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

This standard is issued under the fixed designation D 5598; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method is based on a test procedure developed by the Coordinating Research Council (CRC) and maintains as much commonality as possible with the original test. A similar test method is described in the California Air Resource Board (CARB) report, "Test Method for Evaluating Port Fuel Injector Deposits in Vehicle Engines."

Driveability problems in PFI automobiles were first reported in 1984. These driveability problems were caused by deposits in the tips of pintle-type fuel injectors. In response to this problem, the CRC developed a program to evaluate a method of testing PFI deposit-forming tendencies in gasolines. -h test cycle consisting of 15 min of operation at 88 kph (55 mph) followed by a 45-min soak period was used for the program. This test cycle showed statistically significant differences in deposit-forming tendencies of the test fuels on the vehicles' fuel injectors. The results of the CRC program are discussed in CRC Report No. 565,[2] and SAE Paper 890213.[3]

1. Scope

1.1 This test method covers a vehicle test procedure to evaluate the tendency of an unleaded spark-ignition engine fuel to foul electronic port fuel injectors (PFI).

1.2 The test method is applicable to unleaded spark-ignition engine fuels which may contain antioxidants, corrosion inhibitors, metal deactivators, dyes, deposit control additives, and oxygenates.

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information 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 5598, 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 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)[4]

D 4814 Specification for Automotive Spark-Ignition Engine Fuel[5]

2.2 *ANSI Standard:*

MC 96.1 Temperature Measurement Thermocouples[6]

2.3 *Other Standards:*

"Test Method for Evaluating Port Fuel Injector (PFI) Deposits In Vehicle Engines," State of California—Air Resources Board (CARB), Stationary Source Div., March 1, 1991 (incorporated by reference in California Code of Regulations, Title 13, Section 2257).[7]

Title 1—Provisions for Attainment and Maintenance of National Air Quality Standards, Clean Air Act Amendments of 1990 Public Law 101-549, Nov. 15, 1990.[8]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.A on Gasoline and Oxygenated Fuels.

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[2] CRC Report No. 565 "A Program to Evaluate a Vehicle Test Method for Port Fuel Injector Deposit-Forming Tendencies of Unleaded Base Gasolines," February 1989. Available from Coordinating Research Council, Inc., 219 Perimeter Ctr. Pkwy., Atlanta, GA 30346.

[3] Tupa, Taniguchi, Benson, "A Vehicle Test Technique for Studying Port Fuel Injector Deposits—A Coordinating Research Council Program," Society of Automotive Engineers (SAE) Technical Paper Series: Paper No. 890213, 1989, Available from Society of Automotive Engineers International, 400 Commonwealth Dr., Warrendale, PA 15096.

[4] *Annual Book of ASTM Standards*, Vol 06.04.

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

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

[7] Available from California Air Resources Board, P.O. Box 2815, Sacramento, CA 95812.

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

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, and oxygenates.

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

3.1.2.1 *Discussion*—For the purpose of this test method, the performance evaluation of a deposit control additive is limited to the electronic port fuel injector tip areas.

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

3.1.3.1 *Discussion*—The performance characteristics may include cold starting and warmup, acceleration, vapor lock, and hot starting.

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

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

3.1.6 *pintle, n*—needle-like metering device, that is part of an electronic fuel injector, which controls flow rate and spray pattern.

3.1.7 *test fuel, n*—base fuel with or without the addition of a deposit control additive which is used to accumulate mileage 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 port fuel injectors of a modern spark-ignition engine. This test method described herein utilizes a 2.2-L Chrysler turbocharged engine equipped with an overhead camshaft, two valves per cylinder, and electronic port fuel injection. This test method includes a procedure for running a vehicle on a prescribed test cycle to form deposits in the port fuel injectors and a procedure for determining the resultant flow loss of a set of standardized injectors of known flow rate.

4.2 Each test begins with a new set of standardized fuel injectors which have previously been flow rated. All routine maintenance is performed in accordance with the Chrysler service manual.[9] The entire fuel system is flushed and filled with the new test fuel. To ensure compliance with the established test procedure, a data logger is active at all times after the test has begun, during all mileage accumulation and soak times.

4.3 The vehicle is operated on a cycle consisting of 15 min at a speed of 88 kph (55 mph) and an engine soak time of 45 min. This cycle is repeated for a total of 16 100 km (10 000 miles).

4.4 After the required mileage has been accumulated, the port fuel injectors are removed from the engine and the end-of-test flow rate is measured. The resultant flow loss is then calculated by comparing both end and start of test flow rates. Operational and mechanical criteria are then reviewed to determine if the test shall be considered valid.

5. Significance and Use

5.1 *Test Method*—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, loss of power, or a combination thereof, that are easily noticed by the average driver and 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 design, port fuel injector design, and composition of fuel used. The procedure in this test method has been found to build deposits in injectors on a consistent basis. The deposits formed by this procedure are similar to the deposits experienced in the field in terms of composition and in amount of deposition. This procedure can be used to evaluate differences in unleaded base fuels and fuel additives.

5.1.1 *State and Federal Legislative and Regulatory Action*—Legislative and regulatory activity, primarily by the state of California[7] and the Federal Government[8] necessitate the acceptance of a standard test method to evaluate the port fuel injector deposit-forming tendency of an automotive spark-ignition engine fuel.

5.1.2 *Relevance of Results*—The operating conditions and design of the engine and vehicle used in this test method are not representative of all modern automobiles. These factors must 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 Section 10 will result in a void test. Engineering judgment must be applied during conduct of the test method when assessing any anomalies to ensure validity of the test results.

5.2.2 *Vehicle Compliance*—A test is not considered valid unless the vehicle has met the quality control inspection requirements in accordance with 8.2.

6. Apparatus

6.1 *Automobile*—The vehicle to be used for this test method is a Chrysler Corp. vehicle equipped with a 2.2-L, 4- cylinder turbocharged engine. An intercooled turbocharged engine may also be used. Vehicles equipped with either manual or automatic transmissions are acceptable. Hood vents shall be plugged on vehicles so equipped. Only vehicles from model years 1985 through 1987, inclusive, shall be used. Allowable vehicle models are shown in Table 1.

6.1.1 *Electronic Port Fuel Injectors*—Only Bosch EV1.1A pintle-style injectors with plastic caps shall be used. These

[9] Available from Chrysler Corp. Service Publications, 25999 Lawrence Ave., Center Line, MI 48015.

