Designation: D8350 − 22

Standard Test Method for Evaluation of Automotive Engine Oils in the Sequence IVB Spark-Ignition Engine[1]

This standard is issued under the fixed designation D8350; 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

Portions of this test method are written for use by laboratories that make use of ASTM Test Monitoring Center (TMC)[2] services (see Annex A1 – Annex A4).

The TMC provides reference oils and engineering and statistical services to laboratories that desire to produce test results that are statistically similar to those produced by laboratories previously calibrated by the TMC. In general, the test purchaser decides if a calibrated test stand is to be used. Organizations such as the American Chemistry Council require that a laboratory utilize the TMC services as part of their test registration process. In addition, the American Petroleum Institute and the Gear Lubricant Review Committee of the Lubricant Review Institute (SAE International) require that a laboratory use the TMC services in seeking qualification of oils against their specifications.

The advantage of using the TMC services to calibrate test stands is that the test laboratory (and hence the test purchaser) has an assurance that the test stand was operating at the proper level of test severity. It should also be borne in mind that results obtained in a non-calibrated test stand may not be the same as those obtained in a test stand participating in the ASTM TMC services process.

Laboratories that choose not to use the TMC services may simply disregard these portions. ASTM International policy is to encourage the development of test procedures based on generic equipment. It is recognized that there are occasions where critical/sole-source equipment has been approved by the technical committee (surveillance panel/task force) and is required by the test procedure. The technical committee that oversees the test procedure is encouraged to clearly identify if the part is considered critical in the test procedure. If a part is deemed to be critical, ASTM encourages alternate suppliers to be given the opportunity for consideration of supplying the critical part/component providing they meet the approval process set forth by the technical committee.

An alternate supplier can start the process by initiating contact with the technical committee (current chairs shown on ASTM TMC website). The supplier should advise on the details of the part that is intended to be supplied. The technical committee will review the request and determine feasibility of an alternate supplier for the requested replacement critical part. In the event that a replacement critical part has been identified and proven equivalent the sole-source supplier footnote shall be removed from the test procedure.

1. Scope*

1.1 This test method measures the ability of an engine crankcase oil to control valve-train wear in spark-ignition engines at low operating temperature conditions. This test method is designed to simulate extended engine cyclic vehicle operation. The Sequence IVB Test Method uses a Toyota 2NR-FE water cooled, 4 cycle, in-line cylinder, 1.5 L engine. The primary result is bucket lifter wear. Secondary results include cam lobe nose wear and measurement of iron (Fe) wear

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants.

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[2] The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. Information letters may be obtained from the ASTM Test Monitoring Center (TMC), 203 Armstrong Drive, Freeport, PA 16229, Attention: Director. www.astmtmc.org. This edition incorporates revisions in all Information Letters through No. 22-1.

***A Summary of Changes section appears at the end of this standard**

metal concentration in the used engine oil. Other determinations such as fuel dilution of the crankcase oil, non-ferrous wear metal concentrations, total fuel consumption, and total oil consumption, can be useful in the assessment of the validity of the test results.[2]

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.2.1 *Exceptions*—Where there is no direct SI equivalent such as pipe fittings, tubing, NPT screw threads/diameters, or single source equipment specified.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use. Specific warning statements are provided throughout this document as necessary in each particular section.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C534 Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form
D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D381 Test Method for Gum Content in Fuels by Jet Evaporation
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D3244 Practice for Utilization of Test Data to Determine Conformance with Specifications
D3525 Test Method for Gasoline Fuel Dilution in Used Gasoline Engine Oils by Wide-Bore Capillary Gas Chromatography
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5191 Test Method for Vapor Pressure of Petroleum Products and Liquid Fuels (Mini Method)
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E84 Test Method for Surface Burning Characteristics of Building Materials
E168 Practices for General Techniques of Infrared Quantitative Analysis

2.2 *SAE Standards:*[4]

J300 Engine Oil Viscosity Classification
J304 Engine Oil Tests
J1423 Classification of Energy-Conserving Engine Oil for Passenger Cars and Light-Duty Trucks

2.3 *API Standard:*[5]

API 1509 Engine Oil Licensing and Certification System

2.4 *ANSI Standard:*[6]

ANSI MC96.1-1975 Temperature Measurement—Thermocouples

2.5 *GM Worldwide Engineering Standards:*

GMW3420[7] Coolant – Extended Life – Ethylene Glycol (**Warning—**Health hazard—see appropriate SDS)

NOTE 1—ShellZone[8] dex-cool 50/50 pre-diluted with de-ionized H_2O meeting the specification for GMW3420, GM Worldwide Engineering Standard has been found satisfactory for this purpose.

3. Terminology

3.1 Terminology D4175 lists terms and definitions internationally recognized for testing procedures as they may apply to Petroleum Products, Liquid Fuels, and Lubricant testing. Terminology D4175 may provide the user of this test method a more in-depth reference to the definitions listed in 3.2.

3.2 *Definitions:*

3.2.1 *air-fuel ratio, n—in internal combustion engines*, the mass ratio of air-to-fuel in the mixture being induced into the combustion chambers.

3.2.2 *automotive, adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

[5] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

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

[7] Available from retailers, auto parts stores, or any Shell retailer / distributor.

[8] ShellZone is a registered trademark of Shell Trademark Management BV. Available from retailers, auto parts stores, or any Shell retailer / distributor.

3.2.3 *blowby, n—in internal combustion engines*, that portion of the combustion by-products and unburned air/fuel mixture that leaks past piston rings into the engine crankcase during operation.

3.2.4 *calibrate, v*—to determine the indication or output of a device (e.g., thermometer, manometer, engine) with respect to that of a standard.

3.2.5 *calibrated test stand, n*—a test stand on which the testing of reference material(s), conducted as specified in the standard, provided acceptable test results.

3.2.5.1 *Discussion*—In several automotive lubricant standard test methods, the ASTM Test Monitoring Center provides testing guidance and determines acceptability.

3.2.6 *corrosion, adj*—the chemical or electrochemical reaction between a material, usually a metal surface, and its environment that can produce a deterioration of the material and its properties.

3.2.7 *engine oil, n*—a liquid that reduces friction or wear, or both, between the moving parts within an engine; removes heat, particularly from the underside of pistons; and serves as a combustion gas sealant for piston rings.

3.2.7.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples.

3.2.8 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them.

3.2.9 *lubricant test monitoring system (LTMS), n*—an analytical system in which ASTM calibration test data are used to manage lubricant test precision and severity (bias).

3.2.10 *mass fraction of B, w_B, n*—mass of a component *B* in a mixture divided by the total mass of all the constituents of the mixture.

3.2.10.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of mass (for example, mass fraction of lead is $w_B = 1.3 \times 10^{-6} = 1.3$ mg/kg).

3.2.11 *non-reference oil, n*—any oil, other than a reference oil; such as a research formulation, commercial oil, or candidate oil.

3.2.12 *oxidation, n*—of engine oil, the reaction of the oil with an electron acceptor, generally oxygen, that can produce deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or a combination thereof.

3.2.13 *quality index (QI), n*—a mathematical formula that uses data from controlled parameters to calculate a value indicative of control performance.

3.2.14 *quantity, n—in the SI*, a measurable property of a body or substance where the property has a magnitude expressed as the product of a number and a unit; there are seven, well-defined base quantities (length, time, mass, temperature, amount of substance, electric current, and luminous intensity) from which all other quantities are derived (for example, volume whose SI unit is the cubic metre).

3.2.14.1 *Discussion*—Symbols for quantities must be carefully defined; are written in italic font, can be upper or lower case, and can be qualified by adding further information in subscripts, or superscripts, or in parentheses (for example, $t_{\mathrm{fuel}} = 40$ °C, where *t* is used as the symbol for the quantity Celsius temperature and t_{fuel} is the symbol for the specific quantity fuel temperature).

3.2.15 *reference oil, n*—an oil of known performance characteristics, used as a basis for comparison.

