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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 VIB Spark Ignition Engine[1, 2]

This standard is issued under the fixed designation D6837; 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

The test method described in this standard can be used by any properly equipped laboratory, without outside assistance. However, the ASTM Test Monitoring Center (TMC)[3] 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 American Petroleum Institute (API) imposes such a requirement, in connection with several U.S. Army engine lubricating oil specifications.

Accordingly, this test method is written for use by laboratories, which 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 TMC, Attention: Administrator, 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.~~trucks with gross vehicle weight of 3856 kg or less. The tests are conducted on a dynamometer test stand using a specified ~~4.6-L~~ spark-ignition engine ~~on~~with a ~~dynamometer test stand.~~displacement of 4.6-L. It applies to multiviscosity grade oils used in these applications.

1.2 This test method also provides for the running of an abbreviated length test that is referred to as the VIBSJ. The procedure for VIBSJ is identical to the Sequence VIB with the exception of the items specifically listed in Annex A13. The procedure modifications listed in Annex A13 refer to the corresponding section of the Sequence VIB test method.

~~1.3The unit values stated in this test method shall be regarded as the standard. Values given in parentheses are provided for information purposes only. SI units are considered the primary units for this test method. The only exception is where there is no direct SI equivalent such as screw threads, national pipe threads/diameters, tubing size, and so forth.~~

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

1.3.1 *Exceptions*—Where there is no direct SI equivalent such as screw threads, National Pipe Threads/diameters, tubing size, or single source supply equipment specifications. Brake Specific Fuel Consumption is measured in kilograms per kilowatthour. In Figs. A2.4, A2.5, and A2.8, inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility*

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.01 on Passenger Car Engine Oils.

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[2] 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 VIB was published as Research Report D02-1469 dated April 8, 1999.

[3] ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489. For other information, refer to Research Report D02-1469, Sequence VIB Test Development. This research report and this test method are supplemented by Information Letters and Memoranda issued by the ASTM TMC. This edition incorporates revisions in all Information Letters through No. 07–1.

of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.5 This test method is arranged as follows:

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D86 Test Method for Distillation of Petroleum Products 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
D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
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
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4485 Specification for Performance of Engine Oils
D5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions
D5533 Test Method for Evaluation of Automotive Engine Oils in the Sequence IIIE, Spark-Ignition Engine
D5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)
D5862 Test Method for Evaluation of Engine Oils in Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine
D6202 Test Method for Automotive Engine Oils on the Fuel Economy of Passenger Cars and Light-Duty Trucks in the Sequence VIA Spark Ignition Engine
D6557 Test Method for Evaluation of Rust Preventive Characteristics of Automotive Engine Oils
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~~
IEEE/ASTM SI-10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *SAE Standards:*[5]

J304 Engine Oil Tests
J1423 Classification of Energy-Conserving Engine Oil for Passenger Cars and Light-Duty Trucks

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

2.3 *API Publication:*[6]
API 1509 Engine Oil Licensing and Certification System
2.4 *ANSI Standard:*[7]
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. **D5302**

3.1.2 *automotive*, *adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines. **D4485**

3.1.3 *blowby*, *n—in internal combustion engines*, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D5302**

3.1.4 *BTDC*, *adj*—abbreviation for Before Top Dead Center, used with the degree symbol to indicate the angular position of the crankshaft relative to its position at the point of uppermost travel of the piston in the cylinder. **D5533**

3.1.5 *calibrate*, *v*—to determine the indication or output of a measuring device or a given engine with respect to a standard. **D5862**

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. **D6202**

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. **D5862**

3.1.8 *lubricant*, *n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D5862**

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

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

3.1.10.1 *Discussion*—The preferred term is purchaser. Deprecated terms that have been used are client, requester, sponsor, and customer. **D6202**

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

3.1.12 *test oil*, *n*—any oil subjected to evaluation in an established procedure. **D6557**

3.1.13 *test start*, *n*—introduction of test oil into the engine. **D5533**

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*—the 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*, *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.

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

3.2.4.1 *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 VIB 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.

3.2.5 *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.

3.2.6 *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.

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

3.2.7.1 *Discussion*—Determined by comparing the rate of fuel consumption of a test oil with that displayed by a base line reference oil.

