INTERNATIONAL

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Standard Test Method for Dynamometer Evaluation of Unleaded Spark-Ignition Engine Fuel for Intake Valve Deposit Formation[1]

This standard is issued under the fixed designation D6201; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers an engine dynamometer test procedure for evaluation of intake valve deposit formation of unleaded spark-ignition engine fuels.[2] This test method uses a Ford Ranger 2.3 L four-cylinder engine. This test method includes detailed information regarding the procedure, hardware, and operations.

1.2 The ASTM Test Monitoring Center (TMC)[3] is responsible for engine test stand calibration as well as issuance of information letters after test method modifications are approved by Subcommittee D02.A0 and Committee D02. Users of this test method shall request copies of recent information letters from the TMC to ensure proper conduct of the test method.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered 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 of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Specific warning statements are given throughout this test method.

1.5 This test method is arranged as follows:

[1] This test method is under jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.A0.01 on Gasoline and Gasoline-Oxygenate Blends.

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[2] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1453. Contact ASTM Customer Service at service@astm.org.

[3] ASTM Test Monitoring Center (TMC), 6555 Penn Avenue, Pittsburgh, PA 15206-4489.

***A Summary of Changes section appears at the end of this standard**

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

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D381 Test Method for Gum Content in Fuels by Jet Evaporation
D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)
D873 Test Method for Oxidation Stability of Aviation Fuels (Potential Residue Method)
D1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D1744 Test Method for Determination of Water in Liquid Petroleum Products by Karl Fischer Reagent (Withdrawn 2016)[5]
D2427 Test Method for Determination of C_2 through C_5 Hydrocarbons in Gasolines by Gas Chromatography
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D3237 Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy
D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4814 Specification for Automotive Spark-Ignition Engine Fuel
D4953 Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)
D5059 Test Methods for Lead in Gasoline by X-Ray Spectroscopy
D5190 Test Method for Vapor Pressure of Petroleum Products (Automatic Method) (Withdrawn 2012)[5]
D5191 Test Method for Vapor Pressure of Petroleum Products and Liquid Fuels (Mini Method)
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 (Withdrawn 2003)[5]
D5482 Test Method for Vapor Pressure of Petroleum Products (Mini Method—Atmospheric)
D5500 Test Method for Vehicle Evaluation of Unleaded Automotive Spark-Ignition Engine Fuel for Intake Valve Deposit Formation
E203 Test Method for Water Using Volumetric Karl Fischer Titration
E1064 Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration

2.2 *ANSI Standard:*[6]

MC96.1 Temperature Measurement-Thermocouples

2.3 *Coordinating Research Council (CRC):*[7]

CRC Manual 16, Carburetor and Induction System Rating Manual

2.4 *SAE Standard:*[8]

J254 Instrumentation and Techniques for Exhaust Gas Emissions Measurement

3. Terminology

3.1 For general terminology, refer to Terminology D4175.

3.2 *Definitions:*

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

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

[7] Available from the Coordinating Research Council, Inc., 5755 North Point Pkwy, Suite 265, Alpharetta, GA 30022, http://www.crcao.org.

[8] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

3.2.1 *base fuel, n—in automotive spark-ignition engine fuels*, a material composed primarily of hydrocarbons that may also contain oxygenates, anti-oxidants, corrosion inhibitors, metal deactivators, and dyes but does not contain deposit control or lead additives. **D5500**

3.2.1.1 *Discussion—*

A jurisdiction may set limits on lead content from all sources.

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

3.2.3 *deposit control additive, n*—material added to the fuel to prevent or remove deposits in one or more of the engine fuel, intake, and combustion systems. **D5500**

3.2.3.1 *Discussion—*

For the purpose of this test method, the performance evaluation of a deposit control additive is limited to the tulip area of intake valves.

3.3 *Definitions of Terms Specific to This Standard:*

~~3.3.1 *deposit control additive, n*—material added to the base fuel to prevent or remove deposits in the entire engine intake system.~~

~~3.3.1.1 *Discussion—*~~

~~For the purpose of this test method, the performance evaluation of a deposit control additive is limited to the tulip area of intake valves.~~

3.3.1 *exhaust emissions, n*—combustion products from the test fuel including unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), unreacted oxygen (O_2), and oxides of nitrogen (NO_x).

3.3.2 *intake system, n*—components of the engine whose function it is to prepare and deliver an air/fuel mixture to the combustion chamber and includes the throttle, intake manifold, exhaust gas recirculation (EGR) and positive crankcase ventilation (PCV) ports, cylinder head runners and ports, intake valves, and fuel injectors.

