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 D 6421; 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 D 6421, contact ASTM Headquarters. Other properties of significance to spark-ignition engine fuel are described in Specification D 4814.

2. Referenced Documents

2.1 *ASTM Standards:*

D 4814 Specification for Automotive Spark-Ignition Engine Fuel[3]

D 5598 Test Method for Evaluating Unleaded Automotive Spark-Ignition Engine Fuel for Electronic Port Fuel Injector Fouling[3]

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:*

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

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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] *Annual Book of ASTM Standards*, Vol 05.03.

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[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 Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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 D 5598).

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 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 D 5598. 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]—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] 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

[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] Available from Robert Bosch Corp., 25th Ave., Broadview, IL 60153.

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.[9] 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*[10]—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 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).

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] *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 *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.

[10] Available from Berryman Co., Dallas, TX.

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.

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: (a) the fuel rail pressure, (b) the manifold (aluminum block) temperature, and (c) 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

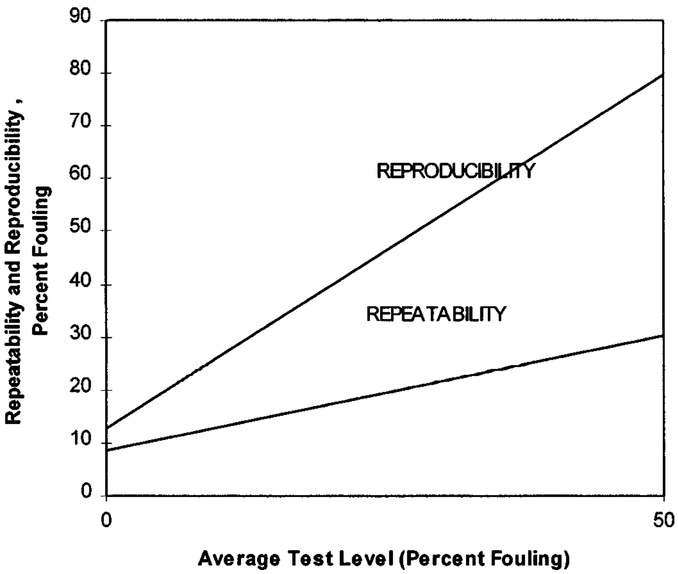

FIG. 1 Precision for Bench Test Apparatus Using Average-Injector Fouling

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), a 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.

A1.3 *Injector Flow Operation*:

A1.3.1 When the injectors are flowed individually or as a group, the fill valve (6), the leak valve (7), the nitrogen valve (8), and the pressure valve (9) (see Fig. A1.1) are open.

A1.3.2 The injectors are opened with 12 V and kept open with a constant 6 V current.

A1.4 *Test Cycle Operation*—During the test cycle, the fill valve (6), the leak valve (7), and the nitrogen valve (8) (see Fig. A1.1) are open. During the pulsing portion of the test cycle, the injectors are opened alternately for 4 ms and then closed for 20 ms. During the cool down portion of the test cycle, the heaters are turned off.

A1.5 *Flush Mode Operation*—When the apparatus is in the flush mode, the electric fuel pump (5), the pressure valve (9), and the flush valve (10) (see Fig. A1.1) are activated while the injectors are held open.

