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:*

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.

[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.

3.2.4 *intake valve deposit, n*—material accumulated on the tulip area of the intake valve of internal combustion engines, generally composed of carbon, decomposition products of fuel, lubricant, and additives, and atmospheric contaminants. **D5500**

3.3 *Definitions of Terms Specific to This Standard:*

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 *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.)

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[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.

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.

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.

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).

6.2.5 *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