Designation: D 6202 – 00a

An American National Standard

Standard Test Method for Automotive Engine Oils on the Fuel Economy of Passenger Cars and Light-Duty Trucks in the Sequence VIA Spark Ignition Engine[1]

This standard is issued under the fixed designation D 6202; 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

This test method can be used by any properly equipped laboratory, without outside assistance. However, the ASTM Test Monitoring Center (TMC)[2] provides reference oils and assessment of the test results obtained on those oils by the laboratory (see Annex A1). By this means, the laboratory will know whether their use of the test method gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory utilize the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army imposes such a requirement, in connection with several Army engine lubricating oil specifications.

Accordingly, this test method is written for use by laboratories that utilize the TMC services. Laboratories that choose not to use those services may simply ignore those portions of the test method that refer to the TMC.

This test method may be modified by means of Information Letters issued by the TMC. In addition, the TMC may issue supplementary memoranda related to the test method. Users of this test method shall contact the Administrator of TMC to obtain the most recent of these.

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 3856 kg (8500 lb), or less, gross vehicle weight trucks. The tests are conducted using a specified 4.6-L spark-ignition engine on a dynamometer test stand. It applies to multiviscosity grade oils used in these applications. Companion test methods used to evaluate engine oil performance for specification requirements are discussed in the latest revision of Specification D 4485.

1.2 The values stated in either SI units or other units shall be regarded separately as the standard. Within the text, the SI units are stated first with the other units shown in parentheses. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other, without combining values in any way.

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.*

1.4 This test method is arranged as follows:

[1] This test method is under the jurisdiction of ASTM CommitteeD02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants. The multi-cylinder engine test sequences were originally developed in 1956 by an ASTM Committee D02 group. Subsequently, the procedures were published in an ASTM special technical publication. The Sequence VIA was published as RR:D02-1364, dated August 24, 1995.

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[2] ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. For other information, refer to RR: D02-1364 Sequence VIA Test Development. This research report and this test method are supplemented by Information Letters and Memoranda issued by the ASTM Test Monitoring Center. This edition incorporates revisions in all Information Letters through No. 00–1.

2. Referenced Documents

2.1 *ASTM Standards:*

D 86 Test Method for Distillation of Petroleum Products[3]

D 240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter[3]

D 287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)[3]

D 323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)[3]

D 381 Test Method for Existent Gum in Fuels by Jet Evaporation[3]

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)[3]

D 525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)[3]

D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption[3]

D 2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel[4]

D 3231 Test Method for Phosphorus in Gasoline[5]

D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry[5]

D 3338 Test Method of Estimation of Heat of Combustion of Aviation Fuels[5]

D 4294 Test Method for Sulfur in Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectroscopy[5]

D 4485 Specification for Performance of Engine Oils[5]

D 5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions[6]

D 5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)[6]

D 5862 Test Method for Evaluation of Engine Oils in the Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine[6]

E 29 Practice for Using Significant Digits in Test Data to

[3] *Annual Book of ASTM Standards*, Vol 05.01.
[4] *Annual Book of ASTM Standards*, Vol. 05.04.
[5] *Annual Book of ASTM Standards*, Vol. 05.02.
[6] *Annual Book of ASTM Standards*, Vol. 05.03.

Determine Conformance with Specifications[7]

E 191 Specification for Apparatus for Microdetermination of Carbon and Hydrogen in Organic and Organo-Metallic Compounds[8]

IEEE/ASTM SI-10 Standard for Use of the International System of Units (SI): The Modern Metric System[7]

2.2 *SAE Standard:*[9]

J304 Engine Oil Tests

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

2.3 *API Standard:*[10]

API 1509 Engine Oil Licensing and Certification System

2.4 *ANSI Standard:*[11]

ANSI MC96.1-1975 Temperature Measurement-Thermocouples

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. **D 5302**

3.1.2 *automotive, adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines. **D 4485**

3.1.3 *calibration, n*—the act of determining the indication or output of a measuring device or a given engine with respect to a standard.

3.1.4 *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.

3.1.5 *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. **D 5862**

3.1.6 *lubricant, n*—any material interspersed between two surfaces that reduces the friction or wear, or both, between them. **D 5862**

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

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

3.1.8.1 *Discussion*—The preferred term is *purchaser*. Deprecated terms that have been used are *client*, *requester*, *sponsor*, and *customer.* **Sub. B Glossary**

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

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.

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

3.2.3 *break-in, n—in internal combustion engines*, the running of a new engine under prescribed conditions until it reaches stabilized conditions.

3.2.4 *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 a new test oil.

3.2.5 *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.

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

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

3.2.7 *pre-test verification, n*—the running of an engine to identify relative magnitudes of stage BSFC, confirm proper test controls, verify proper engine operation, and engine/stand suitability to run another test oil.

3.2.8 *test oil, n*—an oil subjected to a Sequence VIA engine oil test; either a reference oil or a non-reference oil.

4. Summary of Test Method

4.1 The 4.6-L internal combustion engine is installed on a dynamometer test stand equipped with the appropriate controls for speed, load, and various other operating parameters.

4.2 The test method consists of measuring the laboratory engine brake specific fuel consumption at six constant speed/load/temperature conditions for the reference oil, the test oil, and the reference oil once again, for a total of 50 h approximately.

4.3 Aged test oil is compared directly to fresh ASTM BC SAE 5W-30[2] reference oil, which is run before and after the test oil. When changing from test oil to reference oil, an intermediate flush with a special flushing oil (BC flush oil) 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 brake specific fuel consumption relative to the reference oil.

5. Significance and Use

5.1 *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 baseline calibration oil (hereafter referred to as BC oil) has been established for this test method to provide a reference against which all other oils can be compared. The BC oil is an SAE 5W-30 grade fully-formulated lubricant. There is a directional correlation of Test Method D 6202 (Sequence VIA) percent fuel economy improvement (FEI) with the fuel

[7] *Annual Book of ASTM Standards*, Vol. 14.02.

[8] *Annual Book of ASTM Standards*, Vol 14.04.

[9] Available from Society of Automotive Engineers, Inc., 400 Commonwealth Dr., Warrendale, PA 15096-0001. This standard is not available separately. Order either the SAE Handbook Vol. 3 or the SAE Fuels and Lubricants Standards Manual HS-23.

[10] Available from American Petroleum Institute, 1220 L Street NW, Washington, DC 20005-8197.

[11] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10017.

economy results obtained from vehicles representative of current production running under the current EPA testing cycles.

5.1.1 The test procedure was not designed to give a precise estimate of the difference between two test oils without adequate replication. Rather, it was developed to compare a test oil to BC oil.

5.2 *Use*—The Sequence VIA 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 D 4485,

5.2.2 API 1509,

5.2.3 SAE J304, and

5.2.4 SAE J1423.

5.3 *Validity*—The results are valid only when all details of the procedure are followed and when the test is conducted on a TMC calibrated test stand. Good engineering practice should be followed in all aspects of the test procedure. Unexpected deviation in the controlled test parameters are to be judged in accordance with the applicable guidelines established in 14.2.2. Beyond these guidelines, good engineering judgment shall be applied in all unforeseen circumstances to protect the validity of the test results. If anomalies exist within the data generated during a test and are not addressed within this procedure, they should be reported as indicated in X1.1.1.

5.4 *Laboratory Engine/Stand Combination Calibration*—Engine test severity is monitored using reference oils (see X1.1.2). The TMC will assign reference oils for calibration tests. The reference oils used to calibrate Sequence VIA engine test stands have been formulated or selected to represent specific chemical types or performance levels, or both. These oils are normally supplied under code numbers (blind reference oils) to ensure that the testing laboratory is not influenced by preconceived opinions in assessing test results.

5.4.1 Number each Sequence VIA test to identify the stand number, the number of runs on that stand, the engine number, and the number of runs on the engine. For example, 56-21-3-8 defines a test on stand 56, which is the 21st test on stand 56; engine number three; and the eighth test on engine number three. For reruns of operationally invalid or unacceptable tests, the stand run number shall be incremented by one and the engine run number shall be followed by the letter *A* for the first re-run, *B* for the second re-run, and so forth. For example, the next test number for an operationally invalid or unacceptable test would be 56-22-3-8A.

