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Standard Test Method for Measurement of Effects of Automotive Engine Oils on Fuel Economy of Passenger Cars and Light-Duty Trucks in Sequence VIE Spark Ignition[1,2]

This standard is issued under the fixed designation D8114; 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)[3] services (see Annex A1 – Annex A4).

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 (API) 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.

ASTM International policy is to encourage the development of test procedures based on generic equipment. It is recognized that there are occasions where critical/sole-source equipment has been approved by the technical committee (surveillance panel/task force) and is required by the test procedure. The technical committee that oversees the test procedure is encouraged to clearly identify if the part is considered critical in the test procedure. If a part is deemed to be critical, ASTM encourages alternative suppliers to be given the opportunity for consideration of supplying the critical part/component providing they meet the approval process set forth by the technical committee.

An alternative supplier can start the process by initiating contact with the technical committee (current chairs shown on ASTM TMC website). The supplier should advise on the details of the part that is intended to be supplied. The technical committee will review the request and determine feasibility of an alternative supplier for the requested replacement critical part. In the event that a replacement critical part has been identified and proven equivalent the sole-source supplier footnote shall be removed from the test procedure.

[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.B0.01 on Passenger Car Engine Oils.

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[2] The multi-cylinder engine test sequences were originally developed by an ASTM Committee D02 group. Subsequently, the procedures were published in an ASTM special technical publication. The Sequence VIB was published as Research Report RR:D02-1469, dated April 8, 1999.

[3] Until the next revision of this test method, the ASTM Test Monitoring Center will update changes in the test method by means of Information Letters. Information Letters may be obtained from the ASTM Test Monitoring Center, 203 Armstrong Drive, Freeport, PA 16229, www.astmtmc.org. Attention: Director. This edition incorporates revisions in all Information Letters through No. ~~23-1.~~23-2.

1. Scope*

1.1 This test method covers an engine test procedure for the measurement of the effects of automotive engine oils on the fuel economy of passenger cars and light-duty trucks with gross vehicle weight 3856 kg or less. The tests are conducted using a specified spark-ignition engine with a displacement of 3.6 L (General Motors)[4] on a dynamometer test stand. It applies to multi-viscosity oils used in these applications.

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 *Exceptions*—Where there is no direct equivalent such as the units for screw threads, National Pipe threads/diameters, tubing size, and single source supply equipment specifications. Additionally, Brake Specific Fuel Consumption (BSFC) is measured in kilogram per kilowatt hour.

1.3 This test method is arranged as follows:

[4] Trademark of General Motors Corporation, 300 Renaissance Center, Detroit, MI 48265.

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

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[6]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)
D381 Test Method for Gum Content in Fuels by Jet Evaporation
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel
D3231 Test Method for Phosphorus in Gasoline
D3237 Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy
D3338 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
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
D4485 Specification for Performance of Active API Service Category Engine Oils
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D6837 Test Method for Measurement of Effects of Automotive Engine Oils on Fuel Economy of Passenger Cars and Light-Duty Trucks in Sequence VIB Spark Ignition Engine (Withdrawn 2022)[5]
D6894 Test Method for Evaluation of Aeration Resistance of Engine Oils in Direct-Injected Turbocharged Automotive Diesel Engine (Withdrawn 2022)[5]
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E191 Specification for Apparatus For Microdetermination of Carbon and Hydrogen in Organic and Organo-Metallic Compounds
IEEE/ASTM SI-10 Standard for Use of the International System of Units (SI): The Modern Metric System

[6] 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.
[5] The last approved version of this historical standard is referenced on www.astm.org.

2.2 *SAE Standards*[7]

J304 Engine Oil Tests

J1423 Classification of Energy-Conserving Engine Oil for Passenger Cars and Light-Duty Trucks

2.3 *API Standard:*[8]

API 1509 Engine Oil Licensing and Certification System

API 1525 Bulk Oil Testing, Handling, and Storage Guidelines Documentation

2.4 *ANSI Standard:*

ANSI MC96.1-1975 Temperature Measurement—Thermocouples[9]

3. Terminology

3.1 *Definitions:*

3.1.1 *air-fuel ratio, n—in internal combustion engines*, the mass ratio of air-to-fuel in the mixture being induced into the combustion chambers. **D4175**

3.1.2 *automotive, adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines. **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. **D6837**

3.1.5 *calibrate, v*—to determine the indication or output of a (e.g. thermometer, manometer, engine) device or a given engine with respect to a standard. **D4175**

3.1.6 *calibration oil, n*—an oil that is used to determine the indication or output of a measuring device or a given engine with respect to a standard. **D4175**

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

3.1.7.1 *Discussion—*
It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples. **D4175**

3.1.8 *fuel economy, n—in internal combustion engines*, the efficient use of gasoline.

3.1.8.1 *Discussion—*
Determined by comparing the rate of fuel consumption of a test oil with that displayed by baseline oil. **D6837**

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

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

3.1.11 *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 un-calibrated test stand, using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D4175**

3.1.12 *purchaser, n—of an ASTM test*, a person or organization that pays for the conduct of an ASTM test method on a specified product.

