



Standard Test Method for Dynamometer Evaluation of Unleaded Spark-Ignition Engine Fuel for Intake Valve Deposit Formation¹

This standard is issued under the fixed designation D 6201; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope

1.1 This test method covers an engine dynamometer test procedure for evaluation of intake valve deposit formation of unleaded spark-ignition engine fuels. This test uses a Ford Ranger 2.3 L four-cylinder engine. The following details the procedure, hardware, and operations used for this test.

1.2 The ASTM Test Monitoring Center (TMC)² is responsible for engine test stand certification as well as issuance of information letters after test method modifications are approved by Subcommittee D02.A and Committee D02. Users of this test method shall request copies of recent information letters from the TMC to ensure proper conduct of the test method.

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

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 applicability of regulatory limitations prior to use.* Specific precautionary statements are given throughout this test method.

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2. Referenced Documents

2.1 ASTM Standards:

- D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure³
- D 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvents)⁴
- D 287 Test Method for API Gravity of Crude Petroleum and

¹ This test method is under jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.A on Gasoline.

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² ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489.

³ Annual Book of ASTM Standards, Vol. 05.01.

⁴ Annual Book of ASTM Standards, Vol. 06.04.

Petroleum Products (Hydrometer Method)³

D 381 Test Method for Existent Gum in Fuels by Jet Evaporation³

D 525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)³

D 873 Test Method for Oxidation Stability of Aviation Fuels (Potential Residue Method)³

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)³

D 1298 Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method³

D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption³

D 1744 Test Method for Determination of Water in Liquid Petroleum Products by Karl Fischer Reagent³

D 2427 Test Method for Determination of C₂ Through C₅ Hydrocarbons in Gasolines by Gas Chromatography³

D 2622 Test Method for Sulfur in Petroleum Products by X-ray Spectrometry⁵

D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry⁵

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products⁵

D 4294 Test Method for Sulfur in Petroleum Products by Energy-Dispersive X-ray Fluorescence Spectroscopy⁵

D 4814 Specification for Automotive Spark-Ignition Engine Fuel⁶

D 4953 Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)⁶

D 5059 Test Method for Lead in Gasoline by X-ray Spectroscopy⁶

D 5190 Test Method for Vapor Pressure of Petroleum Products (Automatic Method)⁶

D 5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)⁶

D 5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated under Low-Temperature, Light-Duty Conditions⁶

D 5482 Test Method for Vapor Pressure of Petroleum Products (Mini Method - Atmospheric)⁶

E 203 Test Method for Water Using Volumetric Karl Fischer Titration⁷

E 1064 Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration⁷

2.2 *ANSI Standard*:⁸

MC96.1 Temperature Measurement-Thermocouples

2.3 *Coordinating Research Council (CRC)*:⁹

CRC Manual 16, Carburetor and Induction System Rating Manual

2.4 *SAE Standard*:¹⁰

J254 Instrumentation and Techniques for Exhaust Gas Emissions Measurement

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 *blowby, n*—the combustion products and unburned air/fuel mixture that enter the crankcase.

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

3.1.4 *exhaust emissions, n*—combustion products from the test fuel including unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂), unreacted oxygen (O₂), and oxides of nitrogen (NO_x).

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

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

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

4. Summary of Test Method

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

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

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

4.4 The engine is operated on a cycle consisting of two stages. The first stage comprises operating the engine at 2000

⁵ *Annual Book of ASTM Standards*, Vol. 05.02.

⁶ *Annual Book of ASTM Standards*, Vol. 05.03.

⁷ *Annual Book of ASTM Standards*, Vol. 15.05.

⁸ Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

⁹ Available from the Coordinating Research Council, Inc., 219 Perimeter Center Pkwy., Atlanta, GA 30346.

¹⁰ Available from Society of Automotive Engineers, Inc., 400 Commonwealth Dr., Warrendale, PA 15096-0001.

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

5. Significance and Use

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

5.1.1 *State and Federal Legislative and Regulatory Action*—Regulatory action by California Air Resources Board (CARB)¹¹ and the United States Environmental Protection Agency (EPA)¹² necessitate the acceptance of a standardized test method to evaluate the intake system deposit forming tendency of an automotive spark-ignition engine fuel.

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

5.2 Test Validity:

5.2.1 *Procedural Compliance*—The test results are not considered valid unless the test is completed in compliance with all requirements of this test method. Deviations from the parameter limits presented in Sections 12, 13, and 14 will result in an invalid test. Apply engineering judgment during conduct of the test method when assessing any anomalies to ensure validity of the test results.