5.4.2 To ensure proper response to various oil parameters, conduct a reference oil test when a new or previously used test engine is installed in a test stand. Reference test requirements, as described in 10.2, are administered by the TMC.

5.5 *Performance Characteristics of Automotive Engine Oils*:

5.5.1 *Precision Data*— Initial precision data for the individual reference oils are shown in Table A2.1.

5.5.2 *Reference Oil Data*—The precision data for reference oils are reviewed semi-annually by the ASTM Sequence VI/VIA Surveillance Panel.

5.5.3 *Test Oil Data*— Precision data for non-reference oils are also reviewed semi-annually by the ASTM Sequence VI/VIA Surveillance Panel.

6. Apparatus

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

6.1.1 *Class*:

6.1.1.1 *1*—Shall use exact make/model/size specified.

6.1.1.2 *2*—Shall use the recommended make/brand/model or equivalent that meets the specifications as detailed in the text.

6.1.1.3 *3*—Shall include but ue of make/model/size is optional.

6.1.1.4 *4*—Suggested or recommended for inclusion, but use is optional.

6.1.2 The class for each component is shown in the right hand column of Fig. A2.8 for the engine cooling system (see 6.5) and Fig. A2.16 for the external oil system (see 6.6). Prints for special parts are included in this procedure. When using these prints to fabricate special parts, the dimensions specified for the various parts should be used. Do not scale off the drawings or use them as a pattern. All equipment specified in the procedure shall be used. Substitution of equivalent equipment is allowed, but only after equivalency has been proven to the satisfaction of the TMC.

6.2 *Test Engine Configuration*—The test engine is a specially built 1993 4.6-L Ford V-8 engine[12] designed for use with an automatic overdrive electronic (AODE) transmission. (See X1.1.3 for procurement of this engine). Mount the engine on the test stand so that the flywheel friction face is 3.6 ± 0.5° from the vertical with the front of the engine higher than the rear. The U-joint angles shall not be greater than 2.0° in the vertical plane and 0.0° in the horizontal.

6.3 *Laboratory Ambient Conditions*—Do not permit air from fans or ventilation systems to blow directly on the engine. The ambient laboratory atmosphere shall be relatively free of dirt, dust, or other contaminants as required by good laboratory standards.

6.4 *Engine Speed and Load Control*—The dynamometer speed and load control systems shall be capable of maintaining the limits specified in Table 1, Table 2, and Table 3. A typical closed-loop control system maintains speed by engine throttle control and load by dynamometer control. Since these speed and load tolerances require sensitive and precise control, particular attention should be given to achieving and maintaining accurate calibration of the related instrument systems. Control average speed at ± 2 r/min and average load at ± 0.07 N-m (0.05 lbf-ft) as indicated by digital displays, measured over a 100 to 120 s interval.

6.4.1 *Dynamometer*—Use a Midwest or Eaton 37 kW (50

[12] A specially built 1993 4.6L Ford V-8 internal combustion engine is a product of Ford Motor Co., Dearborn, MI 48121. It is available as Part No. R2G-800-XB (AOD-E) from AER, 1605 Surveyor Blvd., P.O. Box 979, Carrollton, TX 75011-0979.

TABLE 1 Sequence VIA Test Operating Conditions Stage Flush and Stage Aging[A]

Test Condition	SI Units	Inch-pound Units
Speed, r/min	1500 ± 5	
Nominal power, kW	15.4	(20.6 hp)
Load, N-m	98.00 ± 0.10	(72.28 ± 0.07 lbf-ft)
Oil gallery temperature,° C	125 ± 2	(257 ± 3°F)
Coolant in temperature,° C	105 ± 2	(221 ± 3°F)
Temperatures,° C		
Oil circulation	record	
Coolant out	record	
Intake air	27 ± 2	(80.6 ± 3.6°F)
Fuel temperature to flowmeter	20 to 32 (± 3 within this range)	(68 to 89.6 ± 4.8°F)
Fuel to fuel rail	20 ± 2	(68 ± 3.6°F)
Oil heater	205	(401°F)
Pressures		
Intake air, kPa	0.05 ± 0.02	(0.20 ± 0.10 in. H_2O)
Fuel to flowmeter, kPa	100 min.	(15 psi min)
Fuel to fuel rail, kPa	205 to 310	(29.7 to 45 psi)
Intake manifold, kPa abs.	record	
Exhaust back pressure, kPa abs	104.00 ± 0.20	(30.80 ± 0.05 in. Hg abs.)
Engine oil, kPa	record	
Flows		
Engine coolant, L/min	130 ± 4	(34.3 ± 1.1 gal/min)
Fuel flow, kg/h	record	
Humidity,intake air, g/kg, of dry air	11.4± 0.8	(79.8 ± 5.6 grains/lb)
AFR	14.25:1 to 15.25:1	(± 0.25 within this range)
Ignition timing	20° BTDC ± 2°	

[A]Counted from the time the temperature set points are initially adjusted to the specific levels. Controlled parameters should be targeted for the middle of the specification range.

hp) Model 758 dry gap dynamometer (see X1.1.4).

6.4.2 *Dynamometer Load*:

6.4.2.1 *Dynamometer Load Cell*—Measure the dynamometer load by a 0 to 45 kg (0 to 100 lb) load cell. The dyno load cell shall have the following features:

(*a*) Good temperature stability:

(1) Zero ≤± 0.001 % full scale output (FSO) per °C (0.002 % FSO per °F).

(2) Span ≤ ± 0.001 % FSO per °C (0.002 % FSO per °F).

(*b*) Nonlinearity ≤± 0.05 % FSO.

(*c*) Temperature compensation over range expected in lab (10 to 49°C) (50 to 115°F).

6.4.2.2 A Lebow Model 3397 load cell is recommended (see X1.5).

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

6.4.2.4 *Dynamometer Load Cell Ambient Temperature Control*—Control the load cell ambient temperature. Enclose the dynamometer load cell to protect it from the variability of laboratory ambient temperatures. Maintain air in the enclosure within the operating temperature range specified by the load cell manufacturer within a variability of no more than ± 3°C (± 5.4°F). Control temperature by a means that does not cause uneven temperatures on the body of the load cell.

6.4.2.5 *Dynamometer Connection to Engine*—Use U-joints for the dynamometer-to-engine connection (see 6.2).

6.5 *Engine Cooling System*—An external engine cooling system, as shown in Figs. A2.1 through A2.8, is required to maintain the specified jacket coolant temperature and flow rate during the test. The system components are listed in Fig. A2.8. An alternative cooling system is shown in Fig. A2.3. The system shall have the following features:

6.5.1 The closed system is relieved of excess pressure using a normally closed 34.5 to 137.9kPa (5 to 20 psi) cap (PC-1 in Figs. A2.1 and A2.2) (see X1.1.6).

6.5.2 The pumping system shall be capable of producing 130 ± 4 L/min (34.3 ± 1.1 gal/min). A Gould G and L centrifugal pump (P-1 in Figs. A2.1, A2.2, and A2.6), Model NPE, size 1ST, mechanical seal, with a 1.49 kW (2 hp), 3450 r/min motor, is specified (see X1.1.7). Voltage and phase of the motor is optional.

6.5.3 The coolant system volume is not specified; however, certain cooling system components are specified, as shown in Figs. A2.1 through A2.6, and adhere to the nominal I.D. of the line sizes, as shown in Figs. A2.1 through A2.6.

6.5.4 The specified heat exchanger (HX-1 in Figs. A2.1 through A2.6) is an ITT Standard brazed plate Model 320-20, Part No. 5-686-06-020-001 (see X1.1.8), or a ITT Bell and Gossett brazed plate Model BP-75H-20, Part No. 5-686-06-020-001 (see X1.1.8). Parallel or counterflow through the heat exchanger is permitted.

6.5.4.1 Approved replacement heat exchangers are ITT Bell and Gossett brazed plate Model BP-420-20, Part No. 5-686-06-020-005, and ITT Bell and Gossett brazed plate Model BP-422-20, Part No. 5-686-06-020-007.