3.2.15.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils.

3.2.16 *Safety Data Sheet (SDS), n*—a fact sheet summarizing information about material identification; hazardous ingredients; health, physical, and fire hazards; first aid; chemical reactivity's and incompatibilities; spill, leak, and disposal procedures; and protective measures required for safe handling and storage.

3.2.17 *standard test, n*—a test on a calibrated test stand, using the prescribed equipment according to the requirements in the test method, and conducted according to the specified operating conditions.

3.2.18 *test oil, n*—any oil subjected to evaluation in an established test procedure.

3.2.18.1 *Discussion*—It can be any oil selected by the laboratory conducting the test. It could be an experimental product or a commercially available oil. Often, it is an oil that is a candidate for approval against engine oil specifications (such as manufacturers' or military specifications, etc.).

3.2.19 *test parameter, n*—a specified component, property, or condition of a test procedure.

3.2.19.1 *Discussion*—Examples of *components* are fuel, lubricant, reagent, cleaner, and sealer; of *properties* are density, temperature, humidity, pressure, and viscosity; and of *conditions* are flow rate, time, speed, volume, length, and power.

3.2.20 *test procedure, n*—one where test parameters, apparatus, apparatus preparation, and measurements are principal items specified.

3.2.21 *test stand, n*—a suitable foundation (such as a bedplate) to which is mounted a dynamometer, and which is equipped with a suitable data acquisition system, fluids process control system, supplies of electricity, compressed air, and so forth, to provide a means for mounting and operating an engine in order to conduct a Sequence IVB engine oil test.

3.2.22 *used oil, n*—any oil that has been in a piece of equipment (for example, an engine, gearbox, transformer, or turbine), whether operated or not.

3.2.23 *volume fraction of B, φ_B, n*—volume of component *B* divided by the total volume of all the constituents of the mixture prior to mixing.

3.2.23.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of volume (for example, $\varphi_B = 0.012 = 1.2$ % = 1.2 cL/L).

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *aging, n*—engine operation at steady state after completion of break-in, to pacify silicon leaching from gaskets, seals, and RTV silicon (room-temperature-vulcanizing silicon) type sealing materials.

3.3.2 *break-in, n*—initial engine operation to reach stabilization of the engine performance after new parts are installed in the engine.

3.3.3 *cam lobe wear, n*—the difference between pre-test and post-test measurement of a cam lobe from heel to nose in µm.

3.3.4 *camshaft lobe failure, n*—a severe form of wear of a camshaft lobe surface, that influences engine operation and makes it impossible to complete a test.

3.3.4.1 *Discussion*—Tests that experience camshaft lobe failure may be considered non-interpretable because the phenomenon may not have a repeatable relationship with the test oil.

3.3.5 *degreasing solvent, n*—mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content 0 % to 2 % by volume, Flash Point (61 °C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning—**Combustible-Health hazard-see appropriate SDS.) A Certificate of Analysis is required for each batch of solvent.

3.3.6 *flushing, n*—the installation of a fresh charge of lubricant and oil filter for the purpose of running the engine to reduce and eliminate remnants of the previous oil charge.

3.3.6.1 *Discussion*—Flushing may be carried out in an iterated process to ensure a more thorough process of reducing previous oil remnants.

3.3.7 *golden stand, n*—Sequence IVB test stand built in accordance with the Sequence IVB test method by the approved supplier(s).

3.3.8 *Keyence VR Macroscope, n*—a wide area optical 3D measurement device produced by the Keyence Corporation used to generate volume loss wear results for Sequence IVB tests.

3.3.9 *lifter crown, n*—the maximum difference in height measured along to reference axis of the bucket lifters.

3.3.10 *lifter volume loss, n*—the difference between the post-test and pre-test volume of a valve-train bucket lifter as measured by a Keyence VR-3000 or later model 3D macroscope.

3.3.10.1 *Discussion*—The pass-fail criteria is the average intake lifter volume loss, the average volume loss of all eight intake bucket lifters. The average of all eight exhaust bucket lifter volume loss is also calculated.

3.3.11 *reference plane, n*—the depth above which volume is calculated for Keyence volume measurements.

4. Summary of Test Method

4.1 *Test Numbering Scheme*—Use the test numbering scheme shown below:

AAAAA-BBBBB-CCCCC

Where:

AAAAA = the stand number;

BBBBB = the number of tests since the last reference calibration test on that stand; and

CCCCC = the total number of Sequence IVB tests conducted on that test stand.

Example: Test number 6-10-175 represents the 175th Sequence IVB test conducted on test stand 6 and the tenth test since the last calibration test. Consecutively number all tests. Number the stand calibration tests beginning with zero for the BBBBB field. Multiple-length Sequence IVB tests are multiple runs for test numbering purposes, such as double-length tests which are counted as two runs and triple-length tests which are counted as three runs. For example, if test 1-3-28 is a doubled-length test, number the next test conducted on that stand 1-5-30. Do not include break in (see 11.8) or aging runs (see 11.9) on new engines in the number of tests since the last reference calibration test on that stand or the total number of Sequence IVB tests conducted on that test stand. Maintain separate numbering for those runs.

4.2 *Test Engine*—This procedure uses a Toyota 2NR-FE water cooled, 4 cycle, in-line four-cylinder, 1.5 L engine as the test apparatus. The engine incorporates dual overhead camshafts, four valves per cylinder (2 intake; 2 exhaust), and a direct acting mechanical bucket lifter valve-train design. The critical test parts (camshafts, direct acting mechanical bucket lifters) are replaced prior to each test. A 95 min break-in schedule, followed by a 50 h aging schedule, for Silicon (Si) pacification, is conducted whenever the long block or cylinder head are replaced with new components, or the long block is rebuilt due to camshaft lobe failure. In addition, a 50 h final break-in schedule (11.10) is conducted following engine aging (11.9) whenever the long block is replaced with new components.

4.3 *Test Stand*—The complete test stand is available from Test Engineering Inc. Thermocouples are to be installed by individual test labs at the locations shown in Annex A7. Mount the engine so that there is a 4.5° incline from the exhaust to the intake side and an angle of 0° from front to back. Control the intake air, provided to the engine air filter housing, for temperature, pressure, and humidity. Control the backpressure of the exhaust leaving the engine. Install the engine on a test stand equipped with computer control of engine speed, torque, various temperatures, pressures, flows, and other parameters outlined in the test procedure (see Section 11).

4.4 *Test Sequence*—After an engine run-in and aging schedule, or after the completion of a previous test, install new test camshafts and bucket lifters, spark plugs, and a new timing chain tensioner. Flush the external oil system with degreasing solvent (**Warning—**Combustible-Health hazard-see appropriate SDS) (see 3.2.16) and the oil pan with EF-411 using external pumps and connections. After completing the external oil system and oil pan flush procedures, remove the external oil flush connections and connect all required oil system test lines. Perform four engine flushes, (see 11.12.1 Engine Flushes) using fresh oil charges for each flush. After completing the fourth flush, drain and install the fresh test oil charge. Run the test for a total of 200 h, with no scheduled shutdowns. A single test cycle is composed of two 7 s steady-state stages separated by 8 s transitions. This test cycle (two steady-state stages and two transitions) is repeated 24 000 times.

4.5 *Analyses Conducted*—At the completion of the test, the camshaft lobes are measured for heel-to-toe wear and the bucket lifters are measured for volume loss. Use these measurements to determine the average, minimum, and maximum wear for the intake and exhaust bucket lifters and the intake and exhaust camshaft lobes. Determine the oil consumption by calculating the difference between the mass of the used drain oil and the mass of the engine's initial oil charge considering oil removed for intermediate oil samples. Analyze the end of test used oil for wear metals, fuel dilution, kinematic viscosity at 40 °C, total acid number, total base number, oxidation and nitration by FTIR, and Karl Fischer water content. Retain a final drain sample of 1 L for a minimum of 90 days. Retain the camshafts and bucket lifters for a minimum of six months.

