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Standard Test Method for Evaluation of Diesel Engine Oils in DD13 Diesel Engine[1]

This standard is issued under the fixed designation D8074; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Portions of this test method are written for use by laboratories that make use of ASTM Test Monitoring Center (TMC)[2] services (see Annex A1).

The TMC provides reference oils, and engineering and statistical services to laboratories that desire to produce test results that are statistically similar to those produced by laboratories previously calibrated by the TMC.

In general, the Test Purchaser decides if a calibrated test stand is to be used. Organizations such as the American Chemistry Council require that a laboratory utilize the TMC services as part of their test registration process. In addition, the American Petroleum Institute and the Gear Lubricant Review Committee of the Lubricant Review Institute (SAE International) require that a laboratory use the TMC services in seeking qualification of oils against their specifications.

The advantage of using the TMC services to calibrate test stands is that the test laboratory (and hence the Test Purchaser) has an assurance that the test stand was operating at the proper level of test severity. It should also be borne in mind that results obtained in a non-calibrated test stand may not be the same as those obtained in a test stand participating in the ASTM TMC services process.

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

1. Scope

1.1 This test method covers an engine test procedure for evaluating diesel engine oils for performance characteristics, including adhesive wear between an uncoated piston ring and cylinder liner. This test method is commonly referred to as the DD13 Scuffing Test.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.2.1 *Exception*—Where there is no direct SI equivalent, such as the units for screw threads, National Pipe Threads/diameters, tubing size, and single source supply equipment specifications.

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 A2 for specific safety precautions.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D97 Test Method for Pour Point of Petroleum Products

D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

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

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

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

D482 Test Method for Ash from Petroleum Products

D524 Test Method for Ramsbottom Carbon Residue of Petroleum Products

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants.

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[2] ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, USA. Tel. +1 412 365 1000. www.astmtmc.cmu.edu.

[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.

D613 Test Method for Cetane Number of Diesel Fuel Oil
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D975 Specification for Diesel Fuel Oils
D976 Test Method for Calculated Cetane Index of Distillate Fuels
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
D2500 Test Method for Cloud Point of Petroleum Products and Liquid Fuels
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
D3338 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D3524 Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4683 Test Method for Measuring Viscosity of New and Used Engine Oils at High Shear Rate and High Temperature by Tapered Bearing Simulator Viscometer at 150 °C
D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5186 Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D5967 Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine
D6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)
D6984 Test Method for Evaluation of Automotive Engine Oils in the Sequence IIIF, Spark-Ignition Engine
D7320 Test Method for Evaluation of Automotive Engine Oils in the Sequence IIIG, Spark-Ignition Engine
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E168 Practices for General Techniques of Infrared Quantitative Analysis

2.2 *Other Standards:*
Code of Federal Regulations Title 40 Part 86.310-79[4,5]

2.3 *Other ASTM Document:*
ASTM Deposit Rating Manual 20 Formerly CRC Manual 20[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *adhesive wear (scuffing), n*—wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface. **D4175**

3.1.2 *blind reference oil, n*—a reference oil, the identity of which is unknown by the test facility.

3.1.2.1 *Discussion*—This is a coded reference oil that is submitted by a source independent from the test facility. **D4175**

3.1.3 *blowby, n—in internal combustion engines*, that portion of the combustion products and unburned air/fuel mixture that leaks past piston rings into the engine crankcase during operation. **D4175**

3.1.4 *break-in, v—in internal combustion engines*, the running of a new engine under prescribed conditions to help stabilize engine response and help remove initial friction characteristics associated with new engine parts. **D4175**

3.1.5 *calibrate, v*—to determine the indication or output of a measuring device with respect to that of a standard. **D4175**

3.1.6 *calibrated test stand, n*—a test stand on which the testing of reference material(s), conducted as specified in the standard, provided acceptable test results.

3.1.6.1 *Discussion*—In several automotive lubricant standard test methods, the ASTM Test Monitoring Center provides testing guidance and determines acceptability. **D4175**

3.1.7 *calibration test, n*—an engine test conducted on a reference oil under carefully prescribed conditions, the results of which are used to determine the suitability of the engine stand/laboratory for such tests on non-reference oils.

3.1.7.1 *Discussion*—A calibration test also includes tests conducted on parts to ensure their suitability for use in reference and non-reference tests. **D4175**

3.1.8 *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. **D4175**

3.1.9 *engine oil, n*—a liquid that reduces friction or wear, or both, between the moving parts within an engine; removes heat particularly from the underside of pistons; and serves as combustion gas sealant for the piston rings.

3.1.9.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit

[4] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

[5] https://www.gpo.gov/fdsys/granule/CFR-2013-title40-vol19/CFR-2013-title40-vol19-sec86-310-79.

[6] For stock #TMCMNL20, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org.

formation, valve train wear, oil oxidation, and foaming are examples. **D4175**

3.1.10 *exhaust gas recirculation (EGR), n*—the mixing of exhaust gas with intake air to reduce the formation of nitrogen oxides (NO_x). **D4175**

3.1.11 *heavy-duty, adj—in internal combustion engine operation*, characterized by average speeds, power output and internal temperatures that are close to the potential maximums. **D4175**

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

3.1.13 *lubricant test monitoring system (LTMS), n*—an analytical system in which ASTM calibration test data are used to manage lubricant test precision and severity (bias). **D4175**

3.1.13.1 *LTMS date, n*—the date the test was completed unless a different date is assigned by the TMC. **D6984/D7320**

3.1.13.2 *LTMS time, n*—the time the test was completed unless a different time is assigned by the TMC. **D6984/D7320**

3.1.14 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D4175**

3.1.15 *mass fraction of B, w_B, n*—mass of a component B in a mixture divided by the total mass of all the constituents of the mixture.

3.1.15.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of mass (for example, mass fraction of lead is $w_B = 1.3 \times 10^{-6} = 1.3$ mg/kg). **D4175**

3.1.16 *non-reference oil, n*—any oil other than a reference oil; such as a research formulation, commercial oil or candidate oil. **D4175**

3.1.17 *non-standard test, n*—a test that is not conducted in conformance with the requirements in the standard test method; such as running on an uncalibrated test stand, using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D4175**

3.1.18 *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. **D4175**

3.1.19 *quality index (QI), n*—a mathematical formula that uses data from controlled parameters to calculate a value indicative of control performance. **D4175**

3.1.20 *quantity, n—in the SI*, a measurable property of a body or substance where the property has a magnitude expressed as the product of a number and a unit; there are seven, well-defined base quantities (length, time, mass, temperature, amount of substance, electric current and luminous intensity) from which all other quantities are derived (for example, volume whose SI unit is the cubic metre).

3.1.20.1 *Discussion*—Symbols for quantities must be carefully defined; are written in italic font, can be upper or lower case, and can be qualified by adding further information in subscripts, or superscripts, or in parentheses (for example, $t_{fuel} = 40$ °C, where t is used as the symbol for the quantity Celsius temperature and t_{fuel} is the symbol for the specific quantity fuel temperature). **D4175**

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

3.1.21.1 *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. **D4175**

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

3.1.23 *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.

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

3.1.24.1 *Discussion*—It can be any oil selected by the laboratory conducting the test. It could be an experimental product or a commercially available oil. Often it is an oil that is a candidate for approval against engine oil specifications (such as manufacturers' or military specifications, and so forth). **D4175**

3.1.25 *test parameter, n*—a specified component, property, or condition of a test procedure.

3.1.25.1 *Discussion*—Examples of components are fuel, lubricant, reagent, cleaner, and sealer; of properties are density, temperature, humidity, pressure, and viscosity; and of conditions are flow rate, time, speed, volume, length, and power. **D4175**

3.1.26 *volume fraction of B, φ_B, n*—volume of component B divided by the total volume of the all the constituents of the mixture prior to mixing.

3.1.26.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of volume (for example, $\varphi_B = 0.012 = 1.2\ \% = 1.2$ cL/L). **D4175**

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

3.1.28 *wear, n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action or a combination of both. **D4175**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *new laboratory, n*—one that has never previously calibrated a test stand under this test method.

3.2.2 *new stand, n*—a test cell and support hardware which has never previously been calibrated under this test method.

3.2.3 *scuff, n*—a distress that disturbs the surface finish of the cylinder liner in such a manner as to prohibit identification of other prior surface finishes, including but not limited to polish and honing marks.

3.3 *Acronyms:*
3.3.1 CAC—charge air cooler
3.3.2 CAN—controller area network
3.3.3 CARB—California air resources board
3.3.4 DACA *II*—data acquisition and control automation II
3.3.5 DD—Detroit diesel
3.3.6 DDCSN—Detroit diesel customer support network
3.3.7 EGR—exhaust gas recirculation
3.3.8 EOT—end of test
3.3.9 ID—internal diameter
3.3.10 MCM—motor control module
3.3.11 OMS—oil mist separator
3.3.12 SOT—start of test

4. Summary of Test Method

4.1 This test method uses a Detroit[7] DD13 12.8 L, six-cylinder diesel engine with EGR.

4.2 The engine is disassembled prior to each test, the parts solvent-cleaned and measured, and rebuilt using all new pistons, uncoated rings, cylinder liners, and connecting rod bearings, in strict accordance with furnished specifications. The engine crankcase is solvent cleaned and worn or defective parts replaced.

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

4.4 Following an engine break-in, the test oil is installed, the engine warmed up to the test conditions, and a two-stage procedure lasting a maximum of 200 h is initiated. Oil samples are taken periodically for the measurement of viscosity, soot, oxidation, and wear metals concentrations.

4.5 Scuffing is determined from analysis of end-of-test parts and test oil samples.

5. Significance and Use

5.1 This test method was developed to evaluate the liner scuffing and ring distress performance of engine oils in turbocharged and intercooled four-cycle diesel engines equipped with EGR, uncoated top rings, and running on ultra-low sulfur diesel fuel. Results are obtained from used oil analysis, operational data, 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 *Laboratory*—The ambient laboratory atmosphere shall be relatively free of dirt and other contaminants as required by good laboratory standards. Air filtration and temperature and humidity control in the engine buildup area helps prevent accumulation of dirt, rust, and other contaminants on engine parts and aids in measuring and selecting parts for assembly.

6.2 *Test Engine:*

6.2.1 The test engine is a Detroit DD13 diesel engine,[8,9,10] common rail fuel system, with high-flow injectors. It is a 12.8 L, open-chamber, in-line, six-cylinder, four-stroke, turbocharged, charge air-cooled, compression-ignition engine. The bore and stroke are 132 mm and 156 mm, respectively.

6.2.1.1 *Detroit Diesel Parts and Part Numbers*—Information about parts and part numbers is provided in Annex A3. Use test parts on a first-in/first-out basis.

6.2.2 *Detroit Diesel Customer Support Network (DDCSN)*—For engine rebuild specifications, use Online Power Service Literature rebuild manual.[11] In the event of a conflict with Section 8, the latter takes precedence.

6.2.3 *Engine Cooling System:*

6.2.3.1 For each test, use fresh Detroit Power Cool[10] (see 7.3) to limit scaling in the cooling system. Pressurize the system at the expansion tank.

6.2.3.2 To prevent air entrainment and to control coolant related parameters within specified limits, use a closed-loop, pressurized, external, engine-cooling system composed of a heat exchanger, an expansion tank, a water-out temperature-control valve, a flow meter, and a flow-control device. A schematic is shown in Fig. A4.1. Install a sight glass between the engine and the cooling tower to check for air entrainment and uniform flow in order to observe and prevent localized boiling. Fit the coolant tank with a radiator cap with a recommended 140 kPa relief pressure. Include in the cooling system a flow-control device between the engine and expansion tank and a flow meter between the expansion tank and engine inlet.

(1) Use the coolant heat exchanger to adequately control the coolant temperature at the jacket outlet to the set point in Table 1.

(2) Use a flow control device to throttle coolant flow within range specified in Table 1.

(3) Supply pressurized air to the top of the expansion tank. Regulate the air pressure to adequately control the coolant pressure at jacket inlet to the set points in Table 1. Depending on the configuration of the cooling system, air pressure up to 140 kPa may need to be supplied to achieve the set point.

6.2.3.3 Block the thermostat[10] wide open at 13 mm as shown in Fig. A4.2.

6.2.3.4 Vent the EGR cooler to the top of the expansion tank, away from the pressure feed, as shown in Fig. A4.3.

6.2.4 *Auxiliary Oil System:*

6.2.4.1 To maintain a constant oil level in the engine sump, connect it to a separate, closed reservoir with a minimum capacity of 15 L. Circulate oil through the reservoir with an

[7] Detroit is a registered trademark of Detroit Diesel Corporation, 13400 Outer Drive, West Detroit, MI 48239-4001, USA.

[8] The sole source of the apparatus known to the committee at this time is Detroit Diesel Corporation, 13400 Outer Drive, West Detroit, MI 48239-4001, USA.

[9] 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.

[10] Purchase from a local Detroit Diesel Dealer. The Detroit Diesel part number can be accessed from information provided in A3.1.

[11] Available at www.ddcsn.com.

TABLE 1 Schedule of Conditions for the Test Procedure

	Set Point for Stage 1	Set Point for Stage 2
Time, h	30	170 standard[A]
Controlled Quantities,[B] units		
Engine Speed, r/min	1800	1800
Fuel Flow Rate, kg/h	32	71
Air Temperature in Engine Intake, °C	35	35
Coolant Temperature at Jacket Outlet, °C	105	105
Oil Temperature in Gallery, °C	118	118
Fuel Temperature at Engine Inlet, °C	38	38
Air Temperature in Intake Manifold, °C	75	87
Coolant Pressure at Jacket Inlet, kPa (gauge)	250	250
Exhaust Pressure in Tailpipe, kPa (absolute)	105.5	125.5
Air Pressure in Intake Manifold, kPa (absolute)	202.5	327.5
Air Pressure in Engine Intake, kPa (absolute)	96.4	94.8
Ranged Quantities,[C] units		
Coolant Flow Rate, L/min	340 to 360	340 to 360
Uncontrolled Quantities, units		
Blowby Flow Rate, L/min	Record	Record
OMS Speed, r/min	Record	Record
Barometric Pressure, kPa (absolute)	Record	Record
Air Pressure at Turbocharger Outlet, kPa (gauge)	Record	Record
Air Pressure at CAC Outlet, kPa (gauge)	Record	Record
Delta Air Pressure across CAC, kPa	Record	Record
Crankcase Pressure, kPa (gauge)	Record	Record
Air Pressure in the Coolant Tank, kPa (gauge)	Record	Record
Coolant Pressure at Jacket Outlet, kPa (gauge)	Record	Record
Delta Coolant Pressure for Jacket kPa (gauge)	Record	Record
Exhaust Pressure Pre-Turbocharger Front, kPa (gauge)	Record	Record
Exhaust Pressure Pre-Turbocharger Rear, kPa (gauge)	Record	Record
EGR Pressure, kPa (gauge)	Record	Record
Oil Pressure in Gallery, kPa (gauge)	Record	Record
Air Temperature at Turbocharger Outlet, °C	Record	Record
Air Temperature of Ambient Conditions, °C	Record	Record
Delta Coolant Temperature across Engine, °C	Record	Record
Delta Coolant Temperature across Coolant Jacket, °C	Record	Record
Coolant Temperature at Engine Inlet, °C	Record	Record
Coolant Temperature at Engine Outlet, °C	Record	Record
Coolant Temperature at Jacket Inlet, °C	Record	Record
EGR Temperature, °C	Record	Record
Exhaust Temperature the Exhaust Tailpipe, °C	Record	Record
Temperature of the Return Fuel, °C	Record	Record
Air Temperature at the CAC Outlet, °C	Record	Record
Oil Temperature in Sump, °C	Record	Record
Dew Point Temperature of Inlet Air, °C	Record	Record
Coolant Temperature at Engine Inlet, °C	Record	Record
Coolant Temperature at EGR Cooler Inlet, °C	Record	Record
Coolant Temperature at EGR Cooler Outlet, °C	Record	Record
Delta Coolant Temperature for EGR Cooler, °C	Record	Record
Torque, N·m	Record	Record
Mass of External Oil Tank, kg	Record	Record
Relative Humidity of Inlet Air, %	Record	Record

[A] Although 170 h is a standard test time, tests run for longer than 170 h are still valid tests.
[B] Target all controlled quantities at mean.
[C] All ranged quantities shall fall within the specified limits.

auxiliary pump. The system schematic is shown in Fig. A4.4. Use lines with 10 mm internal diameter (ID) for the return to engine sump and 13 mm ID for suction from engine sump. Connect the rear, gear cover to a vent line with a minimum ID of 10 mm, as shown in Figs. A4.4 and A4.5.

6.2.4.2 Locate the suction line of the auxiliary oil-system on the intake side of the engine sump, at the lower, modified bulk-head fitting. Modify the (lower) factory plug by drilling a hole through it and welding a ¾ in. pipe coupling to the exterior end. Weld a tube 20 mm diameter by 0.1 m long to one end of a 90° ¾ in. elbow. Bend the 0.1 m long tube at 90°. Clean the threading, as needed, to allow the elbow to mate with the ¾ in. fitting in the modified plug. Trim the 0.1 m long tube so that when the tube is installed into the modified plug in the oil pan, the top of the tube is 267 mm down from the pan rail, as shown in Fig. A4.4. Examples of these modified parts are shown in Fig. A4.6.

6.2.4.3 Locate the return line, shown in Fig. A4.5, at the upper bulk-head fitting, as shown in Fig. A4.7. Modify the bulk-head fitting to connect to the 10 mm ID return line by drilling a hole through the (upper) factory plug and welding a ¾ in. pipe coupling to the exterior end. Connect one end of an elbow to the ¾ in. pipe coupling and connect the other end to the 10 mm ID return line.

6.2.4.4 Connect the vent line of the auxiliary oil-system to the top of the auxiliary oil reservoir and the air compressor block-off plate, as shown in Fig. A4.5.

6.2.4.5 Use Viking Pump Model SG053514[12,9] as the auxiliary oil pumps. Nominal pump speed is specified as 1725 r/min.

6.2.4.6 Locate a ¼ in. oil sampling port within the pressurized oil circuit using a No. 4 Aeroquip[13,9] or equivalent and a small petcock valve, as shown in Fig. A4.5. Use a maximum sample-line length of 2.5 m.

6.2.4.7 Locate a pressurized, oil-filling line between the oil cooler and the oil-filter housing on the return to the filter housing. Connect the line to the oil pressure in gallery line via a tee. Refer to Fig. A4.7.

6.2.5 *Oil-Cooling System:*

6.2.5.1 *Remote Oil Heat Exchanger and Bypass Plate*—This section describes how to modify the engine to rout oil through a remote oil heat exchanger and how to modulate water flow through this oil heat exchanger to adequately control the oil temperature in the gallery to the set points in Table 1.

(1) Remove the stock heat exchanger from the oil-cooler module (see Fig. A4.8) and set the o-rings aside. Fabricate a 6.35 mm thick aluminum block-off plate using the oil cooler as a pattern (see Fig. A4.9). Install the block-off plate with o-rings and new M8 × 1.25 × 25 bolts. Torque the bolts to 30 N·m.

(2) Remove the oil thermostat cover by using Kent-Moore tool W470 589 030 900[14,9] to remove the thermostat. Disassemble the thermostat and set aside the thermostat housing and retaining ring. Machine a piece of aluminum bar stock to a diameter of 37.719 mm and a length of 85.725 mm. Insert this aluminum plug into the thermostat housing and reinstall the retaining ring (see Fig. A4.10).

(3) Connect the oil module to the remote heat exchanger by using two 19 mm ID lines to allow oil to flow through a 127 mm × 356 mm double-pass, stainless-steel, remote oil heat exchanger shown in Fig. A4.11. Oil shall flow through the shell portion of the heat exchanger. The combined length of the oil lines to and from the remote oil heat exchanger and the modified oil module shall not be greater than 2.6 m total length.

(4) Modify the oil module to create a fitting for an oil supply line to the remote oil heat exchanger as follows:

(a) drill a 59⁄64 in. or 15⁄16 in. hole in the bottom of the oil module (see Fig. A4.12);

(b) machine a piece of aluminum bar stock to a diameter of 38 mm and a length of 45 mm;

(c) drill and tap this piece of aluminum for a ¾ in. NPT and cut one end at a 30° angle;

(d) weld this aluminum cylinder onto the previously drilled hole in the bottom of the oil module so the cylinder is pointing away from the side of the engine and towards the front of the engine;

(e) install a straight male ¾ in. NPT to ¾ in. NPT flare fitting.

(5) Modify the oil module to create a fitting for an oil-return line from the remote oil heat exchanger as follows:

(a) locate and remove the plug from the side of the housing;

(b) machine out the middle of the plug;

(c) weld a ¾ in. NPT union half coupling;

(d) reinstall the modified plug and install a 90°, ¾ in. NPT male to ¾ in. flare fitting, as shown in Fig. A4.13.

6.2.5.2 Use the Detroit Diesel oil filter housing.[10]

6.2.6 *Blowby Meter*—Use a meter capable of providing data at a minimum frequency of 1 Hz. To prevent blowby condensate from draining back into the engine, ensure the blowby line has a downward slope to a collection bucket. Ensure the collection bucket has a minimum volume of 19 L. Locate the blowby meter downstream of the collection bucket. The slope of the blowby line downstream of the collection bucket is unspecified. This engine is also equipped with an oil mist separator (OMS) mounted on the engine to evacuate blowby gases.

6.2.7 *Air Supply and Filtration*—Use an air-filter element appropriately sized for a 12.8 L diesel engine. Replace the filter cartridge when the air pressure in engine intake cannot be reached. Install an adjustable valve (flapper) in the inlet air system to control the air pressure in engine intake to set points in Table 1. The adjustable valve (flapper) shall be at least two-pipe diameters before any temperature, pressure, and humidity measurement devices.

6.2.8 *Fuel Supply*—Heating, cooling, or both of the fuel supply may be required to achieve adequate fuel-temperature control with the set points specified in Table 1. A typical system is shown in Fig. A4.14.