[7] Available from the Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001. This standard is not available separately. Order the SAE Handbook Vol 2 or the SAE Fuels and Lubricants Standards Manual HS-23.

[8] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

[9] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.12.1 *Discussion—*
The preferred term is purchaser. Deprecated terms that have been used are client, requester, sponsor, and customer. **D4175**

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

3.1.14 *test oil, n*—any oil subjected to evaluation in an established procedure. **D4175**

3.1.15 *test start, n*—introduction of test oil into the engine. **D4175**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aged test oil, n*—an engine oil to be tested that has been previously subjected to use in a spark-ignited operating engine for a prescribed length of service under prescribed conditions. **D6837**

3.2.2 *aging, n*—the subjecting of an engine oil to use in a spark-ignited operating engine for a prescribed length of service under prescribed conditions. **D6837**

3.2.3 *central parts distributor (CPD), n*—the manufacturer or supplier, or both, of many of the parts and fixtures used in this test method. **D6894**

3.2.3.1 *Discussion—*
Because of the need for availability, rigorous inspection, and control of many of the parts used in this test method, companies having the capabilities to provide the needed services have been selected as the official suppliers for the Sequence VIE test method. These companies work closely with the test procedure developer and with the ASTM groups associated with the test method to help ensure that the critical engine parts used in this test method are available to the testing industry and function satisfactorily.

3.2.4 *engine hours, n*—cumulative time that ignition is powered after engine installation.

3.2.4.1 *Discussion—*
Engine hours will include any time accumulated on a different stand, including engine break-in.

3.2.5 *engine shutdown, n*—the engine is brought to a complete stop.

3.2.6 *flush, v*—to wash out with a rush of engine oil, during a prescribed mode of engine operation to minimize carryover effect from the previous oil and remove residues, before introducing new test oil. **D6837**

3.2.7 *flying flush, n—in internal combustion engines*, the washing out with a rush of engine oil, during a prescribed mode of engine operation to minimize carryover effect from the previously used oil and remove residues without stopping the engine after the previous test. **D6837**

3.2.8 *off test time, n*—time when the test is not operating at the scheduled test conditions, but shutting down the engine is not required.

3.2.9 *stage restart, n*—re-initiate a stage while the engine is running.

4. Summary of Test Method

4.1 The internal combustion engine with a displacement of 3.6 L is installed on a dynamometer test stand equipped with the appropriate controls for speed, torque, and various other operating parameters.

4.2 The test method consists of measuring the laboratory engine brake specific fuel consumption at six (6) constant speed/torque/temperature conditions for the baseline calibration oil, test oil, and a repeat of the baseline calibration oil. The approximate test length is 197 h.

4.3 Aged test oil is compared directly to fresh VIE BL (baseline oil) SAE 20W-30 (see X1.2) baseline calibration oil that is run before and after the test oil. When changing from test oil to baseline oil, an intermediate flush with special flushing oil (FO) is required to minimize the possibility of a carryover effect from the previous oil.

4.4 Test results are expressed as a percent change in weighted fuel consumption relative to the baseline calibration oil.

5. Significance and Use

5.1 *Test Method*—The data obtained from the use of this test method provide a comparative index of the fuel-saving capabilities of automotive engine oils under repeatable laboratory conditions. A BL has been established for this test to provide a standard against which all other oils can be compared. The BL oil is an SAE 20W-30 grade fully formulated lubricant. The test procedure was not designed to give a precise estimate of the difference between two test oils without adequate replication. The test method was developed to compare the test oil to the BL oil. Companion test methods used to evaluate engine oil performance for specification requirements are discussed in the latest revision of Specification D4485.

5.2 *Use*—The Sequence VIE test method is useful for engine oil fuel economy specification acceptance. It is used in specifications and classifications of engine lubricating oils, such as the following:

5.2.1 Specification D4485.

5.2.2 API 1509.

5.2.3 SAE Classification J304.

5.2.4 SAE Classification J1423.

6. Apparatus

6.1 *General*—Standardize certain aspects of each test stand in terms of stand hardware. Examples of components that are specified are certain pumps, valves, heat exchangers, heaters, and piping nominal inside diameter (ID). Where specified, four classes or categories of stand hardware have been designated:

6.1.1 Prints/photos for special parts are included in this procedure. Substitution of equivalent equipment is allowed, but only after equivalency has been proven acceptable by the Sequence VI Surveillance Panel.

6.2 *Test Engine Configuration*—The test engine is a specially built General Motors (GM) 3.6 L (LY7) engine (see X1.3). Mount the engine on the test stand so that the flywheel friction face is 3.0° ± 0.5° from the vertical with the front of the engine higher than the rear. The driveshaft angle shall be 1.5° ± 0.5° from engine to dynamometer. The driveshaft angle shall be 0° ± 0.5° in the horizontal plane. Do not alter, modify, or rework any components of the engine unless authorized by the Sequence VI surveillance panel.

