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Standard Test Method for Evaluating Automotive Spark-Ignition Engine Fuel for Electronic Port Fuel Injector Fouling by Bench Procedure[1]

This standard is issued under the fixed designation D6421; 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 a bench test procedure to evaluate the tendency of automotive spark-ignition engine fuel to foul electronic port fuel injectors (PFI). The test method utilizes a bench apparatus equipped with Bosch injectors specified for use in a 1985-1987 Chrysler 2.2-L turbocharged engine. This test method is based on a test procedure developed by the Coordinating Research Council (CRC) for prediction of the tendency of spark-ignition engine fuel to form deposits in the small metering clearances of injectors in a port fuel injection engine (see CRC Report No. 592).[2]

1.2 The test method is applicable to spark-ignition engine fuels, which may contain antioxidants, corrosion inhibitors, metal deactivators, dyes, deposit control additives, demulsifiers, or oxygenates, or a combination thereof.

1.3 The values stated in SI units are to be regarded as the standard. Approximate inch-pound units are shown in parentheses for information purposes only.

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 and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given throughout this test method.

NOTE 1—If there is any doubt as to the latest edition of Test Method D6421, contact ASTM International Headquarters. Other properties of significance to spark-ignition engine fuel are described in Specification D4814.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D4814 Specification for Automotive Spark-Ignition Engine Fuel

D5598 Test Method for Evaluating Unleaded Automotive Spark-Ignition Engine Fuel for Electronic Port Fuel Injector Fouling

2.2 *ANSI Standard:*[4]

MC 96.1 American National Standard for Temperature Measurement Thermocouples

2.3 *CARB Standard:*[5]

Test Method for Evaluating Port Fuel Injector (PFI) Deposits in Vehicle Engines

2.4 *Clean Air Act Amendment:*[6]

Clean Air Act Amendments of 1990, Public Law 101–549, Title 1 – Provisions for Attainment and Maintenance of National Air Quality Standards

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum ~~Products~~ 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] "A Program to Evaluate a Bench Scale Test Method to Determine the Deposit Forming Tendencies of Port Fuel Injectors," available from Coordinating Research Council, Inc., 219 Perimeter Ctr. Pkwy., Atlanta, GA 30346.

[3] 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.

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

[5] Available from California Air Resources Board, P.O. Box 2815, Sacramento, CA 95815. (Incorporated by reference in California Code of Regulations, Title 13, Section 2257.)

[6] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

3.1.1 *base fuel, n*—unleaded automotive spark-ignition engine fuel that does not contain a deposit control additive but may contain antioxidants, corrosion inhibitors, metal deactivators, dyes, or oxygenates, or a combination thereof.

3.1.2 *cycle, n*—a 15-s pulsing period, followed by a 50-min heating period at 160°C (320°F), followed by a 10-min cool-down period.

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

3.1.3.1 *Discussion*—

For the purposes of this test method, the performance of a deposit control additive is limited to the electronic PFI tip areas.

3.1.4 *driveability, n*—the quality of a vehicle's performance characteristics as perceived by the operator in response to changes in throttle position.

3.1.5 *electronic port fuel injector (PFI), n*—an electromechanical device used to control fuel flow in an internal combustion engine.

3.1.6 *fouling, v*—formation of carbonaceous deposits on the pintle or metering surfaces of an electronic fuel injector, which reduces fuel flow rate.

3.1.7 *pintle, n*—a needle-like metering device extending beyond the electronic fuel injector body that is part of an electronic fuel injector, which controls flow rate and spray pattern.

3.1.8 *test fuel, n*—base fuel, with or without the addition of a deposit control additive, that is used for evaluation as described in this test method.

4. Summary of Test Method

4.1 This test method describes a procedure for evaluating the formation of deposits in PFIs. The test method includes a bench test procedure that has been shown to rapidly form deposits in fuel injectors and a procedure for determining resultant flow loss.

4.2 This test method uses a simulated fuel system consisting of a fuel pump, filter, pressure regulator, fuel rail, and fuel injectors. A heat source is applied to the fuel injectors to simulate the hot-soak portion of the vehicle test (see Test Method D5598).

4.3 Each test begins with screened injectors that are known to foul. The tips of these four clean fuel injectors are placed in an aluminum block. A stainless-steel internal reservoir is filled with 2 L of the test fuel.