TABLE 1 Allowable Vehicle List

Chrysler	Dodge	Plymouth
Laser	Daytona	Caravelle
LeBaron	600	Lancer
LeBaron GTS	Charger	Sundance
New Yorker	Shadow	Omni GLH

injectors are Bosch part number 0280150360.[10] The corresponding Chrysler Corp. part number is 4306024 and is clearly marked on the injector. All tests shall begin with new, flow-tested injectors. Each new injector shall be qualified for leak rate prior to testing using the procedure in Annex A1.

6.1.2 *Tires*—All tires shall be of the same size and as specified by the vehicle manfacturer. Tires shall be inflated to the manufacturer's recommended pressure or up to a maximum pressure of 310 ± 10 kPa (45 ± 0.5 psi) for chassis dynamometer use.

6.1.3 *Miscellaneous Parts*—All powertrain components, front-end accessory drive, air intake system, and exhaust system, except as specified, shall be original equipment, original equipment manufacturer replacement parts, or equivalent.

6.1.4 *New Engine/Vehicle Parts List*—Table 2 contains those frequently replaced parts with the corresponding Chrysler/Mopar part number to be used for the buildup of the vehicle as required by this test method. Part numbers suggested in Table 2 or listed by the manufacturer may vary from model-to-model.

TABLE 2 Frequently Replaced Parts List

Part	Part No.
Air conditioning belt	4343523
Air filter	4342801
Distributor cap (1987)	5226546
Distributor rotor (1987)	5226535
Exhaust pipe hanger	4150798
Fan relay package	4419169
Fuel injector	4306024
Fuel injector O-ring	5277919
Oil filter (1986)	4419970
Oil filter (1987)	4105409
Oxygen Sensor	5227368
Positive crankcase ventilation (PCV) hose	4387387
Positive crankcase ventilation (PCV) valve (1987)	3671076
Power steering belt	4343490
Radiator cap	3781830
Spark plug	RN12YC[A]
Spark plug wires	4419359
Temperature sensor	5226374
Timing chain cover	4105714
Voltage regulator	4275313
Water pump	4293898
Water pump with O-ring	5203542
Fuel pressure regulator	4275313

[A] Champion, or equivalent.

6.2 *Laboratory Facilities*:

6.2.1 *Fuel Injector Testing Area*—The ambient atmosphere of the fuel injector testing area shall be reasonably free of contaminants. The temperature shall be maintained at a uniform temperature between 21 and 27°C (70 and 80°F). Uniform temperature is necessary to ensure repeatable injector flow measurements. **Precaution**—See Note 2.

NOTE 2—**Precaution:** Provide adequate ventilation and fire protection in areas where flammable or volatile liquids, or both, and solvents are used. Suitable protective clothing is recommended.

6.2.2 *Garage/Maintenance Area*—The ambient atmosphere of the garage/maintenance area shall be reasonably free of contaminants. The temperature and humidity shall 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. **Precaution**—See Note 3 and Note 4.

NOTE 3—**Precaution:** Adequate ventilation and fire protection are necessary in areas where automotive spark-ignition engine fuel and deposit control detergent additives are handled. Suitable protective clothing is recommended.

NOTE 4—**Precaution:** Adequate ventilation and fire protection are necessary concerning the venting of the vehicle exhaust and when working on vehicle fuel systems. Suitable protective clothing is recommended.

6.2.3 *Chassis Dynamometer*—A chassis dynamometer may be used for mileage accumulation. The dynamometer shall be calibrated before the beginning of each series of tests and monitored throughout each test. Both single- and dual-roll dynamometers are acceptable for use.

6.2.4 *Deposit Control Additive Blending Facilities*—Instead of supplying a finished test fuel, the test sponsor may supply concentrated additive in bulk to the test laboratory. The test requestor shall obtain concurrence from the test laboratory regarding the supply of base fuels and additives and their packaging. For those laboratories offering the capability of blending additive and base fuel, the laboratories must have the ability to handle and blend the additive into fuel supplied in either bulk, 210-L (55-gal) drums, or both. The laboratory shall have an appropriate balance or graduated cylinder to blend the additive at the recommended concentrations expressed as a mass or volumetric ratio. The base fuel and additive shall be placed, at the appropriate ratio, into 210-L drums or bulk storage tanks and clearly labeled. Provisions to stir or recirculate the fuel/additive blend to ensure a homogeneous mixture are necessary. Safe, clean storage shall be provided for base fuel, additive, and test fuel. The ambient atmosphere of the additive blending facility area shall be reasonably free of contaminants. The testing laboratory shall retain a 1-L sample of the fuel blend. The sample shall be held for one month after test completion date or released to test requestor. **Precaution**—See Note 3.

6.2.5 *Fuel Storage and Refueling Facilities*—Sufficient finished test fuel shall be stored at the refueling station in clearly labeled drums or dispensers. In laboratories that may run several different test methods concurrently, dispensers or hand pumps for the drums shall not be switched between dissimilar test fuels. To ensure the test fuels are not contaminated either by other test fuels or foreign matter, a suitable structure shall be provided to contain the test fuels safely. The laboratory shall have a protocol to ensure the test vehicle receives the proper test fuel. **Precaution**—See Note 3 and Note 4.

6.3 *Laboratory Equipment*:

[10] Available from Robert Bosch Corp., 2800 S. 25th Ave., Broadview, IL 60153.

6.3.1 *Data Acquisition*—A data acquisition device, capable of collecting the raw data in accordance with 10.5, shall be required.

6.3.2 *Temperature Measurement Equipment*—Temperature measurement equipment and locations for the required temperature measurements are specified as follows. Alternative temperature measurement equipment may be used if equivalent performance can be demonstrated. The accuracy and resolution of the temperature measurement sensors and the complete temperature measurement system must follow guidelines detailed in the Research Reports" Data Acquisition Task Force Report"[11] and "Instrumentation Task Force Report to ASTM Technical Guidance Committee."[12]

6.3.2.1 If thermocouples are used, all thermocouples shall be premium, sheathed types. Thermocouples, wires, and extension wires should be matched to perform in accordance with the limits of error as defined by ANSI MC96.1. Either Type J (Iron-Constantan), Type T (Copper-Constantan), or Type K (Chromel-Alumel) thermocouples are acceptable.

6.3.3 *Vehicle Speed*—A suitable sensor shall be utilized to measure vehicle speed ±2 kph (±1 mph).