6.3 *Laboratory Ambient Conditions*—Do not permit air from fans or ventilation systems to blow directly on the engine. Small (<35 L/s) fans may be used to direct air towards the knock sensor and oxygen sensors. The ambient laboratory atmosphere shall be relatively free of dirt, dust, or other contaminants as required by good laboratory standards and practices.

6.4 *Engine Speed and Torque Control*—The dynamometer speed and torque control systems shall be capable of maintaining the limits specified in Tables 1-3. The VIE closed-loop control system maintains speed by electronic throttle and torque by dynamometer control. Since these speed and torque tolerances require sensitive and precise control, give particular attention to achieving and maintaining accurate calibration of the related instrument systems.

6.4.1 *Dynamometer*—Use a Midwest or Eaton 37 kW Model 758 dry gap dynamometer.[10] Replacing an engine dynamometer during a test (reference or non-reference oil) is not acceptable. If a dynamometer needs to be replaced during a test, abort the test. Follow calibration requirements shown in 10.2.3 before starting each new test.

6.4.2 *Dynamometer Torque:*

[10] The sole source of supply of the apparatus known to the committee at this time is Dyne Systems, 3602 West Wheelhouse Road, Milwaukee, WI 53208, www.dynesystems.com. 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.

TABLE 1 Sequence VIE New Engine Cyclic Break-in[A]

	Cycle	
	A	B
Time at Each Step, min	4	1
Time to Decel. to Step A, s		15 max
Time to Accel. to Step B, s	15 max	
Speed, r/min	1500 ± 50	3500 ± 50
Power, kW	6.0	16.5
Torque, nm	38.00 ± 5	45.00 ± 5
Oil Gallery, °C	80 ± 2	80 ± 2
Coolant In, °C	80 ± 2	80 ± 5
Coolant Flow, L/min	80 ± 5	80 ± 5
Intake Air Temperature and Humidity	Control Not Required	
Exh. Back Press., kPa	105	Not Specified
AFR	Record	Not Specified
Fuel Pressure to Fuel Rail, kPa	405 ± 10	405 ± 10
Fuel Temperature to Fuel Rail, °C	22 ± 2	22 ± 2
Fuel Flow, kg/h	Not Specified	Not Specified
BSFC, kg/kWh	Not Specified	Not Specified

[A] The time at each cycle and their acceleration and deceleration times shall be adhered to; target all parameters as close as possible.

6.4.2.1 *Dynamometer Load Cell*—Measure the dynamometer torque by a load cell of 0 kg to 45 kg. The dyno load cell is required to have the following features:

(1) Good temperature stability:

Zero ≤0.0036 % Rated Output per degree Celsius, and

Span ≤0.0036 % Rated Output per degree Celsius.

(2) Nonlinearity ≤0.05 % Rated Output.

(3) Temperature compensation over range expected in laboratory 21 °C to 40 °C. A Lebow Model 3397 (see X1.5) has been found suitable for this application. See Annex A20 for additional approved load cell(s).

6.4.2.2 *Dynamometer Load Cell Damper*—Do not use a load cell damper.

6.4.2.3 *Dynamometer Load Cell Temperature Control*—Control the load cell temperature. Enclose the dynamometer load cell to protect it from the variability of laboratory ambient temperatures. Mount the enclosure to the dynamometer base to minimize vibration effects on the load cell. A band heater is optional as supplementary control. Maintain air in the enclosure within the operating temperature range specified by the load cell manufacturer within a variability of no more than ±6 °C. Control temperature by a means that does not cause uneven temperatures on the body of the load cell. Plumbing the engine intake air supply to the enclosure has been found to be a suitable method for temperature control.

6.4.2.4 *Dynamometer Connection to Engine*—Use a damper system or damped shaft with U-joints for the dynamometer-to-engine connection (see 6.2). The following have been found suitable and are currently used; Vulkan, Machine Service Inc. (see X1.15) with a stiffness of 5.2 kN·m⁄rad.

6.4.2.5 *Dynamometer Load Cell Power Supply*—Laboratory ambient temperatures can affect the accuracy of the load cell power supply. In order to minimize the error introduced by temperature changes to the load cell power supply, select a power supply with a temperature drift spec <15 µV/ºC (manufacturers of power supplies often report this drift specification in ppm, and 15 ppm is equivalent to 15 µV).

6.5 *Engine Cooling System*—Use an external engine cooling system to maintain the specified jacket coolant temperature and flow rate during the test (see Figs. A5.1-A5.5). An alternative cooling system is shown in Fig. A5.3. The systems shall have the following features:

6.5.1 Pressurize the coolant system at the top of the reservoir. Control the system pressure to 100 kPa ± 10 kPa. Install a pressure cap or relief valve capable of maintaining system pressure within the above requirements (PC-1 in Figs. A5.1-A5.3).