4.4 During one 60-min test cycle, the fuel injectors are pulsed for 15 s, followed by a 50-min hot-soak interval in which the injector aluminum block temperature controller is set at a temperature of 160°C (320°F) and the fuel pressure is regulated to 263 kPa (38 psig), followed by a 10-min cool-down period. Flow measurements for each of the injectors are taken at the beginning of the test, after 22 cycles, and at the end of the test at 44 cycles.

4.5 The change in the rate of flow for each injector from the start to the end of the test is used to determine the fouling percentage of each injector.

5. Significance and Use

5.1 Driveability problems in PFI automobiles were first reported in 1984. Deposits are prone to form on the metering surfaces of pintle-type electronic fuel injectors. These deposits reduce fuel flow through the metering orifices. Reductions in metered fuel flow result in an upset in the air-fuel ratio, which can affect emissions and driveability. When heavy enough, these deposits can lead to driveability symptoms, such as hesitation, hard starting, or loss of power, or a combination thereof, that are easily noticed by the average driver and that lead to customer complaints. The mechanism of the formation of deposits is not completely understood. It is believed to be influenced by many factors, including driving cycle, engine and injector design, and composition of the fuel. The procedure in this test method has been found to build deposits in PFIs on a consistent basis. This procedure can be used to evaluate differences in base fuels and fuel additives. A study of PFI fouling was conducted in both the bench test and the vehicle test procedures to obtain a correlation. The vehicle tests were conducted as described in Test Method D5598. The tests were conducted on several base gasolines, with and without additives blended into these base fuels. The PFI bench test proved to be reliable, repeatable, and a good predictor of PFI fouling in test vehicles.

5.1.1 *State and Federal Legislative and Regulatory Action*—Legislative and regulatory activity, primarily by the state of California (see 2.3) and the federal government (see 2.4), necessitate the acceptance of a standard test method to evaluate the PFI deposit-forming tendency of an automotive spark-ignition engine fuel.

5.1.2 *Relevance of Results*—The operating conditions and design of the laboratory apparatus used in this test method may not be representative of a current vehicle fuel system. These factors must be considered when interpreting 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 Section 10 will result in an invalid test. Engineering judgment shall be applied during conduct of the test method when assessing any anomalies to ensure validity of the test results.

6. Apparatus

6.1 *Automatic Electronic PFI Bench Test Apparatus*[7,8]—This apparatus is composed of two units, a fuel handling unit and a controller.

6.1.1 *Fuel Handling Unit*—This unit houses a machined aluminum fuel rail and a heated aluminum block designed to accommodate four PFIs. Heaters and thermocouples are mounted in the heated aluminum block. This unit also houses a 2.25-L stainless steel reservoir, an electric fuel pump, a fuel regulator, and a variety of valves used to transfer fuel to and from the reservoir and to deliver fuel under pressure to the injectors (see Annex A1).

6.1.2 *Programmable Microprocessor Controller or Other Controller*—The controller is used to fill the fuel reservoir, control and measure the temperature of the heated block, pulse the injectors, control the soak period, count the number of test cycles, and control the flow period for the measuring of the flow rate. The unit is programmed to shut down automatically at the end of each 22-cycle period.

6.1.3 *External Pressure Regulator* —This regulator is used to adjust the pressure of the nitrogen gas on the fuel system. This ensures that the pressure of the fuel in the fuel rail is maintained with an accuracy of ±6.8 kPa (±1.0 psi) during the test.

6.1.4 *Electronic PFIs*—Only Bosch EV1.1A (Part Number 0280150360) pintle-style injectors shall be used.[8,9] The corresponding Chrysler Corp. part number is 4306024 and is clearly marked on the injector. The protective cap shall be removed from the injector by cutting the plastic cap with a razor blade and gently heating with a heat gun. The rubber o-rings and spacers shall be removed to expose the bare metal injector tip. Each injector shall be screened for fouling capability prior to use in the procedure. The screening procedure is found in Annex A2.

6.2 *Testing Area*—The ambient atmosphere of the testing area shall be reasonably free of contaminants. The temperature should be maintained at 24 ± 5°C (75 ± 9°F). Uniform temperature is necessary to ensure repeatable injector flow measurements. The specific humidity shall be maintained at a uniform comfortable level. (**Warning** —Provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used. Suitable protective clothing is recommended.)