6.2.9 *Specifications for the Charge Air Cooler (CAC)*—Select a CAC such that the pressure drop across the CAC is ≤10 kPa at test conditions. Provide sufficient cooling capacity to adequately control the air temperature in intake manifold to the set points specified in Table 1. Equip the CAC with a drain to remove condensate formed when moisture in the air passes by the cooler process water. Use the Detroit Diesel intake manifold.[10]

6.2.10 *Exhaust Pressure Control*—Install an adjustable valve (flapper) in the tailpipe after any temperature, pressure, or CO_2 measurement devices to adequately control exhaust pressure in tailpipe to set points in Table 1.

6.2.11 *Dynamometer*—Use a dynamometer capable of controlling engine speed to the set points in Table 1. A Midwest 1014[15,9] dynamometer has been found suitable for this purpose.

6.2.12 *Turbocharger Wastegate*—Supply regulated pressurized air directly to the wastegate on the turbocharger by bypassing the ECM-controlled air modulator to the wastegate on the engine. Regulate the air pressure supplied to the wastegate to adequately control air pressure in the intake

[12] The sole source of supply of the apparatus known to the committee at this time is Viking Pump, Inc., a unit of IDEX Corporation, 406 State Street, P.O. Box 8, Cedar Falls, IA 50613-0008.

[13] The sole source of supply of the apparatus known to the committee at this time is Aeroquip Performance Products. www.aeroquipperformance.com.

[14] The sole source of supply of the apparatus known to the committee at this time is Kent-Moore, which is available from local suppliers.

[15] The sole source of supply of the apparatus known to the committee at this time Dyne Systems, Inc., W209 N17391 Industrial Drive, Jackson, WI 53037, USA. Tel.: +1 800 657 0726.

manifold to set points in Table 1. It is recommended to supply up to 275 kPa of air pressure to allow adequate control of the waste gate.

6.2.13 *Oil Pump*—Use the Detroit Diesel oil pump.[10]

6.2.14 *OMS Speed Sensor*—Use the Detroit Diesel speed sensor[10] with Detroit Diesel bracket[10] and connector.[10] Use OMS gas vent Mack Trucks part number 21122541.[16,9,17]

6.2.15 *Engine-Control System*—The engine controls system is manufactured by Daimler Engineering and is available from Detroit Diesel.[8,9] It includes the CPC module, the Motor Control Module (MCM), the Daimler control station, and the wiring harness for the test stand.

6.2.16 *Block-off Plate for Dosing Injector*—Remove the dosing (7th) injector in the exhaust and install a block off plate as shown in Fig. A4.15. Fit a plug into the dosing block assembly to block the fuel line that would normally run to the dosing injector, as shown in Fig. A4.16.

7. Engine Fluids

7.1 *Test Oil*—Approximately 95 L of test oil are required for the test.

7.2 *Test Fuel*—Approximately 16 600 L of PC-10 ultra low sulfur diesel (ULSD) test fuel[18,9] are required per 200 h test. The required fuel properties and tolerances are shown in Table A5.1.

7.3 *Coolant*—Use 50/50 Premixed Detroit Power Cool.[10]

7.4 *Build-up Oil*—Use Detroit 15W-40 Motor Oil.[10]

7.5 *Cleaning Materials:*

7.5.1 For cleaning engine parts, use only mineral spirits (solvent) meeting the requirements in Specification D235, Type II, Class C for Aromatic Content (volume fraction 0 % to 2 %), Flash Point (142 °C, min) and Color (not darker that +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning—**Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

7.5.2 Heptane. (**Warning—**Flammable. Health hazard.)

8. Preparation of Apparatus

8.1 *Cleaning of Parts:*

8.1.1 *Engine Block*—Thoroughly spray the engine with solvent to remove any oil remaining from the previous test and air-dry. Follow the optional use of an engine parts washer by a solvent wash and air-dry. Use a bristle brush to clean all oil galleries, OMS ports, and oil drainback holes. Use a Scotch-Brite[19,9] pad, or equivalent, to clean gasket surfaces, liner bores, and bearing saddles.

8.1.2 *Rocker Covers and Oil Pan*—Remove all sludge, varnish, and oil deposits. Rinse with solvent and air-dry. Follow the optional use of an engine parts washer by a solvent wash and air-dry.

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

8.1.4 *Oil-Cooler Module*—Remove thermostat. Thoroughly clean with solvent to remove any previous test oil and then air-dry. Follow the optional use of an engine parts washer by a solvent wash and air-dry.

8.1.5 *Cylinder-Head*—Thoroughly clean the cylinder heads on the top side using solvent and a bristle brush. Use a Scotch-Brite, or equivalent, on the bottom side. Replace or rebuild cylinder head as necessary.

8.1.6 *Intake Manifold*—Remove and clean the intake manifold after a maximum of 200 h running under test conditions. Scrub the manifold using a bristle brush and solvent, wash using an engine parts washer and air dry.

8.1.7 *EGR Cooler*—Clean the EGR cooler before every test using either high-pressure air and hot water or an ultrasonic cleaner.

8.1.8 *EGR Venturi Unit*—Clean the venturi thoroughly before each test using a bristle brush. Do not use metal-cleaning equipment. Ensure the holes for the differential pressure sensor are cleaned.

8.1.9 *Fuel Module*—Clean as needed. Method used is not specified.

8.1.10 *Cylinder Liners*—Clean new cylinder liners prior to installing in the engine as follows:

(1) wash with solvent;

(2) scrub using a bristle brush and a detergent (Tide[20,9] has been found suitable for this purpose);

(3) rinse with cold water;

(4) wipe with heptane;

(5) wipe thoroughly with Detroit 15W-40 Motor Oil[10] to protect from rust prior to installing in the engine;

(6) after installing in engine, wipe clean with heptane.

8.2 *Preparation for Engine Build:*

8.2.1 *Fuel Module*—Inspect fuel cooler for debris and replace cooler if debris is found.

8.2.2 *Oil Pump*—Replace the oil pump after a maximum of 400 h running under test conditions.

8.2.3 *Components of the Gear Train*—Inspect and replace gears as necessary. Replace gear thrust washers prior to each engine build.

8.2.4 *Rocker Box*—Inspect saddles and replace as necessary.

8.2.5 *Crankshaft*—Inspect crankshaft prior to each build. At the laboratory's discretion, polish or replace as necessary.

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

8.3.1 *Fitting of Cylinder Liner*—For proper heat transfer, fit cylinder liners to the block using the procedure outlined using DDCSN.[11]

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[16] The sole source of supply of the apparatus known to the committee at this time is Mack Trucks Inc., 13302 Pennsylvania Avenue, Hagerstown, MD 21742, USA.

[17] Available from local Mack Trucks Inc. distributors.

[18] The sole source of the fuel known to the committee at this time is Chevron Phillips Chemical Company LP, 10001 Six Pines Drive, Suite 4036B, The Woodlands, TX 77387-4910, USA. Tel: +1 832 813 4859, email: fuels@cpchem.com.

[19] The sole sources of supply of the material known to the committee at this time is 3M Corporate Headquarters, 3M Center, St. Paul, MN 55144-1000, USA.

[20] The sole source of supply of the apparatus known to the committee at this time is manufactured by Proctor and Gamble Company, 1 P&G Plaza, Cincinnati, OH 45202, USA. Tel. +1-513-983-1100. www.pg.com.

8.3.2 *Piston and Rings*—Cylinder liners, pistons, and rings are provided as a set and shall be used as a set. Examine piston rings for any handling damage. Record the pre-test measurements as detailed in 10.1.

8.4 *Injectors and Injection Pumps:*

8.4.1 *Injectors*—Use high-flow injector nozzles.[10] Injectors shall have a date code 2014 or later, indicated by the first two numbers of the date code (for example, "15…" denotes date code 2015). See Appendix X1 for location of date codes. Use only injectors with approved date codes.

8.5 *Assembly Instructions:*

8.5.1 *General:*

8.5.1.1 Use the test parts specified for this test without material or dimensional modification.

8.5.1.2 Use Detroit Genuine Parts[21,9] for all replacement test engine parts. Build kits containing screened and measured parts are provided by TEI.[22,9] Purchase these kits from TEI. For a list of parts supplied in the TEI kits see A3.2.

8.5.1.3 In the event of a temporary parts supply problem, the TMC may approve alternative parts. If such approved parts are used, record the approval in the test report.

8.5.1.4 Assemble all parts as illustrated in the DDCSN[11] online manual except where otherwise noted in this section.

8.5.1.5 Target all dimensions at the mean values of the specifications. Use Detroit 15W-40 Motor Oil[10] for lubricating parts during assembly.

8.5.2 *Thermostat*—Use the modified coolant thermostat as described in 6.2.3.3.

8.5.3 *Connecting-Rod Bearings*—Install new connecting-rod bearings for each test.

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

8.5.5 *Cooling Nozzles for Piston Undercrown*—Take particular care in assembling the cooling nozzles for the piston-undercrown to insure proper piston cooling (follow installation instructions described in DDCSN[11]).

8.5.6 *Thrust Washers*—Install new thrust washers for each test.

8.5.7 *New Parts*—Use test parts on a first-in/first-out basis. Install new screened and measured parts (see A3.2) for each re-build.

8.6 *Measurements:*

8.6.1 *Calibrations*—Calibrate thermocouples, pressure gauges, and measuring equipment for speed, torque, and fuel-flow prior to each reference oil test or at any time readout data indicates a need.

8.6.1.1 Conduct calibrations with at least two points that bracket the normal operating range.

8.6.1.2 Make these calibrations part of the laboratory record.

8.6.1.3 During calibration, connect leads, hoses and readout systems in the normally-used manner and calibrate with necessary standards.

8.6.1.4 For controlled temperatures, immerse thermocouples in calibration baths. Calibrate standards with instruments traceable to the National Institute of Standards and Technology[23] at a minimum of a yearly basis.

8.6.2 *Temperature Measurement and Delta Temperature Calculation:*

8.6.2.1 *General*—Measure temperature with thermocouples and conventional readout equipment. The thermocouple type is not specified. For temperatures in the 0 °C to 150 °C range, calibrate temperature measuring systems to ±0.5 °C for at least two temperatures that bracket the normal operating range. Insert all thermocouples so that the tips are located midstream of the flow unless otherwise indicated.

8.6.2.2 *Air Temperature of Ambient Conditions*—Locate thermocouple in a convenient, well-ventilated position away from the engine and hot accessories.

8.6.2.3 *Coolant Temperature at Engine Outlet*—Locate the thermocouple within 305 mm of the engine block. An example location is shown in Fig. A4.17.

8.6.2.4 *Coolant Temperature at Engine Inlet*—Locate the thermocouple within 305 mm of the engine block. An example location is shown in Fig. A4.11.

8.6.2.5 *Coolant Temperature at Jacket Inlet*—Locate the coolant jacket inlet thermocouple in the coolant module, at an insertion depth of 76.2 mm from the face of the module, as shown in Fig. A4.7.

8.6.2.6 *Coolant Temperature at Jacket Outlet*—Locate the coolant jacket outlet thermocouple in the coolant module, at an insertion depth of 50.8 mm from the face of the engine block, as shown in Fig. A4.18.

8.6.2.7 *Oil Temperature in Gallery*—Locate the thermocouple at the intake side of the block in the rear, oil-gallery passage at an insertion depth of 60.3 mm from the face of the block. Fitting inserted in place of the factory plug. Refer to Fig. A4.5 for location.

8.6.2.8 *Oil Temperature in Sump*—Using a front sump oil pan configuration, locate a thermocouple on the exhaust side of the oil pan, in the modified bulkhead connector. Thermocouple shall extend a minimum of 25.4 mm into oil pan. Refer to Fig. A4.19.

8.6.2.9 *Air Temperature in Engine Intake*—Locate the thermocouple in the center of the air stream leading to the turbocharger inlet, as shown in Fig. A4.20. Thermocouple shall be approximately 330 mm upstream of the turbo inlet connection.

8.6.2.10 *Fuel Temperature at Engine Inlet*—Locate the thermocouple at the fuel-supply line prior to the fuel-filter housing as shown in Fig. A4.7.

8.6.2.11 *Fuel Temperature at Engine Return*—Locate the thermocouple at the fuel-return line after the fuel-filter housing as shown in Fig. A4.7.

[21] The sole source of supply of the apparatus known to the committee at this time is www.demanddetroit.com/parts-service/parts/demandgenuine.

[22] The sole source of supply of the apparatus known to the committee at this time TEI, 12718 Cimarron Path, San Antonio, TX 78249-3423, USA. Tel. +1 210 690 1958, tei-net.com.

[23] National Institute of Standards and Technology, 100 Bureau Drive, Stop 2300, Gaithersburg, MD 20899-2300, USA. www.nist.gov.

8.6.2.12 *Exhaust Temperature in Tailpipe*—Locate the thermocouple in the exhaust pipe approximately 270 mm downstream of the turbocharger outlet. Locate the thermocouple downstream of the exhaust pressure tap, and upstream of the CO_2 probe. Refer to Fig. A4.15.

8.6.2.13 *Air Temperature in Intake Manifold*—Locate the thermocouple at an insertion depth of 50.8 mm from the exterior face of the manifold, as shown in Fig. A4.21.

8.6.2.14 *EGR Temperature*—Locate the thermocouple on the straight portion of EGR pipe downstream of the pressure tap as shown in Fig. A4.7.

8.6.2.15 *Air Temperature at the Turbocharger Outlet*—Locate the thermocouple downstream of the turbocharger outlet and prior to the CAC, as shown in Fig. A4.20.

8.6.2.16 *Air Temperature at the CAC Outlet*—Locate the thermocouple downstream of the CAC outlet and prior to the EGR mixing, as shown in Fig. A4.22.

8.6.2.17 *Dew Point Temperature of Inlet Air*—Locate the sensor to record the dew point temperature of the inlet air before the air filter.

8.6.2.18 *Delta Coolant Temperature for Engine*—Calculate as coolant temperature at engine outlet minus coolant temperature at engine inlet.

8.6.2.19 *Delta Coolant Temperature for Jacket*—Calculate as coolant temperature at jacket outlet minus coolant temperature at jacket inlet.

8.6.2.20 *Coolant Temperature at EGR Cooler Inlet*—Locate the thermocouple in the crossover pipe in the front of the engine, as shown in Fig. A4.22.

8.6.2.21 *Coolant Temperature at EGR Cooler Outlet*—Locate the thermocouple into the upper plug of the coolant outlet elbow, as shown in Fig. A4.17.

8.6.2.22 *Delta Coolant Temperature for EGR Cooler*—Calculate as coolant temperature at EGR cooler outlet minus coolant temperature at EGR cooler inlet.

8.6.2.23 *Additional Temperature Measurements*—Monitor any additional temperatures that the test laboratory regards as helpful in providing a consistent test procedure.

8.6.3 *Pressure Measurements and Delta Pressure Calculation:*

8.6.3.1 *Oil Pressure in Gallery*—Locate at oil charging manifold at the tee with the oil sampling line as shown in Fig. A4.7.

8.6.3.2 *Air Pressure in Intake Manifold*—Take the measurement as illustrated in Fig. A4.21.

8.6.3.3 *Air Pressure at Engine Intake (Air Restriction at Engine Intake)*—Measure with a static port (pressure tap hole) located upstream of inlet air temperature thermocouple (see Fig. A4.20).

8.6.3.4 *Exhaust Pressure in Tailpipe (Exhaust Back Pressure)*—Measure in a straight section of pipe upstream of the exhaust tailpipe thermocouple, with a pressure tap hole as shown in Fig. A4.15. Do not locate the tap downstream of either the temperature thermocouple or the CO_2 probe.

8.6.3.5 *Crankcase Pressure*—Locate the pickup in the flywheel housing on the modified inspection plate. Refer to Fig. A4.23.

8.6.3.6 *Air Pressure at Turbocharger Outlet*—Locate the pickup as shown in Fig. A4.20. Locate the pressure tap upstream of the compressor outlet thermocouple.

8.6.3.7 *Air Pressure at CAC Outlet*—Locate the pickup after the CAC as shown in Fig. A4.22. Locate the pressure tap upstream of the CAC outlet thermocouple.

8.6.3.8 *Delta Air Pressure Across CAC*—Calculate as turbocharger outlet pressure minus air pressure at the CAC Outlet.

8.6.3.9 *Air Pressure in the Coolant Tank*—Locate the pickup at the top of the coolant system expansion tank, as shown in Fig. A4.23.

8.6.3.10 *Coolant Pressure at Jacket Inlet*—Locate the pickup as shown in Fig. A4.7.

8.6.3.11 *Coolant Pressure at Jacket Outlet*—Locate the pickup as shown in Fig. A4.18.

8.6.3.12 *Delta Coolant Pressure across Jacket*—Calculate as coolant pressure at jacket inlet minus pressure at jacket outlet.

8.6.3.13 *Barometric Pressure*—Record ambient cell pressure.

8.6.3.14 *EGR Pressure*—Locate the pickup on the straight portion of EGR pipe upstream of the thermocouple as shown in Fig. A4.15.

8.6.3.15 *Exhaust Pressures prior to Turbocharger*—Locate pickups in each side of the exhaust manifold section, as shown in Fig. A4.19.

8.6.4 *Carbon Dioxide Measurements:*

8.6.4.1 *General*—Calibrate the sensors prior to each measurement taken during the course of the test. The CO_2 concentrations for the calibration span gases are specified as follows: the intake span gas shall be 3 % to 4 % CO_2; the exhaust span gas shall be 1.5 % to 2 % CO_2. The blend quality for all span gases shall be Primary Standard ±1 %. The intake and exhaust CO_2 samples shall have a dew point no greater than 5 °C.

8.6.4.2 *Probe for Exhaust Carbon Dioxide*—Measure the volume fraction CO_2 in the exhaust gasses. Locate the probe downstream of the exhaust back-pressure tap and exhaust-tailpipe thermocouple. Use a 6.4 mm probe that meets the Code of Federal Regulations, Title 40 Part 86.310-79. The probe diameter shall not exceed the sample line diameter. Refer to Fig. A4.15.

8.6.4.3 *Probe for Intake Manifold Carbon Dioxide*—Measure the volume fraction CO_2 in the intake air. Locate the probe in the intake manifold, as shown in Fig. A4.21. Use a 6.4 mm probe that meets the Code of Federal Regulations, Title 40 Part 86.310-79. The probe diameter shall not exceed the sample line diameter.

8.6.5 *Flow-Rate Measurements:*

8.6.5.1 *Blowby Flow Rate*—Connect the metering instrument to the OMS housing consistent with 6.2.6. An example is shown in Fig. A4.24.

8.6.5.2 *Coolant Flow Rate*—Locate the meter between the expansion tank and engine inlet as shown in Fig. A4.11.

8.6.5.3 *Fuel Flow Rate*—Locate the meter prior to day tank and the engine inlet so that only make-up or consumed fuel is measured (see Fig. A4.14). Use an appropriately sized day tank.

TABLE 2 Other Quantities

Quantity, units	Source of Measurement
Volume fraction CO_2 in intake gasses, %	Emissions Equipment (see 8.6.4.3)
Volume fraction CO_2 in exhaust gasses, %	Emissions Equipment (see 8.6.4.2)
Air Temperature in Intake Manifold, °C	Diagnostic Link
Intake-Manifold Pressure, kPa (absolute)	Diagnostic Link
Torque, N·m	Diagnostic Link
Fuel Flowrate, mg/s	Diagnostic Link
Intake Air Mass Flowrate, kg/s	Diagnostic Link
EGR Flowrate, kg/s	Diagnostic Link
Turbocharger Speed, r/min	Diagnostic Link
Throttle Position, %	Diagnostic Link
Fuel Temperature, °C	Diagnostic Link
Rail-Pressure Valve Position, %	Diagnostic Link
Temperature of Coolant Outlet, °C	Diagnostic Link

8.6.6 *Miscellaneous Measurements:*

8.6.6.1 *Engine Speed*—Measure using an encoder or similar.

8.6.6.2 *OMS Speed*—Measure using equipment outlined in 6.2.14. An example is shown in Fig. A4.19.

8.6.6.3 *Torque*—Use a load cell on the dynamometer. An example is shown in Fig. A4.25.

8.6.6.4 *External Oil Tank Mass*—Use a load cell to suspend the external oil tank. An example is shown in Fig. A4.5.

8.6.6.5 *Controller Area Network (CAN) Data*—Optionally, hand record the quantities in Table 2 from diagnostic link.

8.6.7 *System Time Responses*—The maximum allowable system time responses are shown in Table 3. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report.[24]

9. Procedure

9.1 *General*—The test starts with a sequence involving a warmup, an engine break-in, and a cooldown. The test oil is then installed, the engine warmed up to the test conditions, and a two-stage procedure lasting a maximum of 200 h is initiated. Scuffing is determined from analysis of end of test parts and test oil samples.

9.2 *Pretest Procedure:*

9.2.1 Following the engine assembly, install the engine on the test stand, connect to the stand support system and install a new Detroit Diesel oil filter.[10]

9.2.2 *Initial Oil-Fill*—Charge the engine with 34.4 kg test oil by using an appropriate pump to pressure-feed the oil into the oil module at the location shown in Fig. A4.7.

9.2.3 Within 15 min of the oil being pressure-fed into the engine, start the engine as described in 9.2.4. If the engine is started after 15 min document the time in the comments section of the report form.

9.2.4 *Initial Engine Startup:*

9.2.4.1 Prime the fuel system using a priming pump.

9.2.4.2 Turn ignition on for 60 s to allow a build-up of fuel pressure.

9.2.4.3 Turn ignition off and then back on prior to first start.

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

TABLE 3 Maximum Allowable System Time Responses

Measurement Type	Time Response, s
Speed	2.0
Torque	2.0
Temperature	3.0
Pressure	3.0
Flow Rate	45.0

9.2.4.4 Crank the engine for a maximum of 10 s. If the engine does not start, continue to crank for periods of a maximum of 10 s. Document the total cranking time in the comments section of the report form if it exceeds 30 s.