6.5.2 The pumping system shall be capable of producing 80 L⁄min ± 4 L⁄min. A Gould's G&L centrifugal pump (P-1 in Figs. A5.1-A5.3), Model NPE, Size 1ST, mechanical seal, with a 1.4914 kW, 3450 r⁄min motor, has been found suitable for this application (see X1.6). Voltage and phase of the motor is optional. Variable frequency drive (VFD) devices are acceptable in this application.

TABLE 2 Sequence VIE Test Operating Conditions[A]

Parameter	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Speed, r/min[B]	2000 ± 5	2000 ± 5	1500 ± 5	695 ± 5	695 ± 5	695 ± 5
Load Cell, N·m[B]	105.0 ± 0.1	105.0 ± 0.1	105.0 ± 0.1	20.0 ± 0.1	20.0 ± 0.1	40.0 ± 0.1
Nominal, Power kW	22.0	22.0	16.5	1.5	1.5	2.9
Oil Gallery, °C[B]	115 ± 2	65 ± 2	115 ± 2	115 ± 2	35 ± 2	115 ± 2
Coolant-In, °C[B]	109 ± 2	65 ± 2	109 ± 2	109 ± 2	35 ± 2	109 ± 2
Stabilization Time, min	90	90	90	90	90	90

	All Stages
Temperatures, °C	
Oil Circulation	Record
Coolant Out	Record
Intake Air[B]	29 ± 2
Fuel-to-Flow meter[B]	26 ± 2
Fuel-to-Fuel Rail[B]	22 ± 2
Delta Load Cell[C]	Delta from the max stage average reading shall be ≤12
Oil Heater	205 max
Pressures	
Intake Air, kPa	0.05 ± 0.02
Fuel-to-Flow meter, kPa	110 ± 10
Fuel-to-Fuel Rail, kPa	405 ± 10
Intake Manifold, kPa abs.	Record
Exhaust Back Pressure, kPa abs.[B]	Stages 1-3 = 105.00 ± 0.17 / Stages 4-6 = 104.00 ± 0.17
Engine Oil, kPa	Record
Crankcase, kPa	0.0 ± 0.25
Flows	
Engine Coolant, L/min	80 ± 4
Fuel Flow, kg/h[B]	Record
Humidity, Intake Air, g/kg of dry air	11.4 ± 0.8
Air-to-Fuel Ratio[B]	14.00:1 to 15.00:1
Air-to-Fuel Ratio[C]	Delta from max stage average reading shall be ≤0.50

[A] Controlled parameters should be targeted for the middle of the specification range.
[B] Critical measurement and control parameters.
[C] Difference between the maximum stage average reading of the entire test and the individual stage average readings.

TABLE 3 Sequence VIE Test Operating Conditions[A]
Stage Flush and Stage Aging Hours SI Units

	Stage Flush	Aging Phase I & Phase II
Speed, r/min	1500 ± 5	2250 ± 5
Torque, nm	70.00 ± 0.10	110.00 ± 0.10
	Temperatures, °C[B]	
Oil Gallery	115 ± 2	120 ± 2
Coolant In	109 ± 2	110 ± 2
Oil Circulation	Record	Record
Coolant Out	Record	Record
Intake Air	29 ± 2	29 ± 2
Fuel-to-Flow meter[B]	26 ± 2	26 ± 2
Fuel-to-Rail	22 ± 2	22 ± 2
	Pressures	
Intake Air, kPa	0.05 ± .02	0.05 ± 0.02
Fuel-to-Flow meter, kPa	110 ± 10	110 ± 10
Fuel-to-Rail, kPa	405 ± 10	405 ± 10
Intake Manifold, kPa abs	Record	Record
Exhaust Back, kPa abs	105.00 ± 0.20	105.00 ± 0.20
Engine Oil, kPa	Record	Record
	Flows and Others	
Engine Coolant, L/min	80 ± 4	80 ± 4
Fuel Flow, kg/h	Record	Record
Humidity, Intake Air	Record	Record
g/kg, of dry air	11.4 ± 0.8	11.4 ± 0.8
Air-to-Fuel Ratio	14.00:1 to 15.00:1	14.00:1 to 15.00:1
Crankcase, Pressure, kPa	N/A	0.0 ± 0.25

[A] Controlled parameters should be targeted for the middle of the specification range.
[B] ±3 °C within this range.

6.5.3 The coolant system volume is not specified; however certain cooling system components are specified as shown in Figs. A5.1-A5.3. Adhere to the nominal ID of the line sizes as shown in Figs. A5.1-A5.3.

6.5.4 The specified heat exchanger (HX-1 in Fig. A5.1) is an ITT Standard brazed plate model 320-20, Part No. 5-686-06020-001[11] or ITT Bell and Gossett brazed plate model BP-75H-20, Part No. 5-686-06-020-001.[11] Parallel or counter flow through the heat exchanger is permitted.