6.3.4 *Engine On-Time*—A suitable means shall be utilized to record ignition power on and off time during each 1-h cycle, accurate to the nearest second.

6.4 *Special Measurement and Assembly Equipment*:

6.4.1 *Graduated Cylinder*—Blending of the additive may be required and the concentration may be given as a volumetric ratio (see Note 5). A1000-mL graduate is recommended.

NOTE 5—Volumetric measurement of the deposit control additive is not recommended. Mass-based measurement is preferred.

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 a 0.01-g resolution with a maximum capacity of at least 2000 g is recommended. The balance shall be calibrated following the manufacturer's procedure and frequency recommendations.

6.4.3 *Fuel Injector Flow Apparatus*—A suitable fuel injector flow measurement device shall be capable of accurate, repeatable flow measurements. The injector flow apparatus shall maintain a constant flow fluid temperature between 21 to 27°C (70 to 80°F) and shall be recorded for each set of injector flow measurements. The maximum deviation in temperature between injector flow measurements throughout an entire test shall be less than 5°C (9°F). Be aware that temperature affects a fluid's volume and density and use engineering judgment along with good laboratory practices to enable a high level of test precision and accuracy. The test fluid pressure supplied to the injector(s) shall be 310 ± 3.4 kPa (45 ± 0.5 psi) during the entire test. Maintaining this pressure is very critical because a small change in pressure will have a dramatic effect on the flow rate and spray pattern. Either a direct weight or volumetric measurement technique is acceptable for quantifying fuel injector flow rates. An illustration of a fuel injector flow apparatus is shown in Fig. 1. Necessary requirements of any type of flow bench design include the following:

6.4.3.1 *Fluid Flow Measurement Device*—The device shall have ±0.5-mL accuracy.

6.4.3.2 *Timer Mechanism*—The device shall be capable of ± 0.01-s accuracy.

6.4.3.3 *Analytical Balance*—If a direct weigh method is utilized, an analytical balance shall be used with a 600-g capacity or higher, and ±0.001-g resolution.

6.4.3.4 *System Fuel Pump*—The fuel pump shall be capable of supplying a fuel pressure of 375 kPa (55 psi). Pump shall be compatible with fuel pressure regulator (see also 6.4.3.8 for requirements).

6.4.3.5 *System Fuel Filter*—Chrysler part number 4279987, or equivalent, shall be used.

6.4.3.6 *Power Supply*—An electronically controlled 12-V d-c device shall be used to energize injectors. Batteries shall not be utilized to energize fuel injectors.

6.4.3.7 *Fuel Injector Manifold*—A suitable device shall be utilized which is capable of holding one to four fuel injectors.

6.4.3.8 *Fluid Pressure Regulator*—A suitable device capable of maintaining 310 ± 3.4-kPa (45 ± 0.5-psi) solvent pressure to injectors during injector flow testing shall be used.

6.4.3.9 *Fluid Temperature Measurement Device*—A suitable device capable of ±0.5°C (0.9°F) accuracy shall be used to measure solvent temperature.

6.4.3.10 *Fluid Pressure Measurement Device*—A suitable device capable of ±3.4-kPa (0.5-psi) accuracy shall be used to measure solvent pressure.

6.4.4 *Fuel Injector Leak Test Apparatus*—A suitable method to measure fuel injector leakage shall be used prior to the test to evaluate new injectors for leakage. The injector leak test stand should consist of a supply of compressed air, a fuel rail, fuel injectors, release valves, a fluid reservoir, syringes, and a pressure gage. The air shall be delivered to the fuel injectors at a minimum of 310 kPa (45 psi) to the nonenergized (closed) injector(s). Each injector tip is connected to an immersed 5-mL syringe by a length of tubing. If more than 2 mL of air leak into the syringe in a 1-min period, the injector shall be rejected for PFI testing. See Annex A1 for the injector leak test procedure and an example of a leak test apparatus.

7. Reagents and Materials

7.1 *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 by him, 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. However, it is most desirable to have the additive supplied in premeasured, individual containers. The blended fuel shall be clearly identified.

7.1.1 *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.

[11] Available from ASTM Headquarters. Request RR:D02-1210.
[12] Available from ASTM Headquarters. Request RR:D02:1218.

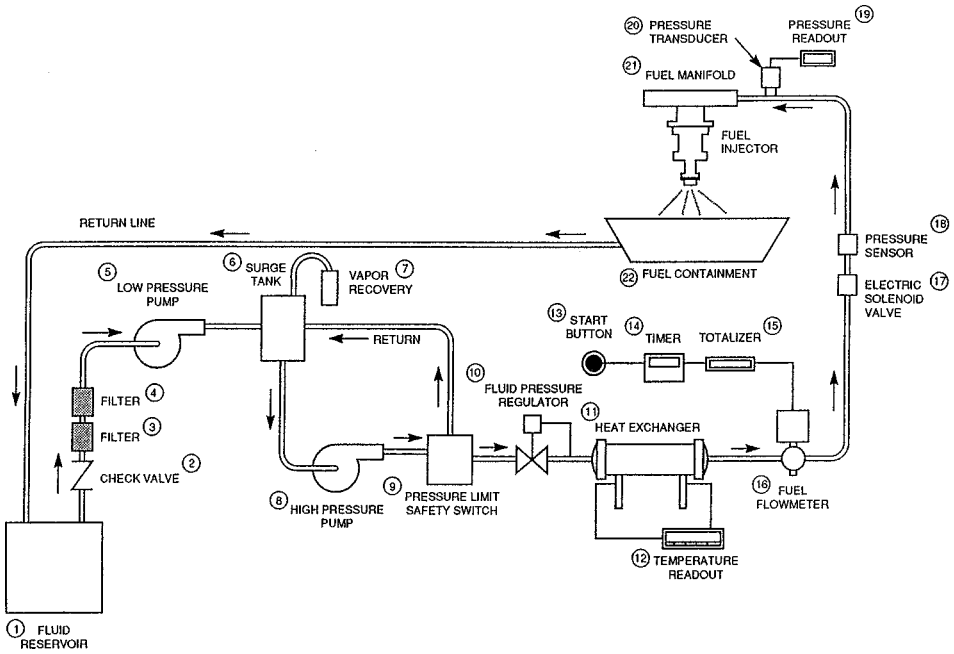


FIG. 1 Fuel Injector Flow Apparatus (example)

7.1.2 *Base Fuel*—The base fuel used for this test procedure should be typical of commercial, unleaded automotive spark-ignition engine fuel. The base fuel may contain oxygenates typical of those being used commercially. The base fuel should allow the vehicle to operate satisfactorily.