6.5.4.2 The specified heat exchanger for the alternative

TABLE 2 Sequence VIA Test Operating Conditions (SI Units)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
[A]Speed, r/min	800 ± 2	800 ± 2	1500 ± 2	1500 ± 2	1500 ± 2	800 ± 2
Nominal power, kW	2.18	2.18	5.81	15.39	15.39	2.18
[A]Load, N-m	26.00 ± 0.07	26.00 ± 0.07	37.00 ± 0.07	98.00 ± 0.07	98.00 ±0.07	26.00 ± 0.07
[A]Oil gallery temperature,° C	105 ± 1	70 ± 1	70± 1	70 ± 1	45 ± 1	45 ± 1
[A]Coolant in temperature,° C	95 ± 1	60 ± 1	60± 1	60 ± 1	45 ± 1	45 ± 1
Stabilization time, min[B]	60	60	60	60	60	60

	ALL STAGES
Temperatures,° C	
Oil circulation	record
Coolant out	record
[A]Intake air	27 ± 2
Fuel temperature to flowmeter	20 to 32 (delta from the maximum stage average reading shall be ≤ 4)[C]
[A]Fuel to fuel rail	20 ± 2
Load cell	variability no greater than ± 3
Oil heater	205 max
Delta load cell temperature	delta from the maximum stage average shall be ≤ 6[C]
Pressures	
Intake air, kPa	0.05± 0.02
Fuel to flowmeter, kPa	100 min
Fuel to fuel rail, kPa	205 to 310
Intake manifold, kPa abs.	record
[A]Exhaust back pressure, kPa abs.	104.00 ± 0.17
Engine oil, kPa	record
Flows	
Engine coolant, L/min	130 ± 4
[A]Fuel flow, kg/h	record
Humidity, intake Air, g/kg of dry air	11.4± 0.8
[A]AFR	14.25:1 to 15.25:1 (delta from the maximum stage average shall be ≤ 0.50)[C]
Ignition Timing	20° BTDC± 2°

[A]Critical measurement and control parameters,. Controlled parameters should be targeted for the middle of the specification range.
[B]Counted from the time the temperature set points are initially adjusted to the specific levels.
[C]Difference between the maximum stage average reading of the entire test and the individual stage average readings.

cooling system (see Fig. A2.3) is an ITT shell and tube, Model BGF 5-030-06-048-001.

6.5.5 An orifice plate (OP-1 in Figs. A2.1 through A2.6) is specified. Size this orifice plate 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 oriface plate (OP-1) is not required when using the alternative cooling system (see Fig. A2.3).

6.5.6 An orifice plate (differential pressure) (FE-103) in Figs. A2.1 through A2.6 is specified (see X1.1.9). This orifice plate is a Daniel Series No. 30 RT threaded orifice flange, 1 ½ NPT. Size this orifice plate to yield a pressure drop of 11.21± 0.50 kPa (45.0 ± 2.0 in. H_2O) at a flow rate of 130 L/min (34.3 gal/min). There should be ten diameters upstream and five diameters downstream of straight, smooth pipe with no reducers or increasers. Flange size shall be 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.

6.5.7 A control valve (TCV-104 in Figs. A2.1 through A2.5) is required for controlling the engine coolant flow rate through the heat exchanger HX-1 and the heat exchanger bypass portion of the cooling system.

6.5.7.1 A Badger Meter Inc. Model No. 9003TCW36SV3AXXL36 (air-to-close), or Model No. 9003TCW36SV1AXXL36 (air-to-open) 3-way globe (divert), 50.8-mm (2-in.) valve is the specified valve (see X1.1.10).

6.5.7.2 A Badger Meter Inc. Model No. 9003TCW36SV3A29L36 (air-to-close) or Model No. 9003TCW36SV1A29L36 (air-to-open) is also acceptable if the trim package used with these valves has a C.V. value of 16.0.

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. A2.3).

6.5.8 A control valve (FCV-103 in Figs. A2.1, A2.2, and A2.6) is required for controlling the coolant flowrate to 130.0 ± 4 L/min (35 ± 1 gal/min). A Badger Meter Inc. Model No. 9003GCW36SV3A29L36, 2-way globe, 50.8 mm (2 in.), air-to-close valve is the specified valve (see X1.1.10).

6.5.9 A Viatran model 274/374, Validyne model DP15, or Rosemount model 1151 differential pressure transducer (see DPT-1 in Fig. A2.6) is required for reading the coolant flow rate at the orifice plate (see FE-103 in Fig. A2.2) (see X1.1.11).

TABLE 3 Sequence VIA Test Operating Conditions (Inch-Pound Units)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
[A]Speed, r/min	800 ± 2	800 ± 2	1500 ± 2	1500 ± 2	1500 ± 2	800 ± 2
Nominal power, hp	2.92	2.92	7.79	20.64	20.64	2.92
[A]Load, lbf•ft	19.18 ±0.05	19.18 ±0.05	27.29 ±0.05	72.28 ±0.05	72.28 ±0.05	19.18 ±0.05
[A]Oil gallery temperature,°F	221 ± 1.8	158 ± 1.8	158 ± 1.8	158 ± 1.8	113 ± 1.8	113 ± 1.8
[A]Coolant in temperature,°F	203 ± 1.8	140 ± 1.8	140 ± 1.8	140 ± 1.8	113 ± 1 .8	113 ± 1.8
Stabilization Time, minutes[B]	60	60	60	60	60	60

	ALL STAGES
Temperatures,° F	
Oil circulation	record
Coolant out	record
[A]Intake air	80.6 ± 3.6
Fuel temperature to flowmeter	68 to 89.6 (delta from the maximum stage average reading shall be ≤ 4)[C]
[A]Fuel to fuel rail	68 ± 3.6
Load cell	delta from the maximum stage average reading shall be ≤ 6[C]
Oil heater	401 max
Pressures	
Intake air, in. H_2O	0.2 ± 0.1
Fuel to flowmeter, psi	15 min
Fuel to fuel rail, psi	30 to 45
Intake manifold, in. Hg abs.	record
[A]Exhaust back pressure, in. Hg abs.	30.80 ± 0.05
Engine oil, psi	record
Flows	
Engines coolant, gal/min	34.3 ± 1
[A]Fuel flow, ib/h	record
Humidity, intake Air, grains/lb	79.8 ± 5.6
[A]AFR	14.25:1 to 15.25:1 (delta from the maximum stage average reading shall be ≤ 0.50)[C]
Ignition Timing	20° BTDC± 2°

[A]Critical measurement and control parameters. Controlled parameters should be targeted for the middle of the specification range.
[B]Counted from the time the temperature set points are initially adjusted to the specific levels.

6.5.10 The engine water pump shall either be (*1*) removed and replaced with a water pump plate as shown in Fig. A2.7 or (*2*) modified by removing the impeller and welding a block off plate onto the front of the pump or tapping the front of the pump and screwing in a pipe plug. The water pump plate can be fabricated by the laboratory or procurred as Part No. OHT6A-014-A (see X1.1.12).

6.5.11 A coolant reservoir, a coolant overflow container, and a sight glass are required, as shown in Figs. A2.1, A2.2, and A2.6. The design or model, or both of these items, is optional.

6.5.12 A control valve (TCV-101 in Figs. A2.1, A2.4, and A2.5) is required for controlling the process water flow rate through the heat exchanger HX-1. A Badger Meter Inc. Model 9001GCW36SV3Axxx36 (air-to-close) or Model 9001GCW36SV1Axxx36 (air-to-open), 2-way globe, 25.4-mm (1-in.) valve is the specified valve (see X1.1.10). The type of trim package that may be used with this valve is optional and is designated with the fourteenth, fifteenth, and sixteenth position of the alphanumeric model number.

6.5.13 A 38.1-mm (1 ½-in.) NPT sight glass is required in the main coolant circuit (SG-1 in Figs. A2.1, A2.2, and A2.6). The make/model is optional.

6.5.14 Brass, copper, 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. A2.9 through A2.19, is required. The external oil system components are listed in Fig. A2.16. 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. The engine oil pan is considered a part of the external oil system. 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 should be minimized to enable more thorough flying flushes.

