Designation: D 6483 – ~~99~~03

An American National Standard

Standard Test Method for Evaluation of Diesel Engine Oils in T-9 Diesel Engine[1]

This standard is issued under the fixed designation D 6483; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method ~~is commonly referred to as the Mack T-9. This test method~~ covers an engine test procedure for evaluating

[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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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 The values stated in either SI or inch-pound units are to be regarded separately as the standard. Within the test method, the inch-pound units are shown The values given in parentheses when combined with SI units. 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 A5 for specific safety precautions.

1.4 *Table of Contents*:

[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 99-1. 02-1. Information Letters may be obtained from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

2. Referenced Documents

2.1 *ASTM Standards:*

D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure[3]
D 93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester[3]
D 97 Test Method for Pour Point of Petroleum Products[3]
D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)[3]
D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[3]
D 287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)[3]
D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)[3]
D 482 Test Method for Ash from Petroleum Products[3]
D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products[3]
D 613 Test Method for Cetane Number of Diesel Fuel Oil[4]
D 664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration[3]
D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator A~~b~~dsor~~b~~ption[3]
D 2500 Test Method for Cloud Point of Petroleum Oils[3]
D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-~~R~~ray Fluorescence Spectrometry[3]
D 2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge[3]
D 2896 Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration[3]
D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[5]
D 4485 Specification for Performance of Engine Oils[5]
D 4737 Test Method for Calculated Cetane Index by Four Variable Equation[5]
D 4739 Test Method for Base Number Determination by Potentiometric Titration[5]
D 5185 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)[5]
D 5302 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]
D 5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)[6]
D 5967 Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine[6]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[7]
E 178 Practice for Dealing With Outlying Observations[7]
E 344 Terminology Relating to Thermometry and Hydromometry[8]

2.2 *SAE Standards:*[9]

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. **D 5844**

[3] *Annual Book of ASTM Standards*, Vol 05.01.
[4] *Annual Book of ASTM Standards*, Vol 05.0~~2~~5.
[5] *Annual Book of ASTM Standards*, Vol 05.0~~3~~2.
[6] *Annual Book of ASTM Standards*, Vol ~~14.02.~~ 05.03.
[7] *Annual Book of ASTM Standards*, Vol 14.0~~3~~2.
~~[8] Available from Society~~
[8] *Annual Book* of ~~*Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.*~~ *ASTM Standards*, Vol 14.03.
[9] Available from ~~the secretary~~ Society of ~~the ASTM D02.B0 Subcommittee: J. L. Newcombe, Infineum USA, 26777 Central Park Blvd., Ste. 300, Southfield, MI 48076-4172.~~ Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

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. **D 5302**

3.1.3 *calibrate*, *v*—to determine the indication or output of a measuring device with respect to that of a standard. **E 344**

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. **D 5844**

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. **D 4485**

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. **D 4485**

3.1.7 *non-reference oil*, *n*—any oil other than a reference oil, such as a research formulation, commercial oil, or candidate oil. **D 5844**

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. **D 5844**

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 Glossary**[10]

3.1.10 *reference oil*, *n*—an oil of known performance characteristics, used as a basis for comparison. **D 5844**

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. **D 5302**

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 specified operating conditions. **D 5844**

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. **D 5302**

3.1.14 *wear*, *n*—the loss of material from, or relocation of material on, a surface. **D 5302**

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 (4⅞ by 6½ 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).

[10] Available from ~~local industrial hose suppliers.~~ the secretary of the ASTM D02.B0 Subcommittee: J. L. Newcombe, Infineum USA, 26777 Central Park Blvd., Ste. 300, Southfield, MI 48076-4172.

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 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. A2.8, 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 (3⁄8 in.) and 13 mm (1⁄2 in.), respectively. Use a minimum No. 8 size vent line. Equivalent lines may be substituted for Aeroquip lines,[11] 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. H_2O) 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.

[11] Available from The Penray Companies, Inc., 100 Crescent Center Pkwy., Suite 104, Tucker, GA 30084. local industrial hose suppliers.

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

Property	Test Method	Minimum[A]	Maximum[A]
Sulfur, % weight	D 2622	0.03	0.05
Gravity, ° API	D 287 or D 4052	32	36 (37)
Hydrocarbon Composition, % Vol.			
Aromatics	D 1319 (FIA)	(27) 28	35
Olefin	D 1319 (FIA)	Report	
Saturates	D 1319 (FIA)	Report	
Cetane number	D 613	(40) 42	48
Copper strip corrosion	D 130		3
Flash point, °C	D 93	54	
Cloud point, °C	D 2500		–12
Pour point, °C	D 97		–18
Carbon residue on 10 % residuum, %	D 524 (10 % bottoms)		0.35
Water & sediment, % Vol.	D 2709		0.05
Ash, % weight	D 482		0.01
Viscosity, cSt @ 40°C	D 445	2.0	3.2
Distillation, °C	D 86		
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.

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[12,13] coolant additive at the manufacturer's recommended rate.

7.4 *Cleaning Materials*—Use aliphatic naphtha, or equivalent, 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 aliphatic naphtha 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 aliphatic naphtha, and air-dry.

8.1.3 *Auxiliary Oil System*—Flush all oil lines, galleries, and external oil reservoirs first with a suitable solvent, such as aliphatic naphtha, 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 first with a suitable solvent, such as aliphatic naphtha, 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 aliphatic naphtha 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.[14]

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[13,15] 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 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.

[12] Available from local Mack Trucks, Inc. distributors.

[12] 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.

[13] Kent-Moore tools

[13] If you are available from Kent-Moore Corp., 29784 Little Mack, Roseville, MI 48066. 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.

[14] Available from United Sensor Corp., 29784 Little Mack, Roseville, MI 48066. local Mack Trucks, Inc. distributors.

[15] Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206–4489, Attention: Administrator.

[15] 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 48066.

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 ± 0.5°C (± 1°F) at 100 ± 1°C (210± 2°F) and to ± 0.5°C (± 1°F) at 0 ± 1°C (32 ± 2°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[13,16] (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. Install the primary fuel filter before the fuel transfer pump, and install the secondary filter before the injection pump. Accurate fuel

~~[16] Available from Rank Precision Industries, 411 East Jarvis Ave., Des Plaines, IL 60018.~~

[16] The sole source of supply of the apparatus known to the committee at this time is United Sensor Corp., 29784 Little Mack, Roseville, MI 48066.

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 on Form 2, Fig. A1.4. (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.[17]

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 on Form 8, Fig. A1.9. (see Annex A1).

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

[17] NAT-50 Natural Orange, a biodegradable detergent, is available

[17] Available from Better Engineering Manufacturing, Inc., 8361 Town Center Court, Baltimore, MD 21236-4964. Telephone: 800-229-3380. ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206–4489, Attention: Administrator.

TABLE 2 Maximum Allowable System Time Responses

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

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.