NOTE 1—Section 9.2.4.4 applies to all startups not just the initial one (see 9.4.1.3).

9.2.5 *Pretest Break-in Sequence:*

9.2.5.1 Carry out the sequence, described in Table A6.1, comprising a 32 min warmup, followed by a 15 min break-in and a 2 min cooldown.

9.2.5.2 Carry out any unscheduled shutdowns and subsequent restarts during the break-in as described in 9.4.2.3 and 9.4.2.4*(2)*, respectively.

9.2.5.3 Following any shutdowns that occur in the break-in, run the remainder of the 15 min break-in before proceeding to 9.2.6.

9.2.6 At the end of the cooldown step of the break-in sequence, stop the engine.

9.3 *Test Procedure:*

9.3.1 Once the engine has come to a stop following the pretest break-in, drain the oil from the oil pan, the external oil tank, the oil module, and the oil heat exchanger and lines. Begin draining oil within 10 min of shutting down the engine. Allow the oil to drain for 30 min ± 1 min.

9.3.2 Install a new Detroit Diesel oil filter.[10]

9.3.3 Before proceeding to the next step, wait until the coolant temperature at jacket outlet and oil temperature in sump are below 60 °C.

9.3.4 *Oil-Fill for Test Procedure*—Charge the engine with 28.2 kg test oil by using an appropriate pump to pressure-feed the oil into the oil module at the location shown in Fig. A4.7.

9.3.5 *Engine Startup*—Start the engine as described in 9.2.4.4 and carry out the stage 1 warmup sequence described in Table A6.2.

9.3.6 *Test Sequence:*

9.3.6.1 Immediately after the end of the stage 1 warmup sequence, start the test timer and carry out the two-stage test procedure summarized in Table 4 and for which the operating conditions and other relevant quantities are shown in Table 1 and Table 2, respectively.

9.3.6.2 *4 h Soak Periods*—Carry out 4 h soaks at the test hours shown in Table 4. Shutdown and restart the engine as described in 9.4.1.2 and 9.4.1.3, respectively.

9.3.6.3 *The Transition from Stage 1 to Stage 2*—At 30 h, carry out the 10 min transition from stage 1 to stage 2 as described by the sequence in Table A6.3. The setpoint ramp during the transition shall be 300 s.

9.3.7 *End of Test (EOT):*

TABLE 4 Test Summary

Test Hours	Stage	
0 h to 20 h	1	
4 h soak		
20 h to 30 h	1	Transition to Stage 2 at 30 h
30 h to 40 h	2	
4 h soak		
40 h to 60 h	2	
4 h soak		
60 h to 80 h	2	
4 h soak		
80 h to 100 h	2	
4 h soak		
100 h to 120 h	2	
4 h soak		
120 h to 140 h	2	
4 h soak		
140 h to 160 h	2	
4 h soak		
160 h to 180 h	2	
4 h soak		
180 h to 200 h	2	

9.3.7.1 The standard maximum test time is 200 h. If scuffing has not occurred at 200 h, shutdown the engine using the normal shutdown sequence described in Table A6.4. Disassemble the engine as described in 9.3.7.6 and carry out the inspection of engine, fuel, and oil as described in Section 10.

9.3.7.2 *Crankcase Pressure Greater than 2 kPa*—If the crankcase pressure exceeds 2 kPa for 5 s or longer shutdown the engine immediately using the normal shutdown sequence described in Table A6.4. Record the test time and the reason the early shutdown sequence was initiated on the appropriate report from. Determine if scuffing has occurred, either by visually examining the cylinders with a bore scope or by taking an oil sample, measuring the concentration of iron by Test Method D5185 (see 10.8.2) and carrying out the calculations described in 10.7.4.

(1) If scuffing has occurred, terminate the test, and record the test time at which the shutdown sequence was initiated. Dismantle the engine as described in 9.3.7.6, carry out the inspection of engine, fuel, and oil as described in Section 10 and determine the hours to scuff as described in 10.7.4.

(2) If scuffing has not occurred determine and rectify the cause of the high crankcase pressure. The shutdown is then treated as an unscheduled shutdown and the engine is restarted as described in 9.4.2.4 to return to test conditions.

NOTE 2—High crankcase pressure denotes high blowby indicating that scuffing may have occurred. (The crankcase pressure is typically 0 kPa during stage 2.) Shutting the engine down is a safety precaution to prevent multiple cylinders scuffing with the consequent potential for a catastrophic and dangerous engine failure.

9.3.7.3 If the engine is shut down and the test ended prior to the test timer reaching 200 h, record the test time at which the shutdown sequence was initiated. Shutdown the engine using the normal shutdown sequence described in Table A6.4. Record the nature of the early end of test on the appropriate report form.

9.3.7.4 The shutdown in 9.3.7.3 is not an acceptable EOT method for calibration tests on reference oils.

9.3.7.5 An engine may run longer than the standard maximum test time of 200 h. Any data recorded after 200 h shall be used toward Stage 2 *QI* calculations and limit count requirements imposed in accordance with Table A7.1. Continue to take 7.4 mL oil samples every 2 h that the test is run starting at 200 h. Measure the concentrations of wear metals by Test Method D5185 (see 10.8.2) on these samples.

9.3.7.6 *Engine Disassembly*—After terminating a test, release the cooling system pressure and drain the coolant. Drain the oil from the engine, auxiliary oil system, and the external oil system. Disconnect the test stand support equipment. (**Warning—**The coolant and oil may be very hot. The installation of a valve to safely vent the cooling system pressure is recommended.) Disassemble the engine and remove the liners and piston rings for rating and measurements.

9.4 *Engine Shutdowns and Restarts:*

9.4.1 *Normal Shutdown and Restart:*

9.4.1.1 *General*—A normal shutdown is one scheduled for the engine soak during stage 1 or stage 2 at the test hours shown in Table 4 (see 9.3.6.2) or at EOT.

9.4.1.2 *Normal Shutdown Sequence*—Carry out by ramping down to step 1 conditions shown in Table A6.4, then stopping the engine by turning the ignition off.

9.4.1.3 *Restart after a Normal Shutdown*—Crank the engine as described in 9.2.4.4 prior to restarting.

(1) If the shutdown occurs during stage 1, restart the engine using the warmup sequence shown in Table A6.2 to resume to stage 1 conditions.

(2) If the shutdown occurs during stage 2, restart the engine using the warmup sequence shown in Table A6.5 to resume stage 2 conditions.

9.4.1.4 Restart after the soak period regardless of the temperatures of the coolant jacket outlet or sump.

9.4.2 *Unscheduled Shutdown and Restart:*

9.4.2.1 *General*—An unscheduled shutdown is any shutdown other than a normal shutdown (see 9.4.1). Although the intent of this test method is to conduct the pretest engine break-in and stages 1 and 2 of the test procedure without unscheduled shutdowns, these may be initiated at the discretion of the laboratory to perform repairs or due to an emergency.

9.4.2.2 *Emergency/Hard Shutdown*—An emergency or hard shutdown occurs when the shutdowns using the sequence described in Table A6.4 cannot be completed, such as under an alarm condition. Emergency or hard shutdowns are considered a laboratory safety procedure and are not specified by this test method.

9.4.2.3 *Shutdown Sequence*—Carry out all non-emergency, unscheduled shutdowns, whether occurring during the break-in stage or during stages 1 or 2 of the test cycle, in the same way as for a normal shutdown, as described in 9.4.1.2.

9.4.2.4 *Restart after an Unscheduled Shutdown:*

(1) Do not initiate a warmup sequence until the coolant temperature at jacket outlet and oil temperature in sump are both below 60 °C.

(2) If the shutdown occurs during the pretest break-in, restart as described in A6.2.

(3) If the shutdown occurs during stage 1 or stage 2 restart as for a normal shutdown (see 9.4.1.3).

(4) If the engine is shutdown at any time after 30 h, including at any point during the transition, restart the engine

using the stage 2 warmup sequence described in Table A6.5 and resume the test at stage 2 conditions for the remainder of the transition time.

9.4.2.5 Record the length, reason, test time, and number of crank attempts performed for each unscheduled shutdown on the appropriate TMC report form.

9.4.3 *Shutdown and Downtime Limits*—To be considered an operationally valid test:

9.4.3.1 The number of unscheduled shutdowns shall not exceed 10.

9.4.3.2 The downtime shall not exceed 150 h, where downtime is calculated as the time, during shutdowns and warmups, between the engine leaving on-test conditions (that is, the test time at which shutdown is initiated) and returning to on-test conditions (that is, the test time at which the warmup sequence is completed).

9.4.3.3 Conduct an engineering review if either condition is exceeded.

9.5 *Test Timer:*

9.5.1 Start the test timer immediately after the two-stage test procedure has been initiated in 9.3.6.1.

9.5.2 *Normal Shutdowns*—The shutdown time, the 4 h soak and the subsequent warmup do not count as test time. Therefore stop the timer immediately at the initiation of the ramp down in 9.4.1.2 and restart at the end of the warmup sequence when the engine is back to test conditions.

9.5.3 *Unscheduled Shutdowns*—The shutdown and warmup times do not count as test time. Therefore stop the test timer immediately at the initiation of the shutdown and restart upon the completion of the warmup sequence when the engine is back to test conditions.

9.5.4 *Transition Period from Stage 1 to Stage 2 Outlined in A6.3*—Count as stage 2 test time.

9.6 *Assessment of Operational Validity:*

9.6.1 Calculate and report the quality index as described in A7.1.

9.6.2 Calculate and report averages, minimums, maximums, and standard deviations as described in A7.2.

9.6.3 Calculate and report limit counts as described in A7.3.

9.6.4 Determine operational validity as described in A7.3.

9.6.5 Perform an engineering review and report the results as described in A7.4.

9.7 *Test Oil Samples:*

9.7.1 Take test oil samples from the oil sample line specified in 6.2.4.6.

9.7.2 *Purge Sample*—Prior to obtaining each test oil sample, take a purge sample whose volume is either 236 mL or $\pi d^2 L/4$ mL, whichever is the greater (here d and L are the internal diameter and length, respectively, of the oil sample line).

9.7.2.1 After sample completion, return the purge sample to the engine through the oil-add tube.

9.7.3 *Standard Oil Samples*—Take oil samples at the test hours and of the volumes shown in Table 5.

9.7.3.1 Take the 0 h oil sample from the fresh-oil drum.

9.7.3.2 Take the break-in oil sample as the engine is being drained of oil in 9.3.1.

9.7.3.3 Take the 30 h oil sample after the transition to stage 2.

9.7.3.4 Take the 20 h, 40 h, 60 h, 80 h, 100 h, 120 h, 140 h, 160 h, and 180 h oil samples following a 4 h soak period when the engine returns to test conditions after the warmup sequence.

9.7.3.5 Take the EOT oil sample during the cooldown sequence at end of test.

9.8 *Fuel Samples*—Take one 120 mL fuel sample from the fresh fuel container at start of test (SOT) (that is, at 0 h on the test timer) and at EOT.

9.9 *Operational Data Acquisition:*

9.9.1 Record all operational quantities shown in Table 1 and Table 2 with automated data acquisition at a minimum frequency shown in Table 6. Recorded values shall have a minimum resolution in accordance with Table 7.

9.9.2 Record the operational data on the appropriate test report form.

9.10 *Carbon Dioxide in Intake and Exhaust Gasses:*

9.10.1 Measuring CO_2 concentration in the intake and exhaust gasses is optional. It is recommended after restarting engine from soak and may also be carried out at the following test hours: 1, 19, 21, 39, 41, 59, 61, 79, 81, 99, 101, 119, 121, 139, 141, 159, 161, 179, 181, and 199.

10. Inspection of Engine, Fuel, and Oil

10.1 *Pistons*—No piston measurements are required.

10.2 *Piston Rings:*

10.2.1 Clean and measure ring mass and gap pre- and post-test in accordance with the Mack Test Ring Cleaning and Measuring Procedure.[16] On the appropriate form, report ring mass to the nearest 0.0 mg and ring gap to the nearest 0.001 mm.

10.2.2 *Piston Ring Mass Loss*—Calculate piston ring mass loss as the difference between the pre-test ring mass and the post-test ring mass. Report results to the nearest 0.0 mg on the appropriate form.

10.3 *TEI Measurements*—On the appropriate report forms, report measurements provided by TEI associated with the engine kit received from TEI.

10.4 *Liner Scuffing Ratings:*

10.4.1 *General*—A general definition of adhesive wear (scuffing) is given in 3.1.1. Scuffing for this test is defined in 3.2.3 and applies to all references to scuffing.

10.4.2 Rate liners for scuffing as described in ASTM Deposit Rating Manual 20, using a 4200 K to 7000 K bulb, and report results on the appropriate forms.

10.4.3 Rate each liner for scuffing as follows:

10.4.3.1 First rate each of ten circumferential segments. For reference purposes, number the segments sequentially from 1 to 10, the number one segment corresponding to the 12:00 o'clock to 1:12 arc when viewed from the top of the liner, 12 o'clock being the front of the engine.

10.4.3.2 Any scuffed segment areas less than 2 mm wide by 10 mm long are classified as not scuffed.

TABLE 5 Schedule for Oil Sampling and Testing

Test Hour	Sample Size, mL	Quantity/Test Method									Comments
		Fuel Dilution	KV at 100 °C	HTHSV at 150 °C	Oxidation, IR Peak Height Method[A]	Oxidation, IR Peak Area Method[A]	Soot by TGA	Wear Metals	Base Number	Acid Number	
		D3524	D445	D4683	Based on E168	Based on E168	D5967	D5185	D4739	D664	
0	300[B]		X	X	X	X	X	X	X	X	From fresh-oil drum
Break-in	300[B]		X				X	X	X	X	At end of break-in
4	7.4							X			
8	7.4							X			
12	7.4							X			
16	7.4							X			
18	60	X	X		X	X	X	X			
20	7.4							X			on test after soak
24	7.4							X			
28	7.4							X			
30	7.4							X			after transition
31	30	X						X			
32	7.4							X			
33	7.4							X			
34	7.4							X			
35	7.4							X			
36	7.4							X			
38	60		X		X	X	X	X			
40	7.4							X			on test after soak
42	7.4							X			
44	7.4							X			
46	7.4							X			
48	7.4							X			
50	7.4							X			
52	7.4							X			
54	7.4							X			
56	7.4							X			
58	60		X		X	X	X	X			
60	7.4							X			on test after soak
62	7.4							X			
64	7.4							X			
66	7.4							X			
68	7.4							X			
70	7.4							X			
72	7.4							X			
74	7.4							X			
76	7.4							X			
78	60		X		X	X	X	X			
80	7.4							X			on test after soak
82	7.4							X			
84	7.4							X			
86	7.4							X			
88	7.4							X			
90	7.4							X			
92	7.4							X			
94	7.4							X			
96	7.4							X			
98	60		X		X	X	X	X			
100	7.4							X			on test after soak
102	7.4							X			
104	7.4							X			
106	7.4							X			
108	7.4							X			
110	7.4							X			
112	7.4							X			
114	7.4							X			
116	7.4							X			
118	60		X		X	X	X	X			
120	7.4							X			on test after soak
122	7.4							X			

TABLE 5 *Continued*

Test Hour	Sample Size, mL	Fuel Dilution	KV at 100 °C	HTHSV at 150 °C	Oxidation, IR Peak Height Method[A]	Oxidation, IR Peak Area Method[A]	Soot by TGA	Wear Metals	Base Number	Acid Number	Comments
		Quantity/Test Method									
		D3524	D445	D4683	Based on E168	Based on E168	D5967	D5185	D4739	D664	
124	7.4							X			
126	7.4							X			
128	7.4							X			
130	7.4							X			
132	7.4							X			
134	7.4							X			
136	7.4							X			
138	60		X		X	X	X	X			
140	7.4							X			on test after soak
142	7.4							X			
144	7.4							X			
146	7.4							X			
148	7.4							X			
150	7.4							X			
152	7.4							X			
154	7.4							X			
156	7.4							X			
158	60	X	X		X	X	X	X			
160	7.4							X			on test after soak
162	7.4							X			
164	7.4							X			
166	7.4							X			
168	7.4							X			
170	7.4							X			
172	7.4							X			
174	7.4							X			
176	7.4							X			
178	60		X		X	X	X	X			
180	7.4							X			on test after soak
182	7.4							X			
184	7.4							X			
186	7.4							X			
188	7.4							X			
190	7.4							X			
192	7.4							X			
194	7.4							X			
196	7.4							X			
198	60		X		X	X	X	X			
EOT	300[B]	X	X	X	X	X	X	X	X	X	at EOT

[A] See 10.8.7.
[B] Sample size may be <300 mL for the 0 h, break-in, and EOT samples provided all the tests specified are carried out.

TABLE 6 Automatic Data Acquisition Frequency

Test Stage/Step	Log Frequency
Warm Up	1 s
Cooldown	1 s
Break-in	1 s
Stage 1 to Stage 2 Transition	1 s
Test Stage 1	1 min
Test Stage 2	1 min
4 h Soak	1 min

10.4.3.3 Do not add together scuffed segments of area less than 2 mm long by 10 mm high to create an area large enough to be considered scuffed in 10.4.3.2.

10.4.3.4 For each of the 10 segments, calculate, and report on the appropriate report form, the percent scuffing value as the quotient of the scuffed area and the surface area of that segment multiplied by 100. (Note that the resolution for liner scuffing rating for each segment is 0.5 % because of the area criteria defined in 10.4.3.2.)

10.4.3.5 For each liner, calculate the average of the scuffing value of the 10 segments and report on the appropriate report form. (Note that the resolution for liner scuffing rating is 5 % because of the area criteria defined in 10.4.3.2.)

10.5 *Ring Distress Ratings:*

10.5.1 *General*—Ring distress for this test is defined by ASTM Deposit Rating Manual 20, Sections A to D, on scuffing, scoring, wiping, and seizing.

10.5.2 Rate each ring for distress as follows:

10.5.2.1 First rate each of ten circumferential segments. For reference purposes, number the segments sequentially from 1 to 10, the number one segment corresponding to the 12:00

TABLE 7 Minimum Resolution of Recorded and Calculated Quantity

Quantity	Record Data to Nearest	Quantity	Record Data to Nearest
Air Temperature at CAC Outlet	1 °C	Air Pressure at CAC Outlet	0.1 kPa
Air Temperature at the Turbocharger Outlet	1 °C	Air Pressure at Turbocharger-Outlet	0.1 kPa
Air Temperature in Engine Intake	0.1 °C	Air Pressure in Engine Intake	0.01 kPa
Air Temperature in Intake-Manifold	0.1 °C	Air Pressure in Intake Manifold	0.1 kPa
Ambient Temperature of Ambient Conditions	1 °C	Air Pressure in the Coolant Tank	1 kPa
Coolant Temperature at Jacket Outlet	0.1 °C	Barometric Pressure	0.1 kPa
Coolant Temperature at EGR Cooler Inlet	1 °C	Blowby Flow Rate	1 L/m
Coolant Temperature at EGR Cooler Outlet	1 °C	Coolant Flow Rate	1 L/m
Coolant Temperature at Engine Inlet	1 °C	Coolant Pressure at Jacket Inlet	0.1 kPa
Coolant Temperature at Engine Outlet	1 °C	Coolant Pressure at Jacket Outlet	0.1 kPa
Coolant Temperature at Jacket Inlet	0.1 °C	Crankcase Pressure	0.01 kPa
Delta Coolant Temperature across Coolant Jacket	0.1 °C	Delta Air Pressure Across CAC	0.1 kPa
Delta Coolant Temperature across Engine	1 °C	Delta Coolant Pressure accross Jacket	0.1 kPa
Delta Coolant Temperature at EGR Cooler	1 °C	EGR Pressure	1 kPa
Dew Point Temperature of Inlet Air	1 °C	Exhaust Pressure in Tailpipe	0.1 kPa
EGR Temperature	1 °C	Exhaust Pressure Pre-Turbocharger Front	1 kPa
Exhaust Temperature in Tailpipe	1 °C	Exhaust Pressure Pre-Turbocharger Rear	1 kPa
Fuel Temperature at Engine Inlet	0.1 °C	Oil Pressure in Gallery	1 kPa
Fuel Temperature at Engine Return	1 °C	External Oil Tank Mass	0.01 kg
Oil Temperature in Gallery	0.1 °C	Fuel Flow Rate	0.1 kg/h
Oil Temperature in Sump	1 °C	Torque	0.1 N·m
OMS Speed	1 r/min	Volume Fraction CO_2 in Exhaust and Inlet Gasses	0.01 %
Speed	1 r/min		

o'clock to 1:12 arc when viewed from the top of the ring, 12 o'clock being aligned with the ring gap.

10.5.2.2 Any distress that is less than 2 mm wide is classified as not distressed.

10.5.2.3 For each of the ten segments, calculate, and report on the appropriate report form, the percent ring distress value as the quotient of the distressed area and the surface area of that segment multiplied by 100. (Note that the resolution for a ring distress rating for each segment is 0.5 % because of the width criteria defined in 10.5.2.2.)

10.5.2.4 For each ring, calculate the average of the distress ratings for each of the 10 segments and report on the appropriate report form. (Note that the resolution for a ring distress rating is 5 % because of the width criteria defined in 10.5.2.2.)

10.6 *Ring-Gap Location*—Record the location of the ring gap for each ring when removing the pistons at EOT and report on the appropriate test form. Number the ring gap locations sequentially from 1 to 10 so that they correspond to the ten liner segments described in 10.4.3.

10.7 *Determination of Hours to Scuff:*

10.7.1 Rate each liner for scuffing as described in 10.4 and measure the mass loss for each top ring as described in 10.2.2.

10.7.2 If one or more liners has a scuff rating less than 27.0 % and one or more top rings associated with the same liner has a mass loss less than 250.0 mg report the hours to scuff as greater than the time on the test counter at EOT.

