Designation: ~~D5704 – 14~~ D5704 – 15

Standard Test Method for Evaluation of the Thermal and Oxidative Stability of Lubricating Oils Used for Manual Transmissions and Final Drive Axles[1]

This standard is issued under the fixed designation D5704; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method is commonly referred to as the L-60-1 test.[2] It covers the oil-thickening, insolubles-formation, and deposit-formation characteristics of automotive manual transmission and final drive axle lubricating oils when subjected to high-temperature oxidizing conditions.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.2.1 *Exceptions*—The values stated in SI units for catalyst mass loss, oil mass and volume, alternator output, and air flow are to be regarded as standard.

1.2.2 SI units are provided for all parameters except where there is no direct equivalent such as the units for screw threads, or where there is a sole source supply equipment specification.

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 and health practices and determine the applicability of regulatory limitations prior to use.* Specific warning information is given in Sections 7 and 8 and Annex A3.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

B224 Classification of Coppers
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D893 Test Method for Insolubles in Used Lubricating Oils
D6984 Test Method for Evaluation of Automotive Engine Oils in the Sequence IIIF, Spark-Ignition Engine
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

2.2 *ANSI Standard:*[4]

ANSI/ISA-S7.3 Quality Standard for Instrument Air

2.3 *Military Specification:*[5]

MIL-L-2105D Lubricating Oil, Gear, Multipurpose

2.4 *ASTM Adjuncts:*[6]

Engineering Drawings

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[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.B0.03 on Automotive Gear Lubricants & Fluids.

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[2] Until the next revision of this test method, the ASTM Test Monitoring Center (TMC) will update changes in this test method by means of Information Letters. Information Letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. Attention: Administrator. This edition incorporates revisions in all Information Letters through ~~13–2.~~14–1. The TMC is also the source of reference oils.

[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] Joint standard of ANSI/ISA. Available from Instrument Society of America, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, NC 27709.

[5] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098.

[6] Detailed drawings necessary for rig construction. Available from ASTM International Headquarters. Order Adjunct No. ADJD5704A.

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

3. Terminology

3.1 *Definitions:*

3.1.1 *carbon, n—in manual transmissions and final drive axles*, a hard, dry, generally black or gray deposit that can be removed by solvents but not by wiping with a cloth.

3.1.2 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D6984**

3.1.3 *sludge, n—in manual transmissions and final drive axles*, a deposit principally composed of the lubricating oil and oxidation products that do not drain from parts but can be removed by wiping with a cloth.

3.1.4 *thermal and oxidative stability, n—in lubricating oils used for manual transmissions and final drive axles*, a lack of deterioration of the lubricating oil under high-temperature conditions that is observed as viscosity increase of the lubricating oil, insolubles formation in the lubricating oil, or deposit formation on the parts, or a combination thereof.

3.1.5 *varnish, n—in manual transmissions and final drive axles*, a hard, dry, generally lustrous deposit that can be removed by solvents but not by wiping with a cloth.

4. Summary of Test Method

4.1 A sample of the lubricant to be tested is placed in a heated gear case containing two spur gears, a test bearing, and a copper catalyst. The lubricant is heated to a specified temperature and the gears are operated at predetermined power and speed conditions for 50 h. Air is bubbled through the lubricant at a specified rate and the bulk oil temperature of the lubricant is controlled throughout the test. Parameters used for evaluating oil degradation after testing are viscosity increase, insolubles in the used oil, and gear cleanliness.

5. Significance and Use

5.1 This test method measures the tendency of automotive manual transmission and final drive lubricants to deteriorate under high-temperature conditions, resulting in thick oil, sludge, carbon and varnish deposits, and the formation of corrosive products. This deterioration can lead to serious equipment performance problems, including, in particular, seal failures due to deposit formation at the shaft-seal interface. This test method is used to screen lubricants for problematic additives and base oils with regard to these tendencies.

5.2 This test method is used or referred to in the following documents:

5.2.1 American Petroleum Institute (API) Publication 1560-Lubricant Service Designations for Automotive Manual Transmissions, Manual Transaxles, and Axles,[7]

5.2.2 STP-512A–Laboratory Performance Tests for Automotive Gear Lubricants Intended for API GL-5 Service,[8]

5.2.3 SAE J308-Information Report on Axle and Manual Transmission Lubricants,[9] and

5.2.4 U.S. Military Specification MIL-L-2105D.

6. Apparatus

6.1 A description of essential apparatus features is given as follows, including mandatory equipment type and performance specification where established. See Annex A1 and Annex A2 for schematics and additional information of a general nature. Those wishing to build this test apparatus shall base construction on full engineering drawings (see 6.2). A list of suppliers is available from ASTM International Headquarters.[6]

6.1.1 *Gear Case Assembly,* used in conjunction with a new test bearing, new lip seals, new O-rings, a pair of new test gears, copper catalyst, and the lubricant to be tested. The gear case assembly has been redesigned to incorporate improvements over designs in use prior to this test method. Construct the gear case and associated parts in accordance with the engineering drawings. The gear case and associated parts shall comply in dimension, material, surface finish where prescribed, and overall design. O-rings and lip seals have been incorporated into this design and are mandatory replacements for the original cork gaskets and shaft slingers used in earlier designs.