TABLE 4 Test Conditions

Parameters	Limits	
	Phase I	Phase II
Time, h	75	425[A]
Injection timing, °BTDC	variable	24
CONTROLLED PARAMETERS[B]		
Speed, r/min	1800 ± 5	1250 ± 5
Fuel flow, kg/h (lb/h)	63.3 ± 0.6 (139.5 ± 1.4)	55.0 ± 0.5 (121.2 ± 1.2)
Inlet manifold temperature, °C (°F)	43 ± 3 (110 ± 5)[C]	43 ± 3 (110 ± 5)[C]
Coolant out temp., °C (°F)	85 ± 3 (185 ± 5)	85 ± 3 (185 ± 5)
Fuel in temperature, °C (°F)	40 ± 1 (104 ± 2)	40 ± 1 (104 ± 2)
Intake air temperature, °C (°F)	25 ± 3 (77 ± 5)	25 ± 3 (77 ± 5)
Inlet air restriction, kPa (in. H_2O)	2.50 ± 0.25 (10 ± 1)	2.50 ± 0.25 (10± 1)
Exhaust back pressure, kPa (in. H_2O)	3.1 ± 0.4 (12.5 ± 1.5)	3.1 ± 0.4 (12.5± 1.5)
Coolant system pressure, kPa (psi)	103 ± 6 (15 ± 1)	103 ± 6 (15 ± 1)
UNCONTROLLED PARAMETERSs		
Torque, N·m (lbf·ft)[C]	1361/1457 (1004/1075)[D]	2118/2208 (1562/1629)[D]
Exhaust temperature, °C (°F)		
Pre-turbine	605/674 (1121/1246)	605/674 (1121/1246)
Tailpipe	428/474 (802/886)	514/559 (957/1039)
Inlet manifold pressure, kPa (in. Hg)	185/201 (55/60)[D]	149/164 (44/49)[D]
Crankcase pressure, kPa (in. H_2O)	0.27-0.60 (1.1-2.4)	0.27-0.60 (1.1-2.4)
Oil temp., °C (°F)	101/109 (214/228)	101/109 (214/228)
Main gallery oil pressure, kPa (psi)	365/436 (53/63)[E]	227/284 (33/41)[E]
Intercooler ΔP, kPa (psi)	Not to exceed 13.6 (2)	Not to exceed 13.6 (2)
Oil filter ΔP, kPa (psi)	Not to exceed 138 (20)[F]	Not to exceed 138 (20)[F]

[A] After 50, 175, and 300 h at Phase II conditions, check and reset the valve lash (that is, at 125, 250, and 375 total test hours).
[B] All control parameters shall be targeted at the mean indicated.
[C] At 98.2 kPa (29 in. Hg) and 29.5°C (85°F) dry air.
[D] When engine performance falls outside these limits, corrective action should be taken. Fuel flow is the primary control parameter.
[E] Note that pressures are typical of SAE 15W40 oils; other oil grades may show different results.
[F] If oil filter ΔP exceeds 138 kPa (20 psi), change the two full flow filters.

(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 since this is a period of stabilization of the oil scale system. Do not include oil drains and samples as oil consumption.

9.7.3 Use the following formula to calculate the oil consumption for a 50 h period:

$$\text{Oil Consumption (g/kW}-\text{h)} = (FW - Wn)/(P \times 50) \tag{1}$$

where:
FW = full weight (g),
Wn = oil scale weight at n test h before additions, samples, or drains (g), and
P = brake power output of the engine (kW).

The reported oil consumption is the average of the nine 50-h period oil consumption calculations.

9.7.4 The full weight may need to be recalculated, depending on the rate of oil consumption of the engine for the 50-h period. If the oil consumption is greater than 0.160 g/kW-h, then recalculate the full weight by subtracting the weight of the oil sample and adding the weight of the oil addition (2.27 kg) to the previous 50-h period's weight.

9.8 *Fuel Samples*— Take fuel samples (two 0.95 L [1 qt] samples) prior to the start of test and at the end of test (EOT).

9.9 *Periodic Measurements*:

9.9.1 Make measurements at 6-min intervals on the parameters listed in 9.9.2, and record statistics ~~on Form 2 Fig. A1.4.~~ (see Annex A1). Automatic data acquisition is required. Recorded values shall have minimum resolution, as shown in Table 5. Characterize the procedure used to calculate the data averages ~~on Form 10, Fig. A1.12.~~ (see Annex A1).

9.9.2 *Parameters*:

TABLE 5 Minimum Resolution of Recorded Measurements

Parameter	Record Data to Nearest	Parameter	Record Data to Nearest
Speed	1 r/min	Blowby	1 L/min
Fuel flow	0.1 kg/h	Coolant in temperature	0.1°C
Coolant out temperature	0.1°C	Oil gallery temperature	0.1°C
Fuel in temperature	0.1°C	Pre-turbine temperatures	1°C
Intake air temperature	0.1°C	Tailpipe temperature	1°C
Intake manifold temperature	0.1°C	Oil gallery pressure	1 kPa
Exhaust back pressure	0.1 kPa	Crankcase pressure	0.1 kPa
Inlet air restriction	0.1 kPa	Intake manifold pressure	1 kPa
Torque	1 N·m	Compressor discharge pressure	1 kPa
Power	1 kW	Intercooler delta pressure	0.1 kPa
Humidity	0.1 g/kg		

9.9.2.1 Speed, r/min.
9.9.2.2 Torque, N·m (lbf·ft).
9.9.2.3 Oil temperature, °C (°F).
9.9.2.4 Coolant out temperature, °C (°F).
9.9.2.5 Coolant in temperature, °C (°F).
9.9.2.6 Intake air temperature, °C (°F).
9.9.2.7 Intake manifold temperature, °C (°F).
9.9.2.8 Intake manifold pressure, kPa (in. Hg).
9.9.2.9 Fuel flow, s/kg or kg/h (s/lb or lb/h).
9.9.2.10 Fuel inlet temperature, °C (°F).
9.9.2.11 Tailpipe exhaust back pressure, kPa (in. H_2O).
9.9.2.12 Before filter oil pressure, kPa (psi).
9.9.2.13 Main gallery oil pressure, kPa (psi).
9.9.2.14 Crankcase pressure, kPa (in. H_2O).
9.9.2.15 Pre-turbine exhaust temperature, front manifold, °C (°F).
9.9.2.16 Pre-turbine exhaust temperature, rear manifold, °C (°F).
9.9.2.17 Inlet air restriction, kPa (in. H_2O).
9.9.2.18 Tailpipe exhaust temperature, °C (°F).
9.9.2.19 Crankcase blowby, L/min (ft^3/min) (see 10.10).
9.9.2.20 Pre-turbine exhaust pressure, front manifold, kPa (in. Hg).
9.9.2.21 Pre-turbine exhaust pressure, rear manifold, kPa (in. Hg).
9.9.2.22 Inlet air humidity, g/kg (grains/lb).

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

9.11 *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 on Fig. A1.2 for non-reference oils and on Fig. A1.3 for reference oils (see Annex A1). Centrifugal oil filter mass gain determination is required for calibration tests and optional for non-reference oil tests.

9.12 *Oil Filter ΔP Calculation* —The reported oil filter ΔP is the maximum oil filter ΔP that occurs as a result of the test. Calculate the oil filter ΔP as follows:

$$\Delta P = \Delta Pmax - \Delta Pinitial \quad (2)$$

where:

$\Delta Pmax$ = the maximum ΔP across the oil filter, and
$\Delta Pinitial$ = the ΔP across the oil filter at the start of test conditions.

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. Change the oil filter if the ΔP exceeds 138 kPa (20 psi).

10. Inspection of Engine, Fuel, and Oil

10.1 *Pretest Measurements*:

10.1.1 *Pistons*—No piston measurements are required.

10.1.2 *Cylinder Sleeves Inside Diameter Surface Finish*—Measurement is to be an average of four readings, taken at 90° intervals over a 12.7-mm (0.50-in.) axial trace length, beginning at 6.35 mm (0.25 in.) from the top of the sleeve and extending to 19.1 mm (0.75 in.) from the top of the sleeve. Identify these trace locations as 12 o'clock (12:00), 3 o'clock (3:00), 6 o'clock

(6:00), and 9 o'clock (9:00). For reference, locate 12:00 towards the front of engine. Designate the cylinder number equivalent permanent mark on the water jacket portion of the sleeve's outside diameter.