10.7.3 If one or more liners has a scuffing rating equal to or greater than 27.0 % and one or more top rings associated with the same liner has a mass loss equal to or greater than 250.0 mg it is necessary to calculate the hours to scuff using the iron (Fe) concentration in the oil as a criteria as follows:

10.7.4 *Hours-to-Scuff Calculation Based on Iron Concentration in Oil:*

10.7.4.1 Calculate the change in concentration of iron in the oil on samples taken at two-hour intervals using Eq 1:

$$\Delta w_{Fe} = w_{Fe}(h) - w_{Fe}(h - 2) \quad (1)$$

where:

Δw_{Fe} = the change in mass fraction of iron between test hours h and h-2 on the timer, mg/kg,

$w_{Fe}(h)$ = the mass fraction of iron in the sample taken at test hour h on the timer, mg/kg, and

$w_{Fe}(h-2)$ = the mass fraction of iron in the sample taken at test hour h-2 on the timer, mg/kg.

10.7.4.2 If no oil sample was taken 2 h prior to a sample, use the previous sample taken more than 2 h earlier to calculate hours to scuff in Eq 1. For example, if the previous sample taken before the test hour 8 sample was at test hour 4, then use the concentrations of iron at test hours 8 and 4 in Eq 1.

10.7.4.3 The hours to scuff is the first value of h for which $\Delta w_{Fe} \geq 25$ mg/kg. Report on the appropriate form.

10.8 *Oil Analyses*—Carry out the following tests and report the results on the appropriate report form on all the test oil samples collected in the oil sampling schedule in Table 5:

10.8.1 *Kinematic Viscosity (KV)*—Measure KV at 100 °C by Test Method D445. Use the minimum viscosity for calculating the viscosity increase.

10.8.2 *Soot Concentration*—Measure mass fraction of soot as % by the TGA procedure described in Annex A4 of Test Method D5967.

10.8.3 *Wear Metals Concentrations*—Determine concentrations of wear metals (iron, lead, copper, chromium, aluminum, nickel), additive metals, silicon, and sodium by Test Method D5185.

10.8.4 *High-Temperature, High-Shear Viscosity (HTHSV)*—Measure HTHSV at 150 °C by Test Method D4683.

10.8.5 *Base Number*—Measure base number by Test Method D4739.

10.8.6 *Acid Number*—Measure acid number by Test Method D664.

10.8.7 *Oxidation*—Use Fourier Transform Infrared (FTIR) to measure oxidation using both integrated IR[25] and peak height IR techniques[26] based on Practice E168.

10.8.8 *Concentration of Diesel Fuel in Used Oil (Fuel Dilution)*—Measure the mass fraction as percent of the fuel in the oil by Test Method D3524.

10.9 *Fuel Inspections:*

10.9.1 Use inspection records provided by the fuel supplier to ensure the fuel conforms to the specifications shown in Table A5.1 and to complete the appropriate form for the last batch of fuel used during the test. In addition, make the following measurements on fresh fuel container at SOT (that is, at 0 h on the test timer) and EOT-fuel samples:

10.9.1.1 API gravity at 15.6 °C by Test Method D287 or Test Method D4052.

10.9.1.2 Mass fraction total sulfur as mg/kg by Test Method D5453 (D2622 or D4294 can be substituted). Use one 120 mL sample for these measurements.

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

11.1 Annex A8 describes calibration procedures using the TMC reference oils, including their storage and conditions of use, the conducting of tests, and the reporting of results.

11.2 Annex A9 describes maintenance activities involving TMC reference oils, including special reference oil tests, special use of the reference oil calibration system, donated reference oil test programs, introducing new reference oils, and TMC information letters and memoranda.

11.3 Annex A10 provides information regarding new laboratories, the role of the TMC regarding precision data, and the calibration of test stands used for non standard tests.

11.4 *New Laboratories and New Test Stands:*

11.4.1 *General*—A new laboratory is one that has never previously calibrated a test stand for this test method. A new stand is a test cell and support hardware that has not completed an acceptable reference-oil test within 24 months of the EOT date of the last acceptable reference-oil test. Perform a calibration as described in 11.4.2 to introduce a new test stand.

11.4.2 *Test Stand Calibration:*

11.4.2.1 Calibrate the test stand by conducting a test with a blind reference oil (see A8.2). Submit the results to the TMC[2] as described in A8.6. Determine the acceptability of a reference-oil test according to the Lubricant Test Monitoring System (LTMS).[27]

11.4.2.2 Calibrate a stand after 12 months or 15 operationally valid non-reference tests have elapsed since the completion of the last successful calibration test. An unsuccessful calibration test voids any current calibration on the test stand.

11.4.2.3 A non-reference test stand is defined as one in which the engine has been installed with the test oil and the engine has been cranked with the intent of firing the engine. Report the date the engine was charged with test oil as the oil charged date on the appropriate form. Report the first time the engine is cranked with the intention of firing the engine as the engine start date on the appropriate form.

11.4.3 *Test Stand and Engine Combination*—For reference-oil and non-reference-oil tests, any engine may be used on any stand. However, use the engines on the test stands on a first available engine basis and do not attempt to match a particular test stand and engine for any given test.

11.4.4 *Stand Modification and Calibration Status*—Stand-calibration status will be invalidated by conducting any non-standard test or modification of the test and control systems, or both. A non-standard test is any test conducted under a modified procedure, or using non-procedural hardware, or using controller-set-point modifications, or any combination thereof. Any such changes terminate the current calibration period. A reference test is required before restarting the current calibration period (see A8.2.2). If changes are contemplated, contact the TMC[2] beforehand to ascertain the effect on the calibration status.

11.4.5 A calibration test that results in a scuff in less than 30 h shall be considered as invalid.

11.5 *Test Numbering*—Number each DD13 test to identify the test-stand number, the test-stand run number, engine-serial number, runs on engine, and TEI engine-kit number. 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 example, 58-30A-00007-6-200 defines a test on stand 58 and stand run 30 as a calibration test that was run twice on engine with serial number 00007, which has run 6 tests, and used parts from TEI kit 200. A test number of 58-14-00007-38-873 defines a test on stand 58 and stand run 14 as a non-reference oil test on engine 00007, which has run 38 tests, and used parts from TEI kit 873.

12. Report

12.1 For reference oil results, use the standardized report form set available from the ASTM TMC and data dictionary for reporting test results and for summarizing operational data.

NOTE 3—Report the non-reference oil test results on these same forms if the results are intended to be submitted as candidate oil results against a specification.

12.1.1 Fill out the report forms according to the formats shown in the data dictionary.

12.1.2 Transmit results to the TMC within five working days of test completion.

12.1.3 Transmit the results electronically as described in the ASTM Data Communications Committee Test Report Transmission Model (Section 2—Flat File Transmission Format) available from the ASTM TMC. Upload files via the TMC's website.

12.2 Report all reference oil test results, whether aborted, invalidated, or successfully completed, to the TMC.

[25] Mack T10 Integrated Infrared Oxidation Measurement Procedure available from TMC.

[26] Mack T12 Infrared Oxidation Peak Height Measurement Procedure available from TMC.

[27] The Lubricant Test Monitoring System may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

12.3 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits.

12.4 *Precision of Reported Units*—Use the Practice E29 rounding off method for critical pass/fail test result data. Report the data to the same precision as indicated in data dictionary.

12.5 In the space provided, note the time, date, test hour, and duration of any shutdown or off-test condition. Document the outcome of all prior reference oil tests from the current calibration sequence that were operationally or statistically invalid.

12.6 If a calibration period is extended beyond the normal calibration period length, make a note in the comment section and attach a written confirmation of the granted extension from the TMC to the test report. List the outcomes of previous runs that may need to be considered as part of the extension in the comment section.

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.[2]

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

NOTE 4—Intermediate Precision is the appropriate term for this test method, rather than repeatability, which defines more rigorous within-laboratory conditions.

13.1.2.1 *Intermediate Precision Limit (i.p.)*—The difference between two results obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the value shown in Table 8 in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

TABLE 8 Test Precision for DD13 Scuffing Test[A]

	Intermediate Precision[B]		Reproducibility[C]	
Test Result	$S_{i.p.}$[D]	i.p.	S_R[D]	R
Hours to Scuff	26	72	26	72

[A] These statistics are based on 12 tests conducted on three stands (one at each of three laboratories) on two ASTM TMC Reference Oils (864 and DD13C) and were calculated on May 5, 2016.
[B] See 13.1.2.
[C] See 13.1.3.
[D] S is the estimated standard deviation.

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

13.1.3.1 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the value shown in Table 8 in only in one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result ± Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.4 The test precision is shown in Table 8. The TMC updates precision data frequently, and this information can be obtained by contacting the TMC.[24]

13.1.5 *Bias*—Bias is determined by applying an accepted statistical technique to reference oil test results and, when a significant bias is determined, a severity adjustment is permitted for non-reference oil test results (refer to the TMC for details).

14. Keywords

14.1 adhesive wear; cylinder liner wear; diesel engine oil; exhaust gas recirculation; ring distress; scuffing

ANNEXES

(Mandatory Information)

A1. ASTM TEST MONITORING CENTER ORGANIZATION

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

ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489
www.astmtmc.cmu.edu

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

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

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

A2. SAFETY PRECAUTIONS

A2.1 *General*:

A2.1.1 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.

A2.1.2 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, and 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 which could become entangled, should be worn near running engines.

A2.1.3 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. 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.

A2.1.4 The test installation should be equipped with a fuel shut-off valve which is designed to automatically cutoff the fuel supply to 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.

A2.1.5 Consider an excessive vibration pickup interlock if equipment operates unattended. Fixed fire protection equipment should be provided.

A2.1.6 Normal precautions should be observed whenever using flammable solvents for cleaning purposes. Make sure adequate fire fighting equipment is immediately accessible.

A3. PARTS LIST

A3.1 A complete list of parts is held by the TMC.[24] The list includes approved parts required for:

A3.1.1 Rebuilt engines.

A3.1.2 Completing newly purchased engines.

A3.2 Build kits containing screened and measured parts are provided by and available from TEI.[22]

A3.3 A list of approved data codes for fuel injectors is held by TMC.[24]

A4. TEMPERATURE, PRESSURE, AND OTHER CONTROL SYSTEMS

A4.1 See Figs. A4.1-A4.25 for details.