6.6.1 The flush system has a high capacity scavenge pump, which fills a 5.68 L (6 qt) dump reservoir while fresh oil is drawn into the engine oil gallery. 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 by-pass the cooling heat exchanger. The temperature is controlled within narrow limits with minimal additional heat (and surface temperatures), and the system can respond quickly to establish the three different oil gallery temperatures required in the procedure. Arrange the proportional three-way control valve to go to its mid-point 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 Cuprous materials are not allowed 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. A2.9) shall have the following features (The items shown in the clouded areas in Fig. A2.9 are not specifically required. However, a system that performs these functions is required.):

6.6.4.1 A scavenge pump (P-3 in Figs. A2.9 and A2.10). A Viking Series 475, gear type, close-coupled pump, Model H475M is specified (see X1.1.13). The pump shall have an 1140 to 1150 r/min electric motor drive with a minimum of 0.56 kW (0.75 hp). Voltage and phase are optional.

6.6.4.2 A reservoir with a minimum capacity of 19 L (5 gal). It is recommended that the system include three reservoirs (one for BC oil, one for BC flush oil (BCF), 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 107 ± 2.8 °C (224.6 ± 5 °F).

6.6.4.5 A dump reservoir (see Figs. A2.9, A2.10, A2.11, and A2.12) with a minimum 6 L (6.34 qt) capacity.

6.6.4.6 A dump reservoir float switch (FLS-136 in Figs. A2.9 through A2.12) is optional. A Gems Series ALS79999, catalog No. A79999, 20 VA, high temperature float switch is recommended (see X1.1.14).

6.6.4.7 Adhere to the nominal I.D. line sizes shown in Fig. A2.10.

6.6.4.8 The oil scavenge discharge system may use any plumbing materials.

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 specified level) of not more than 5.68 L (6 qt) (see 6.6.5.16).

6.6.5.2 An engine oil pan float switch (FLS-152 in Figs. A2.9, A2.13, and A2.19) is required. A Gems Series ALS79999, catalog No. A79999, 20 VA, high temperature float switch is specified (see X1.1.14).

6.6.5.3 A positive displacement oil circulation pump (P-4 in Fig. A2.9) is required. A Viking Series 4125, Model G4125, no relief valve, base mounted is specified (see X1.1.15). The pump shall have a V-belt or direct drive 1140 to 1150 r/min electric drive motor with a minimum of 0.56 kW (0.75 hp). Voltage and phase are optional.

NOTE 1—The explosion proof requirement for the motor is left to the discretion of the laboratory.

NOTE 2—Either V-belt drive or direct-coupled drive may be used. If V-belt drive is used, use a 1:1 pulley ratio so that the final speed of the pump is a nominal 1150 r/min.

6.6.5.4 Solenoid valves (FCV-150A, FCV-150C, FCV-150D, and FCV-150E, in Figs. A2.9 and A2.10) are required (see X1.1.16).

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

(*b*) FCV-150A is a Burkert Type 251 piston-operated valve with Type 312 solenoid valve (or a Burkert Type 2000 piston-operated valve used with a Type 311 or 330 solenoid valve) for actuation of air supply to piston valve, solenoid valve direct-coupled to piston valve, normally closed, explosion proof (left to the discretion of the laboratory), and watertight, 19.1 mm (¾ in.), 2-way, stainless steel.

(*c*) FCV-150C is a Burkert Type 251 piston-operated valve with Type 312 solenoid valve (or a Burkert Type 2000 piston-operated valve used with a Type 311 or 330 solenoid valve) for actuation of air supply to piston valve, solenoid valve direct-coupled to piston valve, normally open, explosion proof (left to the discretion of the laboratory) and watertight, 12.7 mm (½ in.), 2-way, stainless steel.

(*d*) FCV-150D, FCV-150E, and FCV-150F are Burkert Type 251 piston-operated valves used with Type 312 solenoid valve (or a Burkert Type 2000 piston-operated valve used with a Type 311 or 330 solenoid valve) for actuation of air supply to piston valve, solenoid valve, direct-coupled to piston valve, normally closed, explosion proof (left to the discretion of the laboratory) and watertight, 12.7 mm (½ in.), 2-way, stainless steel.

(*e*) Only one type of Burkert piston shall be used on a test stand.

6.6.5.5 Control valve (TCV-144 in Figs. A2.9 and A2.10) is required. The specified valve is a Badger Meter Inc. Model No. 1002TBN36SVOSALN36, 3-way globe (divert), 12.7 mm (½in.), air to open valve (X1.1.16).

6.6.5.6 Control valve (TCV-145 in Figs. A2.9 and A2.10) is optional (see X1.1.17).

6.6.5.7 A heat exchanger (HX-6 in Figs. A2.9 and A2.10) is required for oil cooling. The specified heat exchanger is an ITT Model 310-20 or a ITT Bell and Gossett, Model BP-25-20 (Part No. 5-686-04-020-001), brazed plate (see X1.1.18).

NOTE 3—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.

6.6.5.8 An electric heater (EH-5 in Figs. A2.9 and A2.10) is required for oil heating. The specified heater is a heating element inserted in the liquid Cerrobase inside a Labeco oil heater housing (see X1.1.19). Any 3000 W heater element may be used within the Labeco housing. There are two recommended heating elements: (*1*) a three element with Incaloy sheath, Chromolox Part No. GIC-MTT-330XX, 230 V, single phase, and (*2*) Wiegland Industries/Chromolox, Emerson Electric Model MTS-230A, Part No. 156-019136-014, 240 V single phase.

(a) (*a*) 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 (see Fig. A2.17) to an insertion depth of 244.48 ± 3.18 mm (9.625 ± 0.125 in.). The maximum temperature should not exceed 205°C (401°F).

(b) (*b*) The procedure for replacing a heating element is

detailed in Annex A3.

6.6.5.9 Install two oil filters (see FIL-2 in Figs. A2.9 and A2.10) in the external oil system. The filters specified are Oberg or Racor Model LFS-55 with an Oberg or Racor 28 µm stainless steel screen Part No. LFS 5528 (see X1.1.20).

(*a*) An alternative oil filter, Model LFS-62 with an Oberg or Racor 28-µm stainless steel screen, Part No. LFS 5528 (see X1.1.20), may be used.

(*b*) Both oil filters in the test stand shall have the same model number.

(*c*) Locate one filter anywhere in the external oil system after the oil circulation pump, and locate the other between the engine oil pump and where the oil enters the engine oil gallery.

(*d*) When replacing the test stand's oil filters to the alternative Model LFS-62, do so immediately prior to a calibration test.

6.6.5.10 Adhere to the nominal piping I.D. sizing shown in Fig. A2.9.

6.6.5.11 Use modified oil filter adapter assembly, Part No. OHT6A-007-1 (see X1.1.21) as shown in Fig. A2.18.

6.6.5.12 Engine oil plumbing shall be stainless steel tubing or piping or flexible hose suitable for use with oils at the temperatures specified. Where flexible hose is used in the external oil system, excluding the line to the dump tank, use either Aeroquip No. 8 (Part No. 2807-8) or Aeroquip No. 10 (Part No. 2807-10) (X1.1.22).

6.6.5.13 Insulation of plumbing for the external oil circulation system is mandatory, as shown in Fig. A2.6. Insulation material selection is optional but shall have a maximum thermal conductivity of 0.276 Btu • in./h • ft^2 • °F at a mean temperature of 90°F.

6.6.5.14 *Engine Oil Pan*— Oil pan (Ford Part No. F1AZ-6675-A or F2AZ-6675-A) is required. A modified oil pan may be fabricated by the laboratory or procured as Part No. OHT6A-006-1 (see X1.1.23). All stock baffles shall be removed from the pan. An oil pan baffle, as shown in Fig. A2.14, is required and shall be installed as shown in Fig. A2.13. The oil pan connections for connecting to the external oil system shall be as shown in Figs. A2.13 and A2.15. Install a viewing window on the right side of the oil pan, as shown in Fig. A2.13. An optional additional viewing window may be installed on the left side of the oil pan. Install a float switch (FLS-152 in Fig. A2.9, Gems Series ALS79999, catalog No. 79999) (see X1.1.14) in the oil pan. The float switch may be mounted from the pan bottom, as shown in Figs. A2.13 and A2.15, or from an adjustable rod through the dipstick hole (see A2.19).