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

6. Apparatus

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

6.1 Laboratory Facilities:

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

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

6.1.3 *Fuel Injector Testing Area*—The fuel injector testing area shall be reasonably free of contaminants. The humidity should be maintained at a uniform comfortable level. (**Warning**— In addition to other precautions, provide adequate

ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used.)

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

6.1.5 *Parts Rating and Intake Valve Weighing Area*—The parts rating area shall be reasonably free from contaminants.

6.2 Test Stand Laboratory Equipment:

6.2.1 *Test Stand Configuration*—An example of a similar test stand configuration is described in Test Method D 5302 (Sequence VE lubricant test method) since the same Ford 2.3 L base engine is utilized. Mount the engine on the test stand so that the flywheel friction face is $4.0 \pm 0.5^{\circ}$ from the vertical with the front of the engine higher than the rear. The engine shall be coupled directly to the dynamometer through a driveshaft. Engine driven accessories include engine water pump and alternator or idler pulley configuration as detailed in 10.7.9 The alternator serves only as an idler pulley; it is not energized.

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

6.2.3 *Intake Air Supply System*—The intake air supply system is the production intake air system including the extension between the air filter housing and the upper intake manifold. Locate the intake air pressure and temperature probes in the production air filter housing between the air filter and the engine intake manifold. Install the intake air temperature probe 50 ± 10 mm into the housing. Install the intake air pressure probe 5 ± 3 mm into the housing. Take humidity readings within the ducting of the intake air supply system supplying the engine. See Fig. A1.4 for a detailed description.

6.2.4 *Exhaust System*— The exhaust system consists of the production exhaust manifold, exhaust back pressure control valve, exhaust back pressure probe, exhaust emissions probe(s) (if applicable), and the engine oxygen sensor. Locate the exhaust emissions probe and the exhaust back pressure probe downstream of the engine oxygen sensor at a distance no greater than 400 mm and position the probes at the center of the exhaust stream. Figure A1.6 gives details regarding the exhaust back pressure probe configuration and location.

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

¹¹ State of California Air Resources Board - Stationary Source Division, Test Method for Evaluating Intake Valve Deposits (IVDs) in Vehicle Engines (California Code of Regulations, Title 13, Section 2257). Available from the California Air Resources Board, P.O. Box 2815, Sacramento, CA 95812.

¹² Clean Air Act Amendments of 1990. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

TABLE 1 IVD Dynamometer Test Operating Parameters and Specifications^A

Parameter ^A		Specification	
Stage		1	2
Time	Stage length, min	4	8
Engine Loading	Engine speed, r/min	2000 ± 25	2800 ± 10
	Engine load, kW	<5	record
Engine Oil	Inlet temperature, °C	101 + 3, -5	101 ± 3
	Outlet temperature, °C		record
	Inlet pressure, kPa gage		record
Engine Cooling	Outlet temperature, °C	90 ± 3	
	Inlet temperature, °C		record
	Delta pressure, kPa gage	< 41 kPa	
	Flowrate, L/min	record	64.4 ± 1.9
Intake Air	Inlet temperature, °C	32 ± 3	
	Inlet pressure, kPa gage	0.05 ± 0.01	
	Inlet humidity, g/Kg	11.4 ± 0.7	
Engine Breathing	Manifold absolute pressure, kPa	30.6 ± 1.3	71.8 ± 1.3
	Exhaust back pressure, kPa abs	102 ± 1	105 ± 1
Engine Fueling	Flow - kg/h		record
	Flow - total kg		record
	Inlet temperature, °C		28 ± 5
	Equivalence ratio		1.00 ± 0.03
Exhaust	O ₂ volume %	record	0.5 ± 0.3
Emissions	CO, volume %	record	0.7 ± 0.4
	NO _x , ppm		record
Other	EGR, voltage		record
	Blowby, corrected rate, L/min	-	record
	Spark advance, ° BTDC	30 ± 3	25 ± 3

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

temperature to the engine as specified in Table 1. Deliver the fuel to a high-pressure pump that boosts the pressure and supplies the fuel to the fuel rail. The fuel temperature shall be measured after the high pressure pump and just prior to the engine fuel rail.

6.2.6 Engine Control Calibration—The specified engine control calibration for the test is the modified Ford Ranger Manual Transmission calibration EEC-IV processor available from OH Technologies, Inc.¹³ as detailed in Annex A2. The system should properly control the air-fuel ratio throughout the test. No other method shall be used in conjunction with or in place of the specified EEC-IV processor to adjust the air-fuel ratio, EGR, or ignition spark advance. However, the Ford Ranger non-modified manual transmission calibration EEC-IV processor (Part No. F47F-12A650-BGB), as detailed in Annex A2, shall be used for the engine break-in as described in 12.1.6.