6.5.4.1 Approved replacement heat exchangers are listed in Annex A20.

6.5.4.2 The specified heat exchanger(s) for the alternative cooling system (see Figs. A5.2 and A5.3) are an ITT shell and tube Model BCF 5-030-06-048-001[11] or an American Industrial AA-1248-3-6-SP.[12]

6.5.5 An orifice plate (OP-1 in Fig. A5.1) is specified. It is recommended that the orifice plate be sized to provide a pressure drop equal to that of heat exchanger HX-1 and install it in the bypass loop of the coolant system.

6.5.5.1 An orifice plate (OP-1) is not required when using the alternative cooling system (see Fig. A5.2 and Fig. A5.3).

6.5.6 An orifice plate (differential pressure) (FE-103 in Figs. A5.1-A5.3) may be used (see X1.8). Use an orifice flange, 11/2 NPT. Size the orifice plate to yield a pressure drop of 11.21 kPa ± 0.50 kPa at a flow rate of 80 L/min. There shall be 10 diameters upstream and 5 diameters downstream of straight, smooth pipe with no reducers or increasers. Flange size shall be the same size as pipe size. Threaded, slip-on, or weld neck styles can be used as long as a consistent pipe diameter is kept throughout the required lengths. An orifice obtained from Flowell (see X1.8) has been found suitable. As an alternative to using a differential pressure orifice plate to measure coolant flow, the volumetric coolant flow rate may be measured using any venturi or electronic flow meter that has an accuracy of <±0.5 %.

6.5.7 A control valve (TCV-104 in Figs. A5.1 and A5.2) is required for controlling coolant temperature by directing flow through the heat exchanger, HX-1, or diverting it through the bypass portion of the cooling system.

6.5.7.1 A Badger Meter Model No. 9003TCW36SV3AxxL36[13] (air-to-close), or Model No. 9003TCW36SV1AxxL36[13] (air-to-open) 3-way globe (divert), 2 in. valve is the specified valve.

6.5.7.2 Additional approved part numbers are listed in Annex A20.

6.5.7.3 Install the valve in a manner so that loss of air pressure to the controller results in coolant flow through the heat exchanger rather than through the coolant bypass (fail safe). Air-to-open/air-to-close is optional.

6.5.7.4 Control valve (TCV-104) is not required when using the alternative cooling system (see Fig. A5.2 and Fig. A5.3).

6.5.8 A control valve (FCV-103 in Fig. A5.1 to Fig. A5.3) is required for controlling the coolant flow rate to 80.0 L/min ± 4 L/min. A Badger Meter Model No. 9003GCW36SV3A19L36,[13] 2-way globe, 2 in., air-to-close valve is the specified valve. A VFD device (P-1 in Fig. A17.9) would not require this valve.

6.5.9 Use a Viatran model 274/374,[14] for reading the coolant flow rate at the orifice plate (FE-103 in Fig. A5.1 to Fig. A5.3) if orifice plate is used for flow measurement. See Annex A20 for additional approved transducers.

6.5.10 Replace the engine water pump with a water pump plate OHT6D-005-1, shown in Fig. A5.4.

[11] The sole source of supply of the apparatus known to the committee at this time is ITT Standard, 175 Standard Parkway, Cheektowaga (Buffalo), NY 14227. 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.

[12] The sole source of supply of the apparatus known to the committee at this time is American Industrial Heat Transfer, Inc., 355 American Industrial Drive, LaCrosse VA 23950.. 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.

[13] The sole source of supply of the apparatus known to the committee at this time is Badger Meter, 4545 W Brown Deer Rd, PO Box 245036, Milwaukee, WI 53224. 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.

[14] The sole source of supply of the apparatus (Viatran pressure transducers) known to the committee at this time is Vaitran, 199 Fire Tower Drive, Tonawanda, NY 14150. 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.

6.5.11 A coolant reservoir, a coolant overflow container, and a sight glass are required as shown in Figs. A5.1-A5.3 and Fig. A17.11. The design or model of these items is optional.

6.5.12 Use a control valve (TCV-101 in Figs. A5.2 and A5.3) for controlling the process water flow rate through the heat exchanger HX-1. A Badger Meter Model 9001GCW36SV3Axxx36[13] (air-to-close) or Model 9001GCW36SV1Axxx36[13] (air-to-open), 2-way globe, 1 in. valve have been found to be suitable for this application.

6.5.13 Use an 1½ in. NPT sight glass in the main coolant circuit (SG-1 in Figs. A5.1-A5.3). The make/model is optional.

6.5.14 Brass, copper, galvanized, or stainless steel materials are recommended for hard plumbing in the coolant system.

6.5.15 The materials used for process water, hot water, chilled water, process air, engine coolant overflow, and engine coolant transducer tubing are at the discretion of the laboratory.

6.5.16 The system shall have provisions (for example, low point drains) for draining all of the flushing water prior to installing a new coolant mixture.