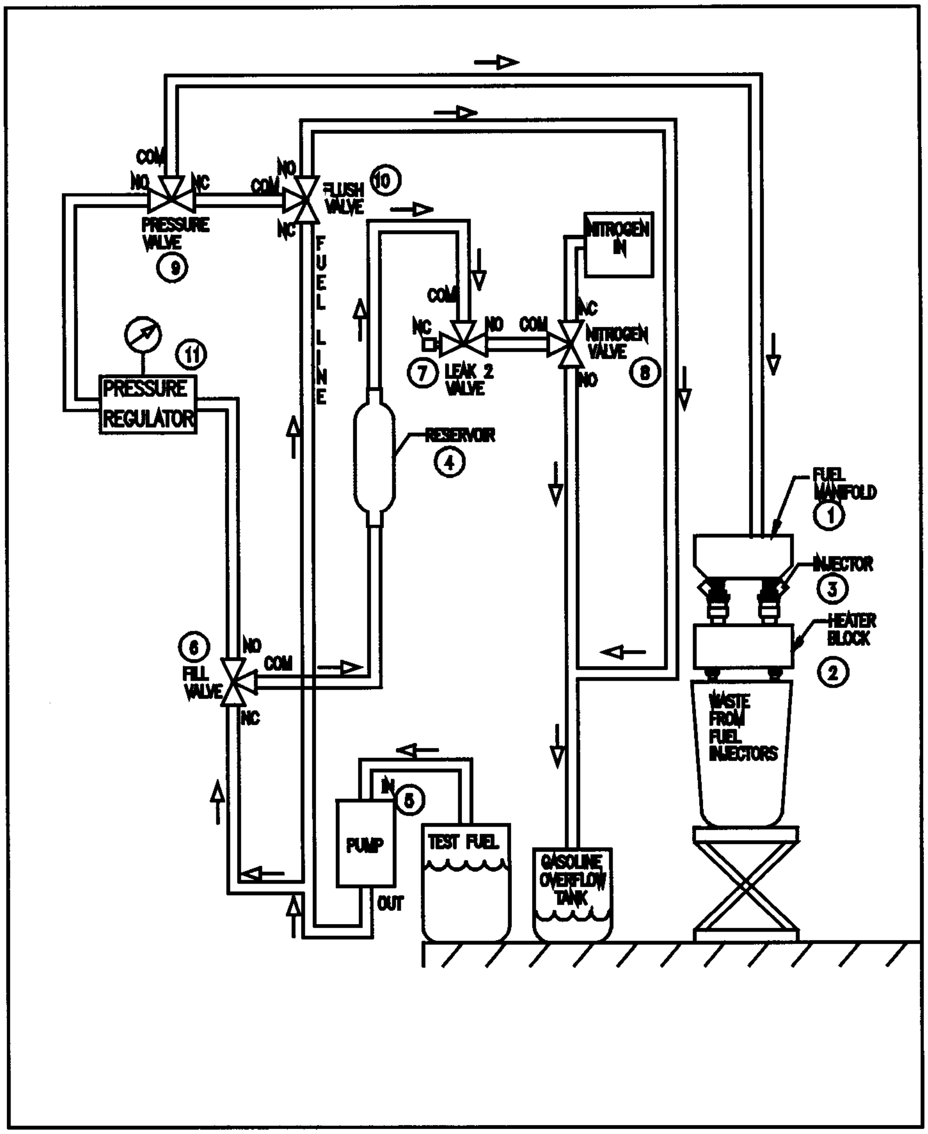

FIG. A1.1 Flow Schematic of PFI Bench Test Apparatus

A2. TEST PROCEDURE FOR SCREENING OF INJECTORS

A2.1 *Scope*—This test method provides the means to evaluate electronic fuel injectors for fouling tendencies. It is important to use injectors that have a tendency to foul so that measurable flow loss may be obtained using the bench test within a 44-cycle test. All injectors shall be screened using this test method before being utilized in the PFI bench test method apparatus.

A2.2 *Initial Screening Test Procedure*—Each set of potential injectors shall be subjected to an initial screening test consisting of 66 cycles using Phillips's Injector Fouling Fuel.[11] If after 66 cycles, an injector does not show 25 % flow loss or greater, it is not suitable for use in this test. Injectors that pass the initial screening test shall be subjected to a second set of runs (66 cycles) and must show a flow loss of at least 25 % to be found acceptable for use in this test. Experience has shown that less than 1 injector in 25 will have sufficient flow loss to be suitable for testing purposes.