7.2 *Engine Coolant*—The coolant is a mixture of equal volumes of a commercial ethylene glycol-based antifreeze and distilled or demineralized water.

7.3 *Engine Oil/Assembly Lubricant*—The standard engine oil and assembly lubricant used for all tests shall be at least of a minimum commercial quality (API SG, EC II) SAE multi-grade that meets the manufacturer's recommendations.

7.3.1 *Petroleum Jelly*—A light petroleum jelly should be used as a lubricant for fuel injector installation. The petroleum jelly should be placed on the fuel injector O-ring.

7.4 *Solvents*:

7.4.1 *Flow Test Solvent*—Solvent should be isooctane of a minimum purity of 99.75 % or a mineral spirit solvent meeting Specification D 235 for TYPE III or IV.

7.5 *Test Fuel*—A test fuel shall be either a base fuel or a homogeneous blend of additives and base fuel. A single batch of base fuel shall be blended before the start of the test. The fuel may be stored in drums or tankage and shall be clearly labeled to prevent misfueling. Quantities of fuel and additive blended and dispensed shall be measured and recorded. Approximately 2300 L (600 gal) of fuel are required for this test method.

7.6 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, where such specifications are available.[13] 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.

8. Preparation of Apparatus

8.1 *Fuel Injector Preparations*:

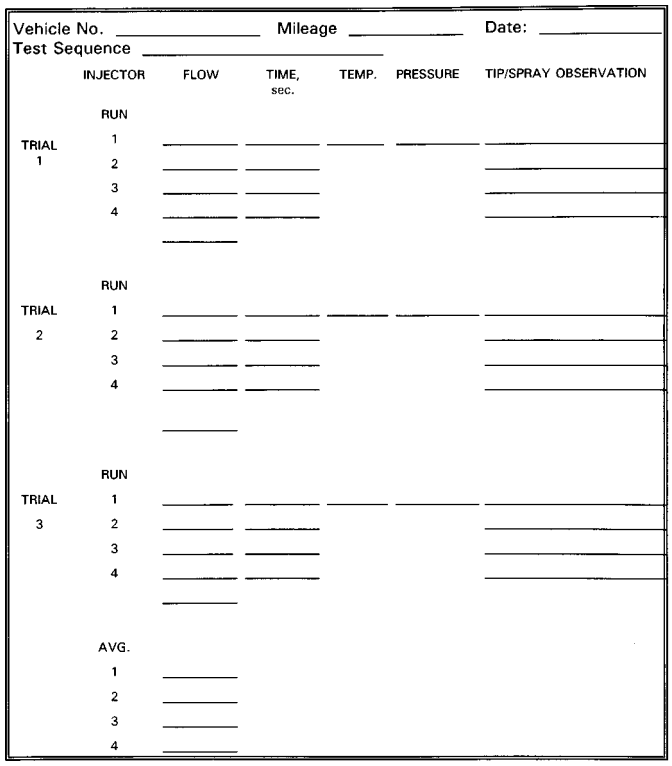
8.1.1 *Flush New Injectors*—New injectors shall be flushed for three 10-s intervals for a total of 30 s using flow test solvent specified in 7.5.1 to cleanse any assembly residue before flow testing.

8.1.2 *Fuel Injector Evaluation*—Prior to installation in the engine, flow rates for each injector shall be measured using flow test solvent specified in 7.5.1 and PFI spray pattern observed using a suitable apparatus as defined in 6.4.3.

8.1.2.1 *Fuel Injector Flow Measurement Procedure*—The injector flow rate data sheet (see Fig. 2) shall be used to calculate the flow rate of each injector. Three static (wide open) flow rate test trials, run for 10 s each, shall be used to calculate the average flow rate for each injector. Measure volume or mass of flow test solvent to the nearest specified unit. If additional injector flow tests are necessary (see 8.1.3.1), allow at least 10 min between successive groups of three flow measurements in order to allow the injectors to cool.

8.1.2.2 *Fuel Injector Spray Quality*—While the injector is flowing, a visual observation shall be made as to the spray pattern quality. Record this observation for each occurrence on the injector flow data sheet. Ideally the spray should be a

[13] *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. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.


Vehicle No. _____ Mileage _____ Date: _____
Test Sequence _____

		INJECTOR	FLOW	TIME, sec.	TEMP.	PRESSURE	TIP/SPRAY OBSERVATION
		RUN					
TRIAL 1		1					
		2					
		3					
		4					
		RUN					
TRIAL 2		1					
		2					
		3					
		4					
		RUN					
TRIAL 3		1					
		2					
		3					
		4					
		AVG.					
		1					
		2					
		3					
		4					

FIG. 2 Fuel Injector Flow Data Sheet (example)

symmetric conical shape with good atomization (see Fig. 3). There should be no *fingers* in the spray pattern. Fuel injectors shall be rejected if any spray abnormalities are encountered. Observe the test injector for at least 30 s after the power to the test injector is shut off. Any injector that drips or leaks during this period shall be rejected.

8.1.3 *Fuel Injector Acceptance Criteria*—The following guidelines shall be met when selecting injectors to be used for this test method. Groups of injectors or individual injectors not meeting the following guidelines shall not be used.

8.1.3.1 *Individual Injector Flow Repeatability Specification*—The difference between the lowest and highest of three consecutive flow tests for each fuel injector shall be no more than 1 %. If this difference between lowest and highest of three consecutive flow tests is greater than 1 %, the injector shall be flow tested three more times. If the difference between any flow rates are still larger than 1 %, the injector may be retested one more time for a total of nine flows maximum. After a potential nine flow determinations, injectors which fail to maintain a difference of less than or equal to 1 % between three successive flow rates shall be rejected for any further testing.

8.1.3.2 *Average Injector Flow Specification*—Data from a set of four fuel injectors shall be averaged. No injector average flow rate shall deviate more than 3 % from another injector average flow rate within each group of four fuel injectors. The deviation in average flow rate shall be calculated using Eq 1:

$$\text{Avg PFI Flow Deviation} = \frac{F_{\text{maxavg}} - F_{\text{minavg}}}{F_{\text{minavg}}} \times 100\ \% \qquad (1)$$

where:

F_{maxavg} = maximum value of an individual fuel injector average, and

F_{minavg} = minimum value of an individual fuel injector average.