6.6 *External Oil System*—An external oil system as shown in Figs. A5.6-A5.10 is required. Although all of the systems are interconnected in some manner, the overall external oil system is comprised of two separate circuits: *(1)* the flying flush system, which allows the oil to be changed while the engine is running, and *(2)* the circulation system for oil temperature control. Consider the engine oil pan (OHT6D-001-1 or OHT6D-001-2) shown in Fig. A5.9 a part of the external oil system. Minimize the external oil volume of all of the circuits as well as the length of connections and surfaces in contact with more than one oil in the flush system to enable more thorough flying flushes.

6.6.1 The flush system has a high capacity scavenge pump that pumps used oil into a minimum 6.0 L capacity dump reservoir while fresh oil is drawn into the engine. The dump reservoir float switch then resets certain solenoids and the engine refills to the level established by the float switch in the engine oil pan (which then closes the solenoid to the fresh oil reservoir).

6.6.2 The oil heat/cool loop uses a proportional controller to bypass the cooling heat exchanger. Control the temperature within narrow limits with minimal additional heat (and surface temperatures). The system can respond quickly to establish the different oil gallery temperatures required in the procedure. Arrange the proportional three-way control valve to go to its midpoint during the flying flushes to avoid trapping oil, and there shall be some cooling during test oil aging so that no oil is trapped in the cooler.

6.6.3 Do not use cuprous materials in any of the oil system (excluding the oil scavenge discharge system) except as may be required by the use of mandatory equipment in this procedure.

6.6.4 The flying flush system (see Fig. A5.6) shall have the following features:

6.6.4.1 A scavenge pump is required. The pump shall have an electric motor drive of 1140 r/min to 1150 r/min with a minimum of 0.56 kW. Voltage and phase are optional. A Viking Series 475,17 gear type, close-coupled pump, model H475M has been found suitable. Any pump meeting the specifications of a Viking series 475 may be utilized; however, when changing to a different model pump, it will be necessary to conduct a new flush effectiveness evaluation (see 11.2).

6.6.4.2 A reservoir with a minimum capacity of 19 L. It is recommended that the system include three reservoirs, one for BL calibration oil, one for FO (flush oil), and one for test oil.

6.6.4.3 An oil stirrer in each oil reservoir.

6.6.4.4 An oil heating system (with appropriate controls) for each oil reservoir with the capability of heating the oil in the reservoir to 93 °C to 107 °C.

6.6.4.5 A dump reservoir (see Fig. A5.8) with a minimum capacity of 6.0 L.

6.6.4.6 A dump reservoir float switch is required. (FLS-136 in Fig. A5.8.) An OHT-6D00104/ Switch, Level, Gems, high temperature float switch has been found suitable for this application.

6.6.5 The circulation system for oil temperature control shall have the following features:

6.6.5.1 A total volume, including oil volume in the oil pan to the full mark, shall be 5.9 L.

6.6.5.2 Use a positive displacement oil circulation pump. A Viking Series 4125,[15] Model G4125, no relief valve, base mounted are specified (Annex A20). The pump shall have a V-belt or direct drive electric drive motor of 1140 r/min to 1170 r/min with a minimum power of 0.56 kW. Voltage and phase are optional. See Annex A20 for additional approved models.

NOTE 1—If using a V-belt drive, use a 1:1 pulley ratio so that the final speed of the pump is a nominal 1150 r/min.

6.6.5.3 Use solenoid valves (FCV-150A, FCV-150C, FCV-150D, and FCV-150E, in Fig. A5.6).

(1) FCV-150F and its related lines/piping are optional.

(2) FCV-150A is a Burkert[16] Type 251 piston-operated valve used with a Type 312 solenoid valve (see Annex A20 for additional approved models) for actuation of air supply to the piston valve, solenoid valve direct-coupled to piston valve, normally closed, explosion proof (left to the discretion of the laboratory), and watertight, ¾ in., 2-way, stainless steel NPT fitting.

(3) FCV-150C is to be Burkert[16] Type 2000 with 13 mm orifice and 50 mm actuator. Additionally, flexible hoses to and from FCV-150C are to be size #12 and the internal diameter of all fittings on the suction side of the engine driven oil pump shall be equal to or greater than 0.50 in. Hose lines to and from FIL-2 are to be size #10.

(4) FCV-150D and FCV-150E are Burkert[16] Type 251 piston-operated valves used with a Type 312 solenoid valve (see Annex A20 for additional approved models) for actuation of air supply to the piston valve, solenoid valve direct-coupled to the piston valve, normally closed, explosion proof (left to the discretion of the laboratory), and watertight, ½ in., 2-way, stainless steel NPT fitting.

6.6.5.4 Use control valve (TCV-144 in Fig. A5.6). The specified valve is a Badger Meter Model No. 1002TBN36SVOSALN36,[13] 3-way globe (divert), ½ in., air to open valve.

6.6.5.5 Use a heat exchanger (HX-6 in Fig. A5.6) for oil cooling. The specified heat exchanger is an ITT model 310-20[11] or an ITT Bell & Gossett,[11] model BP-25-20 (Part No. 5-686-04-020-001), brazed plate.