6.1.2 *Insulated Oven,* surrounds the gear case assembly and provides insulation sufficient to allow the lubricant temperature to be elevated to and maintained at test temperature conditions. This oven also houses the heaters and heater blower. The oven dimensions, heater, blower, and oven temperature sensor locations are specified in the engineering drawings (see Annex A1 for approximate locations).

6.1.3 *Heater Elements*—Since this test method is extremely sensitive to temperature, the following specified heater elements (two total) are mandatory:

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[7] Available from the American Petroleum Institute, 1220 L St. NW, Washington, DC 20005.

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1353.

[9] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

6.1.3.1 Use one 1500W primary heater element manufactured by Chromolox, Inc. The part number may be 118-553661-505, 118-553661-514, or 118-074906-010.[10,11]

6.1.3.2 Use one 150W alternator load heater element part number FD2Z-0895 manufactured by Ogden Manufacturing.[12,11]

6.1.4 *Temperature Controller,* proportional-integral-derivative (PID) type; percent output adjustable.

6.1.5 *Thermocouples*—For determination, recording, and control of the test oil temperature, a ⅛-in. (3.2 mm) Type J open-tip thermocouple is specified. Thermocouples for other data measurements may be used as suitable to the user but in all cases shall be placed behind the baffle plate in the gear box assembly and shall not interfere with normal oil flow patterns during the test.

6.1.6 *Temperature Recorder,* any suitable recording device capable of generating a temperature record using the specified thermocouples and temperature control devices. Submit temperature traces for tests with the test report.

6.1.7 *Alternator*—Use a Remy model 10-SI Series Type 100, 63 A, 12 V negative ground alternator part number 91751 for loading the gearset.[13,11] Modify the alternator by removing the diode trio and resistor as shown in the circuit diagram in Fig. A7.1. The supplied v-belt pulley may be replaced with a multi-groove (so called micro-v) pulley provided the original metal fan and 1:1 pulley ratio are retained.

6.1.8 *Heater Blower*—The heater blower system shall supply to the insulated oven assembly 29.5 ± 5 ft^3/min (835 L/min ± 142 L/min) of air (at free flow conditions) through the 2⅛-in. (54 mm) diameter blower opening as shown in the engineering drawings. The heater blower may be a cage type blower wheel powered by an electric motor or powered by way of a toothed belt from the main drive shaft.

6.1.8.1 Confirm the heater blower system air flow at laboratory ambient conditions with a Preso Low Loss Venturi Meter[14,11] (2-in. model LPL-200NF-38) with carbon steel body, ¼-in. NPT instrument connections and 2-in. 150-lb raised-face process connections and a Dwyer digital manometer,[15,11] part number 475-00-FM. Perform the verification with the heater elements turned off.

6.1.8.2 Send the Preso Low Loss Venturi Meter together with the Dwyer digital manometer to the specified calibration laboratory[16] for cleaning and calibration at least once a year.

6.1.9 *Air Flow Controller*—The air flow controller[17,11] shall be capable of controlling the air supply at a flow rate of (22.08 ± 2.01) mg/min (see Note 1).

NOTE 1—It has been suggested that 20 to 30 ft (6 m to 9 m) of supply line between the air regulator and the mass air flow meter may help to reduce flow meter readout fluctuations.

6.1.10 *Test Gears,* one machine tool change gear (34 teeth, with a width of ⅜-in. (9.5 mm) and one machine tool change gear (50 teeth, with a width of ⅜-in. (9.5 mm)).[18,11]

6.1.11 *Test Bearing,* ball bearing.[19,11]

6.1.12 *O-ring Seals,* O-ring for the seal plate and O-ring for the cover plate.[19,11]

6.1.13 *Lip Seals,* two Chicago Rawhide or SKF shaft oil lip seals, part number 6383, are required.[19,11]

6.1.14 *Speedi-sleeve,* two Chicago Rawhide or SKF speedi-sleeves, part number 99062, are required.[19,11]

6.1.15 *Joint Radial Seal,* two Chicago Rawhide or SKF joint radial (V-ring) seals, part number 400164, are required.[19,11]

6.1.16 *Gear Holder Apparatus,* used to hold the test gears during preparation (Annex A9).

6.2 Construct all new equipment in accordance with the engineering drawings available as an adjunct from ASTM Headquarters[6] in order to meet calibration requirements. Builders unable to obtain specified parts and wishing to use substitutes shall request approval from ASTM Subcommittee D02.B0.03.