(*a*) *Oil Pan Baffle*—Fig. A2.13 illustrates a side view of the oil pan and the position of the baffle on the left inside wall of the pan. The ears on each end of the baffle are bent about 45° toward the wall of the pan. The top edge of the baffle fits tight against the wall and is inclined downward toward the front of the engine approximately 23°, with respect to the pan rail. When the baffle is tack-welded in this position, the opening at the bottom of the baffle will divert the incoming stream of oil downward and a little toward the back of the pan.

6.6.5.15 *Oil Pump Screen and Pickup Tube*—Cut off the steel engine oil pick up tube immediately above the oil screen and weld a 15 to 18-cm (6 to 7-in.) long, straight, stainless steel tube of the same I.D. and outside diameter (O.D.) as the original tube to the end so the tube will project down thru the fitting in the bottom of the pan. The pick up tube can be modified by the laboratory or procured as Part No. OHT6A-008-1 (see X1.1.23). Make the fitting in the bottom of the pan from a Swagelok SS-1210-1-8, ¾-in. compression by ½-in. NPT fitting. Cut the NPT end off and weld remaining part to the underside outside bottom of the oil pan. There will then be an inside shoulder in the fitting to drill out for the ¾-in. O.D. tube to pass through (see Fig. A2.13).

(a) (*a*) Use the double nylon ferrules (Part No. T-1213-1 and T-1214-1) to seal against the steel tube rather than metal ones to avoid crimping the wall of the tube (which can make it difficult to reseal after removing the oil pan).

(b) (*b*) After the oil pan is installed on the engine and the use of a compression fitting is arranged to connect the tube to an external oil hose, the suction tube may be shortened, if necessary.

6.6.5.16 *Engine Oil Level Control*—Fit the engine oil pan with a window on the right side, as shown in Fig. A2.13, as a provision for monitoring the oil level while the engine is running and to allow observation of the *flying flush* oil changes.

(*a*) An oil sump *full* level is specified as 40 ± 10 mm (1.57 ± 0.4 in.) below the machined surface of the oil pan rail at the bottom of the block, measured along the vertical centerline of the window while the engine is running under flush and aging conditions (125°C oil gallery, 105°C coolant in, 1500 r/min, 15.4 kW). A suitable mark is required on the window at this full level. At other oil temperatures, the oil level will be significantly different.

6.7 *Fuel System*— A typical fuel delivery system incorporating all of the required features is shown in Fig. A2.20. 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 10 cm (3.9 in.) 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. The fuel return line from the engine shall have a minimum I.D. of 6.35 mm (0.25 in.).

6.7.2 *Fuel Flow Measurement*—Fuel flow rate measurement is critical and is measured throughout the test. A Micro Motion Model D-6 mass flow meter with an RFT9712 Smart Family or RFT9739 transmitter is specified (see X1.1.24). The Micro Motion sensor may be mounted in a vertical or a horizontal position.

6.7.2.1 Fuel flow measurement is coordinated to allow a meaningful calculation of brake specific fuel consumption in kg/kW-h (lb/hp-h). Specifically, speed, load, fuel flow, and air-fuel ratio (AFR) are time averaged over the same 100 to 120 s interval with reasonable provision exercised to minimize measurement lag factors. The use of frequency output from the fuel flow meter is recommended to avoid electrical noise affecting analog signal output.

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 1-4. Precise fuel pressure control without fluctuation or aeration is mandatory for test precision. The fuel pressure regulator PRG 116 shall have a safety pressure relief, or a pressure relief valve, PRV 113, parallel to PRG 116 for safety purposes.

6.7.4 *Fuel Temperature and Pressure Control to Engine Fuel Rail*—Maintain fuel temperature and pressure to the engine fuel at the values specified in Tables 1-4. 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 is at the laboratory's discretion as long as the requirements for fuel pressure and temperature are met. For providing fuel from the fuel flow meter to the engine fuel rail, use a car type fuel pump, Ford Part No. E7TF-9C407 or E7TC-9C407. The minimum fuel pressure is 205 kPa (30 psig) and the maximum is 310 kPa (45 psig).

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

6.8 *Engine Intake Air Supply*—Suitable apparatus is required to deliver approximately 4.0 m^3/min (140 ft^3/min) of air to the engine intake air filter. The intake air supply system shall be capable of controlling moisture content, dry bulb temperature, and inlet air pressure, as specified in Table 1 and Table 2, which is 11.4 ± 0.8 g/kg of dry air (79.8 ± 5.6 grains/lb of dry air), 27 ± 2°C (80.8 ± 3.6°F), and 0.05 ± 0.02 kPa (0.2 ± 0.1 in H_2O). The engine intake air system components are considered part of the laboratory intake air system and are specified and are shown in Fig. A2.21 and in the 1993 Ford Service manual[13], page 03-12-2.

TABLE 4 Sequence VIA New Engine Cyclic Break-in

	Cycle	
	A	B
Time at each step, min.	4	1
Time to decelerate to Step A, s		15
Time to accelerate to Step B, s	4 to 5	
Speed, r/min	1500 ± 50	3500 ± 50
Power, kW (hp)	7.5 (10.1)	20.9 (28)
Load, N-m (lbf-ft)	48.00 (35.4) ± 5.00 (± 3.69)	57.00 (42.04) ±5.00 (± 3.69)
Oil gallery, °C (°F)	105 (221) ± 2 (± 3)	105 (221) ±2 (± 3)
Coolant, in, °C (°F)	95 (203) ± 2 (± 3)	95 (203) ±2 (± 3)
Coolant flow, L/min (g/min)	130 (34.3) ± 4 (± 2)	130 (34.3) ±4 (± 2)
Intake air temperature and humidity	control not required	
Ignition timing, ° BTDC	record	not specified
Exhaust back pressure, kPa (in. Hg, abs.)	104.0 (30.80) ± 0.34 (± 0.1)	not specified
AFR	record	not specified
Fuel pressure to fuel rail, kPa (psi)	205 to 310 (30 to 45)	205 to 310 (30 to 45)
Fuel temperature to fuel rail, °C (°F)	20 (68) ± 2 (± 3.6)	20 (68) ±2 (± 3.6)
Fuel flow, kg/h (kb/h)	record	not specified
BSFC, kg/kW•h (kb/hp•h)	record	not specified

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

$$\text{Humidity (corrected), grains/lb} = 4354 \times (\text{Psat}/(\text{Pbar} - \text{Psat})) \quad (1)$$

where:
Psat = saturation pressure (in. Hg), and
Pbar = barometric pressure (in. Hg).

SI Units:

$$\text{Humidity (corrected), g/Kg} = 621.98 \times (\text{Psat}/(\text{Pbar} - \text{Psat})) \quad (2)$$

where:
Psat = saturation pressure (mm Hg), and
Pbar = barometric pressure (mm Hg).

6.8.2 *Intake Air Filtration*—The air supply system should 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. Follow the guidelines outlined by RR:D02:1218.[14]

6.9.1 All temperature devices should be checked 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 either Type J or Type K (Chromel-Alumel) 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 of 3.2-mm (⅛-in.) diameter. Thermocouple lengths are not specified, but in all cases should be long enough to allow thermocouple tip insertion to be in mid-stream of the medium being measured. The thermocouples shall not have greater than 5 cm (2 in.) of thermocouple sheath exposed to laboratory ambient.

6.9.3 Some recommended sources of thermocouples are Leeds and Northrup, Conax, Omega, Revere, and Thermo Sensor. In any case, thermocouples, wires, and extension wires should be matched to perform in accordance with the special limits of error as defined by ANSI MC96.1-1975.

6.9.4 System quality shall be adequate to permit calibration to ± 0.56 °C (1 °F) for individual thermocouples.

6.9.5 *Thermocouple Location*—All thermocouple tips should be located 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

[13] Available from HELM, Inc., 14310 Hamilton Ave., Highland Park, MI 48203.

[14] ASTM Instrumentation Task Force Research Report. Available from ASTM. Request RR:D02-1218.

the stream of flow, as shown in Fig. A2.18, (that is, remove the O-ring from the adapter, place the adapter face on a flat surface, and insert the thermocouple into the adapter until the thermocouple tip is flush with the flat surface, and lock thermocouple into place).