3.2.8 *non-standard test*, *n*—a test conducted with operating conditions (that is, engine speeds, ~~loads,~~torques, temperatures, and

[6] Available from The American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005.
[7] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

so forth) outside the normal test operating conditions or with a fuel other than the specified test fuel or with non-specified hardware configuration.

3.2.9 *special parts distributor (SPD)*, *n*—the manufacturer or supplier, or both, of specified parts and fixtures used in this test method.

3.2.10 *special test parts (STP)*, *n*—parts that do not meet all the definitions of critical parts or non-production parts, but shall be obtained from the SPD.

4. Summary of Test Method

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

4.2 The test method consists of measuring the laboratory engine brake specific fuel consumption at five constant ~~speed/load/temperature~~speed/torque/temperature conditions for the baseline calibration oil, test oil, and a repeat of the baseline calibration oil. The approximate test length is 133 h.

4.3 Aged test oil is compared directly to fresh ASTM BC SAE 5W-30 (see X1.2) baseline calibration oil, which is run before and after the test oil. When changing from test oil to baseline calibration oil, an intermediate flush with a special flushing oil (BC Flush Oil or BCFHD) 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 (see Table 6) 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 baseline calibration oil (hereafter referred to as BC oil) has been established for this test to provide a standard against which all other oils can be compared. The BC oil is an SAE 5W-30 grade fully formulated lubricant. There is a direct correlation of Test Method D6837 (Sequence VIB) Fuel Economy Improvement (FEI) by percent with the fuel economy results obtained from vehicles representative of current production running under the current EPA testing cycles. 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. 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 VIB 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:

TABLE 1 Sequence VIB Fuel Specification

	Test Method	
Octane, research min	D2699	96
~~Pb (organic), mg/L max~~	~~D3237~~	~~13.2 (0.05 g/U.S.gal)~~
Pb (organic), mg/L max	D3237	13.2
Sensitivity, min		7.5
Distillation range		
~~IBP, °C~~	~~D86~~	~~23.9 to 35 (75 to 95°F)~~
IBP, °C	D86	23.9 to 35
~~10 % point, °C~~	~~D86~~	~~48.9 to 57.2 (120 to 135°F)~~
10 % point, °C	D86	48.9 to 57.2
~~50 % point, °C~~	~~D86~~	~~93.3 to 110 (200 to 230°F)~~
50 % point, °C	D86	93.3 to 110
~~90 % point, °C~~	~~D86~~	~~148.9 to 162.8 (300 to 325 °F)~~
90 % point, °C	D86	148.9 to 162.8
~~E.P., °C (max)~~	~~D86~~	~~212.8 (415°F)~~
E.P., °C (max)	D86	212.8
Sulfur, weight %, max	D4294	0.10
~~Phosphorous, mg/L, max~~	~~D3231~~	~~1.32 (0.005 g/U.S.gal)~~
Phosphorous, mg/L, max	D3231	1.32
~~RVP, kPa~~	~~D323~~	~~60.0 to 63.4 (8.7 to 9.2 psig)~~
RVP, kPa	D323	60.0 to 63.4
Hydrocarbon composition		
Olefins, % max	D1319	10
Aromatics, % max	D1319	35
Saturates	D1319	Remainder
Existent gum, mg/100mL, max	D381	5.0
Oxidation stability, min	D525	500
Carbon weight fraction	E191	Report
Hydrogen/Carbon ratio, mol basis	E191	Report
~~Net heating value, Btu/lb~~	~~D240~~	~~Report~~
Net heating value, J/kg	D240	Report
~~Net heating value, Btu/lb~~	~~D3338~~	~~Report~~
Net heating value, J/kg	D3338	Report
API gravity	D287	Report