7. Reagents and Materials

7.1 *Air,* compressed, instrument quality, meeting ANSI/ISA-S7.3, that limits dew point, maximum particle size, and maximum oil content of the air at the instrument.

7.2 *Copper Catalyst,* cold-rolled, electrolytic tough pitch copper, conforming to UNS (Unified Numbering System) C11000.[12,11] Shear the two strips from stock of thickness 1⁄16-in. (1.6 mm) to approximately 9⁄16 by 1 13⁄16 in. (14 mm by 46 mm).

NOTE 2—For more information on the classification of coppers and the Unified Numbering System (UNS), consult Classification B224 and Practice E527, respectively.

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[10] The sole source of supply known to the committee at this time is Chromolox, Inc., 103 Gamma Dr., Pittsburgh, PA 15238.

[11] If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will be given careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[12] The sole source of supply known to the committee at this time is Ogden Manufacturing Co., 103 Gamma Dr., Pittsburgh, PA 15238.

[13] The sole source of supply known to the committee at this time is Remy, 600 Corporation Dr., Pendleton, IN 46064.

[14] The sole source of supply of the apparatus known to the committee at this time is SW Controls Inc., 2525 East Royalton Road, Broadview Heights, OH 44147.

[15] The sole source of supply of the apparatus known to the committee at this time is JF Good Company, 11200 Madison Ave., Cleveland, OH 44102.

[16] Bowser-Morner, 4518 Taylorsville Rd., Dayton, OH 45424.

[17] The sole source of supply of the Air Flow Controller Model 840-L-1 known to the committee at this time is Sierra Instruments, Inc., 5 Harris Court, Bldg. L, Monterey, CA 93940.

[18] The sole source of supply of the GA-34 and GA-50 gears known to the committee at this time is Boston Gear Works, 14 Hayward St., Quincy, MA 02171.

[19] The sole source of supply of the R-14 10 ball bearing, No. 2-153 (seal plate O-ring), No. 2-264 (cover plate O-ring), 6383 seals, 400164 seals, and 99062 speedi-sleeves known to the committee at this time is Motion Industries, 4620 Hinckley Parkway, Cleveland, OH 44109.

7.3 *Organic Cleaning Agent.* (**Warning**—Combustible, health hazard (see Annex A3).)[20,21,11]

7.4 *Silicon Carbide Paper,* 180 grit.

7.5 *Solvent,* Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0 to 2% vol), Flash Point (142°F/61 °C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning—**Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.)

7.6 *Toluene,* commercial grade. (**Warning**—Flammable. Health hazard.) An example of a satisfactory volatile hydrocarbon solvent.

7.7 *Heptane,* commercial grade. (**Warning**—Flammable. Health hazard.) An example of a satisfactory volatile hydrocarbon solvent.

8. Preparation of Apparatus

8.1 *Air Box Temperature Limiting Device*—After initial rig installation, preset the oven air temperature limit to 400°F (204 °C). This can be achieved by placing the insulated oven cover in position on the rig and installing the air temperature sensor at a penetration depth of 3 in. (75 mm) below the top inner surface of the cover. Switch on the heaters and circulating fan. Adjust the temperature control device to deactivate the heaters when the air temperature reaches 400°F (204 °C). This oven temperature limit may later be reduced as outlined in 10.3 to meet rig heat-up requirements.

8.2 *Temperature Recording and Controlling Instrumentation*—Since this test procedure is extremely sensitive to temperature, it is necessary to maintain a periodic check upon the accuracy of all items related to temperature measurement and control. Therefore, immediately after the installation of a new test rig, and before every set of reference tests, calibrate the instrumentation used to measure and record the air and oil temperatures against known standards traceable to NIST.[22] For instance, calibrate the oil temperature thermocouple and indicating controller. This can be accomplished by immersing the tip of the probe into an auxiliary temperature-controlled oil bath equipped with a stirrer. Accurately set the bath temperature at 325°F (162.8 °C) and confirm the test measuring equipment to be accurate prior to testing.

8.3 *Gear Case*—Using the organic cleaning agent (see 7.3), clean the gear case, vent tube, vent tube baffle, retainer bushings, seal sleeves, case cover plate, seal plate, nuts, studs, flat washers, baffle plate, spacer bushings, bearing bushings and clamp, keys, shaft ends, shaft nuts, and catalysts. Nylon bristle brushes, steel brushes, and long pipe cleaners can be used to aid cleaning. Do not use any copper or copper-containing brushes or material as a cleaning medium. Following the cleaning procedure with an organic cleaning agent, wash parts thoroughly with cleaning solvent (see 7.5), and finally with a volatile hydrocarbon solvent (see 7.6 or 7.7), to facilitate air drying. Allow parts to air dry.