6.9.5.2 *Oil Circulation*— Locate the oil circulation thermocouple in the tee in the rear 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 15 cm (5.9 in.) of the housing inlet.

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 (3.15 in.) of the housing outlet.

6.9.5.5 *Intake Air*—Locate the thermocouple in the Ford air cleaner assembly on the clean side of the filter as shown in Fig. A2.21.

6.9.5.6 *Fuel to Fuel Flow Meter*—Locate the thermocouple within 10 to 50-cm (3.9 to 19.7-in.) line length upstream of the fuel flow meter inlet.

6.9.5.7 *Fuel to Engine Fuel Rail*—Insert the thermocouple into the center of a tee or cross fitting and locate it a minimum of 15 cm (5.9 in.) downstream of the fuel pump and within 15-cm (5.9-in.) line length of the fuel rail inlet.

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

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

6.10.1 The air fuel ratio analyzer shall meet the following specifications:

Measurement Range	AFR: 10.00 to 30.00 with H/C = 1.85, O/C = 0.00
Accuracy	± 0.1 AFR when 14.7 AFR with H/C = 1.85, O/C = 0.000

Temperature (exhaust gas used by sensor) 700 to 900 °C

A Horiba Model MEXA 110 analyzer is recommended (see X1.1.25).

6.10.2 The specified location of the analyzer sensing element is in the exhaust system, as shown in Fig. A2.22.

6.11 *Exhaust and Exhaust Back Pressure Systems*:

6.11.1 *Exhaust Manifolds*—Use production cast iron exhaust manifolds, Ford Part No. F1AZ-9430 or F1AE-9430 (casting No. RF F1AE-9430-BB) for right hand and Part No. F1AZ-9431 or F1AE-9431 (casting No. RF F1AE-9431-BB) for left hand.

6.11.2 *Laboratory Exhaust System*—The exhaust system specified is shown in Fig. A2.22. Components can be radially oriented to ease installation, but install all components in the order shown. The design of the system downstream from the location shown in Fig. A2.22 is at the discretion of the laboratory.

6.11.3 *Exhaust Back Pressure*—The exhaust system shall have the capability for controlling exhaust back pressure to the pressures specified in Tables 1-4. The specified exhaust back pressure probe is shown in Fig. A2.23, and the specified exhaust back pressure probe location in the exhaust system is shown in Fig. A2.22.

6.11.4 *AFR Analyzer Probe*—The specified AFR analyzer probe (see 6.10) location is shown in Fig. A2.22.

6.12 *Pressure Measurement and Pressure Sensor Locations*—Pressure measurement systems for this test method are specified in general terms of overall accuracy and resolution with explicit pressure tap locations specified. Gages or other pressure devices (such as electronic transducers) may be used but shall follow the guidelines outlined by RR:D02:1218.[14]

6.12.1 Connecting tubing between the pressure tap locations and the final pressure sensors should incorporate condensation traps as directed by good engineering judgment. This precaution is particularly important when low air pressures (as in this test method) are transmitted by way of lines that pass through low-lying trenches between the test stand and the instrument console. Pressure sensors should be mounted at the same elevation as the pressure taps.

6.12.2 *Engine Oil*—Locate the pressure tap for the engine oil pressure at the oil filter adapter. Accuracy of 1 % with 6.9 kPa (1 psi) resolution is required.

6.12.3 *Fuel to Fuel Flow Meter*—Locate the pressure tap within 5 m from the fuel inlet of the fuel flow meter. Accuracy of 3.5 kPa (0.5 psi) is required.

6.12.4 *Fuel to Engine Fuel Rail*—Locate the pressure tap a minimum of 15 cm (5.9 in.) from the outlet of the car type fuel pump and within 15-cm (5.9-in.) line length of the inlet to the fuel rail. Accuracy of 3.5 kPa (0.5 psi) is required.

6.12.5 *Exhaust Back Pressure*—Locate the exhaust back pressure probe, as shown in Fig. A2.23. The sensor shall be accurate to within 2 % with resolution of 25 Pa (0.1 in. H_2O).

6.12.6 *Intake Air*—Measure the intake air pressure at the location shown in Fig. A2.21. Sensor/readout accuracy required is 2 % with resolution of 5.0 Pa (0.02 in. H_2O).

6.12.7 *Intake Manifold Vacuum/Absolute Pressure*—Measure the intake manifold vacuum/absolute pressure at the throttle body adapter. A sensor having accuracy within 1 % and with 0.68 kPa (0.1 in. Hg) resolution is required.

6.12.8 *Coolant Flow Differential Pressure*—See 6.5.9.

6.13 *Engine Hardware and Related Apparatus*—This section describes engine related apparatus requiring special purchase, assembly, fabrication, or modification. Part numbers not otherwise identified are Ford service part numbers.

6.13.1 *Test Engine Configuration*—The test engine is a 1993 4.6-L Ford V-8 engine equipped with fuel injection. Purchase the engine as a test ready unit (for procurement see X1.1.3). The engine may not be disassembled and shall be used in an as received condition. Only external engine dress items are to be installed by the laboratory.

6.13.2 *ECM/EEC (Engine Control) Module*—Use a special modified ECM/EEC IV, Part No. OHT6A-002-1 engine control module, Ford part name SMO-100 (see X1.1.26). This module controls ignition and fuel supply functions. Equip this unit with a special EPROM No. GSALB-OH, Part No. OHT6A-005-1 (see X1.1.27).

6.13.3 *Thermostat/Orifice Plate*—Use an orifice plate, as shown in Fig. A2.24, in place of the thermostat. The orifice plate can be fabricated by the laboratory or procured as Part No. OHT6A-004-1 (see X1.1.28).

6.13.4 *Intake Manifold*— Modify the intake manifold, part No. F1AZ-9424-C, F1AE-9424 or F1AE-9425. Plug the intake manifold coolant by-pass passage (port under the orifice plate).

6.13.5 *Flywheel*—A special manual flywheel, Part No. F622-6375-AB is required (see X1.1.29). Modify the flywheel in accordance with laboratory practice to allow for connection to the test stand driveshaft.

6.13.6 *Wiring Harnesses*— Two wiring harnesses are used. One is a fuel injector sub-harness Part No. F3VB-12522, F3VB-12A522, F3AB-12A522, or F3BL-12A522, which is available from Ford dealers and is similar to that shown in the 1993 Ford Service manual, Fig. K16182-A, page 18-01-22. Disconnect items 11, 14, 21, and 23 shown in Fig. K16182-A. The other wiring harness is an engine wiring harness, Part No. OHT6A-001-1 (see X1.1.30) and is used to connect the car-type harness to the ECM/EEC.

NOTE 4—A full size version of the engine wiring schematic may be obtained from ASTM-TMC. It is not possible to include a reduced size figure in this standard because of the complexity of the details.

6.13.7 *EGR Block-Off Plate*—Remove the EGR valve and replace with a block-off plate, which is to be fabricated by the laboratory. Cut off the EGR tube near the exhaust manifold, crimp, and weld shut or plug.

6.13.8 *Oil Pan*—Use oil pan, Part No. F1AZ-6675-A or F2AZ-6675-A. Modify the oil pan as detailed in 6.6.5.14 and Figs. A2.13 through A2.15.

6.13.9 *Oil Pump Screen and Pickup Tube*—Use oil pump screen and pickup tube, Part No. F2AZ-6622. Remove the oil pump screen and modify the pickup tube as detailed in 6.6.5.15.

6.13.10 *Idle Speed Control Solenoid (ISC) Block-Off Plate*—Remove the idle speed control solenoid (idle air bypass valve) and replace with a block-off plate, which is to be fabricated by the laboratory.

6.13.11 *Engine Water Pump*—Modify or replace as detailed in 6.5.10.

6.13.12 *Thermostat Housing*—Use thermostat housing, Part No. F1VY-8592-A or F1AE-8594. Modify for engine coolant out thermocouple installation (see 6.9.5.4) or procure as Part No. OHT6A-010-1 (see X1.1.31).

6.13.13 *Oil Filter Adapter*—Use oil filter adapter, Part No. F1AZ-6881, F1AE-6881, or F1AE-6884. Modify for engine coolant in thermocouple installation (see 6.9.5.3) or procure as Part No. OHT6A-009-1 (see X1.1.32).