8.2 *Vehicle Preparation*:

8.2.1 *Vehicle Break-in*—In order to ensure adequate engine and transmission break-in, the vehicle powertrain shall have a minimum of 6500 km (4000 miles) prior to the start of the test.

8.2.2 *Tires*—All vehicle tires shall be of the same size and inflated as specified by the vehicle manufacturer. For vehicles run on a chassis dynamometer, drive tires shall be inflated to 310 ± 10 kPa (45 ± 1 psi).

8.2.3 *Initial Tune-up*—The vehicle shall be tuned to the manufacturer's specifications prior to the start of the test. The following services and parts replacements shall be made following the Chrysler service manual; all measurements taken and parts replaced shall be documented.

8.2.3.1 The oil filter, air filter, fuel filter, spark plugs, and positive crankcase ventilation (PCV) valve shall be replaced with Chrysler Corp. service replacement parts.

8.2.3.2 The engine oil shall be replaced with suitable oil as outlined in 7.3.

8.2.3.3 Check and adjust spark timing to the manufacturer's specification.

8.2.3.4 Check and adjust the tension of the alternator, air conditioner, and power steering belts to the manufacturer's specifications.

8.2.3.5 Check cylinder compressions and cylinder leak-downs and compare with the manufacturer's specifications.

8.2.3.6 Check engine oil, engine coolant, transmission fluid, and brake fluid levels and add as required to meet the manufacturer's recommendations. Oil may be changed every 8000 km (5000 miles) during a test.

8.2.3.7 Check exhaust gas recirculation valve function and operation.

8.2.3.8 Check turbocharger for proper function and operation.

8.2.4 *Flush Fuel System*—Note that the tank was drained during the preceding test's end-of-test procedure (see 9.9). Flush the fuel system by placing 20 L (5 gal) of the test fuel in the vehicle tank. Start and run the car for 5 min to allow the new fuel to flow through the entire fuel system. After this 5-min flushing session, shut off the engine and drain the remaining fuel from the tank (see 9.9.2). **Precaution**—See Note 3 and Note 4.

8.2.5 *Install Test Fuel*—After the fuel system is flushed (see 8.2.4), the vehicle shall be refueled with the same test fuel.

8.2.6 *Install Fuel Rail and Injectors*—Install a new set of four injectors in accordance with 6.1.1. Coat the O-ring with a thin layer of petroleum jelly and press each injector into the proper hole in the fuel rail. Rotate each injector so that the electrical connector is easily accessible. Secure the injectors to the rail with the clips and install the fuel rail in the intake runner, again coating the O-ring with a thin layer of petroleum jelly.

8.3 *Vehicle Instrumentation*:

8.3.1 *Measured Parameters*—The test vehicle shall be

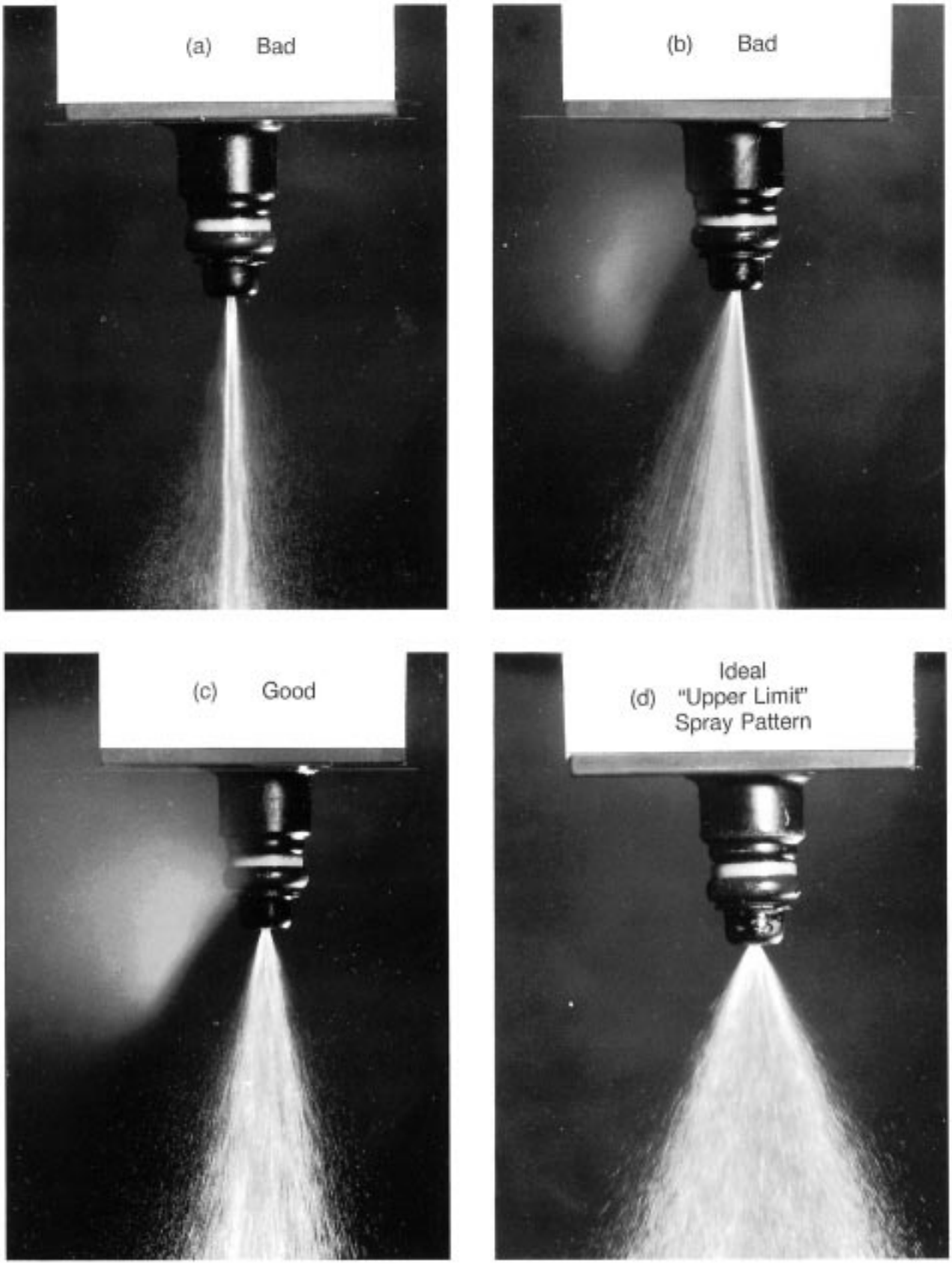


FIG. 3 Fuel Injector Spray Quality

instrumented for the following parameters, and data shall be recorded at a minimum of 5-min intervals while the test is in progress, including the soak period.