8.4 *Test Gears*—Thoroughly clean the test gears with cleaning solvent (see 7.5). Carefully examine the gear teeth for nicks and burrs. Do not use gears with major imperfections. Redress minor gear teeth imperfections with a fine stone or file. After final examination, wash gears once more with cleaning solvent and finally with a volatile hydrocarbon solvent, to facilitate air drying. Allow gears to air dry.

8.4.1 Prepare each gear with new Screen-Kut silicon carbide C-180 paper.[23,11] Place a new piece of silicon carbide paper on a solid surface that has a thickness greater than or equal to ½ in. (12.7 mm). Saturate the entire silicon carbide paper with cleaning solvent (see 7.5). Use one new piece of silicon carbide paper per gear side, using both sides of the silicon carbide paper as necessary. Sand both sides of the test gears, with the required gear holder apparatus (6.1.16) on the silicon carbide paper, using a figure eight motion. Do not apply a downward force to the gear holder while sanding. Sand the gears until the manufacturer's machining marks are removed. After final examination, wash gears once more with cleaning solvent (see 7.5) and finally with a volatile hydrocarbon solvent (see 7.6 or 7.7), to facilitate air drying. Allow gears to air dry. If the gears are not to be used immediately, wrap them in a paper towel and Nox-Rust paper.[24,11]

8.4.1.1 Discard the test gears if not used within 24 h after polishing is completed.

8.5 *Test Bearing*—Prior to installation, wash the test bearing first with cleaning solvent (see 7.5), and finally with a volatile hydrocarbon solvent, to facilitate drying. Allow the bearing to air dry.

8.6 *Copper Catalyst:*

8.6.1 Notch one strip for purpose of identification. The notch shall be triangular in shape centered on the long side of the strip. Sides of the triangular notch shall be equal and approximately 0.2 in. (approximately 5 mm) in length.

8.6.2 Polish both catalyst strips on all six sides with Screen-Kut silicon carbide C-180 paper.[23,11] Use either a new piece of Screen-Kut or one retained from the gear polishing procedure described in 8.4.1.

[20] The sole source of supply of the apparatus known to the committee at this time is Oakite Products, Inc., 13177 Huron River Dr., Romulus, MI 48174.

[21] The sole source of supply of the apparatus known to the committee at this time is Pentone Corp., 74 Hudson Ave., Tenafly, NJ 07670.

[22] National Institute of Standards and Technology (formerly National Bureau of Standards), Gaithersburg, MD 20899.

[23] The sole source of supply of the apparatus (Johnson Abrasives Screen-Kut Part No. 11003) known to the committee at this time is Johnson Abrasives Co., Inc., 49 Fitzgerald Dr., Jaffrey, NH 03452, Attn: Scott Johnson (phone: 800-628-8005).

[24] The sole source of supply of the apparatus known to the committee at this time is DaubertVCI, Inc., 1333 Burr Ridge Parkway, Suite 200, Burr Ridge, IL 60527.

8.6.3 Wipe both catalyst strips with absorbent cotton pads moistened with cleaning solvent (see 7.5), and wash with a volatile hydrocarbon solvent, to facilitate drying. Allow catalyst strips to air dry.

8.6.4 Record the mass of the catalyst with the notched strip to the nearest 0.0001 g prior to installation. Handle cleaned catalyst strips with one of the following: new nitrile gloves, new latex gloves, tweezers, or ashless filter paper to avoid contamination of the catalyst surface from skin contact.

8.7 *Gear Case Assembly*—Assemble the gear case components (see Annex A2 for exploded view).

8.7.1 Inspect all parts prior to assembly of the gear case. Replace any parts that would affect proper rig operation (for example, overly worn parts). Parts replacement is left to the discretion of the rig builder. A modified seal plate, detailed on gear case drawing number C-3963-1277-2[6] may be used to facilitate removal of the lip seals.

8.7.2 Use new elastomer components (O-rings and lip seals) for each test.

8.7.3 Install the retainer bushings and seal sleeves. Replace the seal sleeves if they are grooved.

8.7.4 Install the lip seals and O-ring seal in the seal plate. The application of gasket sealant[25,11] to the lip seals to prevent oil leaks is an approved option.

8.7.5 Install the seal plate in the gear case, using the flat washers to protect the seal plate surface from damage. Torque the seal plate retaining studs to approximately 25 lbf·in. (approximately 2.8 N·m).

8.7.6 Install the external retaining rings on the upper and lower shafts.

8.7.7 Install the upper and lower spacer bushings on the upper and lower shafts.

8.7.8 Install the baffle plate and catalyst holder and torque to approximately 25 lbf·in. (approximately 2.8 N·m), using the flat washers to protect the baffle plate and catalyst holder surfaces.