10.1.3 *Piston Rings*:

10.1.3.1 Prior to measuring rings, identify the cylinder number by a series of small axial notches filed in the top inside diameter corner, to the left of the ring gap, with the gap oriented at 12:00. Be careful not to raise a burr while marking the ring.

10.1.3.2 Clean the rings with aliphatic naphtha (see 7.4). Use a soft brush if necessary. Spray rings dry with air. Rinse in pentane. Do not handle rings with bare hands. Use gloves or plastic covered tongs.

10.1.3.3 The ring measurements specified in 10.1.3.4 are required. The ring measurements specified in 10.1.3.5-10.1.3.9 are optional.

10.1.3.4 Weigh the top rings, second rings, and oil rings on a scale capable of a resolution of 1 mg. Include the oil ring expander in the oil ring weight.

10.1.3.5 Measure ring end gaps for the top ring, second ring, and oil ring with the ring individually confined in a 123.825-mm (4.8750-in.) diameter gage and through a cutout of no more than 12.7 mm (0.50 in.) in length. Be careful not to raise a burr while inserting the ring.

10.1.3.6 Take ring face profile traces at 25.4 mm (1 in.) from gap (both sides) and 180° from gap. Profile traces shall be of sufficient magnification to determine face bearing widths to compare with post-test measurements in order to determine wear.

10.1.3.7 Take ring height measurements for the top ring 25.4 mm (1 in.) from gap (both sides) and 180° from gap. Use a special holder with a 2.54-mm (0.10-in.) gage width for this keystone ring. Use a dial indicator and establish zero by using a calibration ring or a standard made into the holder.

10.1.3.8 Take second ring axial width measurements 25.4 mm (0.10 in.) from gap (both sides) and 180° from gap. To measure the width (top to bottom) of this rectangular ring, use a hand held micrometer.

10.1.3.9 Take oil ring rail face width/profile measurements 25.4 mm (1 in.) from gap (both sides) and 180° from gap.

10.1.4 *Connecting Rod Bearings*:

10.1.4.1 Prior to measuring, mark bearings with a single digit on the locating tang to identify cylinder location.

10.1.4.2 Clean the bearings with aliphatic naphtha (see 7.4). Use a soft brush if necessary. Spray bearings dry with air. Rinse in pentane. Do not handle bearings with bare hands. Use gloves or plastic covered tongs.

10.1.4.3 Weigh bearings on a scale capable of a resolution of 1 mg.

10.2 *Post-Test Engine Measurements* :

10.2.1 *Pistons*:

10.2.1.1 Before removing pistons, carefully remove carbon from top of cylinder sleeve. *Do not remove any metal.*

10.2.1.2 No piston measurements are required.

10.2.2 *Cylinder Sleeves*:

10.2.2.1 To maintain accuracy and precision, conduct all cylinder sleeve post-test wear measurements at a TMC-calibrated laboratory.

10.2.2.2 Prior to removing sleeves from block at end of test, each of the twelve clock positions should be marked on the top of the sleeves with 12:00 position being the front of the engine.

~~10.2.2.3 Profile traces of~~

10.2.2.3 Measure the top ring turnaround wear step ~~can be taken~~ in accordance with ~~a Taylor Hobson Form Talysurf,[16] or similar equipment, at each of the twelve clock face positions. Trace length shall be 50.8 mm (2.00 in.) with a least 2.54 mm (0.10 in.) being on the unworn surface above the ring turnaround. The maximum depth from that unworn surface to the bottom of the wear notch will be used for the evaluation. See~~ Annex ~~A4 for instructions on measuring the cylinder sleeves.~~ A4.

10.2.3 *Piston Rings*:

10.2.3.1 Place the rings in a blaster, and blast the carbon coated surfaces with a walnut shell medium until the carbon has been removed from the grooves in the rings.

10.2.3.2 Mix a solution of 2500 mL water and 50 mL Natural Orange[13,18] (or equivalent) in a container. Place the rings in the solution, and then place the container into a sonic cleaner for 15 min. Visually inspect the rings for cleanliness. If carbon remains on the rings, soak the rings for an additional 5 to 10 min in the sonic cleaner.

10.2.3.3 Rinse the rings in hot water immediately after removing them from the cleaning solution.

10.2.3.4 Spray the rings with aliphatic naphtha and then spray the rings dry with air. Rinse in pentane. Do not handle rings with bare hands. Use gloves or plastic covered tongs.

10.2.3.5 The ring measurements specified in 10.2.3.6 are required. The ring weight loss will be used for the test evaluation. The ring measurements specified in 10.2.3.7-10.2.3.11 are optional.

10.2.3.6 Weigh top rings, second rings, and oil rings on a scale capable of a resolution of 1 mg. Include the oil ring expander in the oil ring weight.

10.2.3.7 Measure ring end gaps for the top ring, second ring, and oil ring with the ring individually confined in a 123.825-mm

~~[18] Available from ASTM Headquarters. Request RR:D02-1439.~~

[18] The sole source of supply of the biodegradable detergent known to the committee at this time is Better Engineering Manufacturing, Inc., 8361 Town Center Court, Baltimore, MD 21236-4964.

(4.8750-in.) diameter gage and through a cutout of no more than 12.7 mm (0.50 in.) in length. Be careful not to raise a burr while inserting or removing the ring.

10.2.3.8 Take ring face profile traces at 25.4 mm (1 in.) from gap (both sides) and 180° from gap. Profile traces should be of sufficient magnification to determine face bearing widths to compare with pretest measurements in order to determine wear.

10.2.3.9 Take ring height measurements for the top ring at 25.4 mm (1 in.) from gap (both sides) and 180° from gap. Use a special holder with a 2.54-mm (0.10-in.) gage width for this keystone ring. Use a dial indicator, and establish zero by using a calibration ring or a standard made into the holder.

10.2.3.10 Take second ring axial width measurements 25.4 mm (1 in.) from gap (both sides) and 180° from gap. Measure the width (top to bottom) of this rectangular ring with a hand held micrometer.

10.2.3.11 Take oil ring rail face width/profile measurements 25.4 mm (1 in.) from gap (both sides) and 180° from gap.

10.2.4 *Connecting Rod Bearings*:

10.2.4.1 Clean the bearings with aliphatic naphtha (see 7.4). Use a soft brush if necessary. Spray bearings dry with air. Rinse in pentane. Do not handle bearings with bare hands. Use gloves or plastic covered tongs.

10.2.4.2 Weigh bearings on a scale capable of a resolution of 1 mg.

10.3 *Oil Inspection*— Analyze oil samples for viscosity at 100°C (212°F) in accordance with either Test Method D 455 or D 5967, Annex A3. Base viscosity increase on the minimum viscosity as reported on Form 5, Fig. A1.7. (see Annex A1). In addition to the viscosity measurements, conduct soot analysis in accordance with Test Method D 5967, Annex A4. To maintain accuracy and precision, conduct all soot measurements at a TMC-calibrated laboratory. Determine wear metals content (iron, lead, copper, chromium, aluminum), additive metals content, and silicon and sodium levels in accordance with Test Method D 5185 every 50 h from 0 h to EOT. Conduct the 400 and 500-h lead content measurements at least twice, and report the average value. Additionally, determine lead content at 425 and 475 h. Conduct oil analysis as soon as possible after sampling. Determine base number every 50 h, including EOT, in accordance with Test Method D 4739; refer to Annex A7 for certain specific instructions for this test. Determine acid number every 50 h, including EOT, in accordance with Test Method D 664; refer to Annex A8 for certain specific instructions for this test.