5. Significance and Use

5.1 This test method was developed to evaluate automotive lubricant's effect on controlling valve-train wear and overall engine wear for overhead camshaft engines with direct acting bucket lifters.

5.2 Average intake lifter volume loss is used as a measure of an oil's ability to prevent valve-train wear.

5.3 End-of-test oil iron concentration is used as a measure of an oil's ability to prevent overall engine wear.

NOTE 2—This test method may be used for engine oil specifications such as API SP, and ILSAC GF- 6A, and GF-6B.

6. Apparatus

NOTE 3—Coordination with the ASTM Committee D02, Subcommittee B, Sequence IV Surveillance Panel is a prerequisite to the use of any equivalent apparatus. Figures are provided throughout the test method to suggest appropriate design details and depict some of the required apparatus.

6.1 *Test Engine*—This test method uses a 2011 model Toyota 2NR-FE, in-line 4-cylinder, 16 valve, 4-cycle, watercooled, port fuel-injected gasoline engine with a displacement of 1.496 L. See Annex A9 for a parts list. Nominal oil sump volume is 3.0 L. The cylinder block and cylinder head are aluminum. The engine features dual overhead camshafts and direct acting bucket lifters. The engine compression ratio is 10.5 to 1. The engine is rated to 132 N·m of torque at 3000 r/min. The ignition timing and multi-port fuel injection system is electronically controlled by a test-specific Engine Control Module (ECM).

6.1.1 *Engine Buildup Area*—The ambient atmosphere of the engine buildup and measurement areas shall be reasonably free of contaminants and maintained at a uniform temperature. Care should be exercised to eliminate the use of any materials which would introduce abrasive dust type particles of any nature in the engine build areas. Maintain the specific humidity at a uniform level to prevent the accumulation of rust on engine parts. The engine buildup area shall maintain uniform temperatures and background luminous intensity to ensure repeatable dimensional measurements performed in the engine buildup area.

6.1.2 *Measurement/Metrology Area*—Use uniform temperatures and background lighting to ensure repeatable dimensional measurements.

6.1.3 Use a Keyence macroscope on a base-plate free of external vibrations.

6.1.4 *Engine Operating Area*—The laboratory ambient atmosphere shall be reasonably free of contaminants and general wind currents, especially if the valve-train parts are installed while the engine remains in the operating area. The temperature and humidity level of the operating area is not specified.

6.1.5 *Parts Cleaning Area*—This test method does not specify the ambient atmosphere of the parts cleaning area (**Warning—**Use adequate ventilation in areas while using solvents and cleansers).

6.2 *External Engine Modifications*—Modify the test engine for the valve-train wear test. Install the modified front cover and oil pan from the approved supplier. Install an oil filter adapter at the location of the stock oil filter housing, as shown in the Sequence IVB Engine Assembly Manual Section 1. Install fittings for various temperature and pressure measurements as required by the test method. Replace the Toyota production rocker arm cover with a specially manufactured aluminum jacketed rocker arm cover (part# OHTIVB-002-1). Route the rocker arm cover coolant through this jacket.

6.3 *Test Stand and Laboratory Equipment*—This engine-dynamometer test is designed for operation using computer control instrumentation and computer data acquisition. Provide an intake air system for the precise control of engine intake air humidity, temperature, and cleanliness.

6.3.1 *Computer Data Acquisition System*—Sections 6.3.1.1 – 6.3.1.3 detail the test stand data logging criterion for operational data with a computer data acquisition system using sensor configurations, and compliances with the Data Acquisition and Control Automation II[9] guidelines. Consider a test that has greater than 2 h without data acquisition on any controlled parameter to be operationally invalid.

6.3.1.1 *Frequency of Logged Data*—Log data at 1 Hz during all four stages of all test cycles.

6.3.1.2 *Resolution of Logged Data*—The laboratory provided data acquisition system must provide 32 analogs to digital channels that meet the resolution requirements in Table 1.

TABLE 1 Data Acquisition Resolution Requirements

Parameter	Units	Required Resolution
Engine speed	r/min	1
Torque	N-m	1
Air-to-fuel ratio	AFR	0.05
All temperatures except exhaust	°C	0.1
Exhaust temperature	°C	1
All gauge pressures	kPa	0.1
Barometer (Absolute)	kPa	0.1
Humidity	g/kg	0.1

[9] ASTM TMC Technical Guidance Committee Report available referenced on www.astmtmc.org.

6.3.1.3 *System Time Response for Logged Data*—Do not exceed the controlled operational parameters for system time response for measurement shown in Table 2. The system time response includes the total system of sensor, transducer, analog signal attenuation, and computer digital filtering. Use single-pole type filters for attenuation.

6.3.1.4 *Quality Index*—The Quality Index (QI) is an overall statistical measure of the variation from test targets of the steady-state operational controlled parameters. The Sequence IVB Surveillance Panel has chosen the QI upper and lower control limits, for Humidity, Temperature, Pressure, Torque, and Flow shown in Table 3, and for Engine Speed (Variable Target) QI Control Limits shown in Table 4.

$$1 - \frac{1}{n}\sum_{i=1}^{n}\left(\frac{U+L-2X_i}{U-L}\right)^2 = QI \quad (1)$$

where:

X_i = values of the parameter measured,
U = allowable upper limit of X,
L = allowable lower limit of X, and
n = number of data points used to calculate QI.

6.3.1.5 *Bad Quality Data (BQD)*—Table 5 shows the BQD limits.

Where missing data or Bad Quality Data (BQD), or both, are encountered, calculate the adjusted Quality Index (QI_{ADJ}) using the following equation:

$$QI_{ADJ} = QI\left(\frac{n}{N}\right) + QI\left(\frac{n}{N}\right) \times \left(\frac{N-n}{N}\right) \quad (2)$$

where:

Q = QI calculated without missing/BQD,
I = points,
n = number of data points used to calculate QI, and
N = number of data points for a complete data set.

If the QI calculation of a controlled parameter is less than zero, investigate the reason, assess its impact on test operational validity, and document such finding in the final test report. For calibration tests, review the operational validity assessment with the TMC. Annex A2 describes calibration procedures using the TMC reference oil, including their storage and conditions of use, the conducting of tests and the reporting of results.

6.3.2 *Test Stand Configuration*—Mount the engine on the test stand like its vehicle orientation (0° in front; sideways 4.5° up on intake manifold side). This orientation is important to the return flow of oil in the cylinder head and ensures reproducible oil levels. Directly couple the engine flywheel to the Midwest MW1014A dynamometer through the approved driveshaft.

6.3.3 *Dynamometer Excitation and Throttle Control*—A DyneSystems Non-Interlock 5 which is provided as part of the golden stand assembly is the only system permitted to be used for dynamometer excitation and throttle control.

TABLE 2 System Time Response

Parameters	Time Response, max (one-time constant)
Temperatures	2.8 s
Pressures	1.7 s
Coolant flow	8.0 s
Torque	2.0 s
Speed	1.8 s

TABLE 3 QI Control Limits

Parameter	U	L
Intake Air Humidity	12.00	11.00
Engine Coolant Out Temperature[A]	53.50	50.75
Exhaust Backpressure[B]	107.50	101.50
Fuel Rail Temperature	24.50	23.50
Intake Air Pressure	0.50	0.00
Intake Air Temperature	32.75	31.25
Oil Gallery Temperature	58.00	50.00
RAC Coolant Out Temperature	20.75	19.25
Torque	26.50	23.50
Engine Coolant Flow Rate	80.40	79.60
RAC Coolant Flow Rate	120.75	119.25
Blow-by Gas Temperature	29.50	28.50
Load Cell Temperature	49.00	41.00
Engine Coolant Pressure	80.00	60.00
Fuel Rail Pressure	345.00	325.00

[A] Only calculated during stages 1 and 2.
[B] Only calculated during stage 2.