6.2.7 Ignition System—Use the modified Ford Ranger manual transmission calibration EEC-IV processor as supplied in the intake valve deposit parts kit detailed in Annex A2 to control the engine ignition.

6.2.8 Engine Coolant System—The engine cooling system used shall meet the criteria detailed in 6.2.12, 6.2.13, and 6.2.14. A typical cooling system is detailed in Fig. A1.11.

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

6.2.9 External Oil System—Configure the external oil system in accordance with the photographs shown in Figs. A1.8 and A1.9. The heat exchanger should be mounted in a vertical plane. Be sure all hoses and fittings on the oil heat exchanger are properly connected and secure.

6.2.10 Blowby Flow Rate Measurement System—A typical apparatus used to measure blowby is detailed in 6.4.12. The system is used to indicate the condition of the piston rings and cylinder bore.

6.2.11 Exhaust Gas Analysis Equipment—Precision instruments and system configuration for measurement of O₂, CO, and NO_x are required, if these gases are measured.

6.2.12 Temperature Measurement Equipment and Locations—Temperature measurement locations for the procedurally required temperatures are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the temperature measurement sensors and complete temperature measurement system shall follow the guidelines detailed in ASTM Research Report RR: D02-1218.¹⁴ If thermocouples are used, all thermocouples except the intake air thermocouple shall be premium, sheathed types. The intake air thermocouple may be an open-tip type. Thermocouples between 3.0 and 6.5 mm (0.125 and 0.25 in.) diameter may be used. However, minimum diameter thermocouples are recommended at locations which require short immersion depths to prevent undesirable temperature gradients. Thermocouple, wires, and extension wires shall be matched to perform in accordance with the limits of error as defined by ANSI publication MC96.1-1975. Type J (Iron-Constantan), Type T (Copper-Constantan), or Type K (Chromel-Alumel) thermocouples are acceptable.

6.2.12.1 Engine Oil Inlet—Install the tip at the center of the flow stream through the oil filter adapter housing at the engine (See Figs. A1.8 and A1.9).

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

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

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

6.2.12.5 Intake Air Inlet—Install the tip through the air filter housing at a depth of 50 ± 10 mm and perpendicular to the housing (see Fig. A1.4)

6.2.12.6 Fuel Temperature—Install the tip at the center of the flow stream after the high pressure pump and just prior to

¹³ Available from OH Technologies, Inc., P.O. Box 5039, Mentor, OH 44061-5039.

¹⁴ Data Acquisition Guidelines - Instrumentation Accuracy and Calibration. Available from ASTM Headquarters. Request RR: D02-1218.

the engine fuel rail (see Fig. A1.7).

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

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

6.2.13.2 *Coolant Delta Pressure (outlet - inlet)*—The coolant delta pressure determines the flow restrictions of the external cooling system. The measurement is the resultant of the absolute value of the difference between the pressure measured as the coolant exists the cylinder head and prior to the coolant entering the water pump. Make pressure measurements within 300 mm of these locations. The coolant delta pressure shall be less than 41 kPa gage.

6.2.13.3 *Air Inlet*—Measure air inlet pressure as detailed in 6.2.3.

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

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

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

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

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

6.2.14.2 *Fuel*—Measure the engine fuel flow rate in an area most applicable to the flow measurement device used so that the most accurate measurement can be taken. The fuel flow rate shall be taken prior to the makeup fuel return line from the fuel rail.

6.2.15 *Speed and Load Measurement Equipment and Locations*—Speed and load measurement locations for the procedural required speeds and loads are not specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the speed and load measurement sensors and complete speed and load measurement system shall follow the guidelines detailed in ASTM

Research Report RR: D02-1218.

6.2.15.1 *Required Capabilities*—The dynamometer speed and load control systems shall be capable of maintaining the limits specified in Table 1.

6.2.16 *Exhaust Emissions Measurement Equipment and Location*—Precision instruments for measurement of O₂, CO, and NO_x are required if exhaust emissions are measured. Equipment suitable for automobile emission measurements is recommended. Precision nondispersive infrared instrumentation for CO and polarographic instrumentation for O₂ are suggested (see SAE J254). Response time is an important consideration in the performance of this instrumentation. Make exhaust emission measurements downstream of the engine oxygen sensor at a distance no greater than 400 mm and at the center of the exhaust stream. Figure A1.6 gives details regarding the exhaust emission probe configuration and location.