3.3.3 *intake valve deposit, n*—material accumulated on the tulip area of the intake valve, generally composed of carbon, other fuel, lubricant, and additive decomposition products, and atmospheric contaminants.

3.3.4 *test fuel, n*—base fuel with or without the addition of a deposit control additive.

4. Summary of Test Method

4.1 This test method utilizes a 1994 Ford 2.3 L in-line, four cylinder, Ford Ranger truck engine with 49 state emission calibration. The cylinder block and cylinder head are constructed of cast iron. The engine features an overhead camshaft, a cross-flow, fast burn cylinder head design, and electronic port fuel injection.

4.2 Each test engine is built to a rigid set of specifications using a specially designated intake valve deposit parts kit produced by the Ford Motor Co. (see Table A2.3). New, weighed, intake valves are used to rebuild the cylinder head. A standard engine oil is used for each test and a new oil filter is installed. The test engine is subjected to a rigorous quality control procedure to verify proper engine operation. To ensure compliance with the test objective, data acquisition of key parameters is utilized during test operation.

4.3 The complete fuel system is flushed of test fuel from the previous test. The fuel system is then filled with the new test fuel.

4.4 The engine is operated on a cycle consisting of two stages. The first stage comprises operating the engine at 2000 r/min and 30.6 kPa (230 mm Hg) manifold absolute pressure for 4 min. The second stage comprises operating the engine at 2800 r/min and 71.8 kPa (540 mm Hg) manifold absolute pressure for 8 min. Ramp time between each stage is 30 s and is independent of the stage times. The cycle is repeated for 100 h.

5. Significance and Use

5.1 *Test Method*—The Coordinating Research Council sponsored testing to develop this test method to evaluate a fuel's tendency to form intake valve deposits.

5.1.1 *State and Federal Legislative and Regulatory Action*—Regulatory action by California Air Resources Board (CARB)[9] and the United States Environmental Protection Agency (EPA)[10] necessitate the acceptance of a standardized test method to evaluate the intake system deposit forming tendency of an automotive spark-ignition engine fuel.

5.1.2 *Relevance of Results*—The operating conditions and design of the engine used in this test method are not representative of all engines. These factors shall be considered when interpreting test results.

5.2 *Test Validity:*

5.2.1 *Procedural Compliance*—The test results are not considered valid unless the test is completed in compliance with all requirements of this test method. Deviations from the parameter limits presented in Sections 12 – 14 will result in an invalid test. Apply engineering judgment during conduct of the test method when assessing any anomalies to ensure validity of the test results.

5.2.2 *Engine Compliance*—A test is not considered valid unless the test engine meets the quality control inspection requirements as described in Sections 10 and 12.

6. Apparatus

NOTE 1—Photographs are provided in Annex A1 depicting the required apparatus and suggesting appropriate design details.

6.1 *Laboratory Facilities:*

6.1.1 *Engine and Cylinder Head Build-up and Measurement Area*—The engine and cylinder head build-up and measurement area shall be reasonably free from contaminants and maintained at a uniform temperature ±3 °C (±5 °F) between 10 °C to 27 °C (50 °F to 80 °F).

6.1.2 *Engine Operating Area*—The engine operating area should be relatively free from contaminants. The temperature and humidity level of the operating area are not specified. Air from a fan can be routed on to the production air intake system to assist in maintaining intake air temperature control.

6.1.3 *Fuel Injector Testing Area*—The fuel injector testing area shall be reasonably free of contaminants. The humidity should be maintained at a uniform comfortable level. (**Warning—**In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used.)

6.1.4 *Intake Valve Rinsing and Parts Cleaning Area*—The intake valve rinsing and parts cleaning area shall be reasonably free of contaminants. The humidity should be maintained at a uniform comfortable level. Because of the delicate nature of the deposits, do not subject the deposits to extreme changes in temperature or humidity. (**Warning—**In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used.)

6.1.5 *Parts Rating and Intake Valve Weighing Area*—The parts rating area and the intake valve weighing area shall be reasonably free of contaminants.

6.2 *Test Stand Laboratory Equipment:*

6.2.1 *Test Stand Configuration*—An example of a similar test stand configuration is described in Test Method D5302 (Sequence VE lubricant test method) since the same Ford 2.3 L base engine is utilized. Mount the engine on the test stand so that the flywheel friction face is 4.0° ± 0.5° from the vertical with the front of the engine higher than the rear. The engine shall be coupled directly to the dynamometer through a driveshaft. A test stand set-up kit is detailed in Table A2.1. A special "dynamometer laboratory" wiring harness, Part No. DTSC.260.113.00E is required. Engine driven accessories include engine water pump and alternator or idler pulley configuration as detailed in 10.7.9. If an alternator is installed, it is to serve only as an idler pulley; it is not to be energized.