6.13.14 *Fuel Rail*—Use fuel rail, Part No. F2AZ-9F792-A or F2AE-9F792. Modify the fuel rail inlet and outlet connections for connection to the laboratory fuel supply system or use a fuel rail adapter set, which may be procurred as Part No. OHT6A-011-1 (see X1.1.33).

6.14 *Miscellaneous Apparatus Related to Engine Operation*:

6.14.1 *Timing Light*— Use an inductive pickup type timing light during the test. (**Warning**—Some types of timing lights will read out double the actual ignition timing when used on this engine.)

7. Reagents and Materials

7.1 *Engine Oil*:

7.1.1 *ASTM Baseline Calibration Oil (BC)*, (see X1.1.2) is used for new engine break-in and as a primary reference oil for evaluation of test oils. It is an SAE 5W-30 grade. Approximately 38 L (10 gal) of BC oil are required for each test.

7.1.2 *ASTM BCF*,, (see X1.1.2) is a special flushing oil (BC oil with increased solubility) that is used when changing oil after a test oil has been in the engine. Approximately 6 L (6.3 qt) of flush oil are required for each test.

7.2 *Test Fuel*—The test fuel required is the U.S. Federal Emission Data fuel, blended to the somewhat tighter specification used by the U.S. test fuel supplier industry. Potential fuel suppliers are Amoco Oil Co.[15], Howell Hydrocarbons and Chemicals, Inc.[16], Phillips Chemical Co.[17], and Sun Refining and Marketing Co.[18] Test repeatability may be improved if one of the above fuels is used, but in any event the fuel used shall meet the specifications of Table 5. (**Warning**—Danger! Extremely flammable. Vapors harmful if inhaled. Vapors may cause flash fire (see A6.2.1).)

7.2.1 *Laboratory Fuel Sampling and Analysis*—Monitor the test fuel in a manner consistent with good laboratory practices. It is suggested that periodic samples be analyzed to ensure that the fuel has neither excessively deteriorated nor been contaminated in storage. The following inspections are recommended:

7.2.1.1 RVP, Test Method D 323 or Automatic Reid Vapor Pressure Analyzer,

7.2.1.2 API Gravity, Test Method D 287,

7.2.1.3 Existent Gum, Test Method D 381,

7.2.1.4 Oxidation Stability, Test Method D 525,

7.2.1.5 Distillation, Test Method D 86,

7.2.1.6 Sulfur, Test Method D 4294, and

7.2.1.7 Lead Content, Test Method D 3237.

7.2.2 *Fuel Batch Usage*— Run complete test sequences on a single batch of test fuel. If a new batch of test fuel is introduced to the laboratory fuel supply system, it shall be done between finite tests.

7.3 *Engine Coolant*— The engine coolant shall be 50/50 volume % commercial additized ethylene glycol coolant/water. Water should be deionized, demineralized, or distilled.

7.4 *Cleaning Materials*:

7.4.1 *Organic Solvent*— Penmul L460 (see X1.1.34). (**Warning**—Harmful vapor. Store at moderate temperature (see A6.2.2).)

7.4.2 *Oakite 811* (see X1.1.35) (**Warning**—Harmful vapor. Store at moderate temperature (see A6.2.3).)

7.4.3 *Aliphatic Naphtha* (see X1.1.36). (**Warning**—Combustible. Harmful vapor (see A6.2.4).)

7.4.4 *Engine Cooling System Cleanser* (**Warning**—Toxic Substance. Avoid contact with eyes, skin, and clothing (see A6.2.5).) Consists of the following (see X1.1.37):

[15] Available from Amoco Oil Co., P.O. Box 3011, Naperville, IL 60566-7011.

[16] Available from Howell Hydrocarbons and Chemicals, Inc., 1201 South Sheldon Rd., P.O. Box 429, Channelview, TX 77530-0426.

[17] Available from Phillips Chemical Co., Specialty Chemicals, P.O. Box 968, Borger, TX 79008.

[18] Available from Sun Refining and Marketing Co., P.O. Box 11325, Marcus Hook, PA 19061.

TABLE 5 Sequence VIA Fuel Specification

Fuel Parameter	Test Method	Analytical Results	
		SI Units	Inch-pound Units
Octane, research min	D 2699	96	
Pb (organic), mg/L, max	D 3237	13.2	(0.05 g/U.S. gal)
Sensitivity, min		7.5	
Distillation range			
IBP, °C	D 86	23.9 to 35	(75 to 95 °F)
10 % point, °C	D 86	48.9 to 57.2	(120 to 135 °F)
50 % point, °C	D 86	93.3 to 110	(200 to 230 °F)
90 % point, °C	D 86	148.9 to 162.8	(300 to 325 °F)
E.P., °C (max)	D 86	212.8	(415 °F)
Sulfur, weight %, max	D 4294	0.10	
Phosphorous, mg/L, max	D 3231	1.32	(0.005g/U.S. gal)
RVP, kPa	D 323	60.0 to 63.4	(8.7 to 9.2 psig)
Hydrocarbon composition			
Olefins, %, max	D 1319	10	
Aromatics, %, max	D 1319	35	
Saturates	D 1319	remainder	
Existent gum, mg/100mL, max	D 381	5.0	
Oxidation stability, min, min	D 525	500	
Carbon weight fraction	E 191 (Specification)	report	
Hydrogen/carbon ratio, mol basis	E 191 (Specification)	report	
Net heating value, Btu/lb	D 240	report	
Net heating value, Btu/lb	D 3338	report	
API gravity	D 287	report	

7.4.4.1 *Oxalic Acid Dihydrate Tech*. (**Warning**—Toxic substance. Avoid contact with eyes, skin, and clothing (see A5.2.6).)

7.4.4.2 *Alkylated Naphthalene, Sodium Salt*—Petro dispersant 425 (soap).

7.4.4.3 *Soda Ash Light*— (Neutralization).

7.5 *Sealing Compounds*—No specific sealing compounds are required (see 9.3.3).

8. Preparation of Apparatus

8.1 This section assumes that the engine test stand facilities and hardware, as described in Section 6, are in place. Emphasis is on the recurring preparations needed in the routine conduct of the test.

8.2 *Test Stand Preparation*:

8.2.1 *Instrumentation Preparation*—Perform the calibration of the temperature measuring system, the dynamometer load measuring system, the fuel flow measuring system, and the pressure measuring system (see 10.3 for additional details concerning instrumentation calibration) in a manner consistent with good laboratory practices and record it for future reference.

8.2.2 *External Oil System Cleaning*—Clean the entire external oil system using the engine cleaning solvent (see 7.4.1) each time a newly built engine is installed.

8.2.3 *Exhaust Back Pressure Probe Renewal*—The exhaust back pressure probe can be used until it becomes cracked, brittle, or deformed. Clean the outer surface of the probe and clear all port holes. Check the probe for possible internal obstruction and reinstall the probe in the exhaust pipe. Stainless steel probes are generally serviceable or several tests; mild steel probes tend to become brittle after fewer tests.

8.2.4 *AFR Sensor Renewal*—Inspect AFR sensor (see 10.3 for AFR system calibration requirements).

8.2.5 *Hose Replacement*— Inspect all hoses and replace any that are deteriorated. Check for internal wall separations that would cause flow restriction.

9. Engine Preparation

9.1 Purchase the engine as a test ready unit (for procurement see X1.1.3). The engine may not be disassembled and shall be used in an as received condition. The only exceptions are external engine dress items to be installed by the laboratory and the valve stem seals can be replaced when necessary. Utilize Ford service parts for a 1993 model year engine (non-AODE transmission) or Sequence VIA parts.

9.2 *Cleaning of Engine Parts*:

9.2.1 *Cleaning*—Soak any parts to be cleaned in degreasing solvent until clean (see X1.1.36).

9.2.2 *Rinsing*—Wash the parts thoroughly with hot water.

9.3 *Engine Assembly Procedure*:

9.3.1 *General Assembly Instructions*—Assemble the external engine dress components in accordance with the detailed description in the 1993 Ford Service Manual. However, in cases of disparity, the explicit instructions contained in this test method take precedence over the service manual.