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

6.2.18 *Spark Advance Measurement Equipment and Location*—Specific measurement locations and equipment for the measurement of spark advance are not specified.

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

6.3.1 *Test Engine Parts*—The test engine parts required are detailed in Annex A2.

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

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

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

- Air cleaner tube assembly, out
- Air cleaner tube assembly, in
- Air cleaner assembly
- Alternator or idler pulley assembly

Belt, alternator or idler pulley
 Bolt, cam sprocket
 Camshaft
 Coil
 Cylinder head^A
 EEC-IV processor
 Engine wire harness
 Engine assembly^B
 Fuel injector^C
 Filter, air
 Guide, timing belt
 Hose, DPFE
 Ignition control assembly
 Ignition wire, LH
 Ignition wire, RH
 Key, valve spring retainer
 Lash adjusters
 Plate, cam
 Pulley water pump
 Regulator, EGR vacuum (EVR)
 Retainers
 Rocker arms
 S&W, cam plate
 Sensor, air charge temperature (ACT)
 Sensor, crankshaft timing assembly
 Sensor, engine coolant temperature (ECT)
 Sensor, heated exhaust gas O₂(HEGO)
 Sensor, mass air flow (MAF)
 Sensor, pressure feedback EGR Assembly (PFE)
 Sensor, throttle position (TPS)
 Sprocket, cam
 Valve, EGR
 Valve spring and damper
 Washer, cam sprocket

^AReuse the cylinder head as long as it meets the procedural requirements for buildup as detailed in 10.4 and 10.5.

^BReuse the engine assembly depending on the condition of the cylinder head bolt holes, cylinder bore wear, blowby, and oil consumption. Procedural requirements have yet to be determined. Refer to 12.4 for procedural requirements for oil consumption.

^CReuse the fuel injectors as long as they meet the procedural requirements detailed in 10.3.1.

6.4 Special Measurement and Assembly Equipment:

6.4.1 *Graduated Cylinder*—Blending of the deposit control additive may be required and the concentration may be given as a volumetric ratio. A 1000 mL graduate is recommended.

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

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

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

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

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

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

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

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

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

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

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

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

6.4.12 *Blowby Meter*— The blowby meter is a device to measure flow rate of the gas passing the piston rings and entering the crankcase. This flow rate provides an indication of the condition of the piston rings and cylinder bore and, therefore, is used as a quality assurance criteria. The device shall have an accuracy of 5 % full scale and a resolution of 0.3 L/min (0.01 ft³/min).

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

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

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

7. Reagents and Materials

7.1 Fuel:

7.1.1 *Fuel Management*— Fuel management is very critical

in this test. The following procedure shall be used each time a new base fuel batch will be used in testing:

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

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

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

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

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

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

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

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

7.1.5 *Engine Break-in Fuel*—The engine break-in fuel shall comply with Specification D 4814 requirements. Approximately 380 L (100 gal) are required for engine break-in.

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

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

7.2 *Engine Oil/Assembly Lubricant*—The standard engine oil and assembly lubricant shall be the IVD Reference Oil (IVD Dynamometer Reference Oil)¹⁵. Approximately 4.7 L (5 qt) are needed for this test method, including engine assembly and initial crankcase fill.

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

7.4 *Solvents and Cleaners:*

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

solvents, or both, are used. Suitable protective clothing is recommended.)

NOTE 3—Reagent-grade chemicals will be used for all test procedures. Unless otherwise noted, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society¹⁶, where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficient purity to permit its use without lessening the accuracy of the determination.

7.4.2 *Naphtha Solvent*— Stoddard solvent conforming to Type I of Specification D 235 is recommended. Proprietary solvents of this general type may be used. This fluid may be used for cleaning parts (that is, valve train parts, cylinder head, intake manifold, throttle body) and as a fuel injector test fluid.

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

7.6 *Valve Lapping Compound*—Use Fel Pro Clover 320 Grade 1A silicon carbide grease compound (Part No. 1A51804) valve lapping compound¹⁷.

7.7 *Crushed Walnut Shells*—A walnut shell blaster may be used to remove carbon and deposits from the head. Use clean, fresh walnut shells which are available commercially from industrial and automotive supply sources.

7.8 *Desiccant*—Use a granular form of anhydrous calcium sulfate (CaSO₄)¹⁸. When not in use, store the desiccant in an airtight container.

8. Hazards

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

9. Reference Fuel

9.1 *Reference Base Fuel Batch Approval Process*—Each new batch of IVD reference base fuel¹⁹ is approved by the following process:

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

9.1.2 A sample of the IVD reference base fuel is shipped to designated independent laboratories. A program involving more than one calibration test is completed using the IVD reference base fuel and reference fuel additives selected by the TMC. The ASTM IVD Dynamometer Test Surveillance Panel is involved in the design of the program. The TMC reviews the

¹⁶ *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.