8.3.1.1 The date of testing shall be included along with 24-h clock time for each day that the actual test was conducted.

8.3.2 *Engine On/Off-Time*—Set up the device in accordance with 6.3.4 to measure engine-on and engine-off times.

8.3.3 *Fuel Injector Skin Temperature*—A thermocouple shall be attached to injector No. 3 to monitor injector skin temperature every 5 min, during both engine-on and engine-off times while the test is being conducted (see Fig. 4). Apply the thermocouple directly to the fuel injector body using the specified method.

8.3.4 *Fuel Rail Pressure*—A suitable device shall be utilized to measure fuel rail pressure at 5-min intervals during both engine-on and engine-off times while the test is being conducted. The gage shall be accurate to ±3.4 kPa (0.5 psi).

8.3.5 *Vehicle Speed*—A suitable device shall be used to monitor vehicle speed during engine-on times at 5-min intervals and accurate to ±2 kph (±1 mph).

8.3.6 *Calibration*—Calibrate thermocouple, pressure gage, and speed transducer prior to each test.

8.3.6.1 *Temperature Measurement Calibration*—The temperature measurement sensor shall be calibrated before every test. The temperature measurement system shall indicate within ±1°C (2°F) of the laboratory calibration standard.

8.3.6.2 *Pressure Measurement Calibration*—The fuel pressure measurement sensor shall be calibrated before every test. The pressure measurement system shall indicate within ±3.4 kPa (0.5 psi) of the laboratory calibration standard.

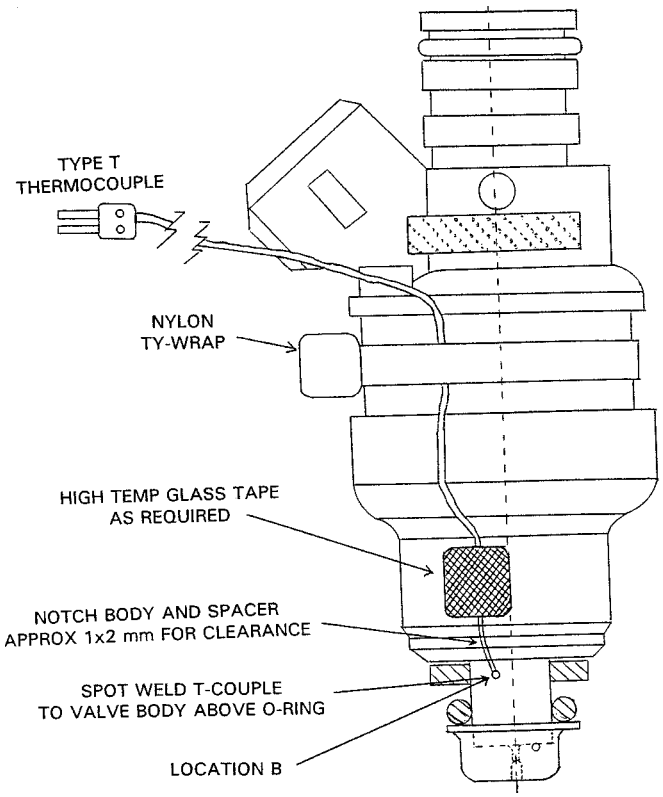


FIG. 4 Fuel Injector Skin Temperature Measurement Location

9. Test Procedure

9.1 *Pre-Test Procedure*:

9.1.1 Prepare the test vehicle in accordance with the previously defined test procedure in 8.2.

9.1.2 Calibrate and verify the operation of data acquisition equipment as outlined in 8.3.

9.1.3 Verify that the proper test fuel was placed in the vehicle by checking fueling records, dispenser, and vehicle designations. Check that precautions have been taken to avoid misfueling during mileage accumulation.

9.1.4 *Chassis Dynamometer Installation Procedure*:

NOTE 6—This section applies to vehicles operated on a chassis dynamometer. For vehicles driven on a test track or over-the-road, see 9.2.

9.1.4.1 *Vehicle Installation*—The test vehicle shall be pushed onto the dynamometer. Center the vehicle by turning the rolls until the vehicle is aligned. Properly secure the vehicle by installing wheel chocks and hold down cables. Hook up vehicle exhaust pipe to outside exhaust vent. On dynamometers not equipped with frontal cooling fans, place a Hartzell (or equivalent) fan in front of the test vehicle. Both frontal cooling fan and stock electric radiator cooling fan shall not be allowed to run when the vehicle is shut down. If exhaust fan is utilized, then make sure it also is not running when the vehicle is shut down. Blanketing the hood may be accomplished to maintain adequate PFI temperature. No external heat source(s) shall be utilized to maintain or increase PFI temperature.

9.1.4.2 *Inertia Weight Settings*—Inertia weight should be set to a nominal 1350 kg (2970 lb). Inertia weight setting is not critical because of the steady-state nature of the test cycle.

9.1.4.3 *Dynamometer Load Settings*—Absorber load shall be set within the appropriate range of values listed in Table 3. The absorber load setting may be adjusted within the specified range so that dynamometer load at 88 kph (55 mph) accurately simulates appropriate underhood temperatures during the engine-off soak period. This load shall be adjusted with the dynamometer warmed up. Dynamometer load settings should be checked and adjusted approximately every 150 test hours, using appropriate means.