6.2.2 *Dynamometer Speed and Load Control System*—The dynamometer used for this test is the Midwest 1014, 175 horsepower, dry gap dynamometer or equivalent. Equivalency means that the dynamometer and dynamometer control system shall be capable of controlling the procedural specifications as detailed in Table 1 and the stage transitions to the specifications in 13.4.3.1 and 13.4.4.1.

6.2.3 *Intake Air Supply System*—The intake air supply system shall be capable of controlling moisture content, dry bulb temperature, and inlet air pressure as specified in Table 1. See 10.7.8 and Fig. A1.4 for details of connection of the laboratory intake air system to the engine.

6.2.3.1 *Intake Air Humidity*—Determination of the dew point may be made either in the laboratory main duct system or at the test stand. However, maintain duct surface temperature at all points downstream of the humidity measurement point above the dew point to prevent condensation loss (loss of absolute humidity).

6.2.3.2 Correct each reading for non-standard barometric conditions using the following equation:

$$\text{Humidity (corrected), g/kg} = 621.98 \times (P_{sat}/(P_{bar} - P_{sat})) \quad (1)$$

where:

P_{sat} = saturation pressure, mm Hg, and
P_{bar} = barometric pressure, mm Hg.

[9] State of California Air Resources Board—Stationary Source Division, Test Method for Evaluating Intake Valve Deposits (IVDs) in Vehicle Engines (California Code of Regulations, Title 13, Section 2257). Available from the California Air Resources Board, P.O. Box 2815, Sacramento, CA 95812.

[10] Clean Air Act Amendments of 1990. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

TABLE 1 IVD Dynamometer Test Operating Parameters and Specifications^A

Parameter^A		Specification	
Stage	...	1	2
Time	Stage length, min	4	8
Engine Loading	Engine speed, r/min	2000 ± 25	2800 ± 15
	Engine load, kW	<5	record
Engine Oil	Inlet temperature, °C	101 + 3, –5	101 ± 3
	Outlet temperature, °C	record	
	Inlet pressure, kPa gage	record	
Engine Cooling	Outlet temperature, °C	90 ± 3	
	Inlet temperature, °C	record	
	Delta pressure, kPa gage	<41	
	Flowrate, L/min	record	64.4 ± 1.9
Intake Air	Inlet temperature, °C	32 ± 3	
	Inlet pressure, kPa gage	0.05 ± 0.01	
	Inlet humidity (corrected), g/Kg	11.4 ± 0.7	
Engine Breathing	Manifold absolute pressure, kPa	30.6 ± 1.3	71.8 ± 1.3
	Exhaust back pressure, kPa abs	102 ± 1	105 ± 1
Engine Fueling	Flow—kg/h	record	
	Flow—total kg	record	
	Inlet temperature, °C	28 ± 5	
Exhaust Emissions	Equivalence ratio or	1.00 ± 0.03	
	O_2, volume %	record	0.5 ± 0.3
	CO_2, volume %	record	
	CO, volume %	record	0.7 ± 0.4
	NO_x, ppm (optional)	record	
Other	EGR, voltage	record	
	Blowby, corrected rate, L/min	...	record
	Spark advance, ° BTDC	30 ± 3	25 ± 3

^{A} Maintain all parameters as close to midrange as possible. The engine load in Stage 1 should be less than 5 kW. The ramp time between each stage is 30 s. Ramp the speed and manifold absolute pressure linearly and at the same time. Fifteen seconds into each ramp the speed shall be 2400 r/min ± 75 r/min, and the manifold absolute pressure shall be 51.2 kPa ± 6.6 kPa (385 mm Hg ± 50 mm Hg).

6.2.4 *Exhaust System*—The laboratory exhaust system shall have the capability of controlling exhaust back pressure as specified in Table 1. The exhaust system shall include the back pressure control valve, exhaust back pressure probe, exhaust emissions probe or UEGO (Lambda) sensor, and the engine oxygen sensor. The Ford production exhaust manifold is to be used to connect the engine to the laboratory exhaust system. Fig. A1.6 and 6.2.11.5 give details regarding the exhaust back pressure probe configuration and location, and Fig. A1.6 and 6.2.14 give details regarding the exhaust emissions probe configuration and location. A catalytic converter may be installed downstream of the exhaust back pressure and air-fuel ratio probes.