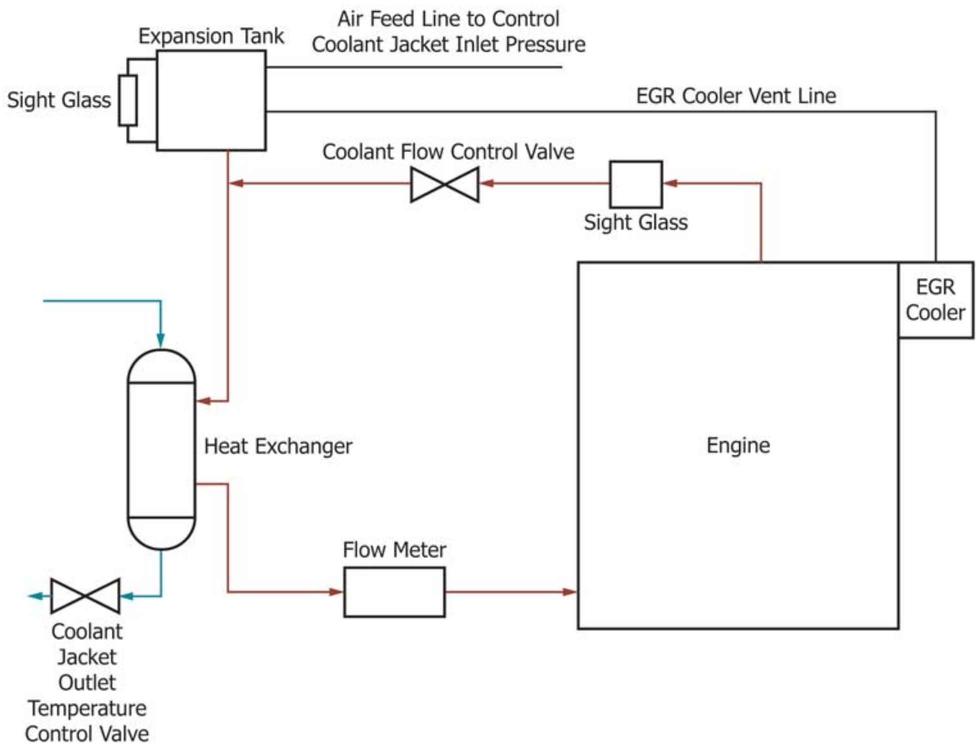

FIG. A4.1 Schematic of Coolant System

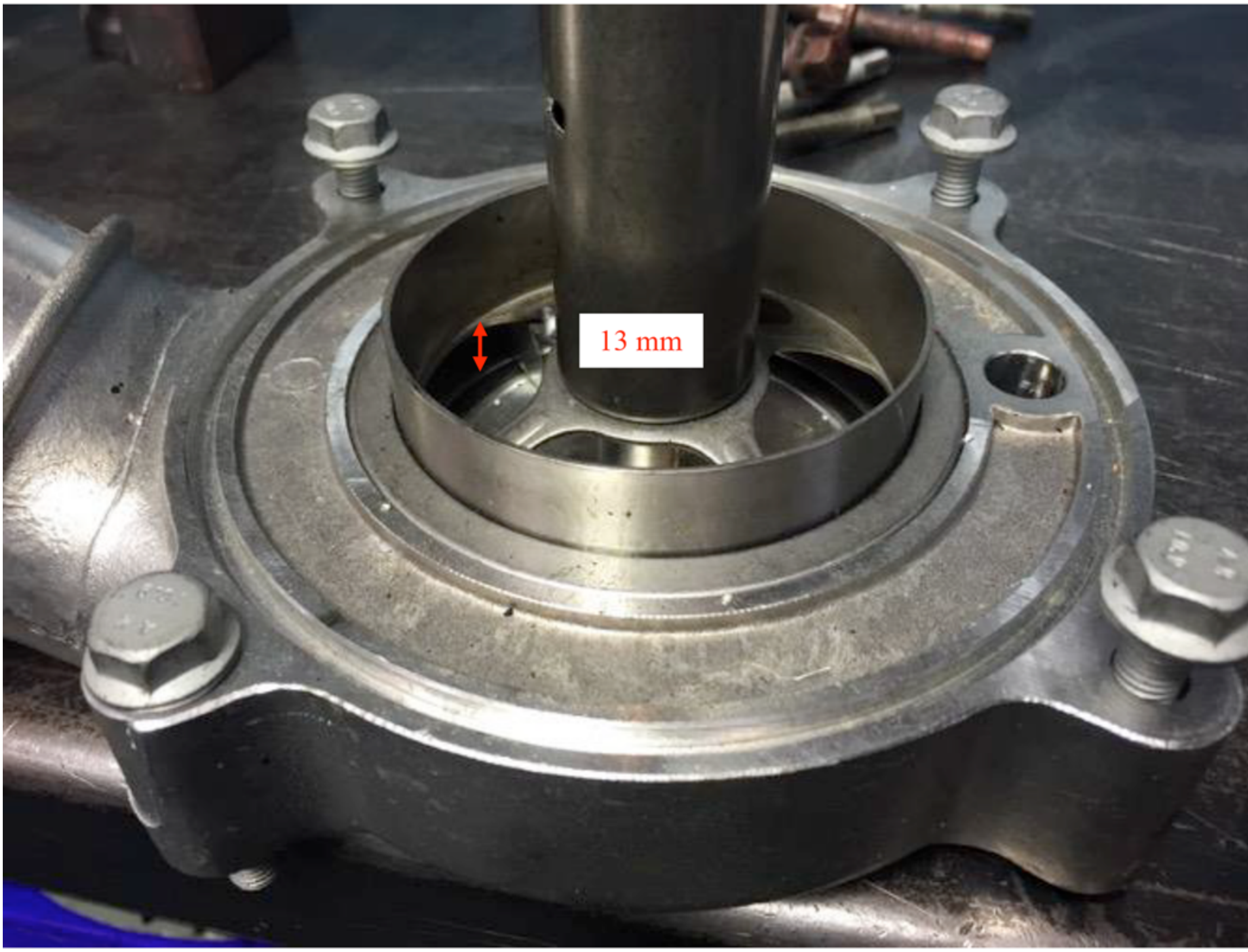

FIG. A4.2 13 mm Blocked Open, Coolant Thermostat

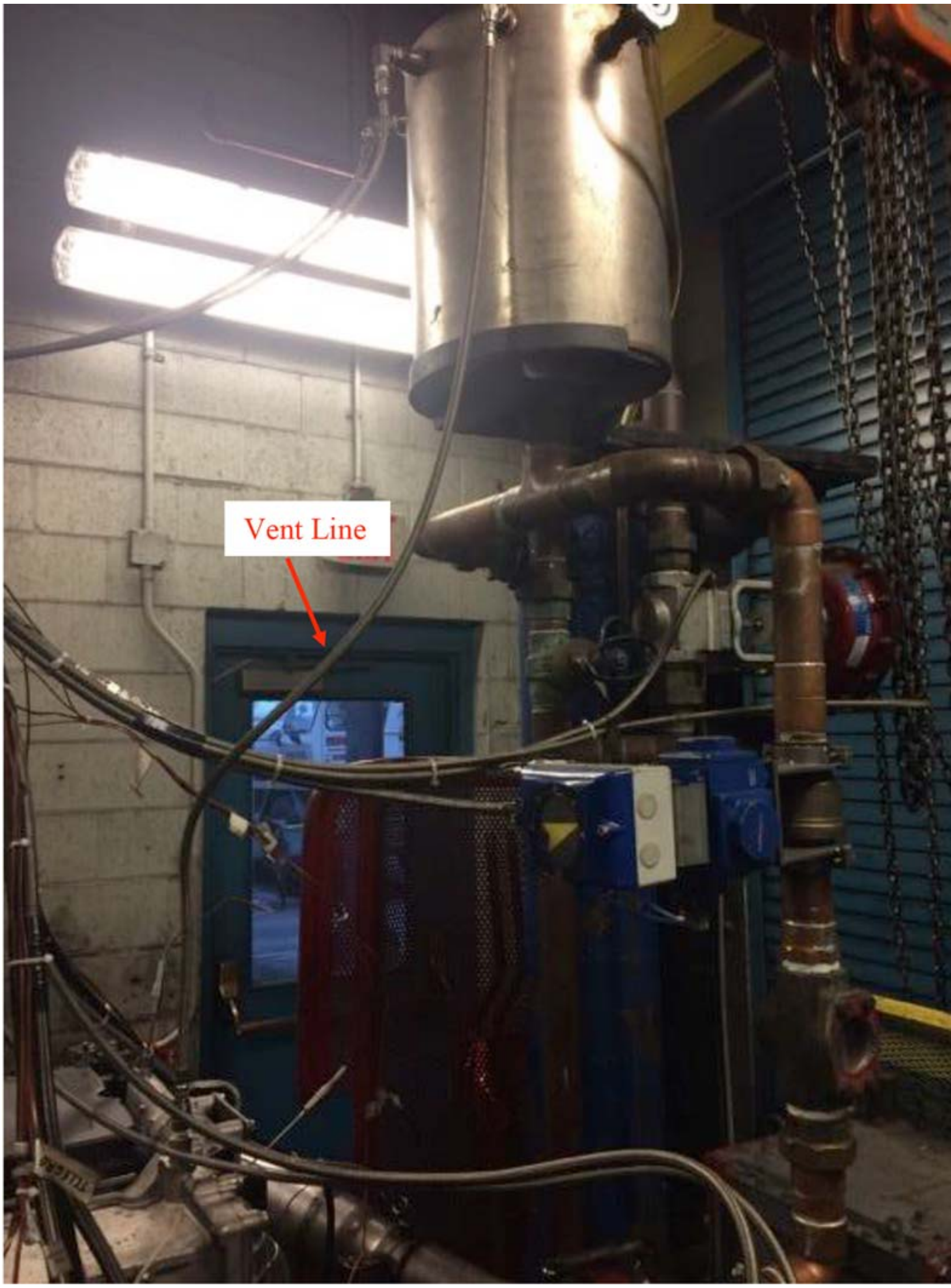

FIG. A4.3 EGR Cooler Vent Line and Coolant Tank

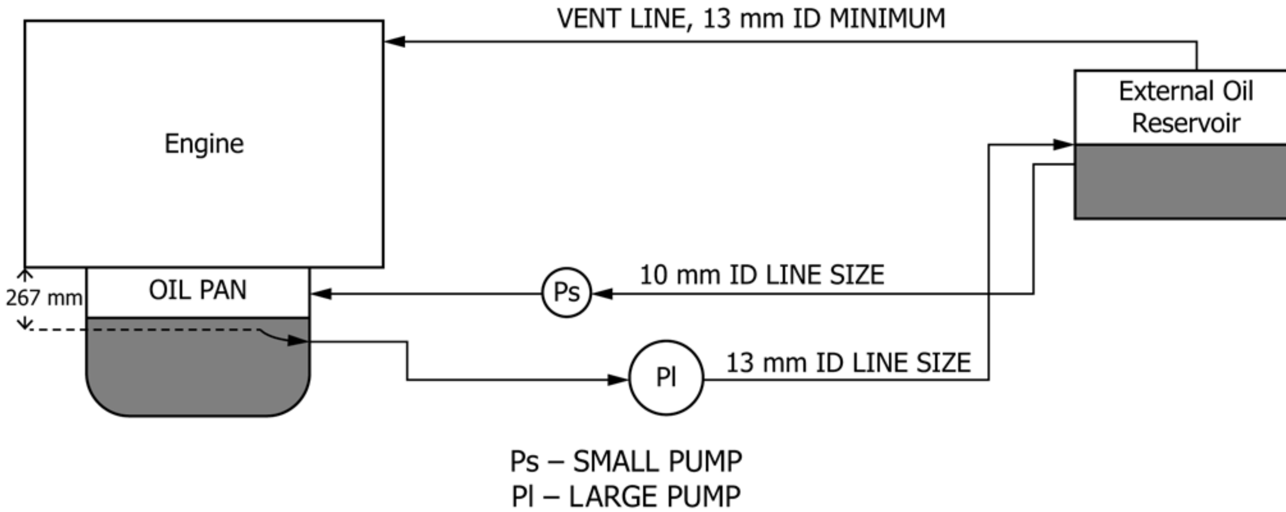

FIG. A4.4 Schematic of Auxiliary Oil System

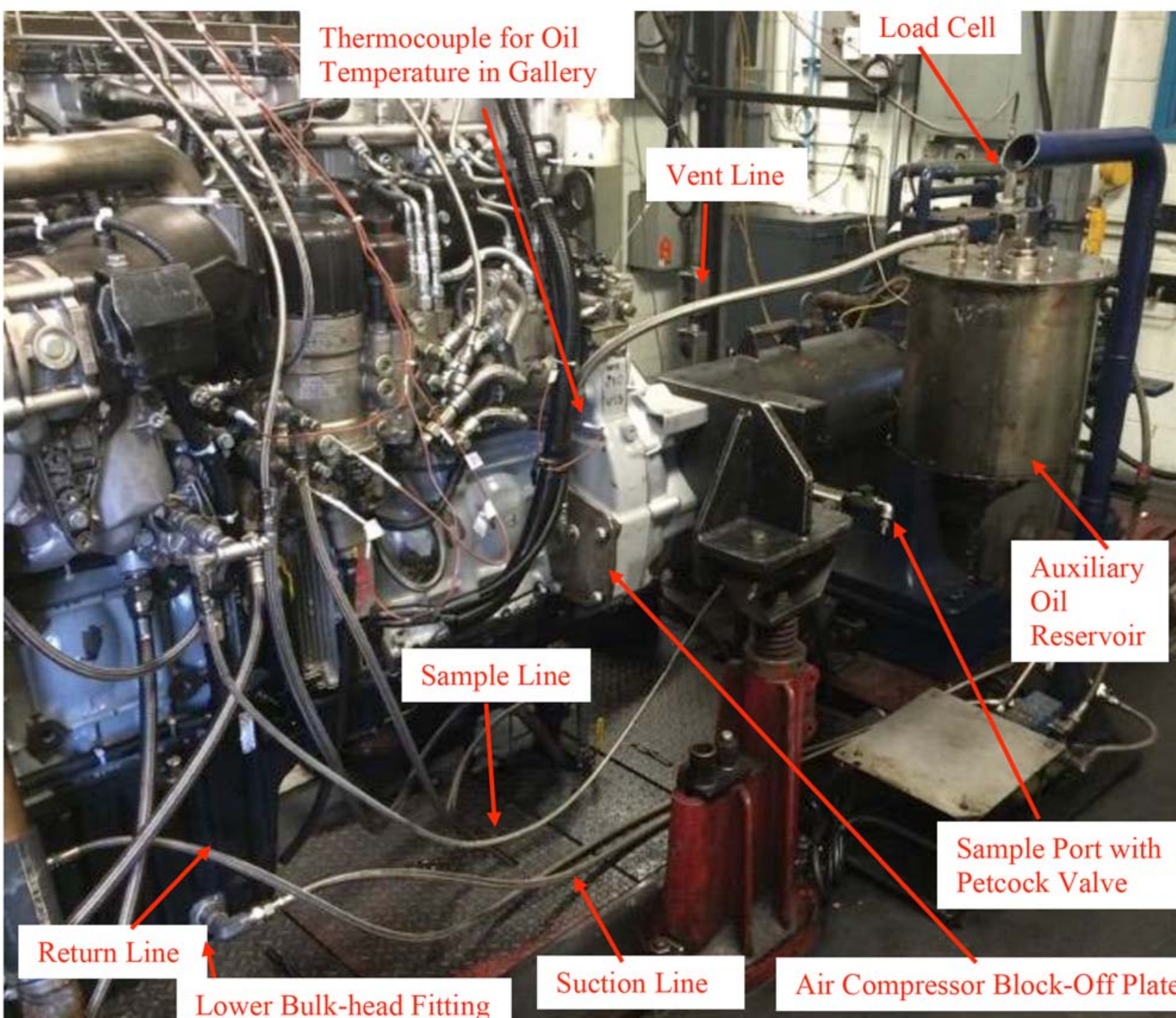

FIG. A4.5 Auxiliary Oil System

FIG. A4.6 Modifications to Oil Pan Bulkhead Fitting for Auxiliary Oil-System Suction Line