8.7.9 Insert the bearing into the test bearing clamp with the bearing clamp shoulder on the opposite side of the bearing manufacturer's number. Use the bearing clamp cap screw to bolt the bearing clamp closed and torque to approximately 25 lbf·in. (approximately 2.8 N·m). Install the locking nut to ensure that the bolt does not move during the test.

8.7.10 Insert the test bearing bushing into the test bearing with the bearing bushing shoulder on the same side of the bearing as the manufacturer's number. Install this entire assembly on the lower shaft so that the bearing manufacturer's number faces the front of the gear case. If the bearing assembly has been assembled properly, the bearing clamp arm will be on the opposite side of the gear case as the catalyst holder.

8.7.11 Install the large gear (GA-50) on the lower shaft and the small gear (GA-34) on the upper shaft along with the shaft keys. Install the test gears so that the manufacturer's name faces the front of the case. Install the retaining nuts and torque to approximately 90 lbf·in. (approximately 10 N·m). The gear retaining nuts are different since the lower shaft is right-hand thread and the upper shaft is left-hand thread.

8.7.12 Insert the test oil thermocouple so that the tip protrudes perpendicular to the slanted lower right side of the gear case assembly and protrudes 0.50 ± 0.04 in. (13 mm ± 1 mm) into the gear case.

8.7.13 Insert catalysts in the grooves on the catalyst holder. Catalysts shall be sized for a tight fit in the catalyst holder to avoid movement of the catalysts during the test. Placement of the notched strip toward the rear of the gear case with the notch facing rearward is recommended for ease of catalyst removal after test with minimal disturbance of deposits.

8.7.14 Install the O-ring seal on the gear case cover.

8.7.15 Install the gear case cover and torque the cap screws to approximately 25 lbf·in. (approximately 2.8 N·m).

8.8 *Air Supply Line*—Ensure that the air supply line is free from obstructions and then connect the air supply line to the bottom of the gear case.

8.9 *Insulated Oven Cover*—Ensure that the oven temperature sensor is at a penetration depth of 3.0 ± 0.2 in. (76 mm ± 5 mm) below the top inner surface of the cover (see 7.5). Install the cover on the rig.

8.10 *Air Flow Controller Calibration:*

8.10.1 As a standard for all Sierra Side Trak model 840 air flow controller calibrations, use either a Sierra Top Trak model number 822S-L-2-OV1-PV1-V1-SCR2700 or 822S-L-2-OV1-PV1-V4-SCR2700 air flow meter (these model numbers supersede 822S-L-2-OV1-PV1-V1-A1 and 822S-L-2-OV1-PV1-V4-A1 which also remain acceptable for use). Calibrate the Sierra Top Trak to a traceable national standard at least once every year at a flow rate of (22.08 ± 2.01) mg/min at the outlet with 30 psig (206 kPa) inlet pressure.

8.10.2 Prior to initiating a test stand calibration run, connect the Sierra Top Trak meter to the inlet of the Sierra Side Trak controller. Connect the Side Trak outlet to the gear box. Install an air pressure measurement device to monitor and regulate air pressure to the inlet of the Top Trak to 30 psig (206 kPa). Charge the gear box with a commercial 80W-90 grade oil and bring to test conditions (325 °F ± 1°F (162.8 °C ± 0.5 °C) at (1750 ± 50) r/min). Adjust the Side Trak until its controlled flow matches that displayed by the Top Trak. Remove the Top Trak after completing the calibration.

8.10.3 Determination of the need to repeat Side Trak calibration following an unsuccessful test stand calibration run is at the discretion of the testing laboratory.

[25] The sole source of supply of the Perfect Seal Gasket Maker No. 4, Part No. 1050026 known to the committee at this time is P.O.B. Manufacturing Inc., 1100 Kenwood Rd., Cincinnati, OH 45242.

9. Calibration and Standardization

9.1 Reference oils for stand calibration are available from the TMC.[2] Laboratories wishing to calibrate test stands using these reference oils shall participate in the referencing and stand calibration program administered for this test by the TMC (see Note 3 and Annex A4).

NOTE 3—*TMC Acceptance Criteria*—Reference oil performance and test operations for this test method are currently monitored by the TMC. Statistics for reference test starts are published periodically by the TMC and provide acceptance ranges for the various reference oils. Users of the test method should contact the TMC for the most current values for evaluation of referencing status.

9.2 To ensure that uniform results are being obtained in the test, complete calibration of test stands by testing reference oil samples supplied by the TMC at the time calibration or recalibration is required.

9.2.1 *New Test Stand Calibration*—For a new test stand, reference tests as prescribed by the TMC shall be completed, giving results within the established limits for the reference oils. Inspection of the new test stand for compliance with this test method by the TMC is also required.