9.2 *Mileage Accumulation*—The dynamometer, test track, road mileage accumulation cycle, or combination thereof, consists of a series of driving cycles and engine-off hot soak cycles. The test vehicle shall be started and accelerated to 88 kph (55 mph) within 30 s of start-up. The test vehicle shall be accelerated to 88 kph, driven for 15 min, or approximately 22 km (14 miles), and then allowed to coast, or vehicle may be braked, to a stop within 30 s. The engine is then turned off and the vehicle undergoes a 45-min hot soak cycle. The vehicle shall be allowed to soak for 45 min in calm air, with all fans

TABLE 3 Road Load Power Settings

Model Year	Engine Family No.	kW	Horsepower
1985	FCR2.2V5FAA2	6.0–6.2	8.1–8.3
1985	FCR2.2V5HCF2	6.0–6.2	8.0–8.3
1986	GCR2.2V5FAAX	5.5–6.3	7.4–8.4
1986	GCR2.2V2HDH6	4.8–5.9	6.4–7.9
1987	HCR2.2V5FAA0	4.8–6.6	6.4–8.9
1987	HCR2.2V5FAC2	5.5–6.6	7.4–8.8

turned off. These test cycles may be run 24 h per day or less. The vehicle shall repeat this cycle for 16 100 km (10 000 miles). The fuel injectors may be removed and flow tested, however, not more than every 1600 km (1000 miles).

9.2.1 If driving to and from the testing site is required, distance traveled shall be less than 16 km (10 miles) total per normal 8-h shift and will not be counted as test time or distance traveled. The drive to the test site, if any, should be kept to a minimum. Any additional driving to and from the testing location will invalidate a test.

NOTE 7—The driving cycle should be conducted in a safe and lawful manner. Consideration should be given to traffic volume when using public roads and the ability to safely comply to the criteria outlined in this test method.

9.3 *Tire Pressure*—Tire pressures should be checked throughout the test. Drive tires shall be 310 ± 10 kPa (45 ± 1 psi) for dynamometer usage. Over-the-road testing and non-drive tires may be 210 ± 10 kPa (30 ± 1 psi).

9.4 *Air Conditioner Usage*—Air conditioning may be utilized during the test.

9.5 *Engine Oil Change*—The engine oil and filter may be replaced every 8000 km (5000 miles). Oil additions are allowed once mileage accumulation has begun. Monitor oil consumption throughout the test.

9.6 *Refueling Procedure*—Refuel the vehicle when necessary.

9.7 *Misfueling Precautions*—The test laboratory shall have a protocol to ensure the vehicle receives the proper fuel during the test.

9.8 *Periodic Measurements and Functions*:

9.8.1 *Data Collection*—Data shall be recorded once per 5-min interval whether the engine is on or off, for vehicle speed, fuel injector No. 3 skin temperature, and fuel rail pressure for the entire test duration. Appropriate data acquisition equipment shall be used and operated to provide the data in accordance with 10.5.

9.8.2 *General Maintenance*—The vehicle shall receive the appropriate maintenance as outlined in this test procedure and the Chrysler service manual.

9.8.2.1 *Check Engine Oil*—Oil level should be monitored. Additions may be made after mileage accumulation has begun.

9.8.2.2 *Check Tramsmission Fluid*—Maintain at indicated level using a fluid as recommended in the Chrysler service manual.

9.9 *End of Test Procedure*:

9.9.1 *Fuel Injector Removal*—Remove the four fuel injectors from the fuel rail for final evaluation of fuel injector flow rates. Any disassembly instructions not detailed in this test method shall be completed in accordance with the Chrysler service manual.

9.9.2 *Drain Fuel*—Drain all remaining fuel at this time from the fuel tank. Installation of a special drain plug at the low point of the fuel tank is recommended.

10. Determination of Test Results

10.1 *Number of Test Cycles*—The total number of test cycles completed within a 16 100-km (10 000-mile) test shall be between 720 to 730 cycles.

10.2 *Fuel Injector Flow Measurement*—Injectors shall be statically flow tested (that is, wide open in accordance with 8.1.2.1) for 10 ± 0.5 s, using flow test solvent (7.5.1). Record the actual time the injector is open to the nearest 0.01 s. To ensure that the test fluid completely fills the injector during flow testing, injectors shall be flushed for at least 3 s, but less than 5 s, with the test fluid prior to the start of flow testing.

10.3 *Calculation of Fuel Injector Fouling*—The amount of individual fuel injector fouling shall be expressed as the percent difference between the mass or volumetric average flow rate of the new, clean injector and the mass or volumetric average flow rate of the same injector during or after the mileage accumulation. Fuel injector fouling shall be calculated using Eq 2:

$$\%\ \text{PFI Fouling} = \frac{F_i - F_f}{F_i} \times 100\ \% \tag{2}$$

where:

F_i = PFI flow at the start-of-test; average of three flow tests, and

F_f = PFI flow after mileage accumulation; average of three flow tests.

10.4 *Timing of Fuel Injector Flows*—Injector flow measurements shall be obtained within 24 h after any mileage accumulation occurs on the vehicle. Fuel injectors shall be reinstalled within 24 h after measuring PFI flows.

10.5 *Determination of Test Validity-Vehicle Conformance*—During each test, conditions of the vehicle shall be strictly adhered to and monitored, recording the following data at 5-min intervals. In addition to these specific parameters, engine-on and engine-off times shall be monitored. At a minimum, the following data shall be logged each 5 min while the engine is running: (*a*) fuel injector (No. 3) skin temperature, (*b*) vehicle speed, and (*c*) fuel rail pressure. At a minimum, the following data shall be logged each 5 min while the engine is not running (during the hot soak): (*a*) fuel injector (No. 3) skin temperature and (*b*) fuel rail pressure.

10.5.1 *Fuel Injector Skin Temperature*—A histogram shall be used to graphically show the percentage of hot soak cycles that the maximum fuel injector No. 3 skin temperature is below 90°C (194°F) and equal to or in excess of 90°C.

10.5.1.1 *Test Cycle Validation Criteria*—If the fuel injector No. 3 maximum skin temperature does not exceed 90°C (194°F) for more than 95 % of the hot soak cycles of a 16 100-km (10 000-mile) test length (or 685 of 725 hot soak cycles) then the test will be declared invalid. However, any hot soaks during the test for which PFI No. 3 skin temperature does not exceed 90°C, may be repeated until a minimum of 685 total hot soak cycles with PFI No. 3 exceeding 90°C are met within an additional 4000 km (2500 miles). Thus the maximum length for any fuel injector fouling test shall be 20 100 kilometers (12 500 miles) or a maximum of 910 hot soaks.

10.5.2 *Vehicle Speed*—A histogram shall be used to graphically show the percentage of engine on-time vehicle speed with a speed of less than 83 kph (52 mph), from and including 83 to 93 kph (52 to 58 mph) and above 93 kph (58 mph). The actual percentages shall be shown.