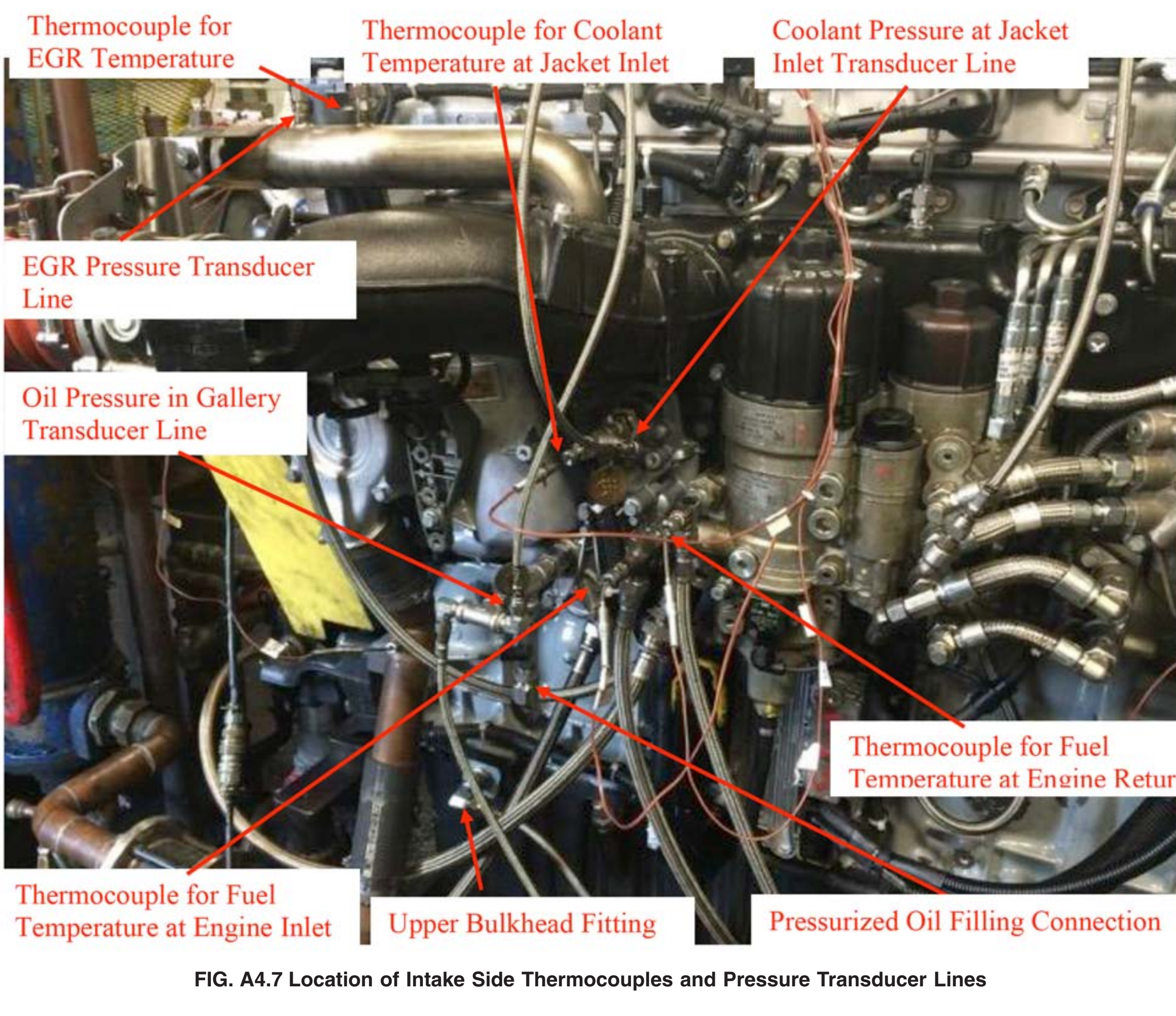

FIG. A4.7 Location of Intake Side Thermocouples and Pressure Transducer Lines

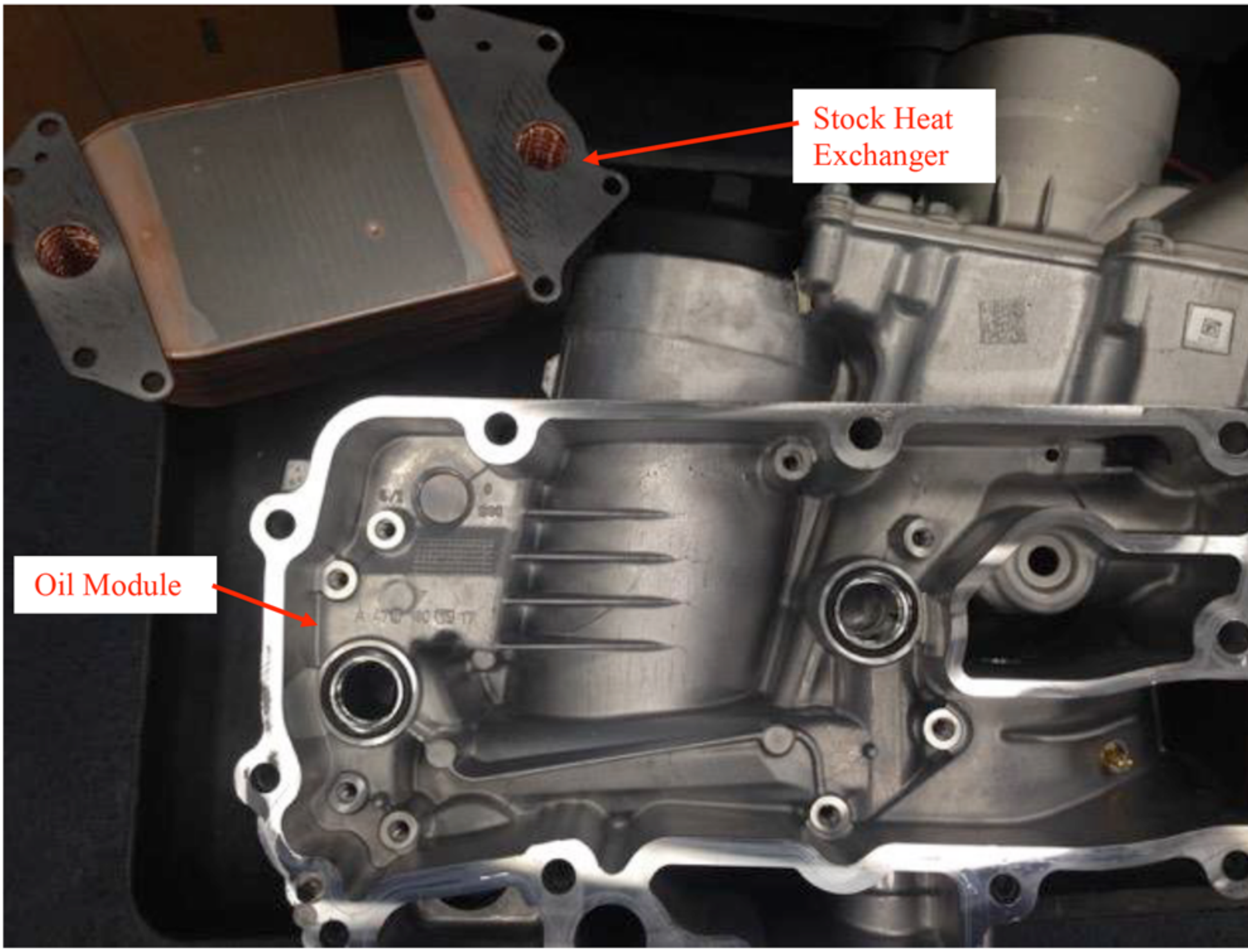

FIG. A4.8 Oil Cooler Heat Exchanger

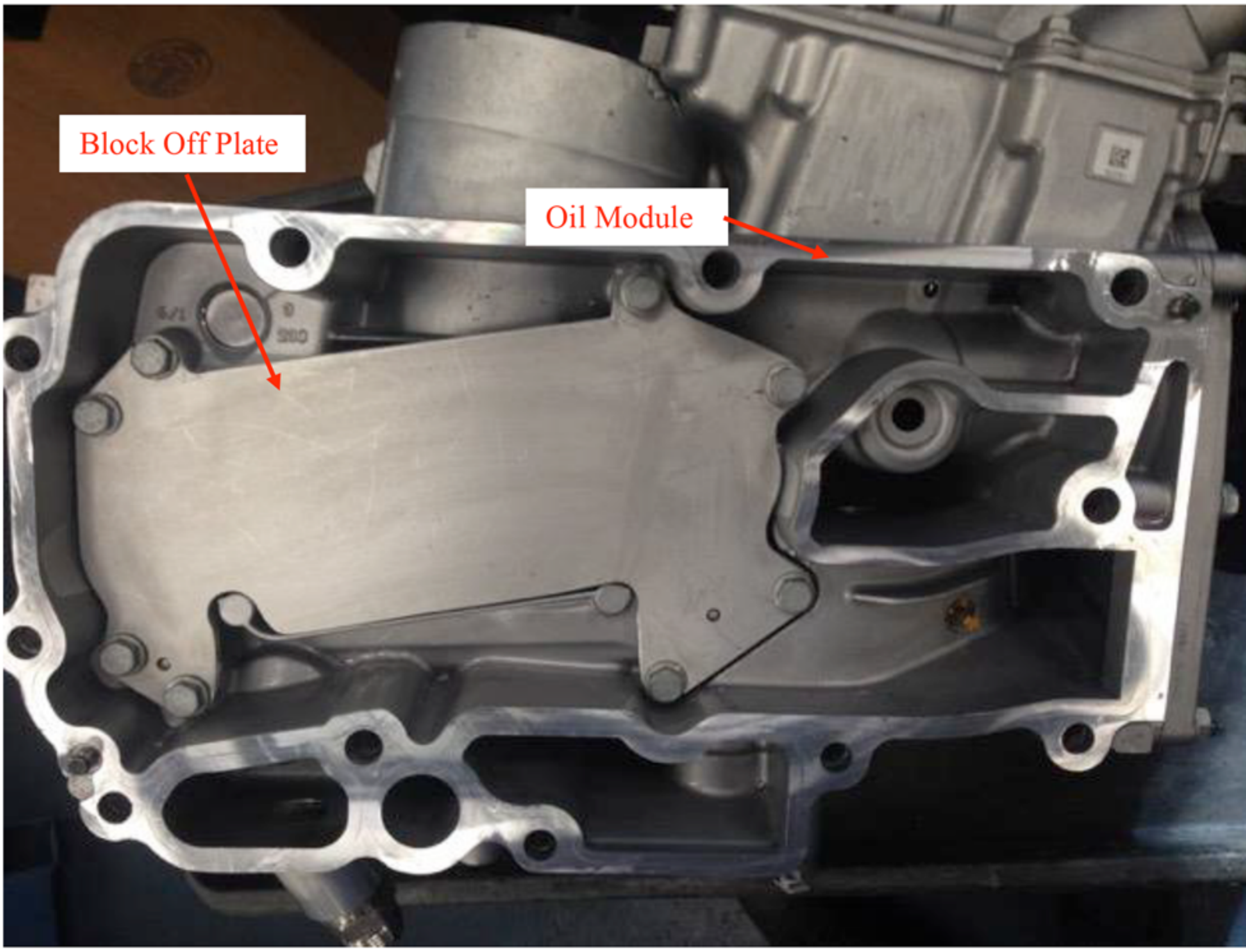

FIG. A4.9 Block-off Plate for Oil Cooler

FIG. A4.10 Oil Thermostat Housing and Machined-Aluminum Plug

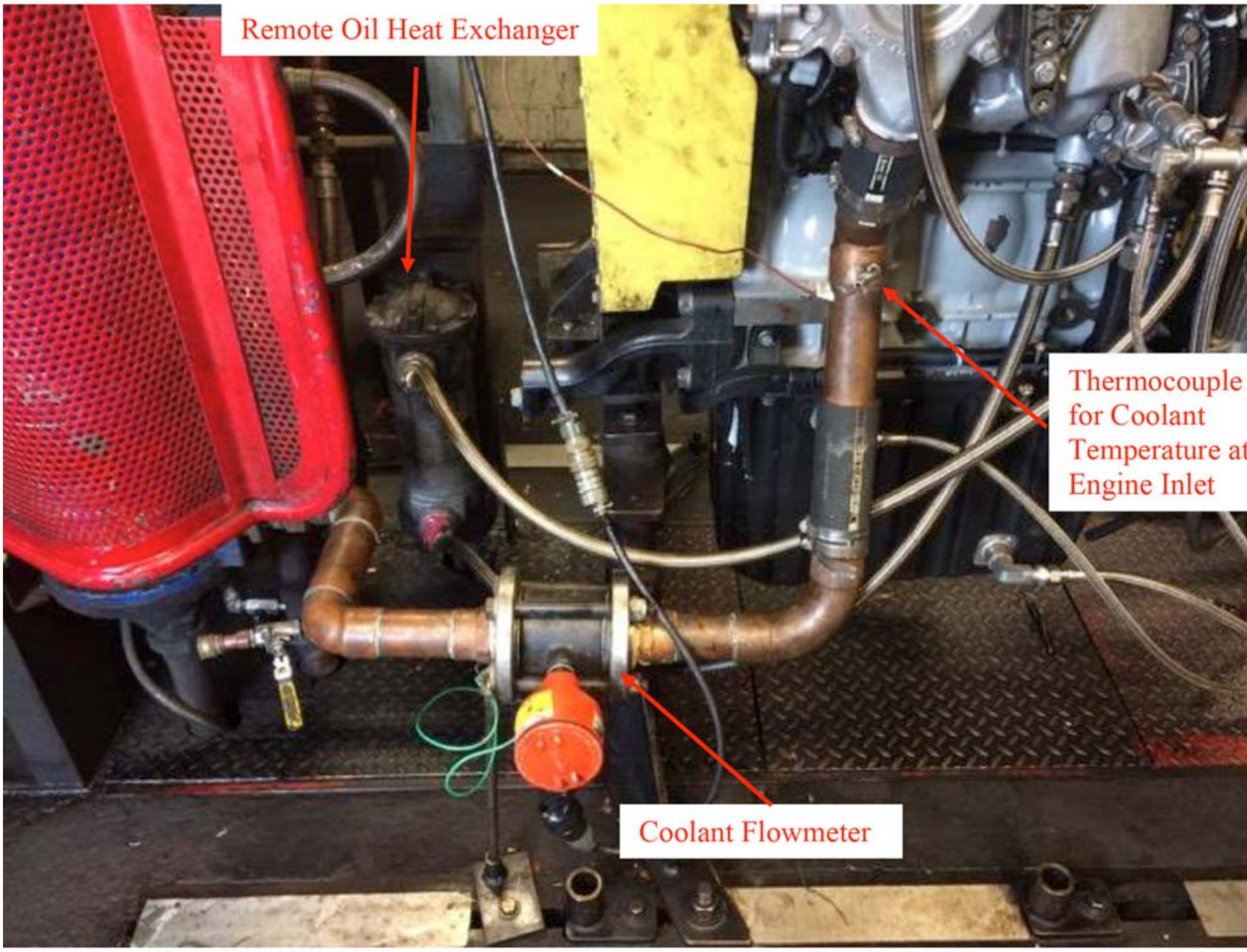

FIG. A4.11 Remote Oil Heat Exchanger and Partial Coolant System

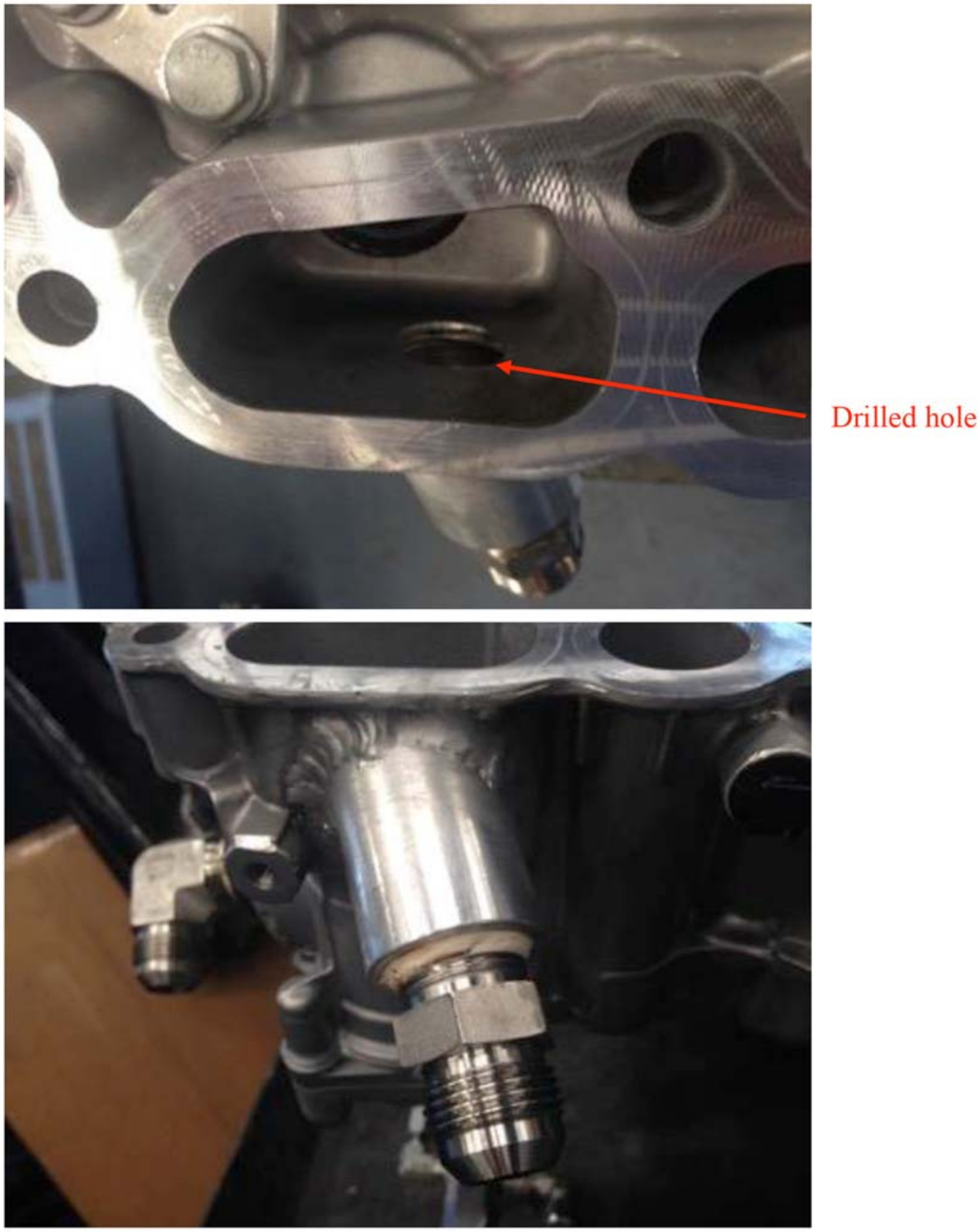

FIG. A4.12 Oil Module to Remote Oil Heat Exchanger Supply Modification

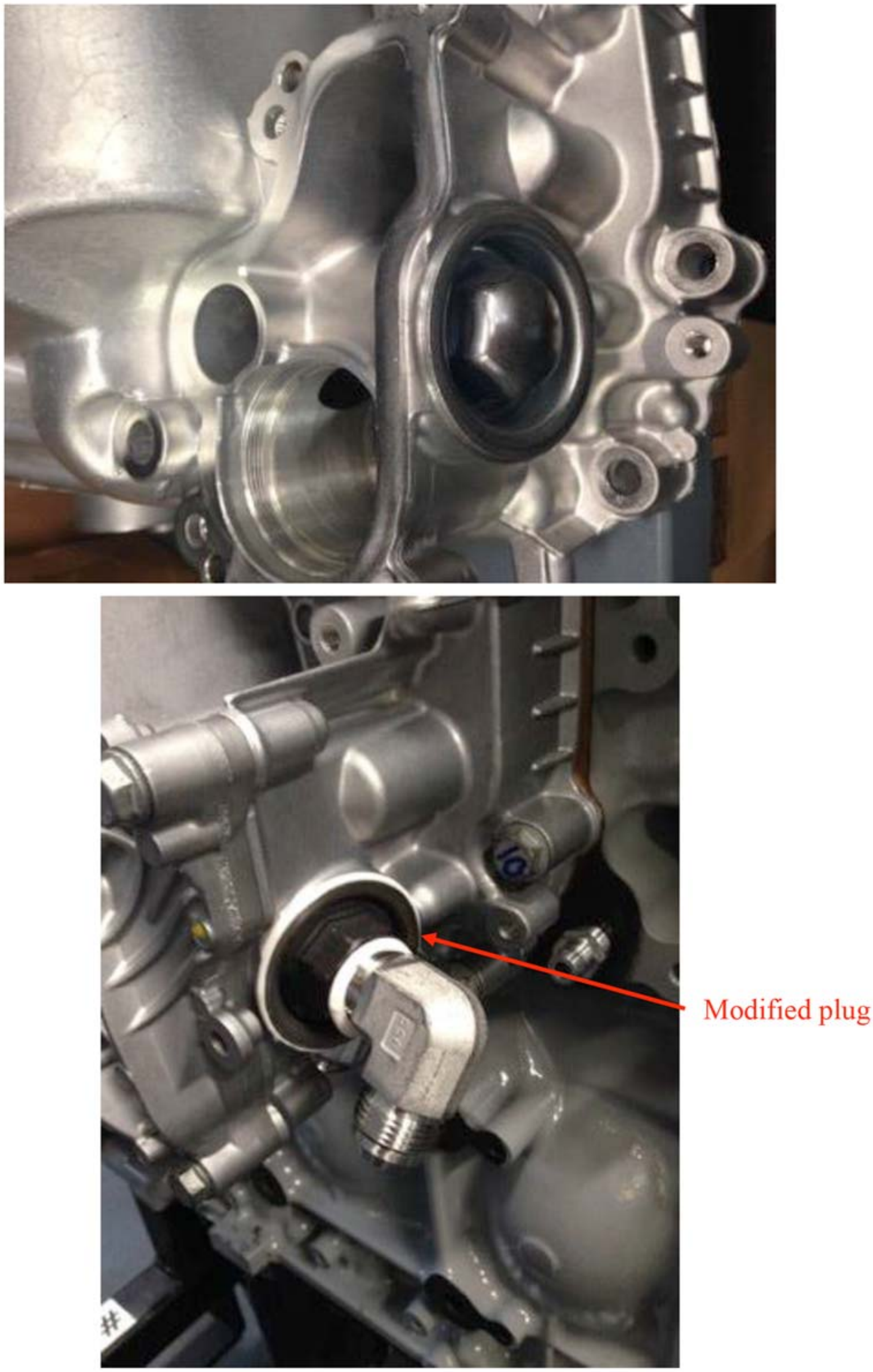

FIG. A4.13 Oil Module to Remote Oil Heat Exchanger Return Modification

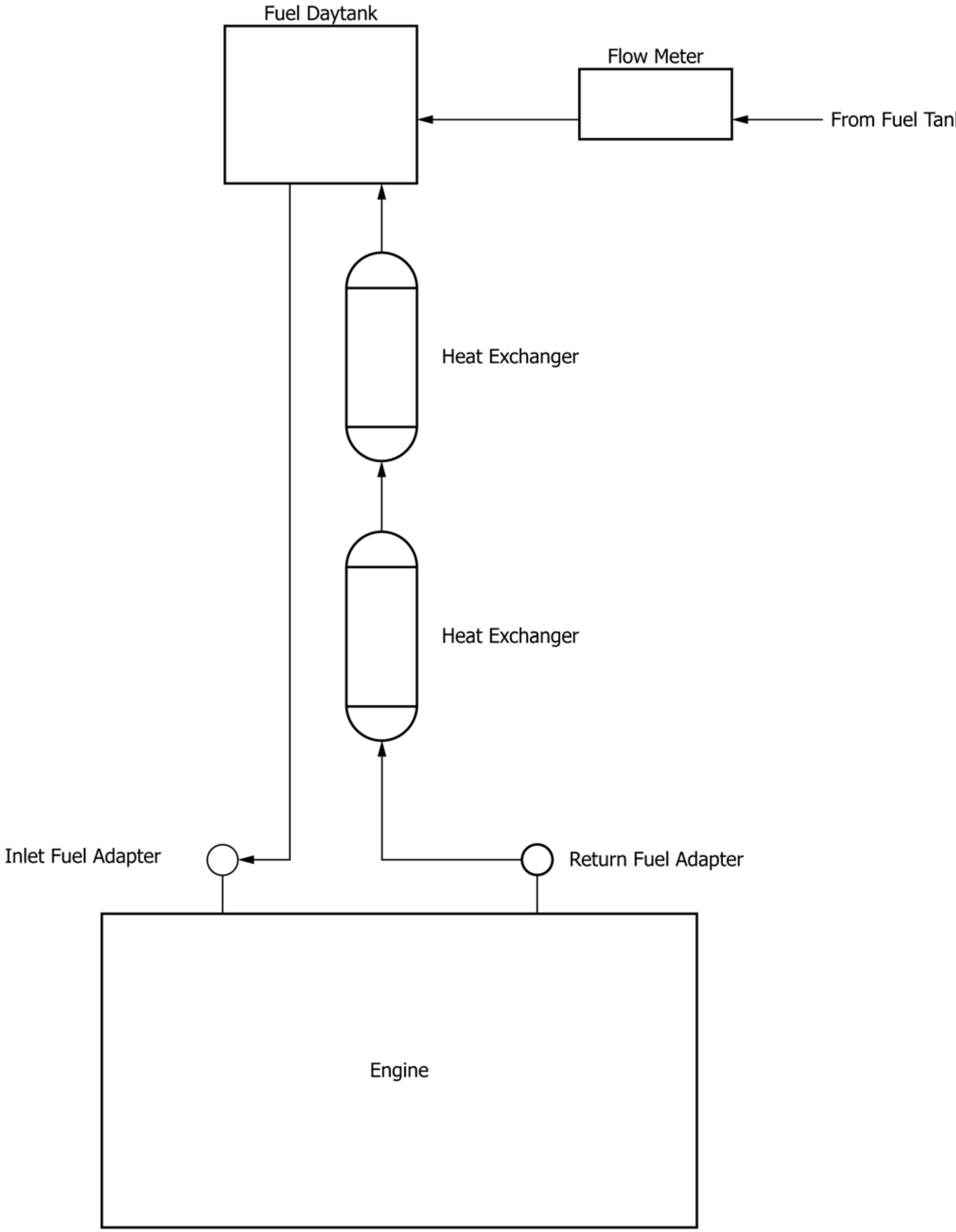

FIG. A4.14 Typical Test Cell, Fuel System

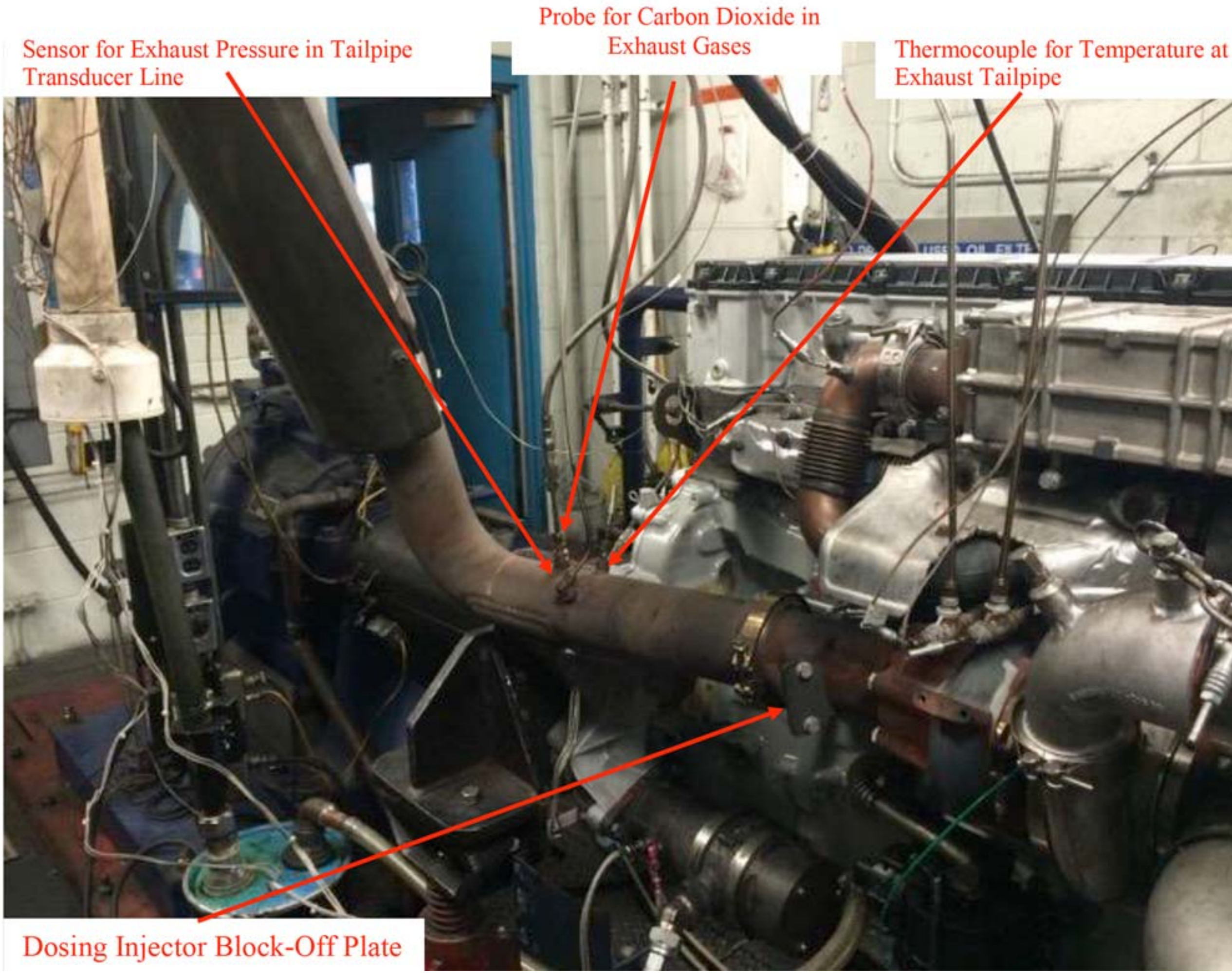

FIG. A4.15 Location of Exhaust Tailpipe Sensors

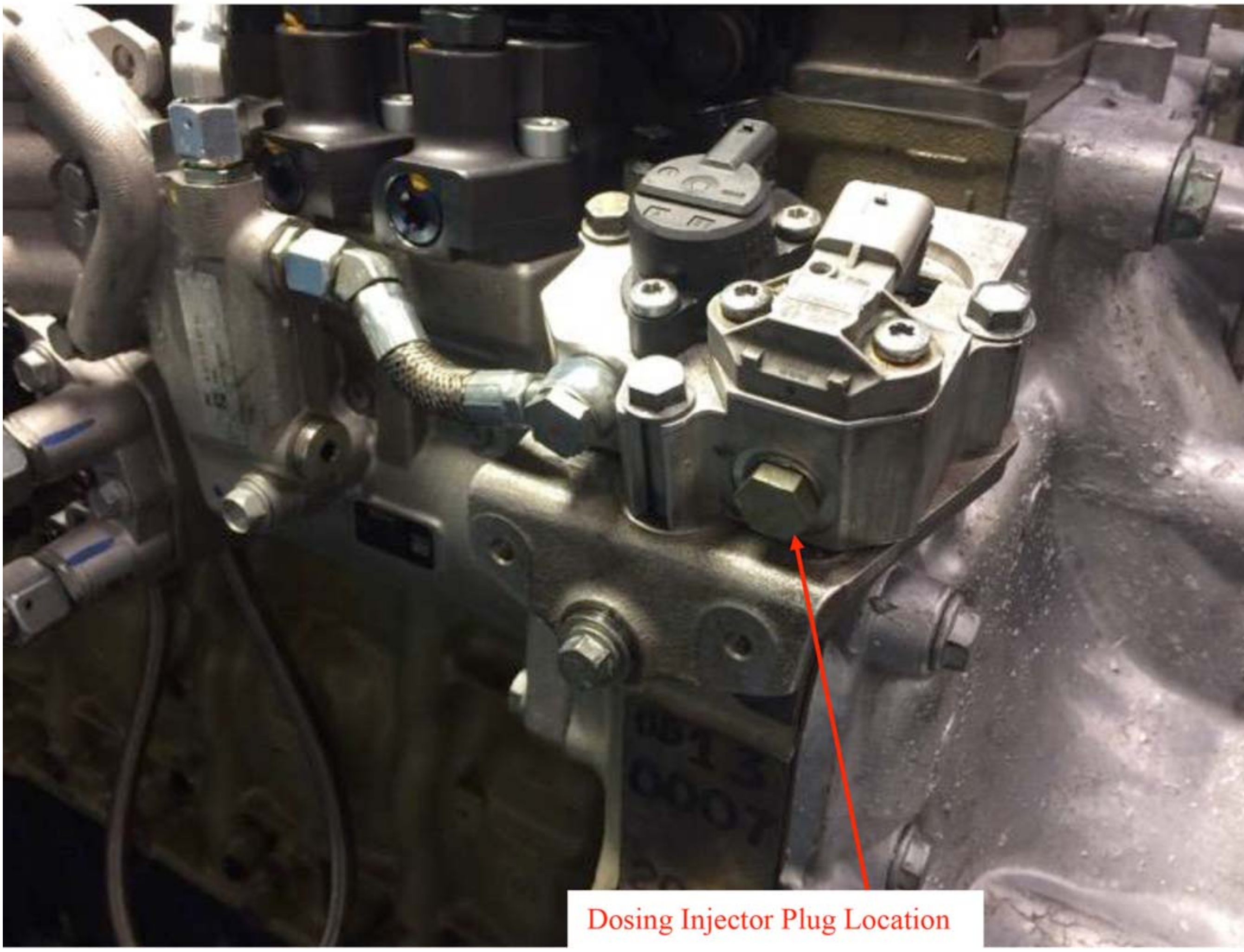

FIG. A4.16 Dosing Injector Block-Off Plug

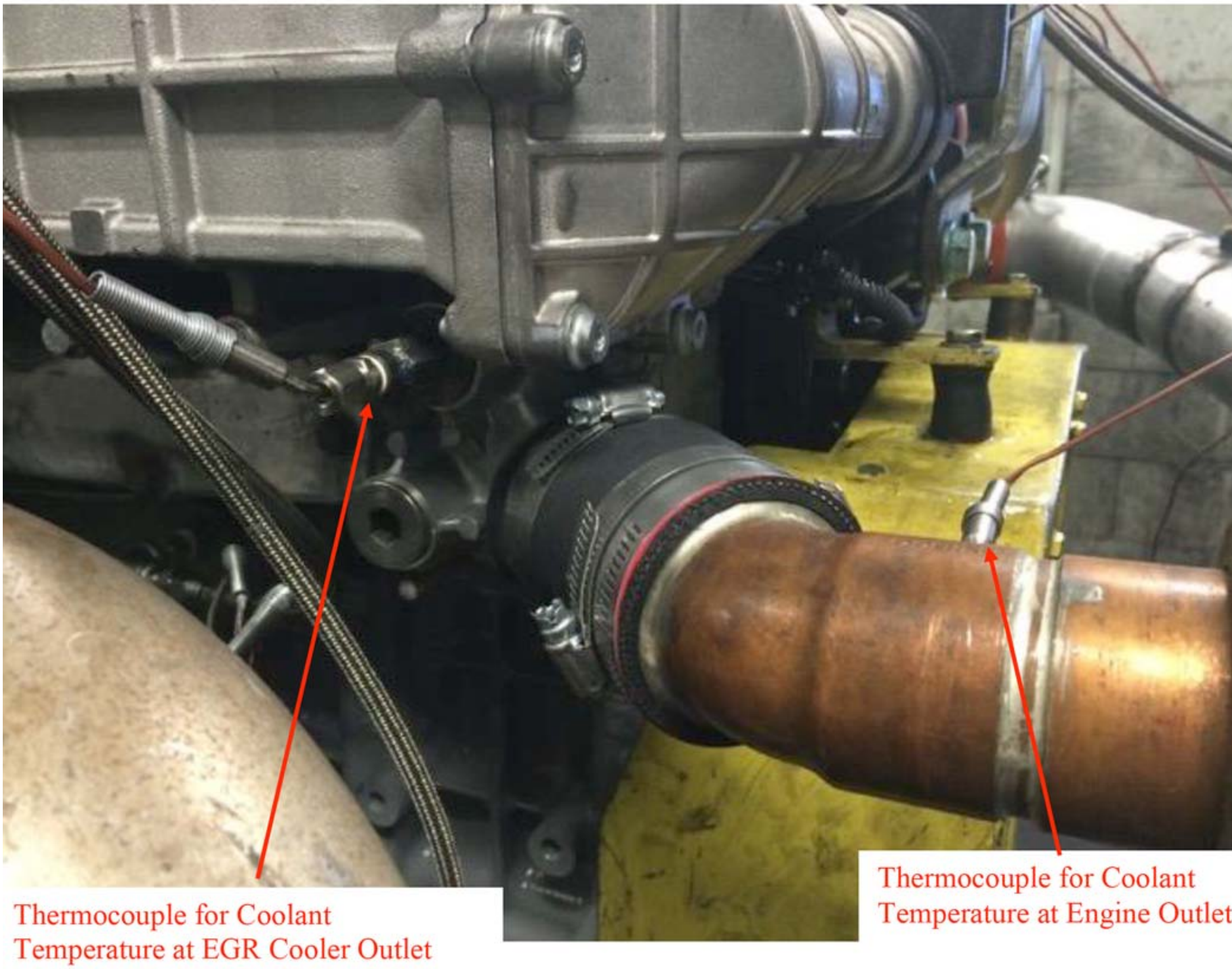

FIG. A4.17 Location of Thermocouples for Coolant Temperature at EGR Cooler Outlet and Coolant Temperature at Engine Outlet