6.2.5 *Fuel Supply System*—A schematic diagram of a typical fuel supply system is shown in Fig. A1.7. Supply an excess volume of fuel to the fuel rail at all times. Introduce make-up fuel (fuel used by the engine) into the loop from an external source. Mix the make-up fuel with fuel that is returned from the fuel rail (fuel not used by the engine). Pump the fuel through a mixing chamber, or small heat exchanger, which is used to mix the two streams and provide fuel of consistent temperature to the engine as specified in Table 1. Deliver the fuel to a high-pressure pump that boosts the pressure and supplies the fuel to the fuel rail.

6.2.6 *Engine Control Processor Calibration and Main Engine Wiring Harness*—Two engine control EEC-IV processors are required for use in this test method, one for use during new engine break-in and one for test operation. The processor for new engine break-in, as detailed in 12.1.6, shall be the Ford Ranger non-modified manual transmission calibration EEC-IV processor (Part No. F47F-12A650-BGC) which is available from local Ford dealers. The specified engine control calibration for the test operation, as detailed in Table 1, shall be the modified Ford Ranger manual transmission calibration EEC-IV processor (OHTIVD-001-02) available from OH Technologies, Inc.[11] See Annex A2 for further details. The system should properly control the air-fuel ratio, the EGR and the ignition timing throughout the test. No other method shall be used in conjunction with or in place of the specified EEC-IV processor to adjust the air-fuel ratio, EGR or ignition timing.

[11] The sole source of supply of the apparatus known to the committee at this time is OH Technologies, Inc., P.O. Box 5039, Mentor, OH 44061-5039. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

6.2.7 *Ignition System*—See 6.2.6 for engine control EEC-IV processors which shall be used for ignition system control. See Annex A2 for a listing of other required ignition system components.

6.2.8 *Engine Coolant System*—A typical cooling system is detailed in Fig. A1.11.

6.2.8.1 Control the coolant outlet temperature and flow rate according to the specifications listed in Table 1. The thermostat is not used. The coolant capacity is 21 L ± 4 L.

6.2.9 *External Oil System*—Configure the external oil system in accordance with the photographs shown in Fig. A1.8 and Fig. A1.9. An oil system adapter assembly (OHT6A-007-1[11]) is required. The heat exchanger should be mounted in a vertical plane. Be sure all hoses and fittings on the oil heat exchanger are properly connected and secure.

6.2.10 *Temperature Measurement Equipment and Locations*—Temperature measurement locations for the procedurally required temperatures are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the temperature measurement sensors and complete temperature measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.[12] If thermocouples are used, all thermocouples except the intake air thermocouple shall be premium, sheathed types. The intake air thermocouple may be an open-tip type. Thermocouples between 3.0 mm and 6.5 mm (0.125 in. and 0.25 in.) diameter may be used. However, minimum diameter thermocouples are recommended at locations which require short immersion depths to prevent undesirable temperature gradients. Thermocouple, wires, and extension wires shall be matched to perform in accordance with the limits of error as defined by ANSI publication MC96.1-1975. Type J (Iron-Constantan), Type T (Copper-Constantan), or Type K (Chromel-Alumel) thermocouples are acceptable and if RTDs are used, they shall be of a quality to give equivalent readings to the specified premium thermocouples. Temperature sensors shall not have greater than 5 cm (2 in.) of sheath exposed to lab ambient. All temperature sensor probe tips shall be located in the center of the stream of the medium being measured unless otherwise specified.

6.2.10.1 *Engine Oil Inlet*—Install the temperature sensor tip at the center of the flow stream through the oil filter adapter housing at the engine (See 6.2.9, Fig. A1.8, and Fig. A1.9).

6.2.10.2 *Engine Oil Outlet*—Install the temperature sensor tip at the center of the flow stream through the cross fitting attached to the bottom of the heat exchanger (see Fig. A1.8).

6.2.10.3 *Engine Coolant Inlet*—Install the temperature sensor tip at the center of the flow stream between the coolant heat exchanger and the engine at a distance of ~~430~~430 mm ± 100 mm from the coolant inlet at the engine block.

6.2.10.4 *Engine Coolant Outlet*—Install the temperature sensor tip at the center of the flow stream through the thermostat housing within 50 mm of the coolant exit orifice on the cylinder head.

6.2.10.5 *Intake Air Inlet*—Locate the intake air temperature sensor probe in the production air filter housing between the air filter and the engine intake manifold. Install the temperature sensor probe tip 50 mm ± 10 mm into the housing and perpendicular to the housing (see Fig. A1.7).

6.2.10.6 *Fuel Temperature*—Install the temperature sensor tip at the center of the flow stream after the high pressure pump and just prior to the engine fuel rail (see Fig. A1.7).

6.2.11 *Pressure Measurement Equipment and Locations*—Pressure measurement locations for the procedurally required pressures are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the pressure measurement sensors and complete pressure measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.[12]

6.2.11.1 *Oil Inlet*—Measure the oil inlet pressure at the oil filter adapter housing (see Fig. A1.9 and 6.2.9).