10.4 *Fuel Inspections*— Use fuel purchase inspection records to ensure conformance to the specifications listed in Table 1 and to complete Form 9, Fig. A1.11 (see Annex A1) for the last batch of fuel used during the test. In addition, perform the following inspections on new (0 h) and EOT (500 h) fuel samples:

10.4.1 API gravity at 15.6°C (60°F), Test Method D 287 or D 4052.

10.4.2 Total sulfur, percent weight, Test Method D 129 or D 2622.

10.4.3 Use one 0.95 L (1 qt) sample for inspections.

10.5 *Oil Consumption*:

10.5.1 Compute average oil consumption for the test and report in g/kW-h. A value of 0.182 g/kW-h (0.0003 lb/bhp-h) or lower is desirable. For calibration tests, if oil consumption exceeds 0.304 g/kW-h (0.0005 lb/bhp-h), consider the test operationally invalid. Oil consumption greater than 0.304 g/kW-h (0.0005 lb/bhp-h) requires further investigation of the test oil or the engine, or both, to determine the cause.

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

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

11.1 *Calibration Frequency*—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.

11.2 *Calibration Reference Oils* :

11.2.1 The reference oils used to calibrate T-9 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).

11.2.2 *Reference Oils Analysis*—Do not submit reference oils to physical or chemical analyses for identification purposes. Identifying the oils by analyses 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 analyses other than those specified within this procedure unless specifically authorized by the TMC. In such cases where analyses are authorized, supply written confirmation of the circumstances involved, the data obtained, and the name of the person authorizing the analysis to the TMC.

11.3 *Test Numbering*— Number each T-9 test to identify the test stand number, the test stand run number, engine serial number, and engine h at the start of the test. The sequential stand run number remains unchanged for reruns of aborted, invalid, or unacceptable calibration tests. However, follow the sequential stand run number by the letter *A* for the first rerun, *B* for the second, and so forth. For calibration tests, engine h shall be zero. For non-reference tests, engine h are the test h accumulated since last reference. For example, 58-12A-2H0380-0 defines a test on stand 58 and stand run 12 as a calibration test, which was run twice on engine 2H0380 (serial number). A test number of 58-14-2H0380-500 defines a test on stand 58 and stand run 14 as a non-reference oil test on engine 2H0380, which has run 500 h since the last reference.

11.4 *New Laboratories and New Test Stands*:

11.4.1 A new laboratory is defined as any laboratory that has never previously calibrated a test stand under this test method or has not calibrated a test stand within two years from the end of the last successful calibration test. All stands at a new laboratory are considered new stands.

11.4.2 A new stand is defined as an engine, dynamometer/cell, and support hardware that has never previously been calibrated under this test method or has not been calibrated within two years from the end of the last successful calibration test on that stand. A new engine in an existing test stand only requires one successful calibration test.

11.4.3 A new test stand shall have two acceptable calibration tests to be considered calibrated.

11.5 *Test Stand and Engine Calibration* :

11.5.1 *Test Stand Calibration*—Perform a calibration test on a reference oil assigned by the TMC after one year or 5000 h of non-reference test time (whichever comes first) have elapsed since the completion of the last successful calibration test. A non-reference test may be started provided at least one h remains in the calibration period. It is permissible to calibrate two engines in a single test stand. An unsuccessful calibration test voids any current calibration on the test stand and the associated engine.

11.5.2 *Engine Calibration*—Perform a calibration test on a reference oil assigned by the TMC after two years, 5000 h of non-reference test time, or one year of idle nontest conditions (whichever comes first) have elapsed since the completion of the last successful calibration test. A non-reference test may be started provided at least 1 h remains in the calibration period.

11.5.3 The TMC may schedule more frequent calibration tests at their discretion.

11.5.4 If nonstandard tests are conducted on a calibrated test stand, the TMC may require the test stand to be recalibrated prior to running standard tests.

11.5.5 The TMC may extend calibrations at their discretion.

11.6 *Test Results*:

11.6.1 The specified test results are average top ring weight loss (mg), adjusted average liner wear (µm), and Δ lead (ppm).

11.6.2 *Average Top Ring Weight Loss* :

11.6.2.1 Examine the top rings for flaking. Remove any rings that exhibit flaking as observed by the unaided eye from the average top ring weight loss calculation. Report flaked rings ~~on Form 4, Fig. A1.6.~~ (see Annex A1).

11.6.2.2 Use Practice E 178, two-sided test at a 95 % significance level, to determine if any of the top ring weight loss values are outliers. Report outlier rings ~~on Form 4, Fig. A1.6.~~ (see Annex A1).

11.6.2.3 Calculate the average top ring weight loss, using all rings that do not exhibit flaking and are not considered outliers. Use a minimum of three rings to calculate average top ring weight loss. If more than two rings exhibit flaking, consider the test noninterpretable as per the minimum of four cylinder liners needed for liner wear measurements (refer to 11.6.3.3).

11.6.3 *Adjusted Average Liner Wear* :

11.6.3.1 For each top ring that exhibits flaking, remove the corresponding cylinder liner from the average liner wear calculation. Report the affected cylinder liners ~~on Form 7, Fig. A1.9.~~ (see Annex A1).

11.6.3.2 Use Practice E 178, two-sided test at a 95 % significance level, to determine if any of the cylinder liner wear step values are outliers. Report outlier cylinder liners ~~on Form 7, Fig. A1.9.~~ (see Annex A1).

11.6.3.3 Calculate the average cylinder liner wear step, using all cylinder liners that are not considered outliers and for which the top ring did not exhibit flaking. Use a minimum of four cylinder liners to calculate the average cylinder liner wear. If, due to ring flaking, less than four liners are available, then consider the test noninterpretable. If, due to ring flaking, exactly four liners are available, then do not screen for outliers as described in 11.6.3.2 and report the measured average cylinder liner wear step as the outlier screened average cylinder liner wear step.

11.6.3.4 Calculate adjusted average liner wear (ALW) in accordance with the following:

$$ALW = ACLW + 10.46\,(1.75 - SOOTAVG)\ \mu m \tag{3}$$

where:

ACLW = outlier screened average cylinder liner wear step, µm, and
SOOTAVG = arithmetic average of the ten soot measurements from 75 to 500 h.

Note that *SOOTAVG* shall be no less than 1.5 and no greater than 2.4. For calculated *SOOTAVG* values outside this range, these limiting values shall be used in the *ALW* calculation.

11.6.4 Δ*Lead*:

11.6.4.1 Δ Lead results are adjusted to account for any upper rod bearing weight loss outliers.

~~*(a)*~~*(1)* Calculate the measured average upper rod bearing weight loss and report the value ~~on Form 3, Fig. A1.5.~~ (see Annex A1).

~~*(b)*~~*(2)* Use Practice E 178, two-sided test at a 95 % significance level, to determine if any rod bearing weight loss values are outliers. Report the outlier screened average upper rod bearing weight loss ~~on Form 3, Fig. A1.5.~~ (see Annex A1). If no outliers were identified, this value will be identical to the measure value calculated in 11.6.4.1 (~~*a*~~*1*).

11.6.4.2 Calculate Δ lead in accordance with the following:

$$\Delta lead = (lead_{500} - lead_{NEW}) \times (OABWLU/ABWLU) \tag{4}$$

where:

$lead_{500}$	=	lead content of the 500 h oil sample, ppm,
$lead_{NEW}$	=	lead content of the new oil sample, ppm,
ABWLU	=	as measured upper rod bearing weight loss, mg, and
OABWLU	=	outlier screened upper rod bearing weight loss, mg.

11.7 *Reference and Non-Reference Oil Test Requirements*:

11.7.1 All operationally valid tests shall produce a TGA soot level between 1.5 and 2.0 % inclusive at 75 h. Any test that misses the 75-h soot window is considered operationally invalid. A lab should terminate a test that has missed the 75-h soot window.

11.7.1.1 Injection timing can be adjusted any time within the first 75 h to meet the 75-h soot window. However, during the first 75 h, do not adjust injection timing more than ± 5° from the initial injection timing.