¹⁷ Available from Jacobs Supply, 729 South Flores, San Antonio, TX 78204.

¹⁸ Drierite has been found to be satisfactory. An equivalent material can be used.

¹⁹ IVD Reference Base fuel is a product of Specified Fuels and Chemicals, LLC, 1201 S. Sheldon Rd., P.O. Box 429, Channelview, TX 77530-0429.

¹⁵ Available from Conoco Oil Co., P.O. Box 80430, Rochester, MI 48308.

TABLE 2 IVD Reference Base Fuel Typical Batch Properties and Transport and Storage Warning Limits

Parameter	Typical Batch Initial Analysis Values	Transport and Storage Warning Limits
API gravity ^A	59.9	58.7 - 61.2
Vapor pressure ^B	61.5 kPa	60 - 63 kPa
Total sulfur ^C	0.025 weight %	0.01 - 0.04 weight % max
Solvent washed gum ^D	1 mg/100 mL	5mg/100 mL, max
Distillation ^E		
IBP	30.1°C	25 - 35°C
10 % evaporated	52.5°C	50 - 55°C
50 % evaporated	102.5°C	95 - 110°C
90 % evaporated	154.9°C	150 - 160°C
EP	204.0°C	196 - 212°C
Hydrocarbon type ^F		
Aromatics	31.0 volume %	27 - 35 volume %
Olefins	7.0 volume %	5 - 10 volume %
Saturates	62.0 volume %	55 - 68 volume %
The following parameters are analyzed on an absolute basis:		
Appearance	clear and bright	clear and bright
Water ^G	0.001 volume %	0.01 volume %, max
Lead ^H	<2.5 mg/L	13 mg/L, max
Oxidation stability ^I	1440+ min	1440 min, min

^AIn accordance with Test Method D 287 or D 1298.

^BIn accordance with Test Method D 4953, D 5190, D 5191, or D 5482 Vapor Pressure.

^CIn accordance with Test Method D 1266, D 2622 or D 4294.

^DIn accordance with Test Method D 381.

^EIn accordance with Test Method D 86.

^FIn accordance with Test Method D 1319.

^GIn accordance with Test Method D 1744, E 203, or E 1064.

^HIn accordance with Test Method D 3237 or D 5059.

^IIn accordance with Test Method D 525.

test results and after satisfactory completion of the program, will authorize the fuel supplier to notify potential purchasers of the approval status of the IVD reference base fuel batch.

9.2 Fuel Batch Analysis:

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

9.2.2 In addition, the fuel supplier shall analyze the contents of each storage tank that contains IVD reference base fuel used for qualified IVD Dynamometer Tests every two months to ensure the fuel has not deteriorated excessively or been contaminated in storage. Laboratories should take composite samples using Practice D 4057 as a guideline. The fuel supplier shall provide an adequate supply of fuel sample containers with packaging and pre-addressed return labels to each dynamom-

eter IVD laboratory. Upon receipt of fuel samples from the laboratories, the fuel supplier will perform the following analyses, report the results to the submitting laboratory, and tabulate the results in a database:

Test Method

D 4953, D 5190, D 5191, or D 5482 Vapor Pressure

D 287 API Gravity

D 86 Distillation

D 381 Solvent Washed Gum

D 381 Unwashed Gum

D 525 Oxidation Stability

9.2.3 In instances where results from the physical and chemical tests listed previously appear to vary significantly from the expected results, a second sample will be analyzed or the following tests will also be conducted, or both:

C₂ through C₅ hydrocarbon determination by gas chromatography, Test Method D 2427

Potential Gum, Test Method D 873

9.2.4 Forward the results of the analyses performed in 9.2.1 and 9.2.2 to the TMC for inclusion in the appropriate data base.

9.3 *Fuel Batch Shipment and Storage*—Ship the fuel in containers with the minimum allowable venting as dictated by all safety and environmental regulations, especially when shipment times are anticipated to be longer than one week. Store the fuel following all applicable safety and environmental regulations.

10. Preparation of Apparatus

10.1 Test Stand Preparation:

10.1.1 *Instrumentation Calibration*—Calibrate all sensors and indicators before or during the test as required by the particular types of instrumentation utilized. Section 11 provides details on all calibration requirements.

10.1.2 *Exhaust Back Pressure and Exhaust Emissions Sample Probe Inspection*—The exhaust back pressure and exhaust emission sample probes can be used until they become unserviceable. Inspect probes for wear, cracks, contamination, residue, and so forth, and replace if necessary.