TABLE 4 Engine Speed (Variable Target) QI Control Limits

Cycle Time, s	Set point, r/min	U, r/min	L, r/min
1	800	950	650
2	800	900	700
3	800	875	725
4	800	850	750
5	800	850	750
6	800	850	750
7	800	850	750
8	927	1077	777
9	1357	1607	1107
10	1888	2288	1488
11	2300	2700	1900
12	2731	3131	2331
13	3168	3568	2768
14	3610	4010	3210
15	4041	4441	3641
16	4300	4400	4200
17	4300	4375	4225
18	4300	4350	4250
19	4300	4325	4275
20	4300	4325	4275
21	4300	4325	4275
22	4300	4325	4275
23	4136	4236	4036
24	3734	3984	3484
25	3283	3683	2883
26	2829	3229	2429
27	2382	2782	1982
28	1946	2346	1546
29	1523	1923	1123
30	1116	1516	716

6.3.4 *Intake-air Supply System*—The intake air supply system shall deliver at least 1000 L/min (2000 L/min preferred) of conditioned and filtered air to the test engine during the 200 h test, while maintaining the intake-air parameters detailed in Table 13.

6.3.4.1 *Induction Air Humidity*—Measure the intake air specific humidity in the main system duct or at the test stand. If using a main system duct dew point temperature reading to calculate the specific humidity, verify the dew point periodically at the test stand. Maintain the duct surface temperature above the dew point temperature at all points downstream of the humidity measurement point to prevent condensation and loss of humidity level.

TABLE 5 BQD Limits

Parameter	U	L
Intake Air Humidity	20.00	1.00
Engine Coolant Out Temperature	195.00	0.00
Exhaust Backpressure	200.00	0.00
Fuel Rail Temperature	195.00	0.00
Intake Air Pressure	5.00	-1.00
Intake Air Temperature	195.00	0.00
Oil Gallery Temperature	195.00	0.00
RAC Coolant Out Temperature	195.00	0.00
Engine Speed	5500.00	0.00
Torque	200.00	0.00
Engine Coolant Flow Rate	200.00	0.00
RAC Coolant Flow Rate	200.00	0.00
Blow-by Gas Temperature	195.00	0.00
Load Cell Temperature	195.00	0.00
Engine Coolant Pressure	200.00	0.00
Fuel Rail Pressure	500.00	0.00

6.3.4.2 *Intake Air Filtering*—Use the production intake air cleaner assembly with filter, at the engine. Use a snorkel adapter that fits over the intake air box inlet to connect the controlled air duct to the air cleaner. Ensure that the top of the air cleaner assembly has been modified for installation of the intake pressure sensor line. Refer to 6.3.4.5 for installation position.

6.3.4.3 *Intake Air Flow*—Do not measure intake airflow.

6.3.4.4 *Intake Air Temperature*—For final control of the inlet air temperature, install an electric air heater strip within the air supply duct. The duct material and heater elements design shall not generate corrosion debris that could be ingested by the engine.

6.3.4.5 *Intake Air Supply Pressure*—Locate the pressure sensing tube on the top cover of the air cleaner 190 mm ± 10 mm from the front (straight edge of the top surface) and 65 mm ± 10 mm from the left (viewed from the front of the box). The tube shall have a depth of 25 mm ± 4 mm into the air cleaner.

6.3.5 *Fuel Supply System*—This test method requires approximately 750 L of unleaded Haltermann KA24E Green test fuel per test (24 000 cycles). A fuel supply pressure of at least 124 kPa (18 psi) to the fuel conditioning system is required. Use a Motorcraft E7T2-9C407-BA fuel pump. The fuel conditioning system is part of the golden stand supplied by Test Engineering Inc.

7. Reagents and Materials

Note 4—Use 12 L and 2600 g (~3000 mL) of the non-reference test oil sample to perform the 200 h Valve-train Wear test.

7.1 *Coolant for Engine and Rocker Arm Cover*—Use a mixture of ShellZone[8] DEX-COOL antifreeze/coolant and de-ionized water with a volume fraction of water of 50 %. (**Warning—**Health hazard—see appropriate SDS).

7.2 *Fuel*—Use Haltermann KA24E10[10] Green test fuel for this test method (**Warning—**Flammable health hazard). It is dyed green to preclude unintentional contamination with other test fuels. Refer to the TMC (https://www.astmtmc.org). Use approximately 750 L of fuel for each test (24 000 cycles). This fuel has a hydrogen-to-carbon ratio of 1.80 to 1.

7.2.1 *Fuel Approval Requirements*—The fuel is blended to a sulfur content of 130 ppm ± 10 ppm and the fuel supplier's requirements. Base the fuel batch acceptance upon the physical and chemical specifications given in Annex A10. Engine validation tests are not necessary for fuel batch acceptance.

7.2.2 *Fuel Analysis*—Monitor the test fuel using good laboratory practices. Analyze each fuel shipment to determine the value of each parameter for fuel sulfur as described in Test Method D5453, existent gum as described in Test Method D381, RVP as described in Test Method D5191, and API Gravity as described in Test Method D4052. Compare the results to the original values supplied by the fuel supplier. The analytical results shall be within the tolerances shown in parentheses beside each parameter. This provides a method to determine if the fuel batch is contaminated or has aged prematurely. If any analytical result falls outside the tolerances, the laboratory shall contact the fuel supplier for problem resolution.

7.2.2.1 *Fuel Deterioration*—Analyze the fuel semiannually to ensure the fuel has not deteriorated excessively or been contaminated in storage.

7.2.2.2 Analyze the fuels using Test Methods D5453, D4052, D381, and D5191.

7.2.3 *Fuel 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 in accordance with all applicable safety and environmental regulations. If the run tank has more than one batch of fuel, document the most recent batch in the test report.

7.3 *Lubricating Oils:*

7.3.1 *Break-in Lubricating Oil*—An engine break-in procedure as shown in 11.8 is immediately conducted following the replacement of new, major engine components (that is, engine short-block, or cylinder head, or both). Use the proper reference oil, 1006-2, from the TMC for the break-in procedure. Use 3 L of this reference oil for each break-in procedure.

7.3.2 *Break-In #2 Lubricating Oil*—A second engine break-in procedure (see Section 11) is conducted following the initial Break-In cycle. Use the proper reference oil, 1012, from the TMC for break-in procedure. Use 19 L of this reference oil for each break-in #2 procedure.

7.3.3 *Short-block Assembly Lubricant and External Oil System Flush*—For engine short-block inspection and reassemble, use EF-411[11] oil as the assembly lubricant. Also used during external oil system flushing.

7.4 *Miscellaneous Materials:*

[10] The sole source of supply of this fuel known to the committee at this time is Haltermann Products, 1201 Sheldon Rd., P.O. Box 429, Channelview, TX 77530–0429, USA. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[11] The sole source of supply of this product known to the committee at this time is Exxon-Mobil Oil Corp., Attention Illinois Order Board, P.O. Box 66940, AMF O'Hare, IL 60666, USA. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

7.4.1 *Solvents and Cleansers*—No substitutions for 7.4.1.1 – 7.4.1.3 are allowed. Use adequate safety provisions with all solvents and cleaners.

7.4.1.1 *Degreasing Solvent*—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0 % to 2 % by volume), Flash Point (61 °C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning—**Combustible-Health hazard-see appropriate SDS.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

7.4.1.2 *Pentane*—(**Warning—**Flammable. Health hazard.) Available from petroleum solvent suppliers.

7.4.1.3 *Cylinder Block and RAC Cleaning Detergent*—Trisodium phosphate and any commercial coolant cleanser. (**Warning—**Caustic. Health hazard.)

7.4.1.4 Use Ultrasonic-7 soap[12] and Ultrasonic-B[12] degreaser in ultrasonic parts washers to clean engine block, cylinder heads and fixed phasers. Cleaning solution shall be at a temperature of 65 °C ± 5 °C.

7.4.1.5 Alternatively, use a 50/50 Brulin US Solution[13] of 815 GD and 815 QR-NF with a volume fraction of 12.5 % provided that the laboratory has conducted a successful reference oil test using this solution.