TABLE 2 Sequence VIB 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	3500
~~Power, kW (hp)~~	~~7.5 (10.1)~~	~~20.9 (28)~~
Power, kW	7.5	20.9
~~Load, N·m (lbf·ft)~~	~~48.00 (35.4)~~	~~57.00 (42.04)~~
Torque, N·m	48.00	57.00
~~Oil Gallery, °C (°F)~~	~~105 (221)~~	~~105 (221)~~
Oil Gallery, °C	105	105
~~Coolant In, °C (°F)~~	~~95 (203)~~	~~95 (203)~~
Coolant In, °C	95	95
~~Coolant Flow, L/min (gal/min)~~	~~130 (34.3)~~	~~130 (34.3)~~
Coolant Flow, L/min	130	130
Intake Air Temperature and Humidity	Control Not Required	
Ignition Timing, °BTDC	Record	Not Specified
~~Exh. Back Press., kPa (in. Hg, abs)~~	~~104.0 (30.80)~~	~~Not Specified~~
Exh. Back Press., kPa	104.0	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 Pressure to Fuel Rail, kPa	205 to 310	205 to 310
~~Fuel Temperature to Fuel Rail, °C (°F)~~	~~20 (68)~~	~~20 (68)~~
Fuel Temperature to Fuel Rail, °C	20	20
~~Fuel Flow, kg/h (lb/h)~~	~~Not Specified~~	~~Not Specified~~
Fuel Flow, kg/h	Not Specified	Not Specified
~~BSFC, kg/kW·h (lb/hp·h)~~	~~Not Specified~~	~~Not Specified~~
BSFC, kg/kW·h	Not Specified	Not Specified

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

5.2.1 Specification D4485.
5.2.2 API Publication 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 (I.D.). Where specified, four classes or categories of stand hardware have been designated:

6.1.1 Prints for special parts are included in this procedure. When using these prints to fabricate special parts, use the dimensions specified for the various parts. Do not scale off the drawings or use them as a pattern. Use all equipment specified in the procedure. Substitution of equivalent equipment is allowed, but only after equivalency has been proven acceptable by the Sequence VIB Surveillance Panel.

6.2 *Test Engine Configuration*—The test engine is a specially built 1993 ~~4.6-L~~ Ford V-8 engine[8] ~~designed for use with an Automatic Overdrive Electronic (AODE) transmission (see~~ with a displacement of 4.6 L, and designed for use with an Automatic Overdrive Electronic (AODE) transmission (see X1.3 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~~Torque Control*—The dynamometer speed and ~~load~~torque control systems shall be capable of maintaining the limits specified in Tables 2-4. A typical closed-loop control system maintains speed by engine throttle control and ~~load~~torque by dynamometer control. Since these speed and ~~load~~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 ~~(50-hp)~~ Model 758 dry gap dynamometer (see X1.4). Replacing an engine dynamometer during a reference or non-reference test is not acceptable. If a dynamometer needs to be replaced during a test, abort the test. Calibrate the new dynamometer and related instrumentation before starting a new test.

6.4.2 ~~*Dynamometer Load*~~Dynamometer Torque:

[8] 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 3 Sequence VIB Test Operating Conditions[A]

Parameter	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Speed, r/min[B]	1500 ±2	800 ±2	800 ±2	1500 ±2	1500 ±2
~~Load, Nm[B]~~	~~98.00~~	~~26.00~~	~~26.00~~	~~98.00~~	~~98.00~~
Torque, N·m[B]	98.00 ±0.07	26.00 ±0.07	26.00 ±0.07	98.00 ±0.07	98.00 ±0.07
Nominal, Power kW	15.39	2.18	2.18	15.39	15.39
Gallery, °C[B]	125 ± 1	105 ± 1	70 ± 1	70 ± 1	45 ± 1
Coolant, °C[B]	105 ± 1	95 ± 1	60 ± 1	60 ± 1	45 ± 1
Stabilization Time, min[C]	60	60	60	60	60

Parameter	All Stages
Temperatures, °C	
Oil Circulation	Record
Coolant Out	Record
Intake Air[B]	27 ± 2
Fuel-to-Flowmeter[D]	20 to 32 (delta from the max stage average reading shall be ≤4)
Fuel-to-Fuel Rail[B]	20 ± 2
Delta Load Cell[D]	Delta from the max stage average shall be ≤6
Oil Heater	205 max
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
Exhaust Back Pressure, kPa abs.[B]	104.00 ± 0.17
Engine Oil, kPa	Record
Crankcase, kPa	0.0 ± 0.25
Flows	
Engine Coolant, L/min	130 ± 4
Fuel Flow, kg/h[B]	Record
Humidity, Intake Air, gr/kg of dry air	11.4 ± 0.8
Air-to-Fuel Ratio[B]	14.00:1 to 15.00:1
Air-to-Fuel Ratio[D]	Delta from max stage average reading shall be ≤0.50
Ignition Timing	20° BTDC ± 2°

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

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

(1) Good temperature stability:

~~Zero ≤ 0.001% FSO (Full Scale Output) per °C (0.002% FSO per °F), and Span ≤ 0.001% FSO per °C (0.002% FSO per °F).~~

Zero ≤ 0.001 % FSO (Full Scale Output) per °C, and

Span ≤ 0.001 % FSO per °C.