NOTE 2—The ITT Standard and ITT Bell and Gossett heat exchangers have been standardized under one model and part number. The new replacement is Model BP410-20, Part No. 5-686-04-020-002.

6.6.5.6 Use an electric heater (EH-5 in Fig. A5.6) for oil heating. The specified heater is a heating element inserted in the liquid Cerrobase or Bolton 255 inside a Labeco oil heater housing (see X1.12). Any heater elements rated at 3000 W may be used within the Labeco housing. See Annex A20 for recommended heating elements.

(*1*) It is specified that a thermocouple be installed in the external oil heater so that the temperature can be monitored. Install this thermocouple into the top of the heater into the Cerrobase or Bolton 255 (see Fig. A5.7) to an insertion depth of 245 mm ± 3 mm. Do not exceed the maximum temperature of 205 °C.

(*2*) The procedure for replacing a heating element is detailed in Annex A6.

6.6.5.7 Install one oil filter (FIL-1 in Fig. A5.6) in the external oil system. The filter specified is OHT6A-012-5 with a stainless steel screen having a rating of 60 µm, Part No. OHT6A-013-3. Locate the filter between the engine oil pump and where the oil enters the engine oil gallery.

6.6.5.8 Use modified oil filter adapter assembly, Part No. OHT6D-003-1, as shown in Fig. A5.10.

6.6.5.9 Engine oil plumbing shall be stainless steel tubing or piping or flexible hose suitable for use with oils at the temperatures specified (see Fig. A5.6). When using a flexible hose in the external oil system, excluding the line to the dump tank, flexible hoses to and from FCV-150C are to be size #12 and internal diameter of all fittings on the suction side of the engine driven oil pump will be equal to or greater than 13 mm. Install Aeroquip No. 10 (Part No. 2807-10) to and from FIL-1 (see X1.13).

6.6.5.10 Insulation of plumbing for the external oil circulation system is mandatory. Insulation material selection is optional.

[15] The sole source of supply of the apparatus known to the committee at this time is Viking Pumps, 401 State Street, Cedar Falls IA 50613. 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.

[16] The sole source of supply of the apparatus known to the committee at this time is Burkert Fluid Control Systems, 11425 Mt Holly-Huntersville Rd, Huntersville NC 28078. –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.

6.6.5.11 *Engine Oil Pan*—Use oil pan OHT6D-001-2. Oil pan OHT6D-001-2 is oil pan OHT6D-001-1 modified with part number 6E00121 oil pan displacement block. A sight glass is provided for monitoring the oil level and determining oil consumption.

6.7 *Fuel System*—A typical fuel delivery system incorporating all of the required features is shown in Fig. A5.11. The fuel system shall include provisions for measuring and controlling fuel temperature and pressure into the fuel flow measuring equipment and into the engine fuel rail.

6.7.1 There shall be a minimum of 100 mm of flexible line at the inlet and outlet of the fuel flow meter (rubber/synthetic suitable for use with gasoline). Compression fittings are allowed for connecting the flexible lines to the fuel flow meter. Fuel supply lines from the fuel flow measurement equipment to the engine fuel rail shall be stainless steel tubing or piping or any flexible hose suitable for use with gasoline.

6.7.2 *Fuel Flow Measurement*—Measure the critical fuel flow rate throughout the test. Use a Micro Motion Model CMF010 or CMFS010[17] mass flow meter with either a RFT9739, 2500 MVD, 2700MVD, or 1700MVD transmitter. The Micro Motion sensor may be mounted in a vertical or a horizontal position.

6.7.3 *Fuel Temperature and Pressure Control to the Fuel Flow Meter*—Maintain fuel temperature and pressure to the fuel flow meter at the values specified in Tables 1-3. Precise fuel pressure control without fluctuation or aeration is mandatory for test precision. The fuel pressure regulator shall have a safety pressure relief, or a pressure relief valve, parallel to pressure regulator for safety purposes.

6.7.4 *Fuel Temperature and Pressure Control to Engine Fuel Rail*—Maintain fuel temperature and pressure to the engine fuel rail at the values specified in Tables 1-3. Precise fuel temperature and precise fuel pressure control without fluctuation or aeration is mandatory for test precision.

6.7.5 *Fuel Supply Pumps*—The method of providing fuel to the fuel flow meter and engine is at the laboratory's discretion as long as the requirements for fuel pressure and temperature are met. The average fuel pressure for this engine is 405 kPa.

6.7.6 *Fuel Filtering*—Filter the fuel supplied to the test stand in order to minimize fuel injector difficulties.

6.8 *Engine Intake Air Supply*—Use suitable apparatus to deliver air to the engine intake air filter at approximately 4.0 m^3/min. The intake air supply system shall be capable of controlling moisture content, dry bulb temperature, and inlet air pressure as specified in Table 2 and Table 3, which is 11.4 g/kg ± 0.8 g/kg of dry air, 29 °C ± 2 °C, and 0.05 kPa ± 0.02 kPa. The specified engine intake air system components are considered part of the laboratory intake air system.