7.4.2 *Sealing Compounds*—Use a silicone based gasketing compound during engine assembly (for example, oil pan). Use only ACDelco Engine Sealant[14] part number 12378521 or ThreeBond Engine Sealant[15] part number TB 1217F recommended silicone gasket materials.

8. Oil Blend Sampling Requirements

8.1 *Sample Selection and Inspection*—The non-reference oil sample shall be uncontaminated, and representative of the lubricant formulation being evaluated.

NOTE 5—If the test is registered using the American Chemistry Council[16] protocols, the assigned oil container formulation number shall match the registration form.

8.2 *Non-reference Oil Sample Quantity*—Use a minimum of 15 L of new oil to complete the Sequence IVB test, including the oil flushes. Normally the supplier provides a 19 L new oil sample to allow for inadvertent losses.

8.3 *Reference Oil Sample Quantity*—The TMC provides a 19 L reference oil sample for each stand calibration test.

9. Preparation of Apparatus

NOTE 6—This section details those recurring preparations necessary for test operation. This section assumes the engine test stand facilities and other hardware described in Section 6 are in place.

9.1 *Test Stand Preparations:*

9.1.1 *Instrumentation Calibration*—Calibrate all sensors and indicators before or during the test for the type instrumentation used. See Section 10 for the calibration requirements.

9.1.2 *External Oil System Cleaning*—Use clean mineral spirits followed by forced-air drying to clean the external oil system.

9.1.3 *Air Cleaner Filter*—Replace the air cleaner filter element when an engine is replaced, or more frequently if intake air pressure is insufficient.

9.1.4 *Draining Exhaust Piping*—Prior to the start of each test, drain the low point of the exhaust piping to eliminate water accumulation. Drain water during a test if exhaust pressure control becomes unstable.

9.1.5 *External Hose Replacement*—Inspect all external hoses used on the test stand and replace any hoses that have become unserviceable. Check for internal wall separations that could cause flow restrictions. Inspect and replace the external oil system hoses as needed.

9.1.6 *Stand Ancillary Equipment*—Service the dynamometer and driveline components, as required. The dynamometer torque measurement shall be accurate (no unaccounted forces from hoses, load cell temperature gradients, or trunnion bearing hysteresis).

9.2 *General Engine Assembly Preparations*—Refer to the Sequence IVB Engine Assembly Manual, available from the ASTM Test Monitoring Center Website. http://www.astmtmc.org.

10. Data Acquisition, Reference Oil Application, and Equipment Calibration and Maintenance

10.1 *Data Acquisition:*

10.1.1 *Computer Data Acquisition*—The test stand should log operational data using a computer data acquisition system, sensor configuration processes are described in 10.1.2 – 10.1.3.1.

10.1.2 *Frequency of Logged Test Cycle Data*—Log the test cycle data at a sampling rate of 1 Hz.

10.1.3 *Signal Conditioning*—Do not exceed the controlled operational parameters for system time response as shown in Table 1. The system time response includes the total system of sensor, transducer, analog signal attenuation, and computer digital filtering. Use single-pole type filters for attenuation. For temperature sensors only grounded thermocouples are acceptable.

10.1.3.1 *Isolated Inputs*—Use signal-conditioning modules to provide isolated inputs to the digital computer.

10.2 *Reference Oil Application:*

NOTE 7—10.2.6 and 10.2.7 and Annex A1 – Annex A4 describe the involvement of the TMC in respect to calibration procedures and acceptance criteria for a testing laboratory and a test stand, and the issuance of Information Letters and memoranda affecting the test method.

10.2.1 *Testing of Reference Oils*—Periodically conduct tests on reference oils according to the following:

10.2.1.1 Conduct reference oil tests on each calibrated test stand within a laboratory according to TMC guidelines.

10.2.1.2 Obtain reference oils directly from the TMC. These oils are formulated or selected to represent specific chemical

[12] Available from TEI, 12718 Cimarron Path, San Antonio, TX 78249, USA, Tel: (210) 690-1958.

[13] The sole source of supply of this product known to the committee at this time is Brulin & Company, 2920 Dr. Andrew J. Brown Av, Indianapolis, IN 46205, 317.923.3211, csr@brulin.com. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[14] Available from retailers, autoparts stores, or any General Motors dealer.

[15] ThreeBond is a registered trademark of ThreeBond International, Inc. Available from retailers, autoparts stores.

[16] American Chemistry Council, 1300 Wilson Boulevard, Arlington, VA 22209.

types or performance levels, or both. They are usually supplied directly to a testing laboratory under code numbers to ensure that the laboratory is not influenced by prior knowledge of acceptable results in assessing the test results. The TMC determines which specific reference oil the laboratory shall test.

10.2.1.3 Unless specifically authorized by the TMC, do not analyze reference oils, either physically or chemically. Identification of reference oils by such analyses could undermine the confidentiality required to operate an effective reference oil system. Therefore, reference oils are supplied with the explicit understanding that they will not be subjected to analyses other than those specified in this procedure, unless specifically authorized by the TMC. If so authorized, prepare a written statement of the circumstances involved, the name of the person authorizing the analysis, and the data obtained; furnish copies of this statement to the TMC.

10.2.2 *Reference Oil Test Frequency*—Conduct reference oil tests according to the following frequency requirements:

10.2.2.1 For a given, calibrated test stand, conduct an acceptable reference oil test after no more than 15 test starts have been conducted, or after six months have elapsed, whichever occurs first.

10.2.2.2 After starting a laboratory reference oil test, non-reference oil tests may be started on any other calibrated test stand.

10.2.2.3 Reference oil test frequency may be adjusted due to the following reasons:

10.2.3 *Procedural Deviations*—On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

10.2.4 *Parts and Fuel Shortages*—Under special circumstances, such as industry-wide parts or fuel shortages, the Surveillance Panel may direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

10.2.5 *Reference Oil Test Data Flow*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

10.2.6 *Special Use of the Reference Oil Calibration System*—The Surveillance Panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The Surveillance Panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. To maintain the integrity of the reference oil monitoring system, each reference oil test is conducted to be interpretable for stand calibration. To facilitate the required test scheduling, the Surveillance Panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

10.2.7 *Donated Reference Oil Test Programs*—The Surveillance Panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The Surveillance Panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, to quantify the effect of a change on severity and precision. Typically, the Surveillance Panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The Surveillance Panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

10.2.8 *Reporting of Reference Oil Test Results*—Report the results of all reference oil tests to the TMC according to the following directives:

10.2.8.1 Transmit results to the TMC within five days of completing post-test measurements by way of electronic data transfer protocol as outlined in the Data Communication Committee, Electronic Test Report Transmission Model (ETRTM). The ETRTM can be obtained from the TMC.

10.2.8.2 If the test was conducted during a time extension permitted by the TMC, so indicate in the Comments section of the test report.

10.2.8.3 For an acceptable reference oil test, conducted following an unacceptable reference oil test, provide sufficient information in the Comments section of the test report to indicate how the problem was identified and corrected, insofar as possible, and how it was related to non-reference oil tests conducted during the period that the problem was being solved.

10.2.9 *Evaluation of Reference Oil Test Results*—The TMC evaluates the reference-oil test results for both operational validity and statistical acceptability. The TMC may consult with the test laboratory in case of difficulty, as follows:

10.2.9.1 Immediately upon receipt of the reference-oil test results from the test laboratory, the TMC evaluates the laboratories decision on operational validity. For operationally valid tests, the TMC then evaluates the pass/fail parameters according to the Sequence IVB Lubricant Test Monitoring System. If the test is judged acceptable, the reference oil code is disclosed by the TMC to the test laboratory. The TMC conveys to the test laboratory its preliminary findings based on the limited information available to them.

10.2.9.2 Subsequently, upon receipt of the information detailed in Annex A1 – Annex A4 the TMC reviews all reference-oil test results and reports to determine final test acceptability.