6.2.11.2 *Coolant Delta Pressure (outlet–inlet)*—The coolant delta pressure determines the flow restrictions of the external cooling system. The measurement is the resultant of the absolute value of the difference between the pressure measured as the coolant exists the cylinder head and prior to the coolant entering the water pump. Make pressure measurements within 300 mm of these locations.

6.2.11.3 *Air Inlet*—Locate the intake air pressure probe in the production air filter housing between the air filter and the engine intake manifold. Install the probe 5 mm ± 3 mm into the housing.

6.2.11.4 *Manifold Absolute* ~~*Pressure —*~~*Pressure—*Measure manifold absolute pressure between the vacuum *tree* and the intake manifold (see Fig. A1.5).

6.2.11.5 *Exhaust Back Pressure*—Measure exhaust back pressure downstream of the engine oxygen sensor at a distance no greater than 400 mm and at the center of the exhaust stream. Fig. A1.6 gives details regarding the exhaust back pressure probe configuration and location. A condensate trap should be installed between the probe and sensor to accumulate water present in the exhaust gas.

6.2.11.6 *Crankcase Pressure*—Measure the crankcase pressure at the dipstick tube. The sensor shall be capable of measuring positive and negative pressure.

6.2.12 *Flow Measurement Equipment and Locations*—Flow measurement locations for the procedurally required flows are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the flow measurement sensors and complete flow measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.[12]

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[12] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1218. Contact ASTM Customer Service at service@astm.org.

6.2.12.1 *Engine Coolant*—Measure the engine coolant flow rate in an area most applicable to the flow measurement device used so that the most accurate measurement can be taken.

6.2.12.2 *Fuel*—The fuel system shall be configured so that the fuel return line from the fuel rail returns downstream of the fuel flow measurement device so that only the make-up fuel flow is measured (see Fig. A1.7).

6.2.13 *Speed and Load Measurement Equipment and Locations*—Speed and load measurement locations for the procedural required speeds and loads are not specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the speed and load measurement sensors and complete speed and load measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.[12]

6.2.14 *Exhaust Emissions Measurement Equipment and Location*—Engine air-fuel ratio may be monitored either by a "real time" equivalence ratio measurement system or by exhaust gas analysis (measurement of O_2, CO, and CO_2). With either system, measurements are to be made downstream of the engine oxygen sensor at a distance no greater than 400 mm and at the center of the exhaust stream.

6.2.14.1 *Real Time—Equivalence Ratio Measurement System*—It is recommended that a real time equivalence ratio measurement system be utilized. One example of a typical system is the Horiba Model MEXA 110. The system utilizes an extended range exhaust gas oxygen sensor (UEGO) air-fuel sensor that is inserted into the exhaust gas stream. The instrument gives instantaneous equivalence ratio measurement which provides the ability to detect when the engine is not operating at normal equivalence ratio conditions (usually indicating an engine or engine management system problem), thus allowing for a problem to be addressed as it occurs. If an equivalence ratio system is utilized, the hydrogen/carbon (H/C) ratio for the specific fuel being run shall be input into the analyzer before conducting the engine test.

6.2.14.2 *Exhaust Gas Analysis*—Precision instruments for measurement of O_2, CO, and CO_2 are required if exhaust emissions are measured for air-fuel ratio determination. Measurement of NO_x is optional. Equipment suitable for automobile emission measurements is recommended. Precision non-dispersive infrared instrumentation for CO and polarographic instrumentation for O_2 are suggested (see SAE J254). Response time is an important consideration in the performance of this instrumentation. Fig. A1.6 provides details regarding the exhaust emissions probe configuration and location.

6.2.15 *DPFE (EGR) Voltage Measurement Equipment and Location*—DPFE voltage measurement locations for the procedural requirements shall be measured at Pin 27 of the EEC-IV processor. Pin 46 is signal return (ground). Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the DPFE voltage measurement equipment shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.[12]

6.2.16 *Ignition Timing Measurement Equipment and Location*—Specific measurement locations and equipment for the measurement of spark advance are not specified.

6.3 *Test Engine Hardware*—This section specifies the engine hardware required for testing.

6.3.1 *Test Engine Parts*—The test engine parts required are detailed in Annex A2. The Engine Parts Kit in Table A2.3 contains a new cylinder head and the necessary parts for assembling the cylinder head for four tests.

6.3.2 *New Engine Parts Required*—The following table contains those new parts to be used for preparing the engine to run this test method.