6.3 *Laboratory Equipment:*

6.3.1 *Analytical Balance*—An analytical balance capable of 0.01 g resolution with a maximum capacity of at least 200 g is recommended. The balance should be calibrated following the manufacturer's procedure and frequency recommendations.

6.3.2 *Graduated Cylinders*—Four graduated cylinders of 50 or 100-mL capacity, accurate to the nearest millilitre are recommended for use in flow testing.

6.3.3 *Low Voltage Power Supply*—A 12 V, variable, direct current power source should be used in cleaning of the injectors.

6.3.4 *Ultrasonic Bath*—An ultrasonic bath with heating capabilities should be used for the cleaning of the injectors.

6.3.5 *Pipette Bulb*—A pipette bulb should be used to draw injector cleaning solution into the injector for cleaning.

6.3.6 *Pipette*—A disposable transfer pipette should be used to fill injectors with the cleaning solution during the cleaning procedure.

6.3.7 *Plastic Disposable Beakers*—Disposable plastic beakers of approximately 150 mL or other containers of equivalent size should be used to contain the injector cleaning fluid during the clean up of the injectors.

6.4 *Data Acquisition*—A data acquisition device, capable of collecting the raw data in accordance with 10.4, shall be required.

7. Reagents and Materials

7.1 *Purity of Reagents*—Reagent grade chemicals shall 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, where such specifications are available.[10] 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 determinations.

7.2 *Berryman Chem-Dip Carburetor and Parts Cleaner*[8,11]—This cleaner has been found effective in removing the deposits built up in the injectors. This cleaner or any other carburetor or engine parts cleaner that is proven effective in removing such

[7] The following instrument has been found suitable by interlaboratory cooperative testing: Port Fuel Injector Bench Test Apparatus. Available from Southwest Research Institute, San Antonio, TX.

[8] 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.

[9] The sole source of supply of the pintle-style injectors known to the committee at this time is Robert Bosch Corp., 25th Ave., Broadview, IL 60153.

[10] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For Suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual 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.

[11] The sole source of supply of the cleaner known to the committee at this time is Berryman Co., Dallas, TX.

deposits shall be used to clean the injectors. (**Warning**—Berryman Chem-Dip contains methylene chloride, monochlorotoluene, xylene, ethyl phenols, and xylenols that are extremely dangerous if inhaled, are skin irritant on contact, and are carcinogenic.)

7.3 *Rinsing Solvent*—A 1:1 mixture of *iso*octane and xylene, or suitable mixture of solvents, shall be used to rinse the bench test apparatus reservoir, injectors, and fuel lines between tests. Approximately 1 L is used.

7.4 *Test Fuel*—A test fuel is either a base fuel or a homogeneous blend of additives and base fuel. A single batch shall be blended before the start of the test. Approximately 8 L (2 gal) of fuel is needed for a single test.

7.5 *Additive/Base Fuel*—Some test requestors may require that the test fuel be blended at the test laboratory and, therefore, will supply the deposit control additive and may, at their option or if a suitable base fuel is not available at the test laboratory, supply untreated base fuel. The test requestor shall supply the deposit control additive and, if supplied, the 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. The blended fuel shall be clearly identified.

7.5.1 *Additive/Base Fuel Shipment and Storage*—The additive shall be shipped in a container as dictated by safety and environmental regulations. The additive shall be stored in accordance with all applicable safety and environmental regulations.

7.5.2 *Base Fuel*—The base fuel used for this test method should be typical of commercial, automotive spark-ignition engine fuel. The base fuel may contain oxygenates typical of those being used commercially.

7.6 *Nitrogen Gas (≥99.9 % Pure)*—This gas shall be used to pressurize the fuel system and the fuel rail.

8. Preparation of Apparatus

8.1 *Fuel Injector Preparation:*

8.1.1 The injectors shall be cleaned (see A3.2) prior to the running of the test. Proper cleaning is essential for running a valid test.

8.1.2 Check the injector flow (see A3.5). Injectors shall meet the conditions of Annex A4 before beginning the test.

8.2 Place the injectors into the fuel handling unit (see A3.3).

8.3 Pressurize the tank and the fuel lines with nitrogen gas.

8.4 Set test parameters as specified in Table 1. If using a programmable controller, program the controller in accordance with A3.4, or refer to your manufacturer's manual.