9.2.2 *In-Service Stand Calibration*—For a previously referenced test stand, reference tests giving results within the established limits for those oils shall be conducted at the frequency specified by the TMC (currently every ten tests or three months, whichever occurs first). Test oils for this purpose are distributed as blind coded samples by the TMC when request for calibration is received. All test starts and test data using reference oils shall be reported to the TMC. Calibration frequency is subject to change as required. Current calibration information is available from the TMC.

9.3 *Reference Oil Test Frequency*—Reference oil test frequency may be adjusted due to the following reasons:

9.3.1 *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.

9.3.2 *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.

9.3.3 *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.

9.3.4 *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. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as 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.

9.4 *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, in order to quantify the effect of a particular 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.

9.5 Every test start on any test stand shall receive a sequential test run number designated before testing begins. All tests, including aborted starts and operationally invalid tests, shall retain their test number.

9.6 *Instrumentation Calibration*—Immediately prior to commencing each reference oil test, calibrate the large gear shaft speed system, alternator output system, blower motor output system, air flow controller system, air box temperature control system, and oil temperature control system against standards traceable to NIST. Instrumentation calibrations prior to reference oil tests that follow a failed or invalid first attempt are at the discretion of the test laboratory. Retain record of these calibrations for a minimum of two years.

9.7 Consider as non-interpretable any non-reference oil test that has not been run in a calibrated test stand or not conducted on approved hardware, or both. Indicate on the cover page of the test report that the test is non-interpretable and that it has not been conducted in a valid manner in accordance with the test method.

10. Procedure for Conducting the Test

10.1 Pour (120 ± 5) mL of the lubricant to be tested into a clean container. Weigh the container of oil. Charge the gear case with the test lubricant. Reweigh the container and determine the oil charged by subtraction. Record the weight of the test oil charge to the nearest 0.01 g.

10.2 Preset air flow rate to (22.08 ± 2.01) mg/min.

10.3 Record the time, turn on the main drive motor, and adjust the temperature control system to maintain the bulk test lubricant temperature at 325 ± 1°F (162.8 °C ± 0.6 °C). Heat the bulk oil test temperature from ambient to 324°F (162.2 °C) in a minimum of 45 min. This heat-up time shall not exceed 60 min. Tests with heat-up times less than 45 min or greater than 60 min are not representative of an operationally valid test and, therefore, cannot be properly interpreted for non-reference oil evaluation. The end-of-heat-up/test start time shall be the first occurrence of 324°F (162.2 °C).

10.3.1 Record all operational data at a minimum of once every 15 min. A reading out of specification using once-every-15 min data recording is considered to be out for the full 15 min unless otherwise documented..

10.4 If the rig heat-up time is less than 45 min, the oven temperature limit should be reduced until the heat-up time is equal to or greater than 45 min but less than 60 min. A possible cause of heat-up times greater than 60 min is improper fit between the insulated oven and insulated oven cover or other areas of excessive oven thermal leakage, or both. Under no circumstances shall the oven temperature limit be set higher than 400°F (204 °C). The rig heat-up time should be checked prior to every set of reference tests to ensure consistent rig performance.

10.5 Adjust the field supply of the alternator for a net output of (128 ± 5) W.

10.6 The large gear shall maintain a speed of (1750 ± 50) r/min throughout the heat-up and test time.

10.7 Run the test at the conditions specified for (50.0 ± 0.1) h. Terminate the test if more than 5 min of total downtime occurs during the test period. Record any downtime on Form 4, Annex A5.

10.7.1 A downtime occurrence is defined as the time at which the test is shut down until the time the test returns to test operating specifications.

10.7.2 Do not calculate percent deviations during downtime occurrences.

10.7.3 Record all operational data at a minimum of once every hour. A reading out of specification using once-every-hour data recording is considered to be out for the full hour unless otherwise documented.

10.8 Upon the completion of the test, immediately shut down the equipment. Remove the air line, and drain the test lubricant into a clean, weighed container. The gear case cover plate may be loosened to facilitate draining but do not remove it. Drain the test stand for 30 min (± 5) min. To determine the final oil mass measurement, weigh the container and drained oil and calculate the oil mass loss percent using the equation below:

$$\text{oil loss in mass \%} = \frac{\text{initial mass} - \text{final mass}}{\text{initial mass}} \times 100 \quad (1)$$

where:

initial mass = initial oil charge mass, and
final mass = drain oil mass.

10.8.1 Any test exceeding a mass loss of 20 % is operationally invalid.

10.9 At the completion of the oil mass loss calculation, transfer the entire oil drain, including solids, using a flat-bladed stainless steel tool from the weighed container into a single sample bottle for kinematic viscosity, pentane insolubles, tolulene insolubles, and total acid number evaluation as outlined in Section 13. The single sample bottle contents shall be homogenous prior to kinematic viscosity, pentane insolubles, toluene insolubles, and total acid number evaluation.