Belt, camshaft drive
Bolt, head to block
Filter, air
Filter, fuel
Filter, oil
Gasket, EGR valve
Gasket, exhaust manifold
Gasket, head
Gasket, low manifold - head
Gasket, plenum manifold
Gasket, rocker arm cover
Gasket - throttle body
Gasket, water outlet connection
PCV valve
Seal, cam
Seal, exhaust valve
Seal, intake valve
Spark plugs
Valve, exhaust
Valve, intake

6.3.3 *Reusable Engine Parts*—The parts listed in the following table may be reused. The replacement frequency is listed in the footnotes. Discard all parts when they become unserviceable.

Air cleaner tube assembly, out
Air cleaner tube assembly, in
Air cleaner assembly
Alternator or idler pulley assembly
Belt, alternator or idler pulley

Bolt, cam sprocket
Camshaft
Coil
Cylinder head[A]
EEC-IV processor
Engine wire harness
Engine assembly[B]
Fuel injector[C]
Filter, air
Guide, timing belt
Hose, DPFE
Ignition control assembly
Ignition wire, LH
Ignition wire, RH
Key, valve spring retainer
Lash adjusters
Plate, cam
Pulley water pump
Regulator, EGR vacuum (EVR)
Retainers
Rocker arms
S&W, cam plate
Sensor, air charge temperature (ACT)
Sensor, crankshaft timing assembly
Sensor, engine coolant temperature (ECT)
Sensor, heated exhaust gas O_2 (HEGO)
Sensor, mass air flow (MAF)
Sensor, pressure feedback EGR Assembly (PFE)
Sensor, throttle position (TPS)
Sprocket, cam
Valve, EGR
Valve spring and damper[D]
Washer, cam sprocket

[A] The cylinder head may be reused as long as it meets the procedural requirements for buildup as detailed in 10.4 and 10.5.
[B] The engine assembly may be reused depending on the condition of the cylinder head bolt holes, cylinder bore wear, blowby, and oil consumption. Procedural requirements have yet to be determined. Refer to 12.4 for procedural requirements for oil consumption.
[C] The fuel injectors may be reused as long as they meet the procedural requirements detailed in 10.3.1.
[D] Reuse the valve springs as long as they meet the procedural requirements detailed in 10.4.

6.4 *Special Measurement and Assembly Equipment:*

6.4.1 *Graduated Cylinder*—Blending of the deposit control additive may be required and the concentration may be given as a volumetric ratio. Use a sensible sized container for measuring.

6.4.2 *Analytical Balance*—Blending of the additive may be required and the concentration may be given as a mass ratio. An analytical balance capable of 0.01 g resolution with a maximum capacity of at least 2000 g is recommended. Also, a balance is required to determine intake valve weight, which is approximately 100 g, with accuracy of 0.25 % of full scale and resolution of 0.0001 g. Calibrate the balance following the manufacturer's procedure and frequency recommendations.

6.4.3 *Desiccator*—An airtight chamber with lid shall contain an adequate amount of desiccant to maintain a relatively moisture-free environment for intake valves with deposits. (see 7.8).

6.4.4 *Oven*—Use a natural convection oven that is capable of maintaining 93 °C ± 5 °C (200 °F ± 9 °F) for evaporating the cleaning solvents from the valves. The oven shall have sufficient dimensions to stand the valve upright. There shall be no arcing contacts in the oven.

6.4.5 *Power Wire Wheel*—Use a power wire wheel (bench grinder fitted with a fine, 150 mm (6 in.) diameter steel wire wheel) to clean the intake valves as specified. See 13.1.

6.4.6 *Walnut Shell Blaster*—Similar to a sand blaster, the walnut shell blaster uses shop air pressure; however, a fine, abrasive media of crushed walnut shells is used instead of sand. The walnut shells are sufficiently abrasive to remove carbon while not removing metal from the surface being cleaned. The walnut shell blaster technique is more effective than solvents and generally preferred over a wire brush for removing carbon deposits from the valves and the cylinder head.

6.4.7 *Valve Stem and Guide Measuring Equipment*—Specific equipment to measure valve stem-to-guide clearances in the cylinder head as required in this test method (see 10.4.6) is not specified. Use any commercially available automotive equipment that is capable of measuring to the specifications and tolerances listed in 10.4.6.

6.4.7.1 Accurate measurements are mandatory to determine stem-to-guide clearance as this parameter can affect oil consumption and intake valve deposit accumulation.

6.4.8 *Vernier Caliper*—A vernier caliper is necessary to measure valve seat width of the cylinder head as required in this test method (see 10.4.7).