10.2.9.3 The TMC decides, with consultation as needed with industry experts (testing laboratories, members of the ASTM Technical Guidance Committee and of the Surveillance Panel, and so forth), whether the reason for any failure of a reference oil test is a false alarm, testing stand, testing laboratory, or industry-related problem. The Sequence IVB Surveillance Panel shall adjudicate all industry problems.

10.2.10 *Status of Non-Reference Oil Tests Relative to Reference Oil Tests*—Non-reference oil tests may proceed within a given laboratory during reference oil testing based upon the following:

10.2.10.1 During the time of conducting a reference oil test on one test stand, non-reference oil tests may be conducted on other previously calibrated stands. If the reference oil test is acceptable to the TMC, the non-reference oil tests shall be considered to have been run in a satisfactorily calibrated laboratory.

10.2.10.2 If a reference oil test is unacceptable, and it is determined that the problem is isolated to an individual test stand, consider other test stands to remain calibrated, and testing of non-reference oils may proceed on those other stands.

10.2.10.3 If a reference oil test is unacceptable, and it is determined that the problem is laboratory related, nonreference tests running during the problem period shall be considered invalid unless there is specific evidence to the contrary for each test.

10.2.11 *Status of Test Stands Used for Non-Standard Tests*—If a non-standard test is conducted on a previously calibrated test stand, conduct a reference oil test on that stand to demonstrate that it continues to be calibrated, prior to running standard tests.

10.3 *Equipment Calibration:*

10.3.1 *Instrumentation Calibration*—Perform a thorough recalibration adjustment of all instrumentation and transducers, including computer channels, according to the requirements that follow. Perform additional calibration checks whenever operational data indicates an abnormality. Standards used for instrumentation calibration shall be traceable to that country's specific national standards organization. The accuracy of the standard shall be a minimum of four times better than the accuracy of the test stand instrumentation.

10.3.2 *Dynamometer Torque Measurement*—Scale the final readout of engine torque (N·m). Calibrate the force measurement and readout system with deadweights. Coolant flow through the dynamometer, reaction forces due to coolant plumbing, and brinelled trunnion bearings of the dynamometer may affect calibration by temperature excursions of the dynamometer electronic force transducer. When calibrating, ensure the dynamometer coolant flow indicator is in the green and that the load cell temperature has been stabilized at 45 °C ± 1 °C for a minimum of one hour. Perform this calibration prior to every test start.

10.3.3 *Instrument Calibration*—Document all instrument calibrations. Retain all calibration documentation for a minimum of three years.

10.3.3.1 Upon initial stand installation and every six months thereafter perform a full instrumentation calibration according to Table 6.

10.3.4 *Humidity of Induction Air Calibration:*

10.3.4.1 Calibrate the primary laboratory measurement system at each test stand every six months using a hygrometer with a minimum dew point accuracy of ±0.55 °C at 16 °C. Locate the sample tap on the air supply line to the engine, between the main duct and 1000 mm upstream of the intake air cleaner. The calibration consists of a series of paired humidity measurements comparing the laboratory system with the calibration hygrometer. The comparison period lasts from 20 min to 2 h with measurements taken at intervals of 1 min to 6 min, for a total of 20 paired measurements. The measurement interval shall be appropriate for the time constant of the humidity measurement instruments.

10.3.4.2 Verify that the flow rate is within the equipment manufacturer's specification and that the sample lines are non-hygroscopic. Correct dew point hygrometer measurements to standard conditions (101.12 kPa) using the appropriate equation. Compute the difference between each pair of readings and calculate the mean and standard deviation of the twenty-paired readings. The absolute value of the mean difference shall not exceed 1.43 g/kg, and the standard deviation shall not be greater than 0.714 g/kg. If these conditions are not met, investigate the cause, make repairs, and recalibrate. Maintain calibration records for two years.

TABLE 6 Parameters to be Calibrated Every 6 Months

Items
Temperatures
Intake Air Temperature, °C
Engine Oil Gallery Temperature, °C
Engine Oil Sump Temperature, °C
Coolant Temperature into Engine, °C
Coolant Temperature Out of Engine, °C
Fuel Rail Temperature, °C
Exhaust Gas Temperature, °C
Valve Cover Coolant In Temperature, °C
Valve Cover Coolant Out Temperature, °C
Dynamometer Load Cell Temperature, °C
Test Cell Air Temperature, °C
Blow-by Gas Temperature, °C
Blow-by Coolant Temperature, °C
Pressures
Engine Coolant Pressure, kPa
Crankcase Gas Pressure, kPa
Oil Gallery Pressure, kPa
Fuel Rail Pressure, kPa
Exhaust Pressure, kPa (absolute)
Intake Air Pressure, kPa
Intake Manifold Pressure, kPa (absolute)
Barometric Pressure, kPa (absolute)
Flows
Air Fuel Ratio, afr
Blow-by Flow Rate, sl/min
Fuel Flow Rate, kg/h
Engine Coolant Flow Rate, L/min
Valve Cover Coolant Flow Rate, L/min
General
Intake Air Humidity, grains/kg
Engine Speed, r/min
Engine Torque (N-m)

10.3.5 *Keyence Measurement Device*—Confirm the calibration of the Keyence measurement device with the reference standard before every use.

11. Procedure

11.1 When installing a new engine and cylinder head or both, conduct break-in and aging procedures, (see 11.8 and 11.9), before running official 200 h tests. After completing the break-in, install the official test valve-train parts as shown in the Sequence IVB Engine Assembly Manual. Then conduct the pre-test procedure shown in 11.3 and four fired oil-flushes as shown in 11.3.1. After performing the four-fired oil-flushes, conduct the 200 h test as shown in section 11.3.2.

11.2 *Engine Start Procedure*—Whenever an engine is started this procedure should be followed.

11.2.1 Before starting the engine, check DyneSystems PAU status, and if necessary, perform reset procedure (See Fig. 1).

11.2.2 When starting the engine, set DyneSystems PAU throttle position to a set percent to achieve >500 r/min (typical range is 5 % to 15 %). (See Fig. 1.)

11.2.3 When starting the engine, set DyneSystems PAU dynamometer excitation to 0 %.

11.2.4 Energize the starter motor for 7 s or until engine speed is greater than 500 r/min, whichever comes first. Then, turn off the starter motor. As soon as the engine speed is greater than 500 r/min proceed to target conditions.

11.3 *Pre-test Procedure:*

11.3.1 *Pre-test Stand Cleaning*—Clean all pressure traps, the external oil system and the external blow-by system prior to starting all tests.

11.3.1.1 Remove, spray clean with degreasing solvent, (**Warning—**Combustible-Health hazard-see appropriate SDS) and air dry the exhaust backpressure and crankcase pressure filters. Re-install the filters and inspect and replace the O-rings (Norgreen part 4380-700) as needed.

11.3.1.2 Disconnect the external oil supply and oil return lines from the remote oil filter housing adapter that is mounted on the engine (refer to Fig. 2).

11.3.1.3 Connect the external oil supply and external oil return lines to a portable oil cleaning flush cart of minimum 1 gal capacity that is equipped with a circulation pump with a flow capacity of at least 3.8 L/m (1.0 gpm). Charge the flush cart with solvent and energize the flush cart pump. Allow the solvent to circulate for 5 min. De-energize flush cart, open both heat exchanger drain valves and allow the external oil system to drain. Close drain valves, re-charge the flush cart, re-energize the flush cart and allow solvent to recirculate for approximately 1 h.

11.3.1.4 After solvent has circulated for at least one hour, de-energize the flush cart pump and open both heat exchanger drain valves and allow the external oil system to drain.

11.3.1.5 Disconnect the external oil supply and external oil return lines from the flush cart and connect the external oil system to a clean and dry compressed air supply at 103 kPa to 206 kPa (15 psi to 30 psi). Allow the air to flow through the system for at least 15 min to dry the system.