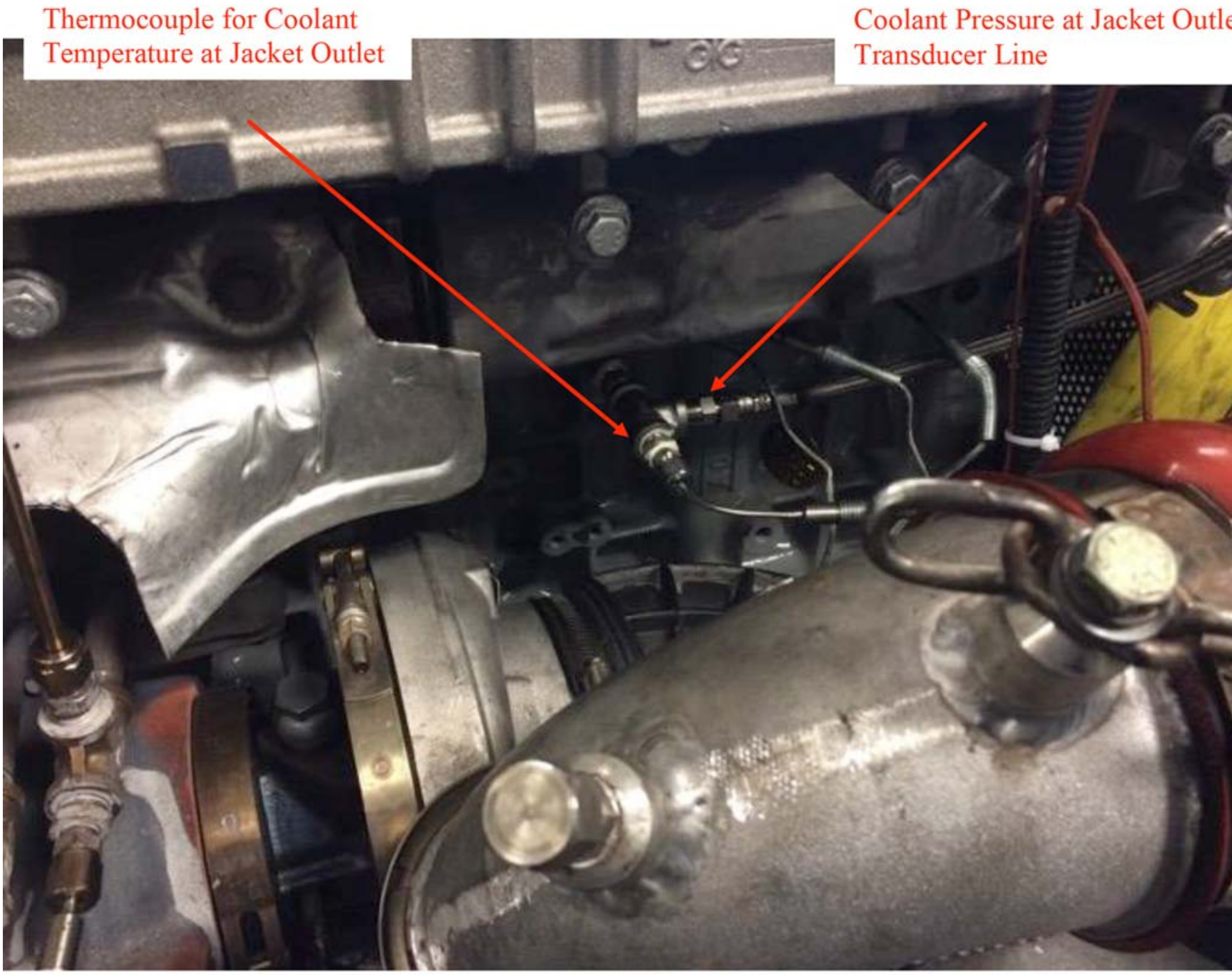

FIG. A4.18 Location of Sensors for Coolant Jacket Outlet Temperature and Pressure

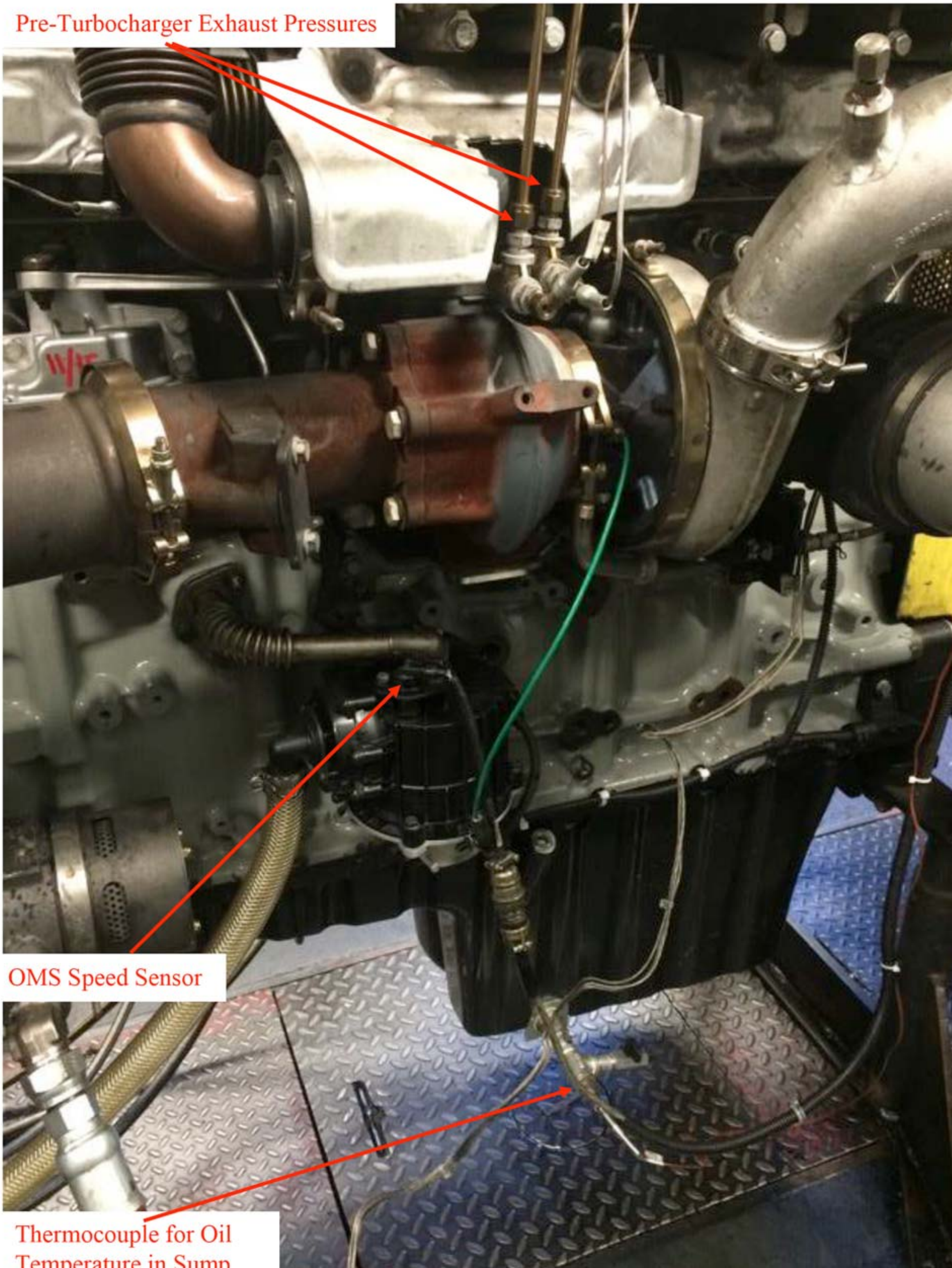

FIG. A4.19 Location of Sensors for Oil Temperature in Sump, OMS Speed and Pre-Turbocharger Exhaust Pressure

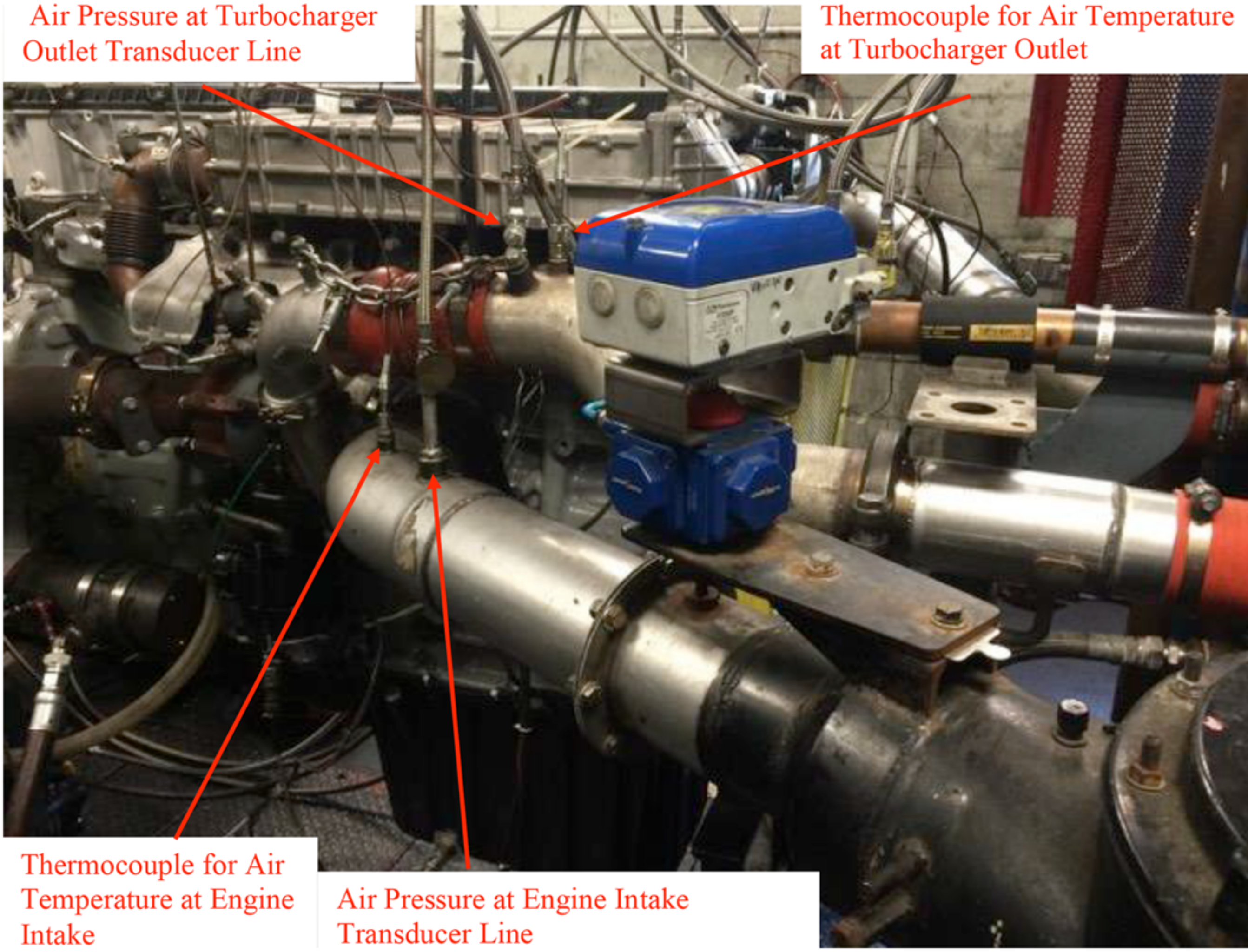

FIG. A4.20 Location of Sensors for Air in Engine Intake and Turbocharger Outlet

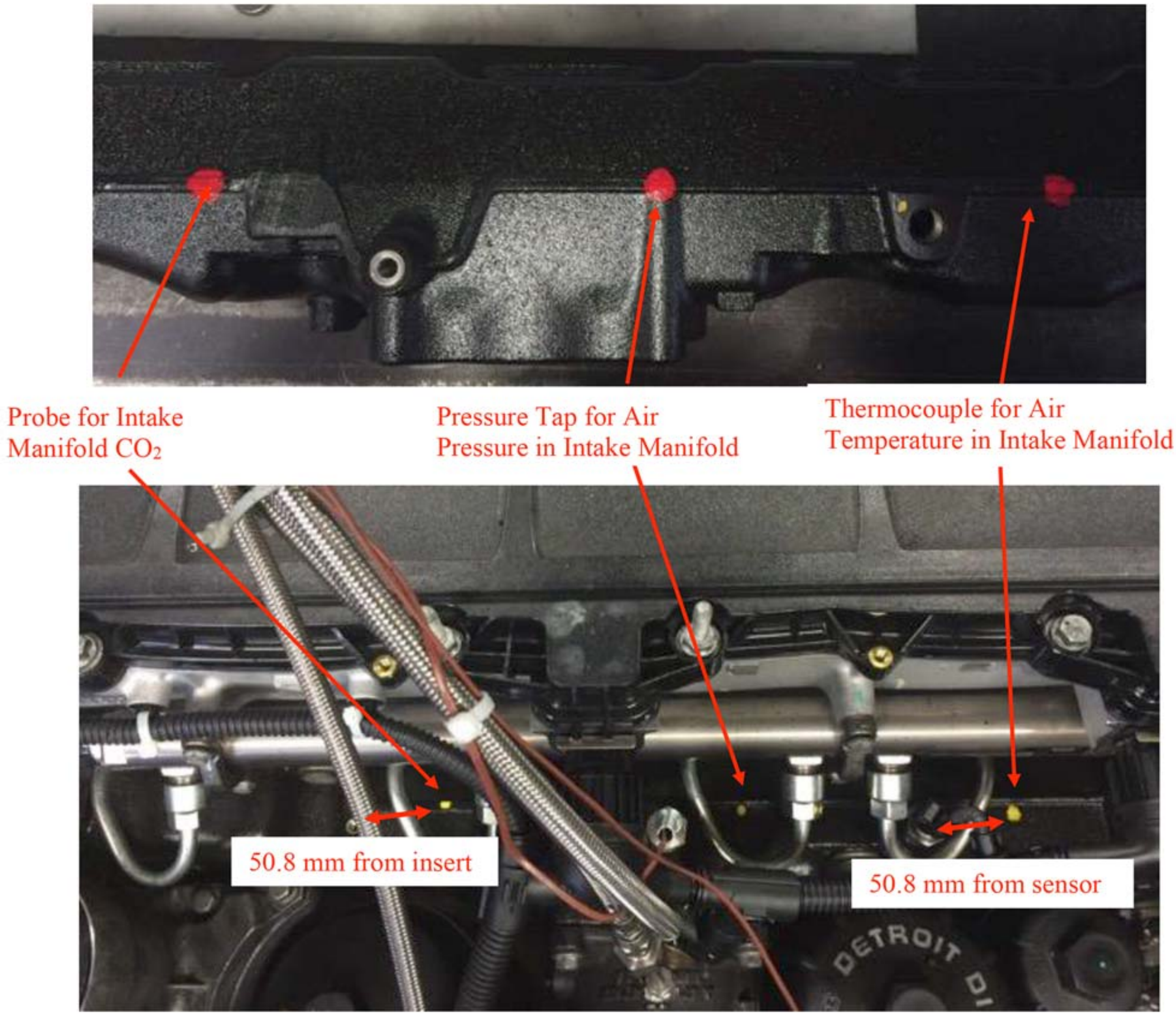

FIG. A4.21 Location of Intake Manifold Sensors

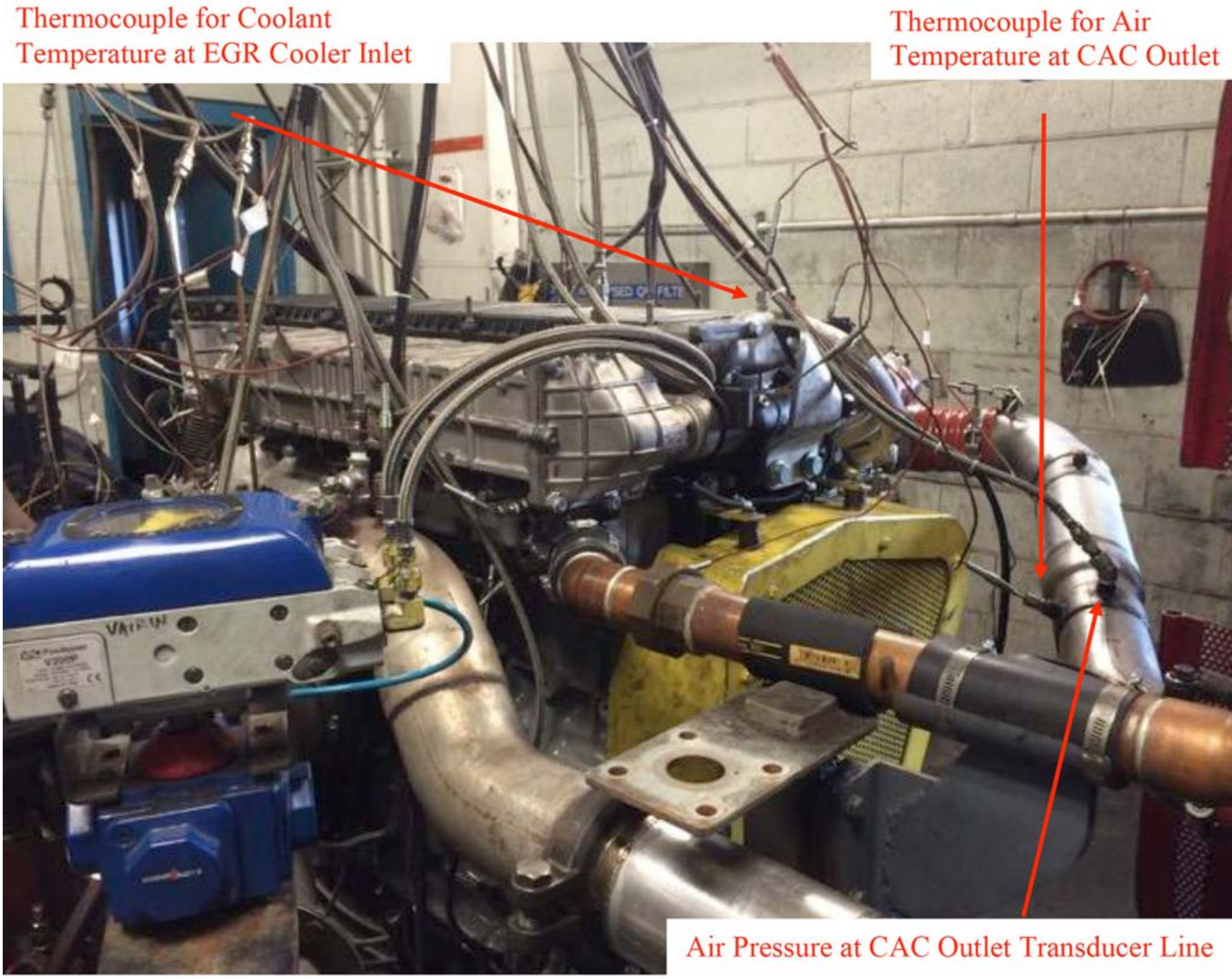

FIG. A4.22 Location of Sensors for Air Temperature and Pressure at CAC Outlet and Coolant Inlet Temperature to EGR Outlet Sensors

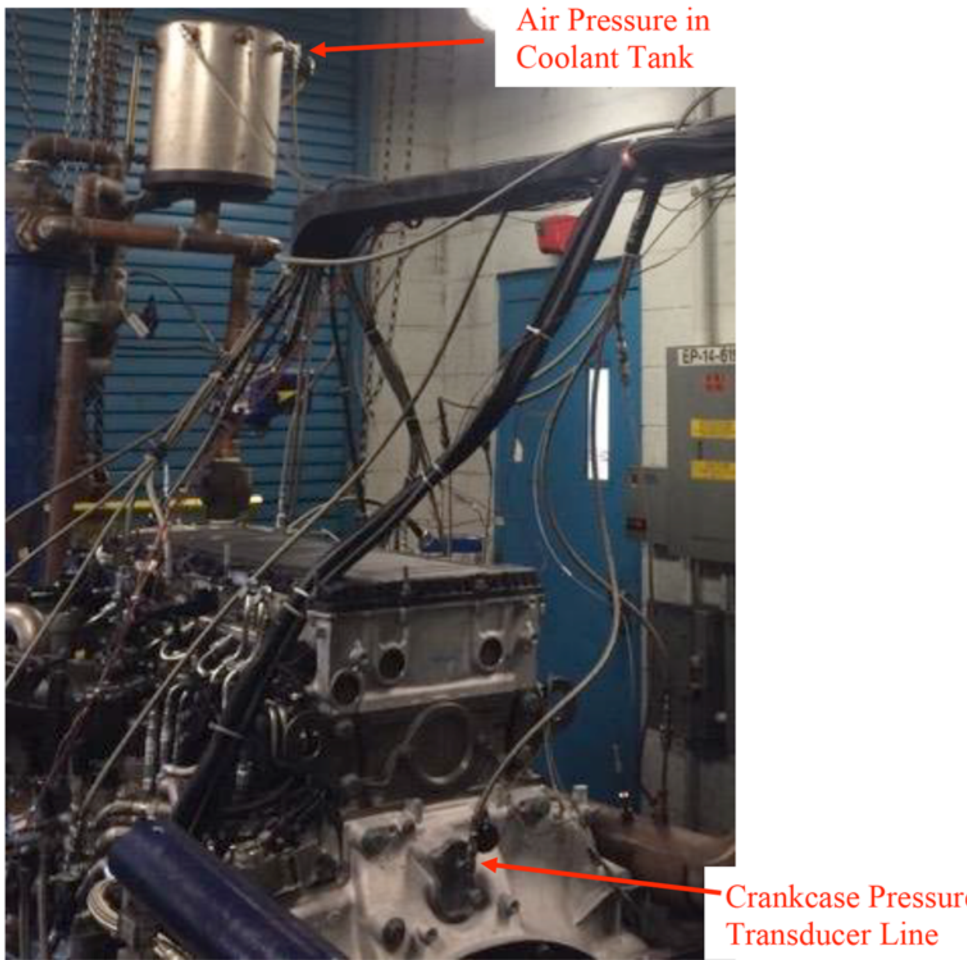

FIG. A4.23 Location of Crankcase and Coolant Tower Pressure Sensors

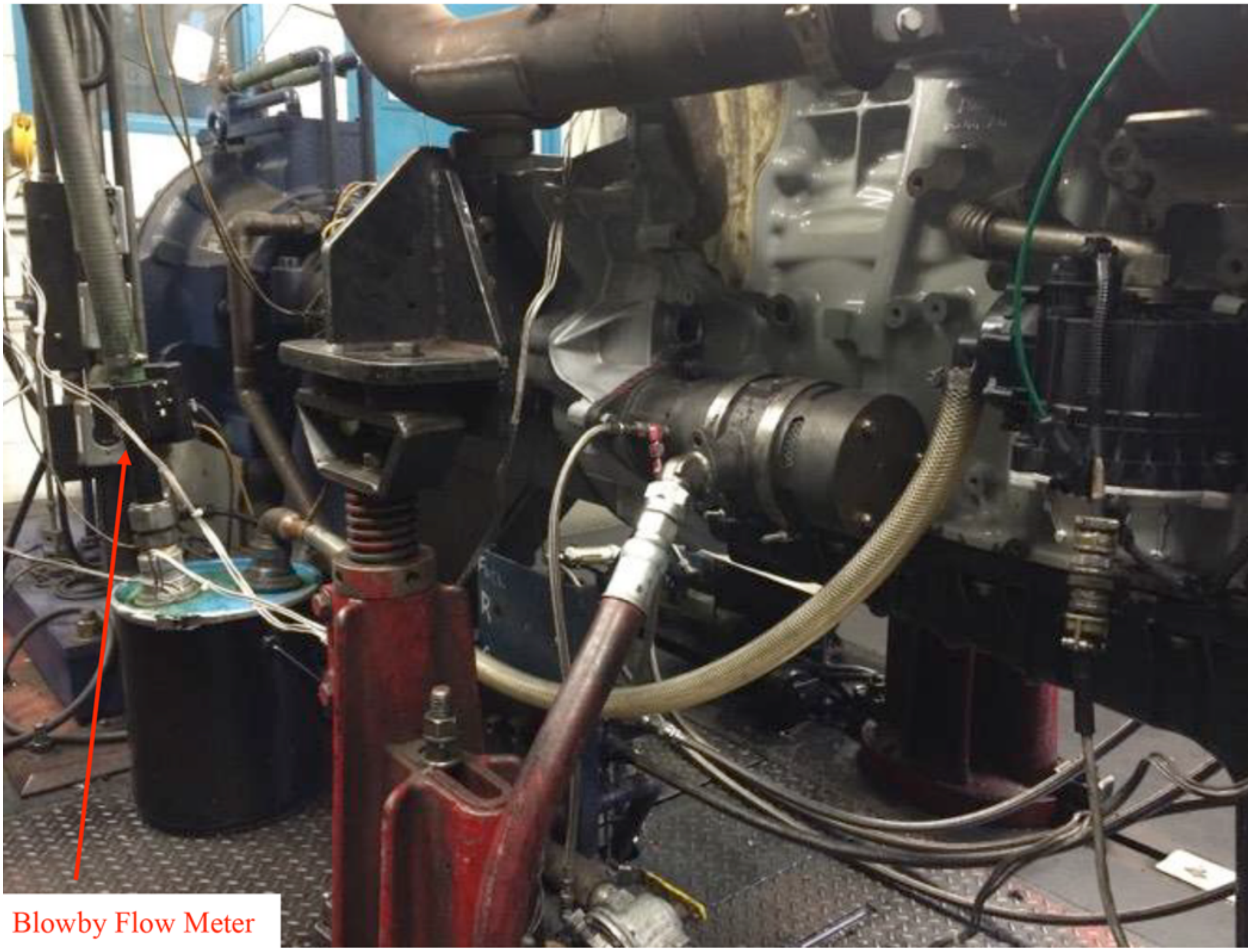

FIG. A4.24 Blowby Measurement System

FIG. A4.25 Dynamometer

A5. FUEL SPECIFICATION

A5.1 The fuel specification is given in Table A5.1.