6.4.8.1 Accurate measurement of valve seat width is required as this parameter can affect heat transfer from the valves, particularly the intake valve and the surface where deposits may accumulate, ultimately affecting deposit accumulation.

6.4.9 *Valve Spring Compression Testing Machine*—A valve spring compression testing machine capable of assessing valve spring condition as specified in 10.4.9 is required. The device shall have an accuracy of 2 % and a resolution of 0.45 kg (1 lb).

6.4.10 *Valve Lapping Tool*—Use a device to rotate or oscillate the valves on the seat to lap the valves. Suitable valve lapping tools are available from automotive tool supply sources. See 10.4.3.

6.4.11 *Valve and Valve Seat Cutting Equipment*—Equipment may be needed to ensure valve and valve seat mating quality as outlined in 10.4.2. Acceptable equipment is available from automotive tool supply sources.

6.4.12 *Blowby Measurement Apparatus*—The blowby measurement apparatus is a device to measure flow rate of the gas passing the piston rings and entering the crankcase. This flow rate provides an indication of the condition of the piston rings and cylinder bore and, therefore, is used as a quality assurance criteria. The device shall have an accuracy of 5 % full scale and a resolution of 0.3 L/min (0.01 ft^3/min).

6.4.13 *Fuel Injector Test Rig*—A suitable device capable of accurate, repeatable flow measurement of port fuel injectors is required. This device shall be capable of performing necessary port fuel injector evaluations as outlined in 10.3.1. No suitable commercially available apparatus has been identified.

6.4.14 *PCV Valve Flow Rate Device*—This device is used to verify the flow rate of the PCV valves. Fabricate the device according to the details shown in Fig. A1.10.

6.4.15 *Timing Light*—An inductive pickup timing light may be used to measure ignition timing.

7. Reagents and Materials

7.1 *Fuel:*

7.1.1 *Fuel Management*—Fuel management is very critical in this test. The following procedure shall be used each time a new base fuel batch will be used in testing:

7.1.1.1 The base fuel storage container(s) shall be relatively free from all contaminants.

7.1.1.2 Take at least a 900 mL fuel sample of the delivered base fuel before the base fuel is installed into the fuel storage container(s). The fuel sample shall be representative of the overall base fuel.

7.1.1.3 Flush the fuel storage container(s) with the base fuel.

7.1.1.4 Add the base fuel to the storage container(s).

7.1.1.5 Take at least a 900 mL fuel sample after the fuel storage container(s) are flushed with the base fuel and the base fuel has been installed into the fuel storage container(s). The fuel sample shall be representative of the overall base fuel.

7.1.2 *Test Fuel Quantity*—Approximately 950 L (250 gal) of test fuel (including all flushes) is required for the test.

7.1.3 *Additive/Base Fuel*—Some test requesters may require the test fuel be blended at the test laboratory and, therefore, will supply the neat deposit control additive and untreated base fuel. The test requester shall supply the deposit control additive and base fuel in appropriate volumes and packaging to ensure safe and efficient handling. Blending instructions detailing the concentration ratio either volumetric-based or mass-based shall accompany all deposit control additives. Mass-based measurement is preferred. However, it is most desirable to have the additive supplied in premeasured, individual containers. Clearly identify the blended fuel.

7.1.4 *Test Fuel*—Test fuel containing deposit control additive shall be a homogeneous blend of additives and base fuel. Blend sufficient fuel before the start of the test. The fuel may be stored in drums or tankage, and shall be labeled clearly to prevent misfueling. Measure and record quantities of fuel and additive blended and dispensed for use in determining the fuel consumption.

7.1.5 *Engine Break-in Fuel*—The engine break-in fuel shall comply with Specification D4814 requirements or Haltermann EEE[13] or equivalent. Approximately 380 L (100 gal) are required for engine break-in.

NOTE 2—Consider using a fuel with a minimum octane rating of 92 ((R+M)/2) to avoid detonation in the engine during the break-in period.

7.1.6 *Reference Fuel*—See Section 9 regarding reference fuel requirements and specifications.

7.2 *Engine Oil/Assembly Lubricant*—The standard engine oil and assembly lubricant shall be the IVD Reference Oil (IVD Dynamometer Reference Oil).[14] Approximately 4.7 L (5 qt) are needed for this test method, including engine assembly and initial crankcase fill.

7.3 *Engine Coolant*—The coolant is a mixture of equal volumes of a commercial ethylene glycol based low-silicate antifreeze and distilled or demineralized water. *Do not use uninhibited ethylene glycol.*

7.4 *Solvents and Cleaners:*

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[13] IVD Reference Base fuel is a product of Haltermann Products, subsidiary of the Dow Chemical Company,1201 S. Sheldon Rd., P.O. Box 429, Channelview, TX 77530-0429.