11.7.2 Calibration acceptance is determined in accordance with the Lubricant Test Monitoring System[17] (LTMS) as administered by the TMC.

11.7.3 Fixed candidate oil pass criteria are published in Specification D 4485. This test method may also be included in other specifications, that may contain criteria other than those in Specification D 4485.

11.8 *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 identifying when a bias becomes significant for average top ring weight loss, adjusted cylinder liner wear, and Δ lead at EOT. When calibration test results identify a significant bias, a SA is determined in accordance with LTMS. Report the SA value on Form 1, Fig. A1.2 (see Annex A1) in the space for SA. Add this SA value to non-reference oil test results, and enter the adjusted result in the appropriate space. The SA remains in effect until a new SA is determined from subsequent calibration test results, or the test results indicate the bias is no longer significant. Calculate and apply SAs on a laboratory basis.

12. Report

12.1 Report the following information:

12.1.1 *Reporting Reference Test Results* —Report forms are shown in Annex A1. Fill out forms in accordance with—For reference oil tests, the formats shown in Annex A6. The Data Dictionary is presented as Fig. A6.2. When transmitting this Data Dictionary, a Header Data Dictionary should proceed standardized report form set and data dictionary for reporting the test results and for summarizing the operational data are required. The latest version of this Header Data Dictionary can be obtained from report forms and data dictionary are available on the ASTM Test Monitoring Center either by ftp (internet) Web Page at http://www.astmtmc.cmu.edu/ or by calling the Test Engineer responsible for this particular test. Round the data can be obtained in accordance with Practice E 29. hard copy format from the TMC.

12.1.1.1 During the test, if the engine is shut down or operated out of test limits, record the engine h, time, and data on Form 8 (see Fig. A1.10). Annex A1). In addition, all prior reference oil tests that were deemed operationally or statistically invalid should be noted in the comment section.

12.1.1.2 When reporting reference oil test results, transmit by facsimile Figs. A1.1, A1.3, A1.4, A1.7, and A1.10 (reference (see Annex A1) and any other supporting information to the ASTM TMC at (412) 365-1045 within five working days of test completion. Mail a copy of the final test report within 30 days of test completion to:

(a)(1) ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489

(b)(2) Electronic transfer of test results to the ASTM TMC is also permitted for approved laboratories (see 12.1.3)

12.1.2 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits on Form 8 (see Fig. A1.10) Annex A1) under Other Comments.

12.1.3 *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 TMC.[17]

13. Precision and Bias

13.1 *Precision*:

13.1.1 Test precision is established on the basis of operationally valid reference oil test results monitored by the TMC. Research Report RR:D02-1439[19] contains industry data developed prior to establishment of this test method.

13.1.1.1 *Intermediate p Precision (r) (formerly called repeatability) is the difference between two Conditions* —Conditions where test results are obtained by a laboratory using with the same test method and using the same oil. For this test oil, with changing conditions such as operators, measuring equipment, test stands, and time.

13.1.1.2 *Intermediate Precision Limit (i.p.)*—The difference between two results obtained, under intermediate precision can be expected to conditions that would in the long run, in the normal and correct conduct of the test method, exceed the values in Table 6 in only one case in twenty.

[19] Available from local hardware retailers.
[19] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1439.

TABLE 6 Test Precision

Test Result	Intermediate Precision, (*r*)	Reproducibility, (*R*)
Test Result	Intermediate Precision, (*i.p.*)	Reproducibility, (*R*)
Measured Units		
Adjusted liner wear, µm	5.96	6.58
Top ring weight loss, mg	80.36	80.36
Transformed Units		
ΔPb, ppm	3.226	3.226

13.1.1.2 Reproducibility (*R*) is the difference between two

13.1.1.3 *Reproducibility Conditions*—Conditions where test results are obtained by different laboratories, within a short time period, using with the same test method and using the same oil. For this test oil in different laboratories with different operators using different equipment.

13.1.1.4 *Reproducibility Limit (R)*—The difference between two results obtained, under reproducibility can be expected to conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 6 in only one case in twenty.

13.1.2 Test precision, as of January 1, 1998, is shown in Table 6.

13.1.3 The TMC will be able to update precision data as it becomes available.

13.2 *Bias*—Bias is determined by applying an accepted statistical technique to reference oil test results. When a significant bias is determined, a severity adjustment is permitted for non-reference oil test results (see 11.8).

14. Keywords

14.1 cylinder liner wear; diesel engine oil; lead; lubricants; soot; top ring weight loss; T-9 Diesel Engine

ANNEXES

(Mandatory Information)

A1. REPORT FORMS

A1.1 The required report forms are available on the ASTM Test results shall Monitoring Center Web Page at http://www.astmtmc.cmu.edu/ or can be recorded to capture obtained in hard copy format from the data necessary to evaluate the engine oil tested. Record these results TMC.

Fig. A1.1 (Form 0)	Cover Sheet
Fig. A1.2 (Form 1)	Non-Reference Oil Test Result Summary
Fig. A1.3 (Form 1a)	Reference Oil Test Summary
Fig. A1.4 (Form 2)	Operational Summary
Fig. A1.5 (Form 3)	Rod Bearing Weight Loss
Fig. A1.6 (Form 4)	Ring Weight Loss
Fig. A1.7 (Form 5)	Oil Analysis Summary
Fig. A1.8 (Form 6)	Liner Surface Roughness and Bore Diameter
Fig. A1.9 (Form 7)	Liner Wear Summary
Fig. A1.10 (Form 8)	Unscheduled Downtime and Maintenance Summary
Fig. A1.11 (Form 9)	Test Fuel Analysis
Fig. A1.12 (Form 10)	Characteristics of the supporting data on Forms 1 through 11. See Figs. A1.1-A1.13. Data Acquisition System

Fig. A1.12 (Form 10)	Characteristics of the Data Acquisition System
Fig. A1.13 (Form 11)	Buildup and Hardware Information

A2. SENSOR LOCATIONS

A2.1 Properly locating the sensor devices is important to this test method. Figs. A2.1-A2.10 indicate the sensor locations for the T-9 engine components.

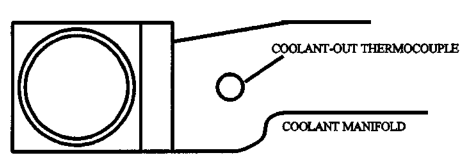

FIG. A2.1 Coolant-out Thermocouple Location (Top View)