9.3.1.1 Do not use sealers in tape form (loose shreds of tape can circulate in the engine oil and plug critical orifices).

9.3.2 *Bolt Torque Specifications*—When installing the engine components, use a reliable torque wrench to obtain the values listed in Table 6. These specifications are for clean and lightly lubricated threads only. Dirty or dry threads produce friction, which prevents accurate measurements of the actual torque. It is important that these specifications be observed. Overtightening can damage threads, which may prevent attainment of the proper torque and may require replacement of the damaged part.

9.3.3 *Sealing Compounds*—Sealing compounds are not specified. Use engineering judgment governing the use of sealing compounds. (**Warning**—Silicone-based sealers may elevate the indicated Si content of used oil.)

9.3.4 New parts required for each new engine (see X1.1.3) are listed in Annex A4.

9.3.5 *Harmonic Balancer*—The balancer, Part No. F1AZ-6316-A, is included on the engine by the engine supplier.

9.3.6 *Oil Pan*—Install oil pan, Part No. F1AZ-6675-A or F2AZ-6675-A, and modify as detailed in 6.5.5.14 and as shown in Figs. A2.13, A2.14, and A2.15. Use gasket, Part No. F1AZ-6710-A. Torque the bolts in the sequence shown in 1993 Ford Service Manual, Fig. A14940-A, page 03-01-19.

9.3.7 *Intake Manifold*— Install intake manifold, Part No. F1AZ-9424-C, F1AE-9424, or F1AE-9425. Use gaskets, Part No. F1AZ-9461-A. Torque the bolts in the sequence shown in 1993 Ford Service Manual, Fig. A14812-A, page 03-01-09.

TABLE 6 Fastener Torque Specifications

Description	N-m	lbf-ft
Air bypass valve to intake manifold adapter	8-11	71-97 lbf-in
Air supply tube clamps	1.7-2.6	15-23
Cable bracket retaining bolt	8-12	70-106 lbf-in
Camshaft covers	8-12	70-106 lbf-in
Crankshaft damper to crankshaft	155-165	114-121
Crankshaft position sensor (CKP) and CID sensor retaining bolts	8-12	70-106 lbf-in
Engine coolant temperature sensor (ECT)	16-24	12-17
EGR valve to intake manifold (block-off plate)	20-30	15-22
EGR valve line nut to exhaust manifold connector	35-45	26-33
EGR tube connector	45-65	33-48
Exhaust manifold nuts	27-41	20-30
Exhaust manifold to cylinder head	20-30	15-22
Engine-to-transmission brackets	25-43	18-31
Flywheel to crankshaft	73-87	54-64
Front engine support insulators	20-30	15-22
Front engine support insulator through bolts	20-30	15-22
Fuel pressure regulator to fuel rail assembly	3.0-4.5	27-40 lbf-in
Fuel rail assembly retaining bolts	8-12	70-106 lbf-in
Heater water hose	20-30	15-22
Heater water hose retaining bolts	20-30	15-22
Heated oxygen sensor (HEGO)	37-45	27-33
Idle air control valve (IAC) bolts	8-12	70-106 lbf-in
Ignition wire tray-to-coil brackets	8-12	70-106 lbf-in
Intake manifold to cylinder head	20-30	15-22
Oil bypass filter to adapter	¾ turn past seal contact	
Oil filter adapter bolt	20-30	15-22
Oil level indicator tube to block	8-12	70-106 lbf-in
Oil pan drain plug	11-16	8-12
Oil pan to cylinder block	20-30	15-22
Oil pressure sender/sensor	16-24	12-18
Rear engine support insulator to support	20-30	15-22
Rear engine support insulator to transmission retaining bolts	40-60	30-44
Spark plug to cylinder head	9-12	80-106 lbf-in
Thermostat to intake manifold	20-30	15-22
Throttle body and adapter bolts	8-12	70-106 lbf-in
Throttle position sensor to throttle body	1.2-1.8	11-16 lbf-in
Water pump to cylinder block (or block-off plate)	20-30	15-22
Water temperature indicator sending unit	16-24	12-17

Modify the intake manifold as detailed in 6.13.4.

9.3.8 *Camshaft Covers*— Camshaft covers are right hand, Part No. F1AZ-6582-A; left hand, Part No. F1AZ-6582-B. Use gaskets, right hand, Part No. F1AZ-6584-A: left hand, Part No. F1AZ-6584-B. These are included on the engine by the engine supplier.

9.3.9 *Thermostat*—Remove the thermostat and replace with a thermostat orifice plate, as shown in Fig. A2.24 (see X1.1.28 and see 6.13.3).

9.3.10 *Thermostat Housing*—Install a modified thermostat housing (see 6.13.12), Part No. F1VY-8592-A, F1AE-8594, or OHT 6A-01010-1. Use gasket, Part No. F1VY-8255-A.

9.3.11 *Coolant Inlet*— Modify the coolant inlet connection, which is cast as a part of the oil filter adapter (see 9.3.12 and 6.13.13). This is included on the engine by the engine supplier.

9.3.12 *Oil Filter Adapter*—The oil filter adapter is Part No. F1AZ-6881, F1AE-6881, or F1AE-6884 and is included on the engine by the engine supplier. Modify the adapter (see 6.13.13) or use Part No. OHT 6A-009-1. Use gasket, Part No. F1AZ-6840-A.

9.3.13 *Dipstick Tube*— Dipstick tube, Part No. F1AZ-6754-A is included on the engine by the engine supplier.

9.3.14 *Water Pump*—Install a modified water pump or a water pump plate (see 6.5.10; Fig. A2.7).

9.3.15 *Sensors, Switches, Valves, and Positioners*:

9.3.15.1 *Oil Pressure Switch and Oil Pressure Sensor*—Install oil pressure switch, Part No. E9SZ-9278-A and oil pressure sensor, Part No. 90290 or plugs.

9.3.15.2 *Camshaft Positioner Sensor (CMP)*—Camshaft position sensor, Part No. F1AZ-6B288-A, is included on the engine by the engine supplier.

9.3.15.3 *Crankshaft Position Sensor (CKP)*—Crankshaft position sensor, Part No. F1AZ-6C315-A, is included on the engine by the engine supplier.

9.3.15.4 *Water Temperature Indicator Sender Unit*—Install water temperature indicator sender unit, Part No. F1SZ-10884-A or F1SF-10884.

9.3.15.5 *Idle Speed Control Solenoid (ISC)*—Idle air control valve (idle air bypass valve) is not used; replace with a block-off plate (see 6.13.10).

9.3.15.6 *EGR Valve*—The EGR valve is not used. Replace with a block-off plate (see 6.13.7).

9.3.15.7 *EGR Valve Positioner (EVP) Sensor*—EGR valve position sensor is not used.

9.3.15.8 *EGR Vacuum Regulator (EVR) Sensor*—EGR vacuum regulator sensor is not used. Plug the vacuum lines that would normally be connected to this sensor.

9.3.15.9 *Throttle Position (TP) Sensor*—Install TP sensor, Part No. F2AZ-9B989-A or FZAF-9B989.

9.3.15.10 *Engine Coolant Temperature (ECT) Sensor*—Install ECT sensor, Part No. F2AZ-12A648-A or F2AF-12A648.

9.3.15.11 *Heated Exhaust Gas Oxygen (HEGO) Sensors*—Use HEGO sensors, Part No. F0TZ-9F472. Make sure that the HEGO sensors are correctly connected. The left side (Cylinders 5 to 8) sensor harness has a red with black stripe wire coming from the bottom right pin of the connector when looking at the plug from the front. The right side sensor (Cylinders 1 to 4) has a gray with light blue striped wire in this position.

9.3.15.12 *PCV*—Remove the PCV valve and vent all PCV points of connection to atmosphere. Plug all associated vacuum lines.

9.3.15.13 *Air Charge Temperature (ACT) Sensor*—Use ACT sensor, Part No. F2DZ-12A697.

9.3.15.14 *Mass Air Flow Sensor*—Use mass air flow sensor, Part No. F0TZ-12B579 or F2VF-12B579 (70-mm diameter).

9.3.16 *Ignition System*:

9.3.16.1 *Ignition Coils*— Install right hand and left hand