(2) Nonlinearity ≤ 0.05 % FSO.

(3) Temperature compensation over range expected in laboratory (10 to ~~49°C) (50 to 115°F).~~49) °C. A Lebow Model 3397 load cell (see X1.5) has been found suitable for this application.

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. 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 (±10.8°F).~~± 6 °C. Control temperature by a means that does not cause uneven temperatures on the body of the load cell.

6.4.2.4 *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-A2.5, is required to maintain the specified jacket coolant temperature and flow rate during the test. An alternative cooling system is shown in Fig. A2.3. 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 (69 ± ~~13.8 kPa (10 ± 2 psi).~~13.8) kPa. Install a pressure cap (PC-1 in Figs. A2.1-A2.3) (see X1.6) capable of maintaining system pressure within the above requirements.

6.5.2 The pumping system shall be capable of producing (130 ± ~~4 L/min (34.3 ± 1.1 gal/min).~~4) L/min. A Goulds G&L centrifugal pump (P-1 in Figs. A2.1-A2.3), Model NPE, Size 1ST, mechanical seal, with a 2-hp, 3450~~-~~ r/min motor, is specified (see X1.7). 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.

TABLE 4 Sequence VIB Test Operating Conditions[A] Stage Flush and Stage Aging Hours SI Units

	Stage Flush	Aging Phase I	Aging Phase II
Speed, r/min	1500 ± 5	1500 ± 5	2250 ± 5
~~Load, Nm~~	~~98.00 ± 0.10~~	~~98.00 ± 0.10~~	~~98.00 ± 0.10~~
Torque, N·m	98.00 ± 0.10	98.00 ± 0.10	98.00 ± 0.10
Temperatures, °C[B]			
Oil Gallery	125 ± 2	125 ± 2	135 ± 2
Coolant In	105 ± 2	105 ± 2	105 ± 2
Oil Circulation	Record	Record	Record
Coolant Out	Record	Record	Record
Intake Air	27 ± 2	27 ± 2	27 ± 2
Fuel-to-Flowmeter[C]	20 to 32	20 to 32	20 to 32
Fuel-to-Rail	20 ± 2	20 ± 2	20 ± 2
Pressures			
Intake Air, kPa	0.05 ± .02	0.05 ± 0.02	0.05 ± 0.02
Fuel-to-Flowmeter, kPa	100 min	100 min	100 min
Fuel-to-Rail, kPa	205 to 310	205 to 310	205 to 310
Intake Manifold, kPa abs	Record	Record	Record
Exhaust Back, kPa abs	104.00 ± 0.20	104.00 ± 0.20	104.00 ± 0.20
Engine Oil, kPa	Record	Record	Record
Flows and Others			
Engine Coolant, L/min	130 ± 4	130 ± 4	130 ± 4
Fuel Flow, kg/h	Record	Record	Record
Humidity, Intake Air	Record	Record	Record
gr/kg, of dry air	11.4 ± 0.8	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	14.00:1 to 15.00:1
Ignition Timing, °BTDC	20 ± 2°	20 ± 2°	20 ± 2°
Crankcase, Pressure, kPa	N/A	0.0 ± 0.25	0.0 ± 0.25

[A] 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] ± 3°C within this range.

A2.1-A2.5. Adhere to the nominal I.D. of the line sizes as shown in Figs. A2.2-A2.5.

6.5.4 The specified heat exchanger (HX-1 in Figs. A2.1-A2.3) is an ITT Standard brazed plate model 320-20, Part No. 5-686-06-020-001 or ITT Bell and Gossett brazed plate model BP-75H-20, Part No. 5-686-06-020-001 (see X1.8). 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 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-A2.5) 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. A2.3).

6.5.6 An orifice plate (differential pressure) (FE-103 in Figs. A2.1-A2.5) is specified (see X1.9). This orifice plate is a Daniel Series No. 30 RT threaded orifice flange, 1½ 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).~~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.

6.5.7 A control valve (TCV-104 in Figs. A2.1-A2.4) 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), 2-in. valve is the specified valve (see X1.10).