10.5.2.1 *Test Validation Criteria*—The percentage of engine on-time that vehicle speed occurs shall be as follows or the test

is invalid: no less than 99 % shall be between 83 and 93 kph (52 to 58 mph).

10.5.3 *Fuel Rail Pressure*—A histogram shall be used to graphically show the percentage of fuel rail pressures, collected during the first 5-min hot soak interval, at a fuel rail pressure of less than 310 kPa (45 psi) and greater than or equal to 310 kPa (45 psi). The actual percentages shall be shown.

10.5.3.1 *Test Validation Criteria*—The percentage of fuel rail pressures, collected during the first 5-min hot soak interval, shall be as follows or the test is invalid: no less than 99 % shall be greater than or equal to 310 kPa (45 psi).

10.5.4 *Engine On-Time*—A histogram shall be used to graphically show the percentage of engine on-time (per each 1-h test cycle) of less than 15.5 min, from and including 15.5 to 16.5 min, and greater than 16.5 min.

10.5.4.1 *Test Validation Criteria*—The percentage of engine on-time (per 1-h cycle) shall be as follows or the test is invalid: no less than 99 % shall be between and including 15.5 to 16.5 min in length.

10.5.5 *Vehicle Downtime*—The maximum allowable unscheduled vehicle downtime should be less than 72 h per occurrence.

11. Final Test Report

11.1 *Standard Report*—The report shall be made to the organization supplying the deposit control additive or test fuel. The standard test report shall include the following sections. Each section shall begin on a new page and the sections shall be inserted in the following order. Deviations in the format are not permitted. However, additional details and data may be attached as an appendix.

11.1.1 Title page including name of testing laboratory, run number, and dates of testing.

11.1.2 Electronic port fuel injector raw flow data and fouling summary.

11.1.3 Summary of test validity criteria.

11.1.4 Fuel inspection/blending data including identification of the test fuel/deposit control additive by the name or code, or both, provided by the submitting organization.

11.2 *Data Acquisition Summary Report*—The test validation criteria report, derived from the data acquisition equipment, shall include the sections listed below. Each section shall begin on a new page and the sections shall be inserted in the following order.

11.2.1 Fuel injector No. 3 maximum skin temperature histogram.

11.2.2 Total number of test cycles, including number of valid and invalid test cycles.

11.2.3 Vehicle speed histogram.

11.3 *Test Summary*:

11.3.1 Make, model, and year of test vehicle.

11.3.2 Test procedure used: chassis dynamometer, mileage accumulation dynamometer, or test track.

11.3.3 Number of test kilometres (miles) and test cycles accumulated.

12. Precision and Bias

12.1 *Precision*—It is not practical to specify the precision in this test method for measuring electronic port fuel injector fouling at this time because sufficient quantity of repeat tests under ASTM protocol are not available. The precision is being determined.

12.2 *Bias*—No estimate of bias is possible as the behavior of the fuel is determined only under the specific conditions of the test and no absolute standards exist.

13. Keywords

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

ANNEX

(Mandatory Information)

A1. TEST METHOD FOR DETERMINING INJECTOR LEAK RATE

A1.1 *Scope*—This test method provides a means to check the leak rate or weepage rate of an electronic fuel injector that is not energized, but under pressure. It is important to know this value because it will affect the rate of accumulation of deposits. This test shall be run on all injectors before being utilized in Test Method D 5598.

A1.2 *Summary of Test Method*—Air pressure is applied to a clean injector in a fluid (water) bath, and the air leakage is collected in a syringe and measured volumetrically.

A1.3 *Apparatus:*

A1.3.1 *Clean Fuel Injector*,

A1.3.2 *Dry Shop Air*, capable of supplying 345 kPa (50 psi),

A1.3.3 *Syringe*, 5 mL, and

A1.3.4 *Hypodermic Needle*.

A1.4 *Preparation of Apparatus:*

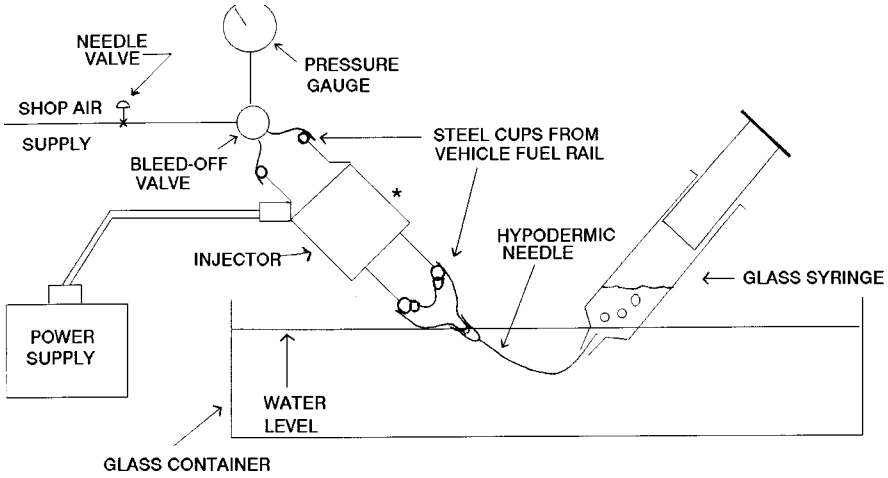
A1.4.1 Blow residual fluids out of injector using clean, dry shop air while holding the injector open.

A1.4.2 Rinse the injector with acetone and blow dry, while holding the injector open.

A1.5 *Procedure:*

A1.5.1 Mount injector in rig and attach hypodermic needle assembly as in Fig. A1.1.

A1.5.2 Place a 5-mL fluid-filled syringe over the hypodermic needle tip for gas collection and volumetric measurements at 0.25, 1.0, and 5.0 mL. Immerse in bath as illustrated.



[A] A clamping device which holds the injector body into the air pressure supply system is not shown.

FIG. A1.1 Injector Leak Test Apparatus[A]

A1.5.3 Apply 345-kPa (50-psi) air pressure and collect air bubbles at the hypodermic needle tip using the 5-mL syringe measured over a minimum of a 3-min time period.

A1.5.4 Record results as millilitres of air collected per 1-min time period.

A1.5.5 Repeat until three consecutive results are obtained on an individual injector with a maximum difference between all three leak tests of 3 %.

A1.5.5.1 Reject fuel injector if consecutive results within 3 % are not obtained after three successive attempts.