NOTE A2.1—The fouling properties of new lots of Phillips Injector Fouling Fuel need to be checked against results from old lots to determine their similarities.

A2.3 *Group Screening Test Procedure*—Each potential set of four injectors shall be tested as a group with a screening test of 44 cycles using a fuel that is known for its fouling properties, such as Phillips Injector Fouling Fuel, and an EPA qualification fuel, such as Amoco Indolene HO Motor Fuel[12] or

[11] Available from Phillips Petroleum Co., Borger, TX.

[12] Available from Amoco Petroleum Products Co., Naperville, Il.

Specified Fuels and Chemicals EEE Fuel.[13] After the 44 cycles, an acceptable set of injectors shall have an average flow loss between 25 and 65 % in the Phillips Injector Fouling Fuel and no greater than 5 % in the EPA qualification fuel. If the average for the set is outside these limits, one of the injectors may be replaced with another screened injector and the testing repeated until an acceptable set of injectors is found.

[13] Available from Specified Fuels and Chemicals, Channelview, TX.

A3. INSTRUCTIONS FOR PREPARATION AND OPERATION OF THE FUEL INJECTOR BENCH TEST APPARATUS

A3.1 The following instructions are included for those laboratories that have PFI bench test apparatus manufactured by Southwest Research Institute. Detailed instructions are provided for performing several of the tasks when using the manufactured apparatus as referenced in the procedure. For equipment from other manufacturers refer to their instruction manuals.

A3.2 *Fuel Injector Preparation*: (**Warning—**Before removing the injectors, release the internal nitrogen pressure and use the *Flow* instruction to release the pressure in the fuel rail.)

A3.2.1 Remove the injectors from the fuel handling unit.

A3.2.1.1 Undo the latches on each side of the fuel rail. Remove the connecting wire plugs from the sockets. Lift the fuel rail and injectors out of the aluminum heating block. Disconnect the fuel line that connects the fuel rail to the unit, and remove the fuel rail from the unit.

A3.2.1.2 Remove the injectors from the fuel rail.

A3.2.2 Connect each injector electrode to a variable 12-V power supply with sufficient voltage (4 to 6 V) to allow the pintle to retract in the *wide-open* mode. Reduce the voltage to 2 to 4 V to avoid damaging the coils.

A3.2.3 Immerse the injectors in 150 mL plastic disposable beakers or similar containers, one-third to one-half filled with injector cleaning solution so that approximately half the injector is submerged.

A3.2.4 Fill each injector with the cleaner using a pipette. Push the cleaner though the injector using a pipette bulb, and refill the injector with cleaner.

A3.2.5 Place the beakers in an ultrasonic bath heated to 50–90°C (122–194°F) for 1 h.

A3.2.6 Every 15 to 20 min, use a pipette bulb to push the cleaner through the injectors and refill them with cleaner.

A3.2.7 Remove the injectors from the beakers, re-install them in the apparatus (see A3.3), and flush with approximately 50 to 100 mL of rinsing solvent or flush with the gasoline to be tested next. Discard the flushing material.

A3.2.8 Test the fuel flow of each injector (see A3.6). If the injectors do not exhibit clean flow, as described in Annex A4, subject them to another 30 min in the ultrasonic bath. Repeat as many times as necessary to obtain clean flow.

A3.3 *Installation of Fuel Injectors*: (**Warning—**Release any build-up of pressure from the internal fuel reservoir.)

A3.3.1 Place the injectors into the fuel rail. Adjust the injectors to ensure that the electrodes are aligned to the sides of the fuel rail. If the electrodes are not aligned properly, the fuel will leak from the fuel rail.

A3.3.2 Hold the fuel rail with the injectors inside the fuel handling unit while the fuel line is attached. (Avoid crimping the fuel line.)

A3.3.3 Place the injector tips into the holes in the aluminum block.

A3.3.4 Plug the connecting wires into their sockets.

A3.3.5 Attach the connecting wires to the injector electrodes.