[14] The sole source of supply of the apparatus known to the committee at this time is Conoco Oil Co., P.O. Box 80430, Rochester, MI 48308. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

7.4.1 *Normal-Hexane or Cyclohexane*—The valves are rinsed with either *n*-hexane or cyclohexane. (**Warning—**In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used. Suitable protective clothing is recommended.)

NOTE 3—Reagent-grade chemicals will be used for all test procedures. Unless otherwise noted, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society,[15] where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficient purity to permit its use without lessening the accuracy of the determination.

7.4.2 *Naphtha Solvent*—Stoddard solvent conforming to Type I of Specification D235 is recommended. Proprietary solvents of this general type may be used. This fluid may be used for cleaning parts (that is, valve train parts, cylinder head, intake manifold, throttle body) and as a fuel injector test fluid.

7.5 *Fuel Injector Flow Test Fluid*—Use naphtha solvent (see 7.4.2).

7.6 *Valve Lapping Compound*—Use Fel Pro Clover 320 Grade 1A silicon carbide grease compound (Part No. 1A51804) valve lapping compound.[16]

7.7 *Crushed Walnut Shells*—A walnut shell blaster may be used to remove carbon and deposits from the head or, if necessary, from the intake valves at end-of-test (see 13.1.6.1). Use clean, fresh walnut shells which are available commercially from industrial and automotive supply sources.

7.8 *Desiccant*—Use a granular form of anhydrous calcium sulfate ($CaSO_4$).[17] When not in use, store the desiccant in an airtight container.

8. Hazards

8.1 *Specific Hazards*—Personnel are exposed to various hazards while in the testing area. Take appropriate care to ensure the safety of all personnel while in the testing area.

9. Reference Fuel

9.1 *Reference Base Fuel Batch Approval Process*—Each new batch of IVD reference base fuel[13] is approved by the following process:

9.1.1 Before initial blending, each of the fuel components is analyzed by the fuel supplier. A small amount of fuel mixture is then blended and analyzed using the methods described in Table 2 and in 9.2.2 and 9.2.3. The TMC, in conjunction with the ASTM IVD Dynamometer Test Surveillance Panel, determines the acceptability of the analytical data and authorizes blending of the entire batch for engine testing.

9.1.2 A sample of the IVD reference base fuel is shipped to designated independent laboratories. A program involving more than one calibration test is completed using the IVD reference base fuel and reference fuel additives selected by the TMC. The ASTM IVD Dynamometer Test Surveillance Panel is involved in the design of the program. The TMC reviews the test results and after satisfactory completion of the program, will authorize the fuel supplier to notify potential purchasers of the approval status of the IVD reference base fuel batch.

9.2 *Fuel Batch Analysis:*

9.2.1 Analyze each IVD reference base fuel shipment upon receipt from the supplier to determine the value of the parameters shown in Table 2. Compare the results to the values obtained by the supplier on that particular batch. The results should be within the ranges shown beside each parameter. This provides a method to determine if the fuel batch is as shipped, has been contaminated, or has aged prematurely. If any results fall outside the ranges shown in Table 2, the laboratory should contact the TMC for help in resolving the problem. These analyses track parameters easily measured at most locations and are usually successful at detecting either gross fuel contamination or significant deterioration with age, heat, oxidation, or mishandling, when compared with initial analysis values for the fuel batch. The primary sources of intake valve deposition species within a fuel are imperfectly defined, but are controlled in initial production of the fuel by the manufacturer, and verified by the user group by the process described in 9.1.2.

9.2.2 In addition, the fuel supplier shall analyze the contents of each storage tank that contains IVD reference base fuel used for qualified IVD Dynamometer Tests every two months to ensure the fuel has not deteriorated excessively or been contaminated in storage. Laboratories should take composite samples using Practice D4057 as a guideline. The fuel supplier shall provide an adequate supply of fuel sample containers with packaging and pre-addressed return labels to each dynamometer IVD laboratory. Upon receipt of fuel samples from the laboratories, the fuel supplier will perform the following analyses, report the results to the submitting laboratory, and tabulate the results in a database:

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[15] ~~Reagent Chemicals, American Chemical Society Specifications,~~*ACS Reagent Chemicals, Specifications and Procedures for Reagents and Standard-Grade Reference Materials,* American Chemical Society, Washington, DC. For ~~Suggestions~~suggestions on the testing of reagents not listed by the American Chemical Society, see ~~*Annual*~~*Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

[16] Available from Jacobs Equipment Distributing Company, 729 South Flores, San Antonio, TX 78204.

[17] Drierite has been found to be satisfactory. An equivalent material can be used.