TABLE A5.1 PC-10 ULSD Fuel Specification

Quantity, units	Specification	ASTM Test Method
Additives	Lubricity additive only	...
Distillation Range, °C, 90 %	293 to 332	D86
Specific Gravity	0.840 to 0.8524	D4052
API Gravity	34 to 37	D4052
Copper Strip Corrosion, 3 h at 50 °C, classification	1 max	D130
Mass Fraction Total Sulfur, mg/kg	7 to 15	D5453 or equivalent
Flash Point, °C	54 min	D93
Pour Point, °C	–18 max	D97
Cloud Point, °C	Report	D2500
Viscosity at 40 °C, mm^2/s	2.0 to 2.6	D445
Mass Fraction Ash %	0.005 max	D482
Carbon Residue on 10 % Residium	0.35 max	D524 (10 % bottoms)
Net Heat of Combustion	Report	D3338
Volume Fraction Water and Sediment, %	0.05 max	D2709
Total Acid Number	0.05 max	D664
Strong Acid Number	0 max	D664
Cetane Index	Report	D976
Cetane Number	43 to 47	D613
Accelerated Stability, mg/100 mL	1.5 max	D2274
Composition:		
Mass Fraction Aromatics, %	26 to 31.5	D5186
Volume Fraction Olefins, %	Report	D1319
Volume Fraction Saturates, %	Report	D1319
SLBOCLE,[A] g	3100 min[B]	D6078

[A] Scuffing Load Ball-on-Cylinder Lubricity Evaluator.
[B] May be altered to be consistent with California Air Resources Board (CARB) or Specification D975 for diesel fuel.

A6. BREAK-IN, START-UP, SHUTDOWN, TRANSITION AND TEST PROCEDURES

A6.1 Use the sequence shown in Table A6.1 for the pretest break-in.

A6.2 Use the sequence in Table A6.2 for the initial engine startup and for a startup during stage 1.

A6.3 Use the sequence shown in Table A6.3 for the transition from stage 1 to stage 2.

A6.4 Use the sequence shown in Table A6.4 for a normal shutdown.

A6.5 Use the sequence shown in Table A6.5 for a stage 2 startup.

TABLE A6.1 Pretest Break-in Sequence

	Step	Time, h:min	Setpoint Ramp Time, s	Engine Speed, r/min	Torque, N·m	Fuel Flow Rate, kg/h	Coolant Flow Rate, L/min	Air Temp in Engine Intake , °C	Coolant Temp at Jacket Outlet, °C	Oil Temp in Gallery, °C	Fuel Temp at Engine Inlet, °C	Air Temp in Intake Manifold, °C	Coolant Pressure at Jacket Inlet, kPa gauge	Exhaust Pressure in Tailpipe, kPa absolute	Air Pressure in Intake Manifold, kPa absolute	Air Pressure at Engine Intake, kPa absolute
Warmup	1[A]			600	idle		340 to 360	35	105	118	38	75	250	97.5	no air to wastegate	97
	2	00:30	180[B]	1800	800		340 to 360	35	105	118	38	75	250	105.5	202.5	96.4
	3	00:02	120	1800		32	340 to 360	35	105	118	38	75	250	105.5	202.5	96.4
Break-in	1	20:00		1800		32	340 to 360	35	105	118	38	75	250	105.5	202.5	96.4
Cooldown	1[A]	00:02	120	600	idle		340 to 360	35	105	118	38	75	250	97.5	no air to wastegate	97

[A] Consider setpoints as maximums for idle conditions.
[B] Setpoint ramp is 180 s for all parameters except temperatures that will take longer, but shall not exceed 30 min.

TABLE A6.2 Stage 1 Startup Sequence

Step	Time, h:min	Setpoint Ramp Time, s	Engine Speed, r/min	Torque, N·m	Fuel Flow Rate, kg/h	Coolant Flow Rate, L/min	Air Temp in Engine Intake, °C	Coolant Temp at Jacket Outlet, °C	Oil Temp in Gallery, °C	Fuel Temp at Engine Inlet, °C	Air Temp in Intake Manifold, °C	Coolant Pressure at Jacket Inlet, kPa gauge	Exhaust Pressure in Tailpipe, kPa absolute	Air Pressure in Intake Manifold, kPa absolute	Air Pressure at Engine Intake, kPa absolute
1[A]			600	idle		340 to 360	35	105	118	38	75	250	97.5	no air to wastegate	97
2	00:30	180[B]	1800	800		340 to 360	35	105	118	38	75	250	105.5	202.5	96.4
3	00:02	120	1800		32	340 to 360	35	105	118	38	75	250	105.5	202.5	96.4

[A] Consider the setpoints as maximums for idle conditions.
[B] Setpoint ramp time is 180 s for all parameters in step 2 except temperature which will take longer but shall not exceed 30 min.

TABLE A6.3 Stage 1 to 2 Transition

Step	Time, h:min	Setpoint Ramp Time, s	Speed, r/min	Torque, N·m	Fuel Flow Rate, kg/h	Coolant Flow Rate, L/min	Air Temp in Engine Intake, °C	Coolant Temp at Jacket Outlet, °C	Oil Temp in Gallery, °C	Fuel Temp at Engine Inlet, °C	Air Temp in Intake Manifold, °C	Coolant Pressure at Jacket Inlet, kPa gauge	Exhaust Pressure in Tailpipe, kPa absolute	Air Pressure in Intake Manifold, kPa absolute	Air Pressure at Engine Intake, kPa absolute
1	00:05[A,B]	300	1800	1800		340 to 360	35	105	118	38	87	250	125.5	327.5	94.8
2	00:05[A]	120	1800		71	340 to 360	35	105	118	38	87	250	125.5	327.5	94.8

[A] Stage 1 to 2 transition counts towards Stage 2 test time.
[B] Setpoint is a linear ramp of 300 s for all parameters.

TABLE A6.4 Normal Shutdown Sequence

Step	Time, h:min	Setpoint Ramp Time, s	Speed, r/min	Torque, N·m	Fuel Flow Rate, kg/h	Coolant Flow Rate, L/min	Air Temp in Engine Intake, °C	Coolant Temp at Jacket Outlet, °C	Oil Temp in Gallery, °C	Fuel Temp at Engine Inlet, °C	Air Temp in Intake Manifold, °C	Coolant Pressure at Jacket Inlet, kPa gauge	Exhaust Pressure in Tailpipe, kPa absolute	Air Pressure in Intake Manifold, kPa absolute	Air Pressure at Engine Intake, kPa absolute
1[A]	0:02	120	600	idle		340 to 360	35	105	118	38	75	250	975	No air to wastegate	97

[A] Consider setpoints as maximums for idle conditions.

TABLE A6.5 Stage 2 Startup Sequence

Step	Time, h:min	Setpoint Ramp Time, s	Speed, r/min	Torque, N·m	Fuel Flow Rate, kg/h	Coolant Flow Rate, L/min	Air Temp in Engine Intake, °C	Coolant Temp at Jacket Outlet, °C	Oil Temp in Gallery, °C	Fuel Temp at Engine Inlet, °C	Air Temp in Intake Manifold, °C	Coolant Pressure at Jacket Inlet, kPa gauge	Exhaust Pressure in Tailpipe, kPa absolute	Air Pressure in Intake Manifold, kPa absolute	Air Pressure at Engine Intake, kPa absolute
1[A]			600	Idle		340 to 360	35	105	118	38	75	250	97.5	No air to wastegate	97
2	0:10	180[B]	1800	800		340 to 360	35	105	118	38	75	250	105.5	202.5	96.4
3	0:20	900[C]	1800	1800		340 to 360	35	105	118	38	87	250	125.5	327.5	94.8
4	0:02	120	1800		71	340 to 360	35	105	118	38	87	250	125.5	327.5	94.8

[A] Consider setpoints as maximums for idle conditions.
[B] Setpoint ramp time is 180 s for all parameters in step 2 except temperature.
[C] Setpoint ramp time is 900 s for all parameters in step 2 except temperature which will take longer but shall not exceed 30 min.

A7. DETERMINATION OF OPERATIONAL VALIDITY

A7.1 *Quality Index Calculation*:

A7.1.1 Calculate Quality Index (*QI*) for all control quantities in accordance with the DACA II Report.[24] Ensure missing or bad quality data are accounted fort in accordance with the DACA II Report.

A7.1.2 Use the U and L values shown in Table A7.1 for the *QI* calculations.

A7.1.3 Do not use the data from the first ten minutes of Stage 2. This is considered transition time.

A7.1.4 Round the calculated *QI* values to the nearest 0.001.

A7.1.5 Report the *QI* values on the appropriate form.

A7.1.6 Record a time-weighted *QI* of Stage 1 and Stage 2 data using Eq A7.1.

$$QI = (t_1 \times QI_1) + (t_2 \times QI_2) / (t_1 + t_2) \tag{A7.1}$$

where:

QI = the reported QI,
t_1 = hours of time in stage 1,
t_2 = hours of time in stage 2 (minus transition time of the first ten minutes of stage 2),
QI_1 = the QI calculated for stage 1, and
QI_2 = the QI calculated for stage 2.

A7.1.7 If a test has scuffed, any data taken after the hours to scuff, as calculated in 10.7, shall not be used in *QI* calculations.

A7.2 *Averages*:

A7.2.1 Calculate averages, minimum, maximum, and standard deviations for all control, ranged, and non-control quantities and report the values on the appropriate form.

A7.2.2 The averages for control and non-control quantities are not directly used to determine operational validity but they may be helpful when an engineering review is required (refer to A7.4).

A7.3 *Limit Count*:

A7.3.1 If any count of 3 or more data points exceeds the limit count values in Table A7.1, conduct an engineering review to determine operational validity for the test. Exclude data taken during the 30 h stage transition.

A7.3.2 During the 30 h stage transition (see Table 4), if any count of 6 or more data points of the torque is greater or less than 50 N·m from the linearly ramped set point or if air temperature in intake manifold is greater or less than 5 °C, conduct an engineering review to determine operational validity for the test.

A7.3.3 During Stage 2 warm-ups, if any count of 6 or more data points of the torque is greater or less than 50 N·m from the linearly ramped set point or air temperature in intake manifold is greater or less than 5 °C, conduct an engineering review to determine operational validity for the test. This is only applied to step 3 in Table A6.5.

A7.3.4 Record the Limit Counts in A7.3.1, A7.3.2, and A7.3.3 on the appropriate report forms.

A7.4 *Determining Operational Validity*:

A7.4.1 *QI* threshold values for operational validity are shown in Table A7.1. Specifications for all ranged quantities are shown in Table A7.1.

A7.4.1.1 A test with EOT *QI* values for all control quantities equal to or above the threshold values and with averages for all ranged quantities within specifications is operationally valid, provided that no other operational deviations exist that may cause the test to be declared invalid.

A7.4.1.2 Conduct an engineering review (see A7.4) to determine the operational validity of a test with any control quantity *QI* value less than the threshold value.

A7.4.1.3 A test with a ranged quantity average value outside the specification is invalid. Conduct an engineering review to determine operational validity for a test.

A7.5 *Engineering Review*:

A7.5.1 Conduct an engineering review when a control quantity *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 quantities 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.

A7.5.2 For reference oil tests, conduct the engineering review jointly with the TMC. For non-reference oil tests, optional input is available from the TMC for the engineering review.

A7.5.3 Determine operational validity based upon the engineering review and summarize the decision in the comment section on the appropriate form. 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 A7.1 Quality Index and Average Calculation Values

Controlled Quantity, unit	Quality Index Threshold	Quality Index U & L Values		Limit Count Values	
		U	L	High	Low
Speed, r/min	0.000	1805	1795	N/A	N/A
Fuel Flow Rate, kg/h	0.000	33 72	31 70	N/A	N/A
Air Temperature in Engine Intake, °C	0.000	36	34	40	30
Coolant Temperature at Jacket Outlet, °C	0.000	106	104	108	102
Oil Temperature in Gallery, °C	0.000	119	117	121	115
Fuel Temperature at Engine Inlet, °C	0.000	39	37	N/A	N/A
Air Temperature in Intake Manifold, °C	0.000	76 88	74 86	80 92	70 82
Coolant Pressure at Jacket Inlet, kPa (gauge)	0.000	255	245	N/A	N/A
Exhaust Pressure in Tailpipe, kPa (absolute)	0.000	106 126	105 125	N/A	N/A
Air Pressure in Intake Manifold, kPa (absolute)	0.000	207.5 332.5	197.5 322.5	217.5 342.5	182.5 307.5
Air Pressure in Engine Intake, kPa (absolute)	0.000	96.65 95.05	95.15 94.55	N/A	N/A
Ranged Quantity, unit	Range				
Coolant Flow Rate, L/min	340 to 360			N/A	N/A

A8. ASTM TMC: CALIBRATION PROCEDURES

A8.1 *Reference Oils*—These oils are formulated or selected to represent specific chemical, or performance levels, or both. They are usually supplied directly to a testing laboratory under code numbers to ensure that the laboratory is not influenced by prior knowledge of acceptable results in assessing test results. The TMC determines the specific reference oil the laboratory shall test.

A8.1.1 *Reporting Reference-Oil Data*—Test laboratories that receive reference oils for stand calibration shall submit data to the TMC on every sample of reference oil they receive. If a shipment contains any missing or damaged samples, the laboratory shall notify the TMC immediately.

A8.2 *Calibration Testing*:

A8.2.1 Full scale calibration testing shall be conducted at regular intervals. These full scale tests are conducted using coded reference oils supplied by the TMC. It is a laboratory's responsibility to keep the on site reference-oil inventory at or above the minimum level specified by the TMC test engineers.

A8.2.2 *Test Stands Used for Non Standard Tests*—If a non standard test is conducted on a previously calibrated test stand, the laboratory shall conduct a reference-oil test on that stand to demonstrate that it continues to be calibrated, prior to running standard tests.

A8.3 *Reference-Oil Storage*—Store under cover in locations where the ambient temperature is between –10 °C and +50 °C.

A8.4 *Analysis of Reference Oils*—Unless specifically authorized by the TMC, do not analyze TMC reference oils, either physically or chemically. Do not resell ASTM reference oils or supply them to other laboratories without the approval of the TMC. The reference oils are supplied only for the intended purpose of obtaining calibration under the ASTM Test Monitoring System. Any unauthorized use is strictly forbidden. The testing laboratory tacitly agrees to use the TMC reference oils exclusively in accordance with the TMC's published Policies for Use and Analysis of ASTM Reference Oils, and to run and report the reference-oil test results according to TMC guidelines. Additional policies for the use and analysis of ASTM Reference oils are available from the TMC.

A8.5 *Conducting a Reference-Oil Test*—When laboratory personnel are ready to run a reference calibration test, they shall request an oil code via the TMC website.

A8.6 *Reporting Reference-Oil Test Results*—Upon completion of the reference-oil test, the test laboratory transmits the data electronically to the TMC, as described in Section 12. The TMC reviews the data and contacts the laboratory engineer to report the laboratory's calibration status. All reference-oil test results, whether aborted, invalidated, or successfully completed, shall be reported to the TMC.

A8.6.1 All deviations from the specified test method shall be reported.

A9. ASTM TEST MONITORING CENTER: MAINTENANCE ACTIVITIES

A9.1 *Special Reference-Oil Tests*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. Occasionally, the majority or even all of the industry's test stands will conduct calibration tests at roughly the same time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference-oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss or gain in calibration status.

A9.2 *Special Use of the Reference-Oil Calibration System*—The surveillance panel has the option to use the reference-oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference-oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration status is left pending for an excessive length of time. In order to maintain the integrity of the reference-oil monitoring system, each reference-oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel may direct the TMC to lengthen and shorten reference-oil calibration periods within laboratories such that the laboratories incur no net loss or gain in calibration status. To ensure accurate stand, or laboratory, or both severity assessments, conduct non reference-oil tests the same as reference-oil tests.

A9.3 *Donated Reference-Oil Test Programs*—The surveillance panel is charged with maintaining effective reference-oil test severity and precision monitoring. During times of new parts introductions, new or re blended reference-oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may choose to conduct a program of donated reference-oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference-oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

A9.4 *Intervals Between Reference-Oil Tests*—Under special circumstances, such as extended downtime caused by industry wide parts or fuel shortages, the TMC may extend the intervals between reference-oil tests.

A9.5 *Introducing New Reference Oils*—Reference oils produce various results. When new reference oils are selected, participating laboratories will be requested to conduct their share of tests to enable the TMC to recommend industry test targets. ASTM surveillance panels require a minimum number of tests to establish the industry test targets for new reference oils.

A9.6 *TMC Information Letters*—Occasionally it is necessary to revise the test method, and notify the test laboratories of the change, prior to consideration of the revision by Subcommittee D02.B0. In such a case, the TMC issues an Information Letter. Information Letters are balloted semi annually by Subcommittee D02.B0, and subsequently by D02. By this means, the Society due process procedures are applied to these Information Letters.

A9.6.1 *Issuing Authority*—The authority to issue an Information Letter differs according to its nature. In the case of an Information Letter concerning a part number change which does not affect test results, the TMC is authorized to issue such a letter. Long term studies by the surveillance panel to improve the test procedure through improved operation and hardware control may result in the issuance of an Information Letter. If obvious procedural items affecting test results need immediate attention, the test sponsor and the TMC issue an Information Letter and present the background and data supporting that action to the surveillance panel for approval prior to the semiannual Subcommittee D02.B0 meeting.

A9.7 *TMC Memoranda*—In addition to the Information Letters, supplementary memoranda are issued. These are developed by the TMC and distributed to the appropriate surveillance panel and participating laboratories. They convey such information as batch approvals for test parts or materials, clarification of the test procedure, notes and suggestions of the collection and analysis of special data that the TMC may request, or for any other pertinent matters having no direct effect on the test performance, results, or precision and bias.

A10. ASTM TEST MONITORING CENTER: RELATED INFORMATION

A10.1 *New Laboratories*—Laboratories wishing to become part of the ASTM Test Monitoring System will be requested to conduct reference-oil tests to ensure that the laboratory is using the proper testing techniques. Information concerning fees, laboratory inspection, reagents, testing practices, appropriate committee membership, and rater training can be obtained by contacting the TMC Director.

A10.2 *Information Letters: COTCO Approval*—Authority for the issuance of Information Letters was given by the committee on Technical Committee Operations in 1984, as follows: "COTCO recognizes that D02 has a unique and complex situation. The use of Information Letters is approved providing each letter contains a disclaimer to the affect that such has not obtained ASTM consensus. These Information Letters should be moved to such consensus as rapidly as possible."

A10.3 *Precision Data*—The TMC determines the precision of test methods by analyzing results of calibration tests conducted on reference oils. Precision data are updated regularly. Current precision data can be obtained from the TMC.

APPENDIX

(Nonmandatory Information)

X1. DATE CODES FOR INJECTOR NOZZLES

FIG. X1.1 Location of Date Codes for Injector Nozzles

X1.1 Fig. X1.1 shows the location of the date code on the injector nozzles (see 8.4.1). The first two numbers in the red box denote the last two digits of the date, for example, 15266 denotes date code 2015.