ft) above ground level in convenient location in the lab.

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.

¹³ The sole source of supply of the apparatus known to the committee at this time is United Sensor Corp., 29784 Little Mack, Roseville, MI 48069.

TABLE 2 Maximum Allowable System Time Responses

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

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 as not to affect temperature and pressure measurements. Measure humidity at 8 h intervals, and report (see [Annex A1](#)).

8.7 *System Time Responses*—The maximum allowable system time responses are shown in [Table 2](#). Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report.¹⁴

9. Procedure

9.1 Pretest Procedure:

9.1.1 *Initial Oil Fill for Pretest Break-In*—The initial oil fill is 39.2 kg (86.4 lb) of test oil: 22.9 kg (50.4 lb) for the pan, 3.3 kg (7.2 lb) for the filters, 1.6 kg (3.6 lb) for the engine oil cooler, and 11.4 kg (25.2 lb) for the auxiliary oil reservoir and lines. Add the first 3.3 kg (7.2 lb) of fresh test oil to the oil filters (half in each filter), then turn on the auxiliary oil pumps and add an additional 35.9 kg (79.2 lb) of test oil to the engine. This oil can be added directly through the engine oil fill tube.

9.1.2 Pretest Break-In:

9.1.2.1 Start the engine, as described in [9.2](#). Run the break-in sequence described in [Table 3](#).

9.1.2.2 After the 1 h break-in, drain the oil and replace all oil filters. Refill the engine with test oil, and conduct the test in accordance with [9.4](#).

9.2 *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 (150 to 170°F). This takes approximately 10 min for a cold engine. Then go to test conditions. Start-ups are not included as test time. Start test time as soon as the engine returns to the test cycle. Define the start date and time of a test as when the engine reaches test conditions as shown in [Table 4](#). (**Warning**—The engine should be cranked prior to start-up to fill the engine oil passages. This practice will enhance engine durability significantly.)

9.3 Engine Shutdown:

9.3.1 The engine is 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. Do not count the shutdown operation as test time. Record the length and reason of each shutdown (see [Annex A1](#)).

TABLE 3 Break-in Operating Conditions

Conditions	New or Rebuild Break-in	
Time, min	30	30
Speed, r/min	1250	1800
Load, torque, N·m (lbf·ft) ^A ± 1 % ^B	1731 (1277)	1384 (1021)

^A At 98.3 kPa (29 in. Hg) and 29.5°C (85°F) dry air.

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

9.3.2 All operationally valid tests shall not exceed 15 shutdowns. Additionally, all operationally valid tests shall not exceed 200 h of downtime.

9.4 Test Cycle:

9.4.1 The test cycle includes a break-in at the conditions shown in [Table 3](#). Conduct the test at 1800 r/min full power conditions for 75 h (Phase I), followed by 1250 r/min full torque conditions for 425 h (Phase II), as described in [Table 4](#).

9.4.1.1 Based upon oil analysis, injection timing may be changed within the first 75 h of the test (Phase I) to ensure meeting the 75-h soot window of 1.5 to 2.0 %.

9.4.1.2 Check the valve lash and, if necessary, reset at 125, 250, and 375 h (50, 175, and 300 h into Phase II) ± 8 h.

9.4.2 *Operational Validity*—Determine operational validity in accordance with [Annex A9](#).

9.5 Oil Addition/Drain:

9.5.1 Initially establish the *full mark* as the oil weight after 1 h of running at Phase I test conditions. At the end of the first 50 h period, perform a forced drain that equates to an oil consumption of 0.170 g/kW·h (0.00028 lb/bhp·h). If a sample is required, follow the guidelines set forth in [9.6](#). If a sample is *not* required, then drain a sufficient amount of oil to obtain an oil weight that is 2.27 kg (5.0 lb) below the *full mark*. Then add 2.27 kg (5.0 lb) of new oil to the engine.

9.5.2 Reestablish the *full mark* as the oil weight after 1 h of running at Phase II test conditions, but *do not* add any new oil until 100 test hours (25 h into Phase II). At 100 test hours and each 50 h period thereafter, perform a forced drain that equates to an oil consumption of 0.160 g/kW·h (0.00025 lb/bhp·h). If a sample is required, follow the guidelines set forth in [9.6](#). If a sample is *not* required, then drain a sufficient amount of oil to obtain an oil weight that is 2.27 kg (5.0 lb) below this new *full mark*, and add 2.27 kg (5.0 lb) of new oil to the engine. After a shutdown, use the drain level of the previous period to determine the forced drain quantity.

9.6 *Oil Samples*—Take 118-mL (4 oz) oil samples at 25-h intervals for the first 100 h, then at 50-h intervals from 100 to 400 h. Take oil samples at 25-h intervals from 400 to 500 h. The 425 and 475 h samples are for lead content analysis only, and 30 mL (1 oz) samples may be taken instead of 118 mL (4 oz) samples. Obtain oil samples through a drain petcock located in the oil rig return line (oil pan return pump) (see [Fig. A2.8](#)). Always take oil samples before new oil is added.

9.7 Oil Consumption Calculations:

9.7.1 Record the oil weight hourly, and compute the oil consumption from these readings.

9.7.2 Calculate the average oil consumption for the test as the average of the nine 50-h periods from 51 to 500 h. Do not use the first 50-h period to calculate oil consumption.

¹⁴ Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.