10.1.3 *External Hose Inspection*—Inspect all external hoses for wear, cracks, contamination, unspecified restrictions, and so forth, and replace as necessary.

10.1.4 *Engine Wire Harness Inspection*—Inspect the engine wire harness for broken connectors, broken wires, frayed wires, general integrity, and replace or repair as required.

10.1.5 *EGR Voltage Readout Preparation*—The EGR voltage signal is located at Pin 27 of the Ford EEC-IV Processor. Connect a voltage readout device to Pin 27 (output) and Pin 46 (signal return) of the Ford EEC-IV Processor.

10.2 Engine Block Preparation:

10.2.1 *Piston Top Preparation and Inspection*—Inspect piston tops for integrity. Ensure there are no unusual wear patterns on piston tops (pitting, scratches, and so forth). Make sure piston tops are completely clean of all deposits. Use appropriate solvents (see 7.4), a walnut shell blaster, or other appropriate tools to clean the piston tops. Make sure the tools used do not alter the piston top surface, and the piston-to-cylinder wall crevices are clean of all contaminants.

10.2.2 *Cylinder Bore Inspection*—Inspect cylinder bores for unusual wear (scores, pits, etc.). Inspect the integrity of the

engine block by monitoring the engine's compression pressure, percent leakdown, and oil consumption (see 12.3.4). The block should be replaced if unusual wear is detected.

10.2.3 *Cylinder Head-to-Cylinder Block Mating Surface*—Clean the cylinder head-to-cylinder block mating surface of any gasket material or deposit using a gasket scraper, the appropriate solvents (see 7.4), a walnut shell blaster, or other appropriate tools.

10.3 *Preparation of Miscellaneous Engine Components:*

10.3.1 *Fuel Injector Preparation*—Prior to engine installation, evaluate all injectors (new and used) for spray-pattern and flow-rate using a suitable apparatus as defined in 6.4. The evaluation procedure is outlined in this section. Injectors may be cleaned and reused if the criteria outlined in this section are satisfied.

10.3.1.1 *Flush New Injectors*—Flush new injectors for 30 s to remove any assembly residue before flow testing.

10.3.1.2 *Operating Flow Rig*—Using a rig as described in 6.4.13, turn on the fuel pumps, the flow meter, and the timer. After the pumps are turned on, the test fluid (see 7.5) will start to flow through the slave injector. Maintain the test fluid pressure supplied to injector at 290 ± 1.4 kPa (42 ± 0.2 psi) during the entire test. The maintenance of this pressure is very critical because a small change in pressure will have a dramatic effect on the flow rate and spray pattern.

10.3.1.3 *Flow-test Injectors*—Flow-test each injector for three 60-s periods. Record each of these measurements. The final flow rate of the injector is based on the average of these three, 60-s trials.

10.3.1.4 *Observe Spray Quality*—While the injector is flowing, make a visual observation of the spray pattern quality. Record this observation for each occurrence. Reject any injector that demonstrates an abnormal spray pattern. When the injector is not open, the injectors shall not leak or drip with the test fluid under pressure. Replace any injector that drips or leaks.

10.3.1.5 *Acceptance Criteria*—Meet the following guidelines when selecting injectors to be used for this test method. Do not use groups of injectors or individual injectors not meeting the following guidelines.

(a) *Flow Specification-Individual Injectors*—Flow-test individual injectors at 290 ± 1.4 kPa (42 ± 0.2 psi) using Stoddard solvent at 15 to 25°C (59 to 77°F) and specific gravity of 0.754 to 0.82. Adjust flow rates for test conditions of fluid temperature and pressure. Individual injectors shall have flow rates of 2.13 to 2.18 mL/s.

(b) *Flow Specification-Groups*—Groups of four injectors shall not have any one injector deviate from the four injector average by more than 3 %.

(c) *Visual inspection Criteria*—Injectors shall not drip while under pressure for at least 30 s when the injectors are not open. Any injector that demonstrates an abnormal spray pattern while the injectors are being flowed shall not be used.

10.3.2 *Intake Manifold Preparation*—Make sure the intake manifold is clean before each test. Use an acceptable cleaning agent such as a commercially available carburetor cleaner or Stoddard solvent. Inspect the intake manifold for integrity. The intake manifold can be used in repeated engine builds until it

becomes unserviceable.