A3.3.6 Clamp the fuel rail into place using the brackets on each side.

A3.4 *Programming the Controller Unit*:

A3.4.1 Turn the controller on. Use the touch screen to select *Test Configuration* from the menu.

A3.4.2 Press *Mode Selection*, and select *Constant Pressure*. Then press *Exit* to return to the main screen.

A3.4.3 Press *Test Number*, and enter a number (optional). Then select *Save Number*.

A3.4.4 Press *Fuel Name*, and enter the name of the test fuel (optional). Then select *Save Fuel Name*.

A3.4.5 Select test parameter settings as listed in Table 1, being careful to save each setting as it is entered.

A3.4.6 Select *Exit* to return to the main menu.

A3.4.7 Connect an external source of nitrogen to the unit. An in-line pressure release valve attached to the external nitrogen port is recommended for convenience.

A3.4.8 Use the *Other Functions* key to display the *Other Functions Menu*. Press *Set Pressure* to access a screen for gas regulation. Adjust the pressure (see 6.1.2) using nitrogen from a laboratory cylinder by pressing the *Increase* or *Decrease* key and then adjusting the valve regulator at the nitrogen source. Upon pressing the *Done* key, the system will automatically maintain constant pressure during the test, and the main menu will return to the screen.

A3.5 *Filling the Internal Reservoir*:

A3.5.1 Attach the quick-disconnect tubes to the fuel ports, and place the other ends in the fuel.

A3.5.2 Fuel from a previous test is removed from the internal fuel reservoir by pressing *Flow* and is removed from the fuel pump by pressing *Flush*. Select *Other Functions* and then *Flush*.

A3.5.3 With the quick disconnect lines in place, the internal reservoir shall be completely rinsed at least three times with 300 mL of rinsing solvent and once with 300 mL of the new fuel. Be sure to rinse the flow lines and the flush lines. Rinsing solvent is introduced into the reservoir by pressing *Other Functions* and then *Fill*.

A3.5.4 To fill the internal reservoir with fuel, press *Other Functions*, then *Fill*. Continue filling until fuel returns to the original container.

A3.5.5 The filling can be discontinued at any time by pressing *Abort*.

A3.6 *Measuring Injector Flow*:

A3.6.1 Place a large beaker (approximately 1000 mL) under the mounted injectors to catch the flow of all four injectors.

A3.6.2 Press *Injector Mode* key, and select *All at Once*, then press *Done* to return to the main menu.

A3.6.3 Bleed off any gas bubbles in the fuel lines by pressing the *Flow* key. The process can be discontinued by pressing *Abort*. Discard the fuel collected in the beaker.

NOTE A3.1—To eliminate the bubbles formed from a test fuel with a high vapor pressure, the rinsing solvent can be substituted for all of the flow mass measurement.

A3.6.4 Place a graduated cylinder under each injector.

A3.6.5 Press *Injector Mode* key, and select *Cycle Through*, then press *Done* to return to the main menu.

A3.6.6 Press the *Flow* key, which allows the fuel to flow for 12 sec.

A3.6.7 Discard the first flow volume. Record the mass of fuel for each injector three times, and take the average. Measure the mass to the nearest tenth of a gram.

A3.6.8 Check the injectors to determine if fuel is leaking because of a faulty seated pintle. If leakage is observed and cannot be corrected, the injector must be replaced.

A4. TEST METHOD FOR DETERMINATION OF FUEL INJECTOR CLEAN FLOW

A4.1 *Scope*—This test method provides a means to establish a clean flow measurement for the electronic PFIs. It is important to know this value because the initial flow value may affect the rate of deposit accumulation. This test method shall be run on all injectors before being utilized in the bench test apparatus.

A4.2 *Summary of Test Method*—A screened injector shall be monitored to determine an average clean flow, which may be achieved by repeated cleaning of the injector. Records should be made of the injector flow each time it is cleaned to establish this value. Once a value is established, the injector should be cleaned sufficiently after each use to return it to a clean flow condition defined as ±5 % of its original average flow.