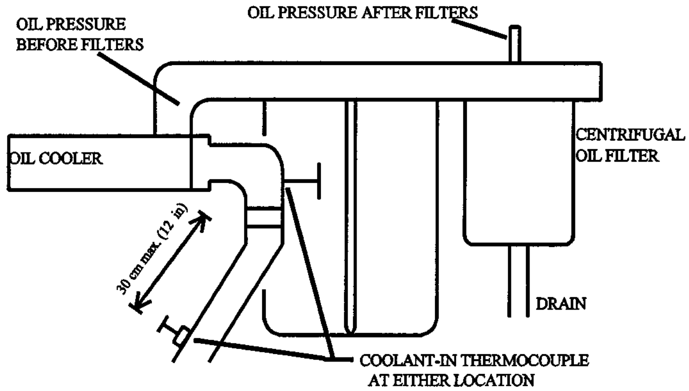

FIG. A2.2 Oil Pressure Taps and Coolant-in Thermocouple Locations

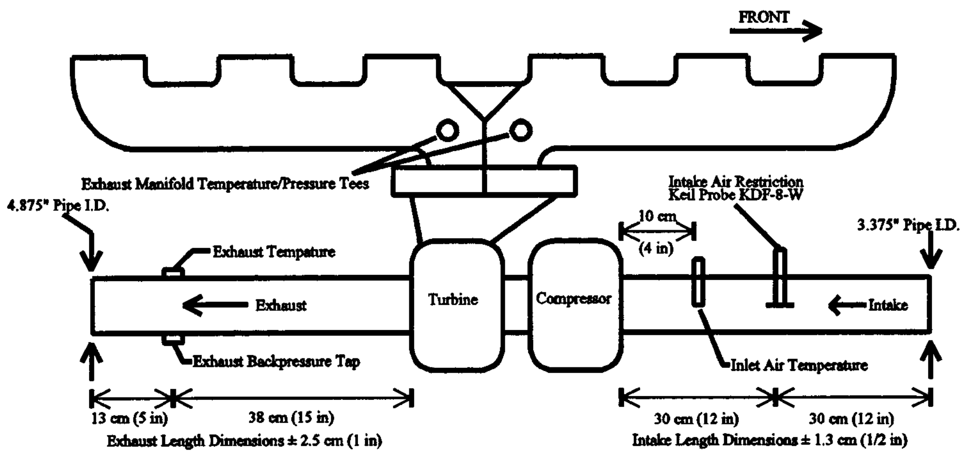

FIG. A2.3 Intake Pipe, Exhaust Manifold, and Exhaust Pipe Temperature and Pressure Sensor Locations