10.3.3 *PCV Valve Preparation*—Use the PCV valve flow rate measuring device to verify the flow rate of the PCV valves before and after the test. Measure and record the flow rates of the test PCV valves before and after the test. The appropriate PCV flow rate measuring device to use is detailed in 6.4.14. Measure the flow rate twice and average the readings. Reject any PCV valve that does not adhere to the following specifications:

24.1 to 32.6 L/min (0.85 to 1.15 ft³/min) at 60.8 kPa (18 in. Hg) vacuum

52.4 to 60.9 L/min (1.85 to 2.15 ft³/min) at 27.0 kPa (8 in. Hg) vacuum

10.4 *Cylinder Head Preparation:*

10.4.1 *Valve Labeling*—Use new intake and exhaust valves for each test. Mark each valve prior to valve weighing. For example, an intake valve that is going to be used in Test No. 5 and inserted into the number one cylinder intake valve position could be marked T5No.1In. Place all valve markings on the valve stem between the top of the valve and the valve seal-to-valve stem contact area.

10.4.2 *Valve Seat and Face Cutting*—Cut intake and exhaust valve faces (areas that contact the valve seats) to a 45° angle. Double cut the intake and exhaust valve seats. The first cut should be at a 45° angle. The second cut should be at a 30° angle perpendicular to the axis of the valve guide and located on the outer diameter of the seat. A 60° cut can be utilized to adjust the valve seat to valve face interface as required.

10.4.3 *Valve Seat and Face Lapping*—Lap each intake and exhaust valve using Fel Pro Clover 320 Grade 1A Silicone Carbide Grease Compound (Part No. 1A51804)¹⁷ for 20 s.

10.4.4 *Valve Seat and Face Cleaning*—Clean the valves by dipping in Stoddard solvent and wiping with a soft towel. Clean the seats with Stoddard solvent and wipe dry with a soft towel. Wash valves with n-hexane or cyclohexane. Gently shake off any remaining solvent. Place valves in an oven (see 6.4.4) at $93 \pm 5^\circ\text{C}$ ($200 \pm 9^\circ\text{F}$) for 5 min. Place valves in a desiccant for 1 h.

10.4.5 *Valve Weighing*—Weigh and record the valve weights to the nearest 0.0001 g.

10.4.6 *Valve Stem-to-Guide Clearance Measurements*—Measure and record intake and exhaust valve stem-to-guide clearances at the top, center, and bottom of the guide. Two sets of measurements shall be taken in the guide. The first set of measurements shall be taken 3 mm from the top of the guide, at the center of the guide, and 3 mm from the bottom of the guide. The second set of measurements shall be taken 90° from the first set of measurements. The valve stem shall be measured in the three locations that correspond to the valve guide measurements. The clearances shall be within the specifications listed below:

10.4.6.1 *Valve Stem-to-Guide Clearance Specifications:*

Exhaust: 0.038 to 0.140 mm (0.0015 to 0.0055 in.)

Intake: 0.025 to 0.069 mm (0.0010 to 0.0027 in.)

10.4.7 *Valve Seat Width Measurements*—Measure and record the valve seat widths to the nearest 0.025 mm (0.0009 in.).

10.4.7.1 *Valve Seat Width Specifications:*

Intake: 1.524 to 2.032 mm (.060 to .080 in)

Exhaust: 1.778 to 2.286 mm (.070 to .090 in)

10.4.8 *Valve Spring Free Length Measurements*—Measure and record the valve spring free length dimensions. Experience has shown that the springs should fall within the specifications shown in 10.4.9.

10.4.9 *Valve Spring Loading Measurements*—If the springs are within the specifications for free length dimensions, measure the load on an unassembled valve spring calibration device. The spring loading is measured at a compressed height of 29.5 mm (1.16 in.). Experience has shown that the valve spring parameters should be within the specifications shown below.

10.4.9.1 *Valve Spring Specifications:*

Free length: 50.3 to 53.8 mm (1.98 to 2.12 in.)

Load: 67.3 ± 3.6 kg at 29.5 ± 0.76 mm deflection (148 ± 8 lb at 1.16 ± 0.03 in.)

10.5 *Cylinder Head Assembly:*

10.5.1 *Valve and Valve Seal Installation*—Lubricate each valve seal and valve stem with the specified test oil. Insert each valve into the cylinder head. Install the valve seal over the end of the valve stem with a plastic installation cap in place. Carefully seat the seals fully on the guides.

10.5.2 *Valve Spring and Retainer installation*—Install pre-screened valve springs and retainers. When installing the valve springs and retainers, do not compress the springs excessively. *Excessive spring compression can damage the valve seals.*

10.5.3 *Valve Spring Assembled Height Measurements*—Measure and record the assembled height of the valve springs according to the procedure described in the 1994 Ford Aerostar, Ranger, Explorer Service Manual²⁰. The assembled height shall be between 37.85 mm and 39.37 mm (1.49 in. and 1.55 in.).