11.3.1.6 Disconnect the supply and return lines from the compressed air source and connect the external oil supply and external return lines back to the remote oil filter housing adapter that is mounted on the engine. Close the heat exchanger drain valves.

11.3.1.7 Remove the Oberg oil filter element (B in Fig. 3) for cleaning. Clear any debris retained in the Oberg oil filter element with degreasing solvent (**Warning—**Combustible-Health hazard-see appropriate SDS) and air dry. Re-install the Oberg oil filter element in the Oberg filter housing (see Fig. 3) and secure the four retaining bolts. Part number and supplier info is available in Appendix X1.

11.3.1.8 Disconnect the oil pressure sense line between the engine and oil sample valve. Rinse this line using clean degreasing solvent (**Warning—**Combustible-Health hazard–see appropriate SDS) and air dry.

11.3.1.9 Disconnect the oil pressure sense line between the oil sample valve and the oil pressure transducer. Rinse this line using clean degreasing solvent (**Warning—**Combustible-Health hazard–see appropriate SDS) and air dry.

11.3.1.10 Open the oil sample valve and allow any trapped oil to drain. Then close the valve and reconnect both oil pressure and sample lines to their respective locations.

11.4 *Oil Pan Flush*—Flush the oil pan with EF-411 oil supplied by an external pump prior to all tests.

11.4.1 Pour 1 gal of new EF-411 into a clean oil flush apparatus.

11.4.2 The apparatus must include a pump with at least 1 gpm of flow, an oil filter, and if pipe fittings are used, they must be black or stainless. A NAPA 1-8429 oil filter adapter, and unused Motorcraft FL 1A oil filter, and GP201-12L pump are examples of suitable parts.

11.4.3 Connect the apparatus supply to the #8 AN fitting on the side of the modified Sequence IVB oil pan and the return to the rear oil pan drain plug.

11.4.4 Run the pump and circulate the EF-411 through the oil pan for 10 min.

11.4.5 Turn off the pump, remove the apparatus, and allow the EF-411 to drain for 5 min.

FIG. 1 DyneSystems PAU

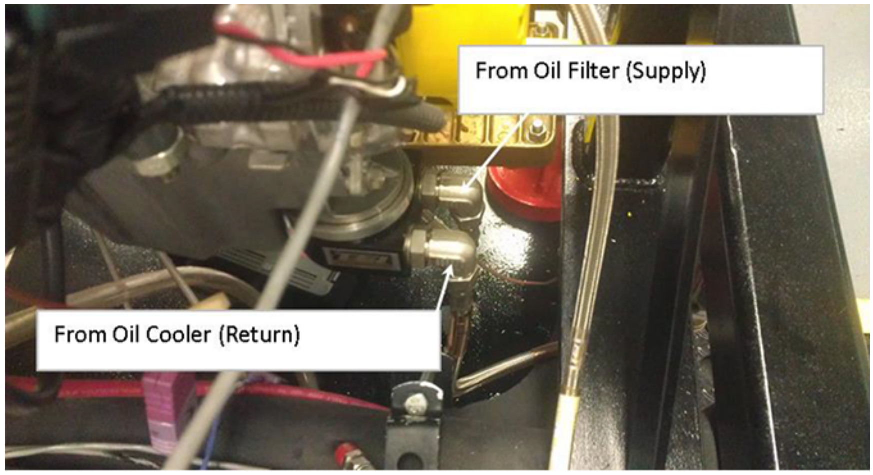


FIG. 2 Remote Oil Filter Housing Adapter

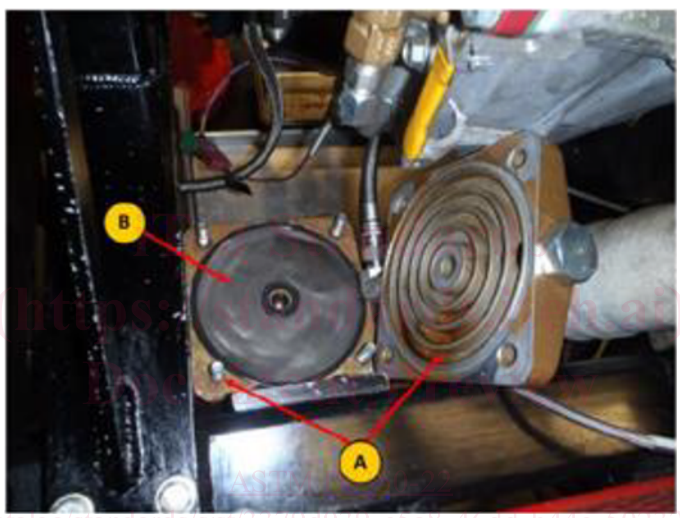


FIG. 3 Disassembled Oberg Filter Housing (A) with Filter Element (B)

11.4.6 Re-install a stainless-steel cap on the #8 fitting on the side of the oil pan and re-install the oil pan drain plug.

11.5 *Blow-by System Cleaning*—Clean the blow-by heat exchanger, plumbing and oil separator before every test. Reference Annex A8 and Annex A12 for detailed instruction.

11.5.1 Remove the blow-by heat exchanger, plumbing and oil separator from the test stand and remove the insulation from the plumbing and oil separator.

11.5.2 Disassemble the heat exchanger and oil separator for cleaning.

11.5.3 Spray clean the inside of separator and gas side of the heat exchanger with degreasing solvent (**Warning—** Combustible-Health hazard–see appropriate SDS) and air dry.

11.5.4 Remove all the short Tygon hose sections between the valve cover and external blow-by system heat exchanger and replace as needed.

11.5.5 Spray clean the inside of all plumbing fittings and any Tygon hose sections that will be reused.

11.5.6 Insulate the oil separator and blow-by plumbing, and reinstall on the test stand, in accordance with the Oil Separator and Blow-by Plumbing Insulation Procedure, Annex A8.

11.5.7 Reconnect the external blow-by system and assembly components to the valve cover.

11.6 *Engine Coolant Fill Procedure*—Charge the engine coolant, rocker cover coolant, and blow-by heat exchanger coolant tanks with coolant that conforms to 7.1 prior to the start of all tests.

11.6.1 Fill the engine coolant system with approximately 26 L of coolant so that coolant is visible within 50 mm of the top of tank level indicator.

11.6.2 Fill the rocker cover coolant system with approximately 20 L of coolant so that coolant is visible within 50 mm of the top of tank level indicator.

11.6.3 Fill the blow-by coolant system so that coolant is visible within 50 mm of the top of tank level indicator.

11.6.4 Pressurize the coolant system to 70 kPa ± 10 kPa.

11.6.5 Minimize air bubbles in the engine, valve cover, and blow-by coolant systems.

11.7 *Dynamometer Load Cell Calibration*—Calibrate the load cell in accordance with the specifications in Table 7. A Dyne Systems Traceable Weight Set DS-A266 is recommended.

11.7.1 Apply the calibration weights onto the dyno load arm that will result in the load cell being in tension. The calibration reference values used must be within ±0.2 kg of the values in Table 7.

11.7.2 Ensure that dynamometer load cell temperature has stabilized at 45 °C ± 1 °C before beginning calibration.

11.8 *Engine Break-in Procedure*—Conduct the break-in procedure and aging procedures prior to lubricant evaluation testing when installing a new engine block or new cylinder head assembly on a test stand. The break-in allows for monitoring test stand and engine performance. Use the engine block assembly for six tests and the head for six tests. Follow the break in conditions in Table 8. Use the following break-in steps:

11.8.1 Install break-in parts according to Assembly Manual Section 2. Install a stock unmodified Toyota intake camshaft, stock valve springs, and unmeasured bucket lifters for break-in.

11.8.2 Install the stock black plastic valve train cover (item D in Fig. 3) and stock crankcase ventilation setup.

11.8.3 Refer to Fig. 4, connect the PCV valve (A) in the valve cover to the intake manifold port (C) with the stock 19 mm ventilation hose (B).