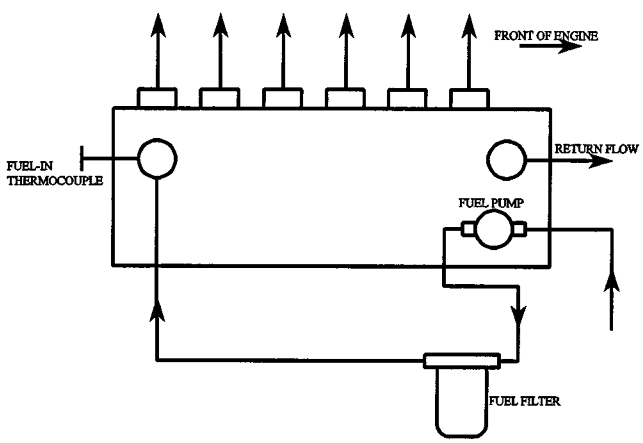

FIG. A2.4 Fuel-in Thermocouple Location

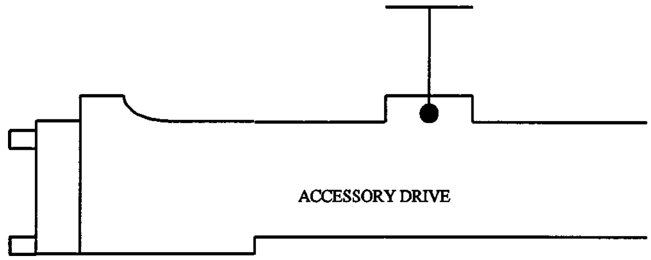

FIG. A2.5 Oil Temperature Thermocouple Location

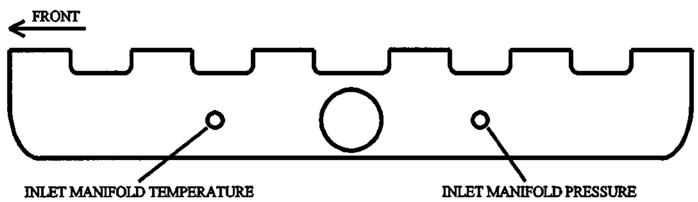

FIG. A2.6 Inlet Manifold Temperature and Pressure Sensor Locations

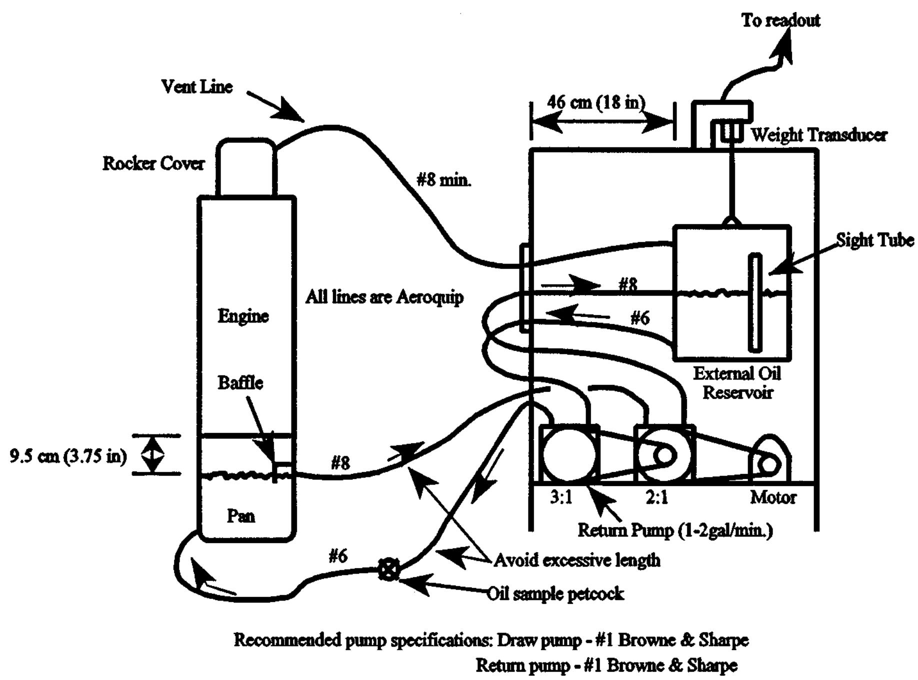

FIG. A2.7 Oil Rig Plumbing

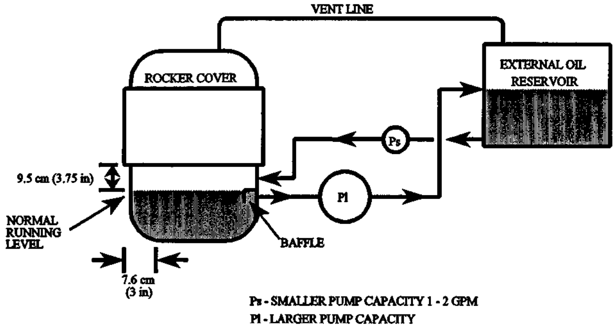

FIG. A2.8 Auxiliary Oil System

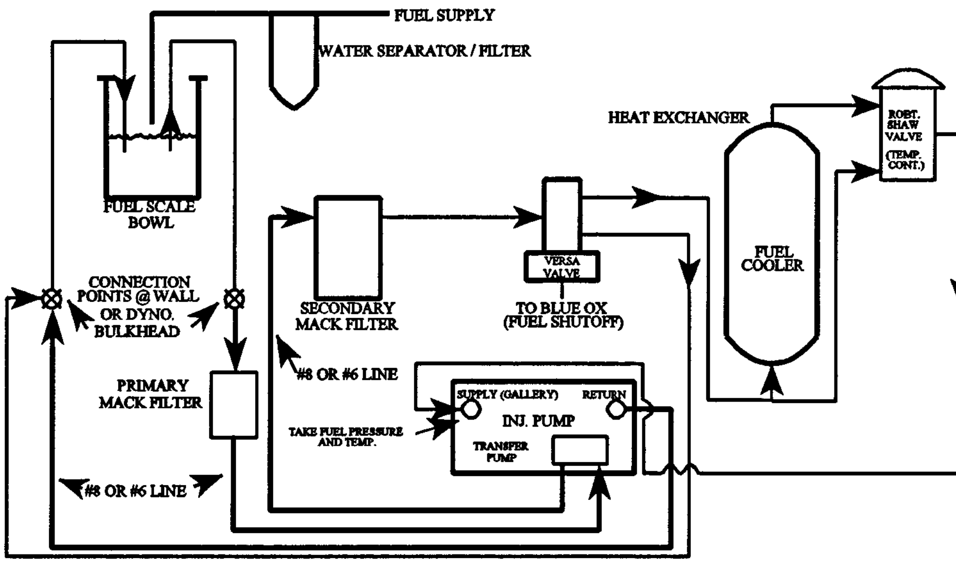

FIG. A2.9 Test Cell Fuel System Schematic

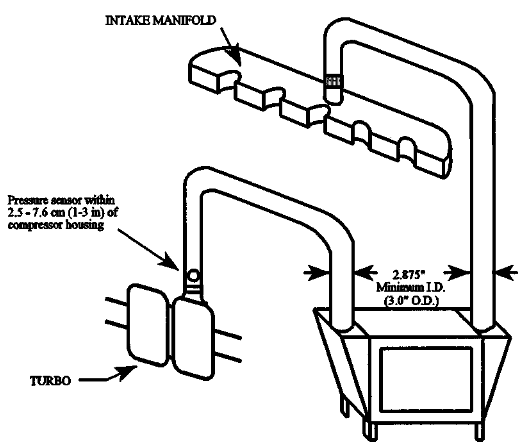

FIG. A2.10 Test Cell Intercooler Arrangement

A3. PROCUREMENT OF TEST MATERIALS

A3.1 Throughout the test method, references are made to necessary hardware, reagents, materials, and apparatus. In many cases, for the sake of uniformity and ease of acquisition, certain suppliers are named. If substitutions are deemed appropriate for the specified suppliers, obtain permission to substitute in writing from the TMC before such substitutions will be considered to be *equivalent* . The following entries of the annex represent a consolidated listing of the ordering information necessary to complete the references found in the test method.

A3.2 Parts shown in Table A3.1 are available from:

Test Engineering, Inc.
12758 Cimarron Path - Suite 102
San Antonio, TX 78249-3417

A3.3 *Air Filtration* —Mack air filter element (p/n 57MD33) and Mack air filter housing (p/n 2MD3183) are available from Mack Trucks, Inc.

A3.4 *Intercooler* —When ordering the Modine cooler from Mack Trucks Inc., instruct the dealers to use P/N 5424 03 928 031. Because it is a nonstocked part in the Mack Parts Distribution System, it will appear as an invalid P/N. Explain that the P/N is valid and that you want to have it expedited on a *Ship Direct* purchase order. It will then be shipped from Modine to you, bypassing the normal parts distribution system.

A3.5 Aliphatic naphtha (Stoddard solvent) is available from local petroleum product suppliers.

A3.6 Noncompounded oil ISO VG 32 (SAE 20) is available through lubricant marketers.

A3.7 EF-411 is supplied by Mobile Oil Corp., Att: Illinois Order Board, P.O. Box 66940, AMF-O'Hare, IL 60666. Request P/N 47503-8.

A3.8 Low Sulfur Reference Diesel Fuel is available from Specified Fuels & Chemicals, 1201 S. Sheldon Rd., P.O. Box 429, Channelview, TX 77530-0429.

A4. INSTRUCTIONS FOR MEASURING T-9 CYLINDER ~~SLEEVES USING TAYLOR HOBSON FORM TALYSURF~~ SLEEVES

A4.1 ~~Use a *green* Scotchbrite fiber pad[19] and WD40~~ Measure cylinder wear step according to Instructions For Measuring Cylinder Sleeves, which is available from the ~~sleeve inside diameter above ring travel. Be sure to remove any traces of carbon. Clean away any remaining oil or dirt residue by wiping with a lens cleaning tissue dipped in alcohol.~~

~~A4.2 Mark the sleeve every 30° (use the clock face positions numbered in a clockwise direction). Looking~~ ASTM Test Monitoring Center Web Page at ~~the top of the sleeve, *front* shall~~ http://www.astmtmc.cmu.edu/ or can be ~~the 12:00 position.~~

~~A4.3 It is recommended that the sleeve be fixed~~ obtained in ~~a V-block for tracing of the PRt data. This allows a full 360° rotation of the sleeve on a common centerline. To obtain the ± 0.1° slope tolerance, the V-block should also be adjustable to facilitate leveling. It is recommended that the V-block be located on the thin wall section of the sleeve, just below the sleeve seat, and that a weight, such as a piston pin, be placed inside the sleeve so that it will maintain good contact with the V-block.~~

TABLE A3.1 New Parts for Each Rebuild

NOTE 1—A P/N 57GC3116 Cylinder Rebuild Kit contains items 1, 2, and 3. Six kits are required per engine rebuild. A P/N 57GC2120B Filter Kit contains items 5, 6, 7, and 8. A P/N 62GB2401 Service Bearing Pair contains one each of P/N 62GB328 and P/N 62GB327 (Item 11).

Part Name	Mack Part Number	Quantity
1. Cylinder liners	509GC471	6
2. Piston assembly	240GC2256M	
Piston crown	240GC5114M	6
Piston skirt	240GC5119M	6
3. Piston ring set	353GC2141	
#1 Compression ring	349GC3107	6
#2 Compression ring	349GC3108	6
Oil ring	350GC343	6
4. Overhaul gasket sets	57GC2115A	2
	57GC2118A	1
	57GC2119	1
5. Spin-on filters	485GB3191B	2
Centrifugal filter cartridge	239GB244A	1
6. Engine coolant conditioner	25MF435B	1
7. Primary fuel filter	483GB444	1
8. Secondary fuel filter	483GB440	1
9. Valve guides	714GB222	1
10. Valve stem seals	446GC296	24
11 Connecting rod bearings		
Upper	62GB327	6
Lower	62GB328	6

~~A4.4 The stylus and trace area dimensions are shown in Fig. A4.1. The overall length of the trace shall be 50.8 mm (2 in). Note that 2.54 mm (0.1 in) of the trace shall be above top ring turnaround.~~

~~A4.5 The required settings for trace length, multiple reference, and unfiltered mode are shown in the Screen View No. 1 portion of Fig. A4.2.~~

~~A4.6 A representation of a completed trace is shown in the Screen View No. 2 portion of Fig. A4.2. Note that F2 reference is set for straight. Before computing, the operator shall set cursor lines to bracket the wear area. Do not expand this area. Compute on the area below top ring travel, outside the cursor lines.~~

~~A4.7 The result of the computation is shown in the Screen View No. 3 portion of Fig. A4.3. The data is shown in the Screen View No. 4 portion of Fig. A4.3. Exclude any scratch that goes below the valley of wear~~ hard copy format from the ~~trace by using the cursor lines to bracket the scratch using the F5 key.~~

~~A4.8 When excluding any part of the profile, obtain the PRt value from the graph in Screen View No. 3 (see Fig. A4.3). The Taylor Hobson instrument will not change the PRt value on the data screen when excluding any portion of the profile.~~

~~A4.9 The parameters shown in Screen View No. 4 (see Fig. A4.3) are defined in Table A4.1.~~

TMC.

A5. SAFETY PRECAUTIONS

A5.1 *General* :

A5.1.1 The operating of engine tests can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation, and operation of engine test stands.

A5.1.2 Each laboratory conducting engine tests should have their test installation inspected and approved by their safety department. Personnel working on the engines should be provided with proper tools, be alert to common sense safety practices, and avoid contact with moving or hot engine parts, or both. Guards should be installed around all external moving or hot parts. When engines are operating at high speeds, heavy duty guards are required and personnel should be cautioned against working alongside the engine and coupling shaft. Barrier protection should be provided for personnel. All fuel lines, oil lines, and electrical wiring should be properly routed, guarded, and kept in good order. Scraped knuckles, minor burns, and cuts are common if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines, and no loose or flowing clothing, including long hair or other accessory to dress that could become entangled, should be worn near running engines.