10.5.4 *Valve Leak Check*—It is recommended to perform a valve leak check on the cylinder head. Seal off the cylinder head's combustion chambers with a metal plate and a cylinder head gasket. Apply 480 kPa (70 psi) to each combustion chamber through the spark plug hole and record the percent leakdown. The percent leakdown should not be greater than 5 % in any of the combustion chambers. If the percent leakdown is greater than 5 % in any of the combustion chambers, then the suspect valve(s) should be re-cut or re-lapped, or both, as well as reweighed until the percent leakdown is less than 5 %.

10.6 *Cylinder Head Installation:*

10.6.1 *Cylinder Head Torquing*—Install the assembled test cylinder head on the engine. Do not use any sealing or anti-seizure compound on the cylinder head gasket. Install and torque the head bolts according to the procedure described in the 1994 Ford Aerostar, Ranger, Explorer Service Manual.

10.6.2 *Spark Plug Installation*—Install new Motorcraft F3TE-12405-BA spark plugs into the cylinder head. Gap the spark plugs to 1.06 to 1.17 mm (0.042 to 0.046 in.). Torque the spark plugs to 6.8 to 13.6 N·m (5 to 10 lbf·ft).

10.7 *Final Engine Assembly:*

10.7.1 *Camshaft, Rocker Arms, and Camshaft Drive*

Sprocket Installation—Install the camshaft, rocker arms, and camshaft drive sprocket. Collapse all lash adjusters before the rocker arms are installed to prevent potential damage to the valves when the timing belt is installed and tensioned.

10.7.2 *Camshaft Drive Installation*—Install the auxiliary shaft sprocket and align the camshaft drive. Torque the sprockets according to the procedure noted in the 1994 Aerostar, Ranger, Explorer Service manual. Install a camshaft drive belt. Use a new camshaft drive for each test. Tension the camshaft drive belt according to the procedure noted in the 1994 Aerostar, Ranger, Explorer Service Manual.

10.7.3 *Water Pump and Water Pump Pulley Installation*—Install the water pump and water pump pulley.

10.7.4 *Camshaft Drive Belt Cover and Crankshaft Pulley Installation*—Install the camshaft drive belt cover. Install the crankshaft pulley. It is advisable to make a reference mark on the crankshaft pulley corresponding to top dead center of the number one and number two pistons. The reference marks are used for the required percent leakdown test.

10.7.5 *Lower Intake Manifold Runner Installation*—Install the lower intake manifold runner to the test head. The lower intake manifold may be installed onto the cylinder head prior to the cylinder head being installed onto the engine block.

10.7.6 *Fuel Injectors and Fuel Injector Rail Installation*—Install the fuel injectors and the fuel injector rail to the lower intake manifold runner. Install injectors such that the electrical connection is at the top most (12 o'clock) position. Reference scribe markings should be placed on the fuel injectors and the lower intake manifold runner and the scribe markings should be lined up for each test.

10.7.7 *Rocker Cover and Upper Intake Manifold Installation*—Install the rocker cover and the production upper intake manifold.

10.7.8 *Intake Air System Installation*—Install the specified test intake air system. The specified test intake air system consists of the air cleaner housing, air filter, and rubber flexible tube which attaches from the air cleaner housing to the throttle body of the upper intake manifold. Refer to Fig. A1.4. Route conditioned intake air per the temperature and humidity specifications dictated in Table 1 to the inlet of the air cleaner housing. Replace the specified test air filter every test.

10.7.9 *Miscellaneous Parts Installation*—Install the exhaust manifold, belt tensioning system, accessory drive belt, ignition coil packs, and spark plug wires.

10.7.9.1 The belt tensioning system shall consist of the water pump pulley and the crankshaft pulley as specified by the test engine parts list detailed in Annex A2. Other parts used in the belt tensioning system shall be certified Ford OEM parts. All parts used in the belt tensioning system shall be *free wheeling* and shall not add any additional load to the engine other than normal frictional load losses.

10.7.10 *Engine Cooling System Installation*—A typical engine cooling system configuration is detailed in Fig. A1.11. Equal volumes of a commercial ethylene glycol-based low-silicate antifreeze and distilled or demineralized water shall be utilized in the cooling system. Coolant capacity is specified in 6.2.8.1.

10.7.11 *External Oil System Installation*—Refer to 6.2.9 for

²⁰ Available from Helm, Inc., P.O. Box 07150, Detroit, MI 48207.