6.5.7.2 A Badger Meter Inc. Model No. 9003TCW36SV3A29L36 (air-to-close), or Model No. 9003TCW36SV1A29L36 (air-to-open) are also acceptable if the trim package used with these valves has a CV 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 (TCV104) 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-A2.5) is required for controlling the coolant flow rate to ~~130.0~~(130 ± ~~4 L/min (35 ± 1 gal/min).~~4) L/min. A Badger Meter Inc. Model No. 9003GCW36SV3A29L36, 2-way globe, 2-in., air-to-close valve is the specified valve (see X1.10).

TABLE 5 Test Schedule

		Estimated Elapsed Time, h^A
BC Oil Test		
1.	Double flush to BC	1:30
2.	S60, BSFC/fuel flow × 6 at Stage 1^B	1:30
3.	S60, BSFC/fuel flow × 6 at Stage 2	1:30
4.	S60, BSFC/fuel flow × 6 at Stage 3	1:30
5.	S60, BSFC/fuel flow × 6 at Stage 4	1:30
6.	S60, BSFC/fuel flow × 6 at Stage 5	1:30
7.	Warm-up to Stage Flush	0:30
	Subtotal	9:30
Test Oil Test		
1.	Double flush to test oil	1:00
2.	Age 16 h at Stage Age Phase I	16:00
3.	S60, BSFC/fuel flow × 6 at Stage 1	1:30
4.	S60, BSFC/fuel flow × 6 at Stage 2	1:30
5.	S60, BSFC/fuel flow × 6 at Stage 3	1:30
6.	S60, BSFC/fuel flow × 6 at Stage 4	1:30
7.	S60, BSFC/fuel flow × 6 at Stage 5	1:30
8.	Age 80 h at Stage Age Phase II	80:00
9.	S60, BSFC/fuel flow × 6 at Stage 1	1:30
10.	S60, BSFC/fuel flow × 6 at Stage 2	1:30
11.	S60, BSFC/fuel flow × 6 at Stage 3	1:30
12.	S60, BSFC/fuel flow × 6 at Stage 4	1:30
13.	S60, BSFC/fuel flow × 6 at Stage 5	1:30
14.	Warm-up to Stage Flush	0:30
	Subtotal	112:30
BC Oil Test		
1.	Detergent flush to BC	3:30
2.	S60, BSFC/fuel flow × 6 at Stage 1	1:30
3.	S60, BSFC/fuel flow × 6 at Stage 2	1:30
4.	S60, BSFC/fuel flow × 6 at Stage 3	1:30
5.	S60, BSFC/fuel flow × 6 at Stage 4	1:30
6.	S60, BSFC/fuel flow × 6 at Stage 5	1:30
	Subtotal	11:00
End of Test Shutdown	Overall Total	133:00

^{A} Adhere to stabilization times and times for the 6 replicate BSFC measurements. Warm-up and cool-down times included in flushing elapsed times are estimates.
^{B} Example: Stabilize 60 min followed by 6 replicate BSFC measurements at 5-min intervals (3 min for set-up, 2 min for time averaged BSFC with Stage 1 operating conditions).

6.5.9 A Viatran model 274/374, Validyne model DP15, or Rosemount model 1151 differential pressure transducer (DPT-1 in Fig. A2.5) is required for reading the coolant flow rate at the orifice plate (FE-103 in Figs. A2.1-A2.3) (see X1.11).

6.5.10 Either replace the engine water pump with a water pump plate as shown in Fig. A2.6 or modify the pump 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 procured as Part No. OHT6A-014-A (see X1.12).

6.5.11 A coolant reservoir, a coolant overflow container, and a sight glass are required as shown in Figs. A2.1-A2.3 and Fig. A2.5. The design or model of these items is optional.

6.5.12 A control valve (TCV-101 in Fig. A2.1 and Fig. A2.4) 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, 1-in. valve is the specified valve (see X1.10). The type of trim package that may be used with this valve is optional.

6.5.13 A1½-in. NPT sight glass is required in the main coolant circuit (SG-1 in Figs. A2.1-A2.3, and Fig. A2.5). 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. A2.7 and A2.8 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. The engine oil pan is considered 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, which fills a ~~6.0-L (6.34-qt)~~6.0 L 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

TABLE 6 Calculation of Test Results

NOTE 1—For Stage 1, steps 1 through 6, round and record the 5- min BSFC measurements to 4 decimal places using ASTM rounding.