A4.3 *Procedure*:

A4.3.1 Four screened injectors (see Annex A2) are submerged in 150-mL plastic beakers, half filled with an appropriate engine parts cleaner. The pintles are held open by exposing the injectors to 2 to 4 V of direct current. The beakers with the injectors are placed in an ultrasonic bath that is heated to 50 to 80°C for an hour. During that time, cleaner is pushed through the injectors and additional cleaner is used to fill the injectors at 10 to 15 min intervals (see Annex A3).

A4.3.2 Flow readings are taken for each of the four injectors and recorded.

A4.3.3 The injectors are returned to the cleaning process for an additional 30 min.

A4.3.4 Flow readings are taken a second time, and the flows are compared to the first set of readings. If there is an increase of 2 %, or more, in the flow rate for any of the four injectors, repeat step A4.3.3 until there is no increase. If the flow of a single injector varies by more than ±5 % from the average of the four injectors, then continue with the cleaning (see A4.3.3).

A4.3.5 When the four injectors meet the criteria specified in A4.2, the injectors can be considered to have full flow.

A4.4 After determining full flow, and over the life span of the injector, the flows should remain constant, all injectors being within ±5 % of the average of the four injectors. If an injector does not remain within these ranges, it should be considered for replacement.

APPENDIX

(Nonmandatory Information)

X1. RESULTS OF CRC INTERLABORATORY STUDY

X1.1 Table X1.1 summarizes the results of an interlaboratory study conducted by the CRC. The study consisted of eight fuels on seven apparatus.

X1.2 An additional study was done to determine the repeatability of this test at the low range of this test method (see Fig. X1.1). The data from 2 of the fuels in the interlaboratory study and 22 other fuels that gave fouling of 10 % or less were analyzed. The results showed that for low fouling fuels, the repeatability would, in the normal and correct application of the test method, exceed the values below in only one case in twenty.

$$r = 3.151 + 0.14 \times \text{(average percent fouling)}$$

TABLE X1.1 Interlaboratory Study Results: Analysis of Bench Test Results Average Percent Fouling

Fuel	Runs	Average	Repeatability	Reproducibility
A	15	22.1	23.6	54.2
B	17	25.4	13.1	56.7
C	15	38.5	20.0	55.8
D	17	7.0	14.5	19.5
E	15	0.7	5.4	11.1
F	15	19.1	12.4	32.6
G	18	23.4	31.7	41.9
H	16	–0.9	6.4	11.6

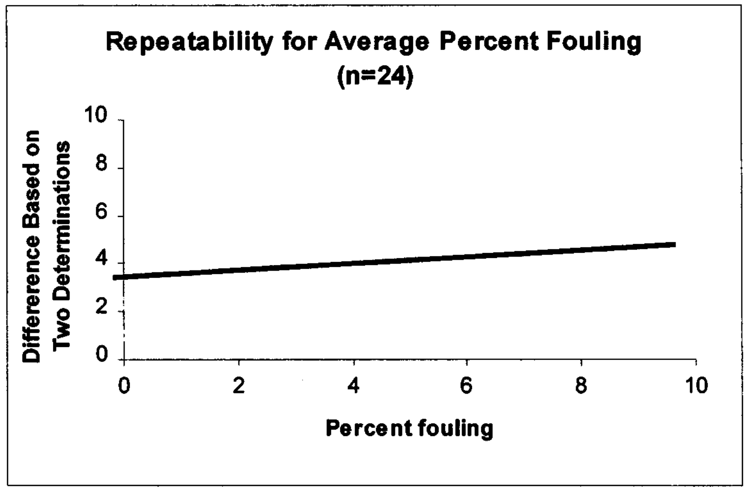

FIG. X1.1 Repeatability for Low Fouling Fuels