A5.1.3 The external parts of the engines and the floor area around the engines should be kept clean and free of oil and fuel spills. In addition, all working areas should be free of tripping hazards. In case of injury, no matter how slight, first aid attention should be applied at once and the incident reported. Personnel should be alert for leaking fuel or exhaust gas. Leaking fuel represents a fire hazard, and exhaust gas fumes are noxious. Containers of oil or fuel cannot be permitted to accumulate in the testing area.

A5.1.4 The test installation should be equipped with a fuel shut-off valve, that is designed to automatically cutoff the fuel supply to the engine when the engine is not running. A remote station for cutting off fuel from the test stand is recommended. Suitable interlocks should be provided so that the engine is automatically shutdown when any of the following events occur: engine or dynamometer water temperature becomes excessive; engine loses oil pressure; dynamometer loses field current; engine overspeeds; exhaust system fails; room ventilation fails; or the fire protection system is activated.

A5.1.5 Consider an excessive vibration pickup interlock if equipment operates unattended. Fixed fire protection equipment should be provided.

A5.1.6 Normal precautions should be observed whenever using flammable solvents for cleaning purposes. Make sure adequate fire fighting equipment is immediately accessible.

A6. DATA DICTIONARY

A6.1 Fig. A6.1 contains specifications and field groupings for fields in the Data Dictionary.

A6.2 The D required data D dictionary is presented as Fig. A6.2.

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.

A7. TBN MEASUREMENT PROCEDURE FOR T-9 SAMPLES

A7.1 Follow Test Method D 4739, except for the modifications shown in A7.2-A7.7. These modifications have been made to enhance testing precision for T-9 samples.

A7.2 *Electrodes* :

A7.2.1 On a daily basis, use aqueous buffers to verify an Acceptable Slope Response of 95–100 %.
A7.2.2 Use a silver-silver chloride electrode as the reference electrode.
A7.2.3 Use saturated lithium chloride as the reference electrolyte.
A7.2.4 After each titration, soak electrodes in deionized water for at least 5 min.
A7.2.5 After each titration, clean the electrodes by wiping with tissue.

A7.3 *Buffers* —Use fresh nonaqueous buffer *A* to determine endpoint. The shelf life of fresh buffer is two weeks.

A7.4 *Sample*:

A7.4.1 Before weighing, shake the sample container by hand for 1 min.
A7.4.2 Sample weight shall be 1.000 ± 0.005 g.

A7.5 *Titrator* :

A7.5.1 On a daily basis, flush automatic titrators with at least 10 mL of fresh titrant before using.
A7.5.2 Clean automatic titrators at least once per month.
A7.5.3 With the exception of the physical cleaning of electrodes, do not use automatic sample handlers.

A7.6 *Titration* :

A7.6.1 Titrate incrementally to buffer endpoint.
A7.6.2 Predosing is not permitted.

A7.7 *Reporting* —Report only the buffer base number value.

A8. TAN MEASUREMENT PROCEDURE FOR T-9 SAMPLES

A8.1 Follow Test Method D 664 except for the modifications shown in A8.2-A8.7. These modifications have been made to enhance testing precision for T-9 samples.

A8.2 *Electrodes* :

A8.2.1 On a daily basis, use aqueous buffers to verify an Acceptable Slope Response of 95–100 %.
A8.2.2 Use a silver-silver chloride electrode as the reference electrode.
A8.2.3 Use saturated lithium chloride as the reference electrolyte.
A8.2.4 After each titration, soak electrodes in deionized water for at least 5 min.
A8.2.5 After each titration, clean the electrodes by wiping with tissue.

A8.3 *Buffers* —Use fresh nonaqueous buffer *B* to determine endpoint. The shelf life of fresh buffer is two weeks.

A8.4 *Sample*:

A8.4.1 Before weighing, shake the sample container by hand for 1 min.
A8.4.2 Sample weight shall be 5.00 ± 0.01 g.

A8.5 *Titrator* :

A8.5.1 On a daily basis, flush automatic titrators with at least 10 mL of fresh titrant before using.
A8.5.2 Clean automatic titrators at least once per month.
A8.5.3 With the exception of the physical cleaning of electrodes, do not use automatic sample handlers.

A8.6 *Titration* :

A8.6.1 Titrate dynamically to buffer endpoint.

A8.6.2 Predosing is not permitted.

A8.7 *Reporting* —Report only the buffer acid number value.

A9. DETERMINATION OF OPERATIONAL VALIDITY

A9.1 *Quality Index Calculation*:

A9.1.1 Calculate Quality Index (QI) for all control parameters in accordance with the DACA II Report. Be sure to account for missing or bad quality data in accordance with the DACA II Report as well.

A9.1.2 Use the U, L, Over Range, and Under Range values shown in Table A9.1 for the QI calculations.

A9.1.3 Do not use the data from the first 30 min of Phase II. This is considered transition time, and the data is not to be used to calculate QI.

A9.1.4 Round the calculated QI values to the nearest 0.001.

A9.1.5 Report the QI values ~~on Fig. A1.4.~~ (see Annex A1).

A9.2 *Averages* —Calculate the average for control and noncontrol parameters, and report the values ~~on Fig. A1.4.~~ (see Annex A1). Note that the averages are not directly used to determine operational validity, but they may be helpful when an engineering review is required (refer to A9.4).

A9.3 *Determining Operational Validity*—QI threshold values for operational validity are shown in Table A9.1.

A9.3.1 A test with all control parameter QI values greater than or equal to the threshold value is operationally valid.

A9.3.2 A test with any control parameter QI value less than the threshold value requires an engineering review to determine operational validity.

A9.4 *Engineering Review*:

A9.4.1 Conduct an engineering review when a control parameter QI value is below the threshold value. A typical engineering review involves investigation of the test data to determine the cause of the below threshold QI. Other affected parameters may also be included in the engineering review. This can be helpful in determining if a real control problem existed and the possible extent to which it may have impacted the test. For example, a test runs with a low QI for fuel flow. An examination of the fuel flow data may show that the fuel flow data contains several over range values. At this point, an examination of exhaust temperatures may help determine whether the instrumentation problem affected real fuel flow versus affecting only the data acquisition.

A9.4.2 For reference tests, the engineering review shall be conducted jointly with the TMC. For non-reference tests, optional input is available from the TMC for the engineering review.

A9.4.3 Determine operational validity based upon the engineering review, and summarize the decision in the comment section ~~on Fig. A1.10.~~ (see Annex A1). It may be helpful to include any supporting documentation at the end of the test report. The final decision regarding operational validity rests with the laboratory.

TABLE A9.1 Quality Index Calculation Values

Control Parameter	Units	Quality Index Threshold	Quality Index U and L Values				Over and Under Range Values	
			U		L		Low	High
Speed[A]	r/min	0.000	1802.5	1252.5	1797.5	1247.5	1073	1976
Fuel flow[A]	kg/h	0.000	64.28	56.00	62.28	54.00	0	138
Coolant out temperature	°C	0.000	86.2		83.8		0	169
Fuel in temperature	°C	0.000	40.6		39.4		0	105
Intake air temp.	°C	0.000	26.6		23.4		0	135
Intake manifold temp.	°C	0.000	43.6		42.4		0	81
Exhaust back pressure	kPa	0.000	3.3		2.9		0	16
Inlet air restriction	kPa	0.000	2.7		2.3		0	14

[A] U and L values for speed and fuel flow are split by test phase.