NOTE 2—Average the BSFC measurements of the six steps to 5 decimal places using ASTM rounding. Units for BSFC are kg/kW-h.

NOTE 3—Multiply the average by the shown nominal power and time factor for Stage 1 and record the answer to 6 decimal places. The unit for this number is kilograms of fuel consumed.

NOTE 4—Perform calculation steps 1, 2, and 3 for the remaining test stages (2 to 5) using the respective nominal power and time factors.

NOTE 5—Total the mass fuel consumption values for all 5 stages.

NOTE 6—Complete the total fuel consumed calculation detailed in Steps 1 to 5 above for the BC Before Test Oil, Test Oil Phase I, Test Oil Phase II, and BC After Test Oil.

NOTE 7—Compute the test oil fuel economy improvement (FEI) as follows:

$$\%\ \text{FEI Test Oil Phase I} = \{[(\text{BC Before} \times 80\ \%) + (\text{BC After} \times 20\ \%) - \text{Test Oil}] \div [(\text{BC Before} \times 80\ \%) + (\text{BC After} \times 20\ \%)]\} \times 100$$

$$\%\ \text{FEI Test Oil Phase II} = \{[(\text{BC Before} \times 10\ \%) + (\text{BC After} \times 90\ \%) - \text{Test Oil}] \div [(\text{BC Before} \times 10\ \%) + (\text{BC After} \times 90\ \%)]\} \times 100$$

NOTE 8—Adjust the FEI result(s) on non-reference oil tests for the stand/engine severity in accordance with Annex A7.

Test Stage	Nominal Speed, r/min	Nominal Power, kW	Time Wt. Factor, h
1	1500	15.39	0.0802
2	800	2.18	0.0787
3	800	2.18	0.0848
4	1500	15.39	0.0864
5	1500	15.39	0.0699

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 four 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. A2.7) shall have the following features:

NOTE 1—The items shown in the clouded areas in Fig. A2.7 are not specifically required. However, a system that performs these functions is required.

6.6.4.1 A scavenge pump (P-3 in Figs. A2.7 and A2.8). A Viking Series 475, gear type, close-coupled pump, model H475M is specified (see X1.13). The pump shall have an (1140 to 1150~~-~~) r/min electric motor drive with a minimum of ~~0.75 hp.~~0.56 kW. Voltage and phase are optional.

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

6.6.4.5 A dump reservoir (see Figs. A2.7-A2.9) with a minimum ~~6-L (6.34-qt)~~6 L capacity.

6.6.4.6 A dump reservoir float switch is required. (FLS-136 in Figs. A2.7-A2.9) The make and model is optional. A Gems Series ALS79999, Catalog No. A79999, 20 VA, high temperature float switch has been found suitable for this application (see X1.14).

6.6.4.7 Adhere to the nominal I.D. line sizes shown in Fig. A2.8.

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 6.0 ~~L (6.34 qt).~~L. See 6.6.5.16.

6.6.5.2 An engine oil pan float switch (FLS-152 in Fig. A2.7, Fig. A2.10, and Fig. A2.16) is required. A Gems Series ALS79999, Catalog No. A79999, 20 VA, high temperature float switch is specified (see X1.14).

TABLE 7 Calculation of BSFC

~~1W = 1N·m/s~~
Power is one of the components of BSFC
~~1kW = 1000 N·m/ s~~
Power = torque x rotational speed
~~1 kW = 60 000N·m/min~~
In SI units, Power as kW = [torque (N·m)] × [speed (r/min)] / 94549.3
~~1kW = 2π TN/60 000~~
Note: The 9549.3 constant is rounded and is derived from:
~~1kW = T N /9549.3~~
[60 (s/min) × 1000 (W/kW)] / 2 π (radians/revolution)

Then,
~~Example:~~

$$BSFC,\ kg/kWh = \frac{[fuel\ flow\ (kg/h)] \times 9549.3}{[Torque\ (N{\cdot}m)] \times [speed\ (r/min)]}$$

~~Speed = 800 r/min~~

~~Torque = 19.18 lbf·ft = 26.004 N·m~~
BSFC Example:
~~hp = T N/5252 = (800 × 19.18)/5252 = 2.92~~
Speed = 800.3 r/min
~~kW = T N/9549.3 = (800 × 26.004)/9549.3 = 2.1785052~~
Torque = 26.04 N·m
~~2.1785052 kw/.746 = 2.92hp~~
Fuel flow = 3.258 kg/h