11.8.4 Refer to Fig. 5, connect the valve cover port (A) to the intake air filter housing port (B) with a 15.8 mm diameter Tygon hose (C).

11.8.5 Refer to Fig. 6, connect the braided stainless-steel hose (B) from the crankcase pressure transducer to the quick disconnect (A) on the modified oil fill cap.

11.8.6 Perform all pre-test procedures, sections 11.8.1 to 11.8.5.

11.8.7 Fill the engine with 3000 mL of reference oil 1006-2 as break-in oil.

11.8.8 Start the engine and begin the break-in schedule provided in Table 8. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.8.9 Control the parameters specified in Table 9 below to constant set-points over the entire course of the break-in, aging, and oil sampling.

11.8.10 Record the values of all the controlled parameters listed in Table 8 and Table 9 during break-in steps 5 and 8.

11.8.11 Following the completion of engine break-in, establish the oil sampling conditions listed in Table 10. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.8.12 Once the conditions have stabilized, take a 240 mL purge sample followed by a 3 mL to 10 mL oil sample and return the 240 mL purge sample to the oil fill cap. This step should be completed within 10 min of the oil sampling conditions being achieved. If that is not possible, the engine should be shutdown.

11.8.13 Turn off the engine and allow to rest for 10 min prior to checking the oil level with the OHT IVB dipstick (part # IVB022-3) that is located on the side of the oil pan. The scribe mark on the OHT dipstick should align with the mark on the dipstick tube when it is inserted. Ensure that no air is applied to the engine while checking the oil level.

11.9 *Engine Aging Procedure*—Engine oil aging ensures that the silicone sealant within the engine has been pacified. It should be done immediately following break-in using the same oil charge when a new engine or head is installed on a test stand.

11.9.1 Start the engine and run the aging conditions in Table 11 below and Table 8 for 5 h. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.9.2 After 5 h of aging have been completed, establish the oil sampling conditions listed in Table 9. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.9.3 Once the conditions have stabilized, take a 240 mL purge sample followed by a 3 mL to 10 mL oil sample and return the 240 mL purge sample to the oil fill cap. This step should be completed within 10 min of the oil sampling conditions being achieved. If that is not possible, the engine should be shutdown.

11.9.4 Turn off the engine and allow to rest for 10 min prior to checking the oil level with the OHT IVB dipstick (part # IVB022-3) that is located on the side of the oil pan. The scribe mark on the OHT dipstick should align with the mark on the dipstick tube when it is inserted. Ensure that no air is applied to the engine while checking the oil level.

11.9.5 Conduct section 11.9.1 – 11.9.4 ten total times for a total of 50 h of aging.

11.9.6 Examine the results of the Test Method D5185 for high wear anomalies using Fe, Cu, and Al and to ensure the Si levels have plateaued. Also examine values of K as an indicator of coolant leaks. K values exceeding 15 ppm are suspicious and the engine should be evaluated for an internal coolant leak. If an internal coolant leak is confirmed, make repairs and repeat the run-in and aging procedure. An example of the plateau of Si during break-in and aging is given in Fig. 7.

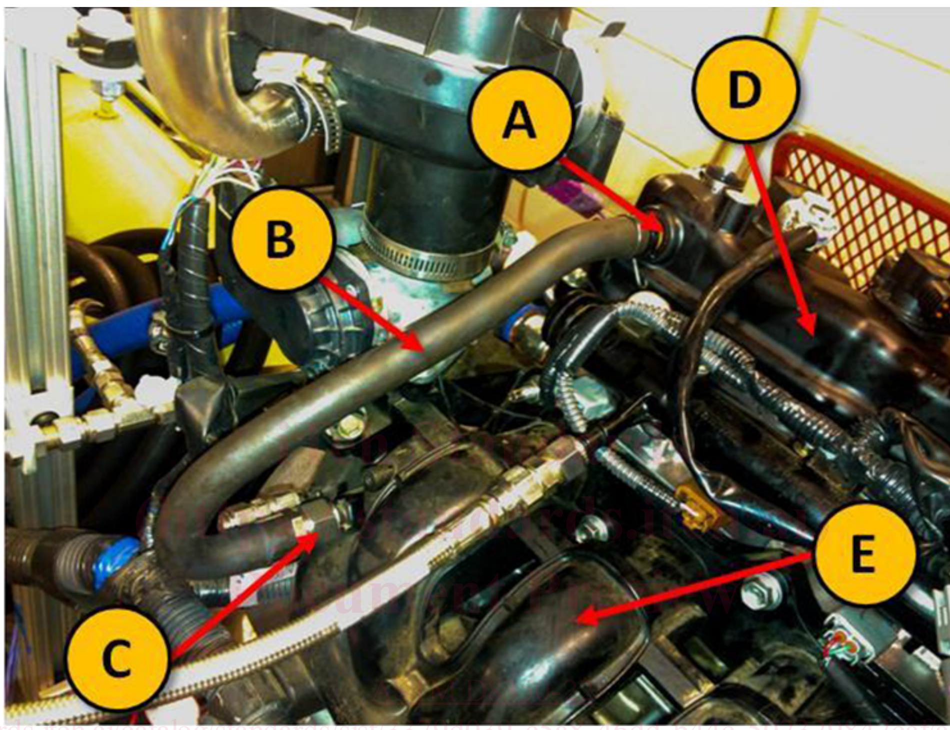
11.9.7 Drain the oil charge after aging is completed.

TABLE 7 Dynamometer Load Cell Calibration Reference

Calibration Point	Reference Calibration Target Mass, kg	Resulting Reference Torque, N·m	Maximum Error
Zero	2.535	9.94	0.5 %
Mid-range	7.130	27.97	0.5 %
Span	11.335	44.47	0.5 %

TABLE 8 Engine Break-in Schedule

Break-in Step #	Duration, min	Engine Speed, r/min	Engine Load, Nm	Gallery Oil Temperature, °C	Coolant Out Temperature, °C
1	10	800	6.3	50	50
2	10	1600	6.3	55	50
3	10	2000	25.0	60	55
4	10	2400	25.0	65	60
5	10	2400	46.9	70	65
6	15	2800	46.9	75	70
7	15	3200	46.9	80	75
8	15	3200	68.8	85	80



(a) Stock PCV valve,
(b) 19 mm diameter hose,
(c) Hose adapter to intake manifold,
(d) Stock valve train cover,
(e) Intake manifold.
The 19 mm diameter hose is the OEM provided crankcase ventilation hose which is installed on new engines.

FIG. 4 Routing of Crankcase Gases

11.10 *Final Break-in*—For new engines or heads, a 50 h final break-in step conducted over the test cycle is required following engine aging (11.9) and prior to any candidate or reference testing.

11.10.1 Using reference oil 1012 and the existing stock break-in parts, complete the flushing detailed in 11.12.1, except for taking oil samples during the flushes.

11.10.2 Conduct a 50 h test consisting of 6000 thirty second 4-stage cycles under the conditions specified by Table 4, Table 5, and Table 13.

11.10.3 Complete steps 11.10.1 to 11.10.4 to conduct a 50 h test at standard conditions. Obtain new and used oil samples (0 h; 25 h; 50 h), but only Test Method D5185 (ICP) analysis is required for final break-in.

11.10.4 After 50 h, which should be 6000 cycles, final break-in is complete.

11.11 *Engine Silicone Pacification*—Conduct the engine silicone pacification procedure when a used engine that has been reassembled is installed on a test stand. Removal and re-installation of an oil pan or front cover is considered reassembly.

11.11.1 Perform all pre-test procedures, sections 11.11.1 to 11.11.3.

11.11.2 Fill the engine with 3.0 L of reference oil 1006-2 as break-in oil.

11.11.3 Perform engine oil aging, see 11.9.

11.12 *Test Procedure:*

11.12.1 *Engine Flushes*—Conduct four fired flushes with 3000 mL of test evaluation oil at the conditions listed in Table 12. Engine load and speed is ramped and stabilized within the first 60 s and 90 s respectively.