10.10 Remove the test gears from the gear case ~~cover and test gears within (60 + 5) min of test completion without disturbing~~ between 30 min and 60 min after test completion. Do not disturb any of the deposits on the ~~various test~~ gears.

11. Procedure for Determination of the Gear Cleanliness Ratings[26,11]

11.1 Evaluation of the test gears is performed after removing the catalyst strips, test gears, test bearing, and internal gear case components.

11.2 After gear case disassembly, as specified in 10.10, immediately place test parts side-by-side in a draining position (a draining position is a position within 15° of vertical.) at room temperature for a minimum of 1 h before rating. Rate the test parts within 64 h of test completion.

11.3 *Gear Sludge Rating:*

[26] The sole source of the apparatus (L-60-1 Gear Rating Jig) known to the committee at this time is ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206.

11.3.1 To fix the distance from the rating light to the gear face and to control the angle of incidence of the light on the gear, mount the gear being rated onto the L-60-1 Gear Rating Jig.[26]

11.3.2 Handle the gears at the gear teeth lands to avoid any contact with the rated area.

11.3.3 Use a cool white type fluorescent 4500 K color temperature light with a minimum illumination level of 200 fc (2150 lx).

11.3.4 Place the gear on the L-60-1 Gear Rating Jig with the keyway vertical and the front side up.

11.3.5 Using a lint-free cloth, wipe an approximately ¾ in. (20 mm) wide area across the diameter of the face of the gear along the keyway. Wipe the gear five times in the same direction.

11.3.6 Position the light on the two brackets on the top of the L-60-1 Gear Rating Jig. Verify light fixture is approximately level in all directions.

11.3.7 Rate the top half of the gear looking down on the gear.

11.3.8 Subdivide the total ratable area into percentage areas of different sludge depths and ratings using ASTM Deposit Rating Manual 20[27] (use the sludge scale and sludge gauge, included in the manual). Calculate and record the sludge volume factor for each subdivided area. The total volume factor for a gear face is determined by adding the individual area volume factors for that gear face.

11.3.9 Convert the total volume factor for each gear face to a merit rating using ASTM Deposit Rating Manual 20. Report this rating to two decimal places.

11.3.10 Do not rate the wiped area, the gear teeth, or the spacer bushing contact area for sludge.

11.3.11 Rotate the gear 180 degrees and rate the other half of the gear.

11.3.12 Repeat the same steps for the small gear.

11.3.13 The sludge rating is defined as the average of the four merit ratings of the four gear faces.

11.4 *Gear Carbon/Varnish Rating:*

11.4.1 To fix the distance from the rating light to the gear face and to control the angle of incidence of the light on the gear, mount the gear being rated onto the L-60-1 Gear Rating Jig.

11.4.2 Handle the gears at the gear teeth lands to avoid any contact with the rated area.

11.4.3 Use a cool white type fluorescent 4500 K color temperature light with a minimum illumination level of 200 fc (2150 lx).

11.4.4 Place the gear on the L-60-1 Gear Rating Jig with the keyway vertical and the front side up.

11.4.5 If not already done for previous sludge rating, use a lint-free cloth to wipe an approximately ¾ in. (20 mm) wide area across the diameter of the face of the gear along the keyway. Wipe the gear five times in the same direction.

11.4.6 Position the light on the two brackets on the top of the L-60-1 Gear Rating Jig. Verify light fixture is approximately level in all directions.

11.4.7 Rate the top half of the gear looking down on the gear.

11.4.8 The wiped area on each gear face, excluding the gear teeth and spacer bushing contact area, is the ratable area. Subdivide the total ratable area into percentage areas of different carbon depths and varnish intensities. Use any of the three Rating Scales (A, B, or C) of the ASTM Rust/Varnish/Lacquer Rating Scale for Non Rubbing Parts found in ASTM Deposit Rating Manual 20 to determine varnish rating factors for each subdivision containing varnish deposits.

11.4.9 Rate carbon from 0.00 (heavy carbon) to 0.99 (trace carbon) using an expanded rating scale. Determine carbon rating factors by referring to the ASTM L-60-1 Rating Aid in ASTM Deposit Rating Manual 20. Calculate the carbon merit rating by multiplying the rating factor by the percentage area. Report this rating to two decimal places.

11.4.10 Rotate the gear 180 degrees and rate the other half of the gear.

11.4.11 Determine the carbon/varnish merit rating for a gear face by adding the individual area merit ratings for the wiped area of that face. Determine the carbon/varnish rating using the large gear only. The small gear may be rated for additional information. Rate the front and back faces of both gears individually.

11.4.12 The carbon/varnish rating is defined as the average of the front and back face merit ratings for the large gear. The small gear should be rated similarly, but separately, for additional information.