~~In SI Units:~~
And,
~~BSFC = (fuel flow, kg/h)(9549.3)/(speed, r/min)(Torque, N·m)~~

$$BSFC = \frac{[3.258\ (kg/h)] \times 9549.3}{[26.04\ (N{\cdot}m)] \times [800.3\ (r/min)]} = 1.4929\ kg/kWh$$

~~In Inch-Pound Units:~~
~~BSFC = (fuel flow, lb/h)(5252) /(speed, r/min)(Torque, lbf · ft)~~

6.6.5.3 A positive displacement oil circulation pump (P-4 in Fig. A2.7) is required. A Viking Series 4125, Model G4125, no relief valve, base-mounted is specified (see X1.15). 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).~~kW. Voltage and phase are optional.

NOTE 2—The explosion proof requirement for the motor is left to the discretion of the laboratory.

NOTE 3—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. A2.7 and A2.8) are required (see X1.16).

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

(2) FCV-150A is a Burkert Type 251 piston-operated valve used with a 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 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.

(3) FCV-150C is a Burkert Type 251 piston-operated valve used with a 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 the piston valve, solenoid valve direct-coupled to the piston valve, normally open, explosion proof (left to the discretion of the laboratory) and watertight, ½ in., 2-way, stainless steel.

(4) FCV-150D, FCV-150E, and FCV-150F are Burkert Type 251 piston-operated valves used with a 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 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.

(5) Use only one type of Burkert piston and solenoid valve on a test stand.

6.6.5.5 Control valve (TCV-144 in Figs. A2.7 and A2.8) is required. The specified valve is a Badger Meter Inc. Model No. 1002TBN36SVOSALN36, 3-way globe (divert), ½-in., air to open valve (see X1.17).

6.6.5.6 Control valve (TCV-145 in Figs. A2.7 and A2.8) is optional (see X1.17).

6.6.5.7 A heat exchanger (HX-6 in Figs. A2.7 and A2.8) is required for oil cooling. The specified heat exchanger is an ITT model 310-20 or a ITT Bell & Gossett, model BP-25-20 (Part No. 5-686-04-020-001), brazed plate (see X1.18).

NOTE 4—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. A2.7 and A2.8) is required for oil heating. The specified heater is a heating element inserted in the liquid Cerrobase inside a Labeco oil heater housing (see X1.19). 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.

(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 (see Fig. A2.14~~) to an insertion depth of 244.48 ± 3.18 mm (9.625 ± 0.125 in.). Do not exceed the maximum temperature of 205°C (401°F).~~) to an insertion depth of (244.48 ± 3.18) mm. Do not exceed the maximum temperature of 205 °C.

(2) The procedure for replacing a heating element is detailed in Annex A3.

6.6.5.9 Install two oil filters (FIL-2 in Figs. A2.7 and A2.8) in the external oil system. The filters specified are Oberg or Racor model ~~LFS-55~~LFS-60 with an Oberg or Racor ~~28-mm~~ 28 µm stainless steel screen, Part No. LFS ~~55286~~6028 (see X1.20).

(1) An alternative oil filter model LFS-62 with an Oberg or Racor ~~28-mm~~ 28 µm stainless steel screen, Part No. LFS ~~55286~~6028 (see X1.20), may be used.

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

(3) 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.

(4) When replacing the test stand's oil filters to the alternative model LFE-62, do so immediately prior to a calibration test.

6.6.5.10 Adhere to the nominal piping I.D. sizing shown in Fig. A2.8.

6.6.5.11 Use modified oil filter adapter assembly, Part No. OHT6A-007-1 (see X1.21), as shown in Fig. A2.15.

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) (see X1.22).

6.6.5.13 Insulation of plumbing for the external oil circulation system is mandatory. Insulation material selection is optional but shall have a maximum thermal conductivity of 0.0398 W/(m·K) at a mean temperature of ~~32.2°C (0.276 Btu·in./h·ft^2·°F at a mean temperature of 90°F).~~ 32.2 °C.