6.8.1 *Intake Air Humidity*—Measure humidity with the laboratory's primary humidity system. Correct each reading for non-standard barometric conditions, using the following equation:

$$H_c = 621.98\,(P_{sat}/(P_{bar} - P_{sat})) \tag{1}$$

where:

H_c = corrected humidity, g/kg,
P_{sat} = saturation pressure, Pa, and
P_{bar} = barometric pressure, Pa.

6.8.2 *Intake Air Filtration*—The air supply system shall provide either water-washed or filtered air to the duct. Any filtration apparatus utilized shall have sufficient flow capacity to permit control of the air pressure at the engine.

6.8.3 *Intake Air Pressure Relief*—The intake air system shall have a pressure relief device located upstream of the engine intake air filter snorkel. The design of the relief device is not specified.

6.9 *Temperature Measurement*—The test requires the accurate measurement of oil, coolant, and fuel temperatures, and care must be taken to ensure temperature measurement accuracy.

[17] The sole source of supply of the apparatus (Micromotion flow meters) known to the committee at this time is Emerson Electric Co., 8000 West Florissant Avenue, PO Box 4100, St. Louis MO 63136. 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.

6.9.1 Check all temperature devices for accuracy at the temperature levels at which they are to be used. This is particularly true of the thermocouples used in the oil gallery, the coolant in, the inlet air, and the fuel to fuel rail. Iron-Constantan (Type J) thermocouples are recommended for temperature measurement, but Type J, Type K (Nickel-Chromium/Chromel-Alumel), or Type E (Chromium/Constantan) thermocouples may be used.

6.9.2 All thermocouples (excluding the oil heater thermocouple) shall be premium grade, sheathed types with premium wire. Use thermocouples with a diameter of 3.2 mm. Thermocouple lengths are not specified, but in all cases shall be long enough to allow thermocouple tip insertion to be in mid-stream of the medium being measured. The thermocouples shall not have thermocouple sheath greater than 50 mm when exposed to laboratory ambient temperature.

6.9.3 Some sources of thermocouples that have been found suitable for this application are: Leeds and Northrup, Conax, Omega, Revere, and Thermo Sensor (see X1.11). Match thermocouples, wires, and extension wires to perform in accordance with the special limits of error as defined by ANSI in publication MC96.1-1975.

6.9.4 System quality shall be adequate to permit calibration to ±0.56 °C for individual thermocouples.

6.9.5 *Thermocouple Location*—Locate all thermocouple tips in the center of the stream of the medium being measured unless otherwise specified.

6.9.5.1 *Oil Inlet (Gallery)*—Insert the thermocouple into the modified oil filter adapter plate so that the thermocouple tip is flush with the face of the adapter and located in the center of the stream of flow.

6.9.5.2 *Oil Circulation*—Locate the oil circulation thermocouple in the tee in the front of the oil pan where the oil from the external heat/cool circuit returns oil to the pan. The tip of the thermocouple shall be at the junction of the side opening in the tee with respect to the through passage in the tee.

6.9.5.3 *Engine Coolant In*—Locate the thermocouple tip in the center of the stream of flow and within the outside of the OHT6D-005-1 water pump adapter inlet by 150 mm.

6.9.5.4 *Engine Coolant Out*—Locate the thermocouple tip in the center of the stream of flow and in the coolant return neck within 8 cm of the housing outlet.

6.9.5.5 *Intake Air*—Locate the thermocouple in the GM plastic elbow in front of the throttle body as shown in Fig. A5.12.

6.9.5.6 *Fuel to Fuel Flow Meter*—Locate the thermocouple upstream of the fuel flow meter inlet within a line length of 100 mm to 500 mm.

6.9.5.7 *Fuel to Engine Fuel Rail*—Insert the thermocouple into the center of a tee or cross fitting and locate it within 600 mm from the center point of the fuel rail (see Fig. A5.22). Locate the thermocouple upstream of the fuel pressure measurement point.

6.9.5.8 *Load Cell*—Locate the thermocouple within the load cell enclosure.

6.10 *AFR Determination*—Determine engine air-fuel ratio (AFR) by an AFR analyzer. Analysis equipment shall be capable of near continuous operation for 30 min periods.

6.10.1 The AFR analyzer shall meet the following specification:

Accuracy	±0.1 AFR when 14.7 AFR with H/C = 1.85, O/C = 0.000

6.10.1.1 Temperature of exhaust gas used by sensor: –7 °C to 900 °C. A Horiba MEXA 110 analyzer has been found suitable for this application (see X1.14). See Annex A20 for additional analyzers which have also been found suitable for this application.

6.10.2 The specified location of the analyzer sensing element in the exhaust system is shown in Fig. A5.13.

6.11 *Exhaust and Exhaust Back Pressure Systems:*