8.4.1 The test will run for 44 cycles with measurements taken at the end of each 22-cycle segment.

8.5 Add fuel to the internal fuel reservoir (see A3.5).

9. Procedure

9.1 Mount screened and cleaned injectors into the fuel handling unit and fasten in place (see A3.3).

9.2 Ensure that test parameters are set in accordance with Table 1 and that all other steps in Section 8 have been completed.

9.3 Measure the initial or pre-test injector flow (see A3.6).

9.3.1 Prior to making the measurement, bleed off any gases in the fuel rail (see A3.6) and discard the fuel.

9.3.2 Measure the flow masses for the four injectors independently. Hold the injector pintle open for 12 s while subjecting fuel to an initial nitrogen pressure of 263 kPa (see 6.1.3).

9.3.3 Record and average three separate flow mass measurements for each injector.

9.4 Begin test.

9.5 After completing 22 cycles, allow the base (aluminum block) temperature to cool to 24 ± 3°C (75 ± 5°F). The flow measurement (see A3.6) shall be performed within 4 h of completing 22 cycles and with the same test fuel used for the pretest flow. Record flow measurement results (see A3.6) and the base temperature at which the flow measurements were generated.

TABLE 1 Testing Parameters

Test Parameter	Setting
Mode selection	Constant pressure
Number of cycles	22
Pulse time	15 s
Soak time	60.00 min
Flush time	10 s
Fill time	0–99 s
Base temperature	160°C
Cool time	10 min
Flow time	12 s
Injector mode	All at once

9.6 The test may be aborted at this point if the test parameters detailed in 10.4 have been compromised, or if any equipment malfunction has been detected. Otherwise, continue testing for an additional 22 cycles.

9.7 After 44 cycles have been completed, allow the base temperature to cool to 24 ± 3°C (75 ± 5°F). Perform the flow measurement within 4 h of test completion and with the same test fuel as used for the pretest flow. Record flow measurement results (see A3.6) and the base temperature at which the flow measurements were generated.

10. Calculation

10.1 *Number of Test Cycles*—Complete 44 test cycles. Break the 44 cycles into two groups of 22 cycles run consecutively, with a break in between of less than 4 h.

10.2 *Fuel Injector Flow Measurement*—Statically flow test (see A3.6) injectors while still in the apparatus for 12 ± 0.5 s, using the test fuel. To ensure that the test fuel completely fills the injector during flow testing, flush injectors for at least 10 s with the test fuel prior to the start of the flow testing.

10.3 *Calculation of Fuel Injector Fouling*—Express the amount of fuel injector fouling as the percent difference between the 12 s flow mass of the cleaned injector and the 12 s flow mass of the same injector during or after the test period. Calculate fuel injector fouling using the following equation:

$$F_o = \frac{F_1 - F_2}{F_1} \times 100 \quad (1)$$

where:

F_o = percent fouling,
F_1 = initial flow mass to nearest tenth gram, and
F_2 = flow mass at end of test to nearest tenth gram.

For each injector, calculate the percent fouling of each of the three flow mass readings, and report the average. Take the average of the four injectors and report to the nearest percentage point.

10.4 *Determination of Test Validity*—During each test, strictly adhere to and monitor conditions of the bench test apparatus. As a minimum, record the following data while the apparatus is running: (*1*) the fuel rail pressure, (*2*) the manifold (aluminum block) temperature, and (*3*) the time of each portion of the test cycle (pulse, heating, cool down).

10.4.1 *Fuel Rail Pressure*—In a graphical representation of the pressure in the fuel rail, show that the pressure is maintained through the 60-min soak period at 263 ± 7 kPa (38 ± 1 psi).

10.4.2 *Manifold Temperature*—In a graphical representation of the temperature of the manifold (aluminum block), show that the temperature of the manifold is maintained at 160 ± 5°C (320 ± 9°F) for a minimum of 40 min of each cycle.

10.4.3 *Test Timing*—Use a timer, accurate to 0.1 s to verify that the pulse time of the injectors is 15 ± 1 s.