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 X1.23). Remove all stock baffles from the pan. An oil pan baffle as shown in Fig. A2.12 is required and installed as shown in Figs. A2.10 and A2.11. These two figures also show the oil pan connections for connecting to the external oil system. Installation of viewing windows are optional as shown in Figs. A2.10 and A2.11. Install a float switch (FLS-152 in Fig. A2.7 and Fig. A2.16, Gems Series ALS79999, Catalog No. 79999) (see X1.14) in the oil pan. The float switch may be mounted from the pan bottom as shown in Fig. A2.10 or from an adjustable rod through the dipstick hole.

(1) Oil Pan Baffle—Figs. A2.10 and A2.11 illustrate a side view of the oil pan and the position of the baffle on the left inside wall of the pan. Bend the ears on each end of the baffle about 45° toward the wall of the pan. Fit the top edge of the baffle tight against the wall and incline 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*:

(1) Cut off the steel engine oil pick up tube immediately above the oil screen and weld a (150 to ~~18 cm (6 to 7 in.)~~180) mm long straight stainless steel tube of the same inside and outside diameters as the original tube to the end so it will project down through 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 X1.23). 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. outside diameter (O.D.) tube to pass through (see Figs. A2.10 and A2.11).

(2) 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).

(3) 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*—Install a sight glass tube, as shown in Fig. A2.24, as a provision for monitoring the oil level and determining oil consumption. See Annex A9 for instructions on oil consumption measurement/calibration.

6.7 *Fuel System*—A typical fuel delivery system incorporating all of the required features is shown in Fig. A2.17. 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.)~~ 100 mm of flexible line at the inlet and outlet of the fuel flowmeter (rubber/synthetic suitable for use with gasoline). Compression fittings are allowed for connecting the flexible lines to the fuel flowmeter. 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.).~~ mm.

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 or a Model CMF010 mass flow meter with an RFT9739 transmitter is specified. Series 1700 and 2700 transmitters have also been found to be acceptable in this application (see X1.24). The Micro Motion sensor may be mounted in a vertical or a horizontal position.

~~6.7.2.1Fuel 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 AFR are time-averaged over the same 100 to 120-s interval. The use of frequency output from the fuel flowmeter is recommended to avoid electrical noise affecting analog signal output.~~

6.7.2.1 Fuel flow measurement is coordinated to allow a meaningful calculation of brake specific fuel consumption in kilograms per kilowatthour. Specifically, speed, torque, fuel flow, and AFR are time-averaged over the same (100 to 120) s interval. The use of frequency output from the fuel flowmeter is recommended to avoid electrical noise affecting analog signal output.

NOTE 5—The kWh unit is not an SI unit. The correct SI unit is the joule (J). 1 kWh = 3.6 MJ.

6.7.3 *Fuel Temperature and Pressure Control to the Fuel Flow Meter*—Maintain fuel temperature and pressure to the fuel flowmeter at the values specified in Tables 2-4. 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 rail at the values specified in Tables 2-4. Precise fuel temperature and precise fuel pressure control without fluctuation or aeration is mandatory for test precision.

6.7.5 *Fuel Supply Pumps*—The test method of providing fuel to the fuel flowmeter is at the laboratory's discretion as long as the requirements for fuel pressure and temperature are met. For providing fuel from the fuel flowmeter 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).~~kPa. Purchase this part from the CPD (see X1.38).

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 pressure as specified in Tables 3 and 4~~, 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 specified engine intake air system components are considered part of the laboratory intake air system and are shown in~~ , which is (11.4 ± 0.8) g/kg of dry air, (27 ± 2) °C, and (0.05 ± 0.02) kPa. The specified engine intake air system components are considered part of the laboratory intake air system and are shown in Fig. A2.18 and in the 1993 Ford Service manual, p. 03-12-2.[9,10]

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:

(1)

~~where:~~
~~*Psat* = saturation pressure, in. Hg, and~~
~~*Pbar* = barometric pressure, in. Hg.~~

~~SI Units (Modernized Metric System):~~

~~(2) Humidity (corrected), g/Kg = 621.98 × (*Psat*/(*Pbar* − *Psat*))~~

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

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. Follow the guidelines outlined by the research report.[11]

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-Constantine (Type J) thermocouples are recommended for temperature measurement, but either Type J or Type K (Chromel-Alumel) thermocouples may be used.

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

[10] The sole source of supply of the apparatus known to the committee at this time is HELM, Inc., 14310 Hamilton Avenue, Highland Park, MI 48203.

[11] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.01 on Passenger Car Engine Oils.

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