11. Report

11.1 Report the following information:
11.1.1 Dates of testing.
11.1.2 Fuel identification.
11.1.3 Temperature of heat soak.
11.1.4 Flow length.
11.1.5 Pulsing length.
11.1.6 Cool period time.
11.1.7 Fuel rail pressure.
11.1.8 Temperature at time of flow readings.
11.1.9 Mass flow readings (3) for each injector at the beginning of the test (initial), at 22 cycles and 44 cycles.
11.1.10 Average flow readings for each injector at 22 cycles and 44 cycles.
11.1.11 Percent flow loss (3) for each injector at 22 cycles and 44 cycles.
11.1.12 Average percent flow loss for each injector at 22 cycles and 44 cycles.
11.1.13 Average percent flow loss for the four injectors at 22 cycles and 44 cycles.

11.2 *Data Acquisition Summary Report*—The test validation criteria report, derived from the data acquisition equipment, shall include a graphical representation of the fuel rail pressure, a graphical representation of the manifold temperature, and a graphical representation of the timing of the test cycles.

12. Precision and Bias

12.1 The precision of this test method was determined based on a 1995 interlaboratory round-robin test program. A total of six labs participated, and each lab analyzed samples of eight fuels. All labs analyzed duplicate samples, and some examined triplicate samples of each fuel. Statistical examination yielded the interlaboratory test results for repeatability and reproducibility given in

Fig. 1. These were obtained using the precision statistics given in Table X1.1 (see Appendix X1), which include the number of runs, the average percent fouling, the repeatability value, and the reproducibility value.

12.2 *Repeatability*—The difference between successive test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct application of the test method, exceed the values below in only one case in twenty.

$$r = 8.65 + 0.43 \times \text{(average percent fouling)}$$

12.3 *Reproducibility*—The difference between two single and independent test results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the values below in only one case in twenty.

$$R = 12.75 + 1.34 \times \text{(average percent fouling)}$$

12.4 *Bias*—Since there is no accepted reference fuel suitable for determining the bias for the procedures used in this test method, bias has not been determined.

13. Keywords

13.1 base fuel; bench test; deposit control additive; deposits (in internal combustion engines); electronic port fuel injector (PFI); flow rate, hot soak; injector fouling; pintle; spark-ignition engine fuel; test fuel

ANNEXES

(Mandatory Information)

A1. ESSENTIAL COMPONENTS AND FUNCTION OF THE BENCH TEST APPARATUS

A1.1 The essential components of the PFI apparatus are indicated in Fig. A1.1. The apparatus consists of a fuel manifold (1), an injector-heater block assembly (2), injectors (3), a 2000-mL reservoir (4), an electric fuel pump (5), a fill valve (6), a leak valve (7), a nitrogen valve (8), a pressure valve (9), a flush valve (10), a pressure regulator (11), a system of valves and tubing, and the system's PC-based controller. A fire suppression system accompanies the fuel handling unit.

A1.2 *Reservoir Filling Operation*—When the 2000-mL reservoir is being filled, the electric fuel pump is started, which actuates the fill valve (6), the leak valve (7), and the nitrogen valve (8) (see Fig. A1.1). When the reservoir is filled, excess fuel is bled off through the overflow tubing.

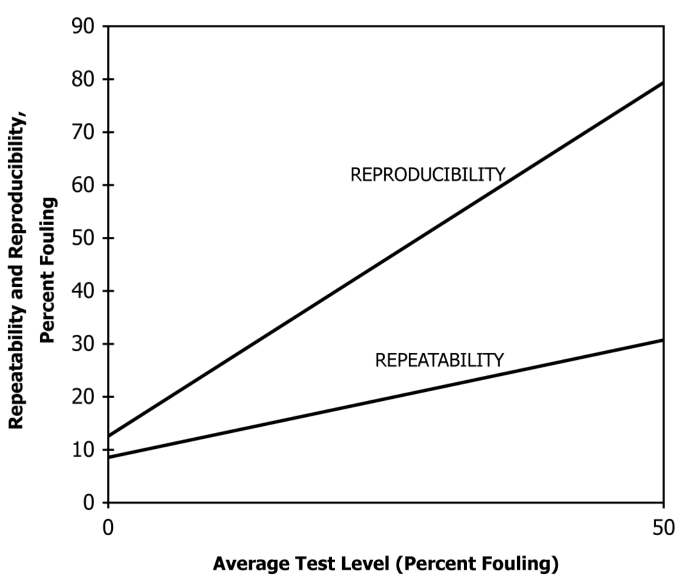

FIG. 1 Precision for Bench Test Apparatus Using Average-Injector Fouling