11.5 Use Form 5, Annex A5 for calculating and reporting carbon/varnish and sludge rating measurements.

11.6 For the test rating to be valid, the gears shall be rated by an individual who has participated in a ASTM-sponsored, high-volume, gear-rater calibration workshop within the previous twelve months.

[27] ASTM Deposit Rating Manual 20 available at the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org.

12. Procedure for Determination of Catalyst Mass Loss

12.1 *Determine the Catalyst Mass Loss:*

12.1.1 Carefully remove all the deposits from the notched copper catalyst strip by soaking for approximately 30 min in Oakite 811, Penmul L460, or equivalent.

12.1.2 Wash in cleaning solvent (see 7.5).

12.1.3 Remove deposit residue from the surface by rubbing lightly with a clean cloth.

12.1.4 Wash in cleaning solvent (see 7.5).

12.1.5 Wipe with absorbent cotton pads moistened with a volatile hydrocarbon solvent.

12.1.6 Wash in a volatile hydrocarbon solvent. Allow catalyst strip to air dry.

12.1.7 Handle the cleaned catalyst strip with tweezers or ashless filter paper in order to avoid inaccurate mass loss information. Record the mass of the cleaned catalyst with the notched strip to the nearest 0.0001 g to determine the copper activity of the test lubricant. The mass loss is reported as a percent loss based upon the original mass of the notched strip.

13. Procedure for Evaluation of Drain Oil

13.1 Determine the following test lubricant parameters (pay particular attention to the sample handling instructions in the relevant standard):

13.1.1 Kinematic viscosity of the untested oil and of the drain oil in centistokes at 212°F (100 °C) using Test Method D445. Do not filter the sample. Run the post-test viscosity determination within 48 h of the end of the test.

13.1.2 Total acid number of the drain oil using Test Method D664.

13.1.3 *n*-Pentane and toluene insolubles using Test Method D893, Procedure A without coagulant. Evaluate the pentane/toluene insolubles within 48 h of the end of the test.

14. Calculation

14.1 Calculate the percent viscosity increase by Eq 2, using the initial oil kinematic viscosity and the drain oil kinematic viscosity.

$$\text{percent viscosity increase} = \frac{\text{final KV} - \text{initial KV}}{\text{initial KV}} \times 100 \quad (2)$$

where:

KV = kinematic viscosity.

14.2 Calculate the catalyst percent mass loss using Eq 3:

$$\text{percentage loss in catalyst mass} = \frac{\text{catalyst initial mass} - \text{catalyst final mass}}{\text{catalyst initial mass}} \times 100 \quad (3)$$

where:

catalyst initial mass = initial catalyst mass as determined in 8.6.4, and
catalyst final mass = final catalyst mass as determined in 12.1.7.

14.3 Use the following equations to transform reference and non-reference oil results:

Parameter	Transformations
EOT viscosity increase (%)	LN(VI)
EOT pentane insolubles (mass fraction %)	LN(Pentane)
EOT toluene insolubles (mass fraction %)	LN(Toluene)
Average carbon/varnish (merits)	LN(CV/(10-CV))
Average sludge (merits)	–LN(10-Sludge)

14.4 Correct non-reference oil results for industry severity using the equations detailed in Annex A6. Correct non-reference oil results for stand severity using the equations detailed in Annex A8.

14.5 Calculate percent out for each parameter in Table 1 using the following equation and record results in Form 6, Annex A5.

$$\text{percent out} = \sum_{i=1}^{n} \left(\frac{Mi}{0.5R} \times \frac{Ti}{D} \right) \times 100 \quad (4)$$

where:

Mi = magnitude of test – parameter out from specification limit at occurrence *i*,
R = test parameter specification range,
Ti = length of time the test parameter was outside of specification range at occurrence *i*, (*Ti* is assumed to be no less than the recorded data-acquisition frequency unless supplemental readings are documented.), and

TABLE 1 Test Validity Parameters

	Parameter			
	Oil Temperature	Air Flow	Alternator Power	Large Gear Speed
Specification	325°F (163 °C)	22.08 mg/min	128 W	1750 r/min
Range	2°F (-17 °C)	4.02 mg/min	10 W	100 r/min
% Out of specification (warm up)	NA	10 %	10 %	5 %
% Out of specification (test)	5 %	5 %	5 %	2 %

D = test or test phase duration in same units as *Ti*.

14.5.1 Invalidate any test that exceeds the percent out limits in Table 1 for either warm up or on test conditions.

14.6 Round test results according to Practice E29.

15. Report

15.1 For reference oil tests, the standardized report form set and data dictionary for reporting the test results and for summarizing the operational data are required. The final test report will include a complete report form package. See Annex A5 for information on obtaining report forms and the data dictionary.

NOTE 4—If non-reference oil test results are to be used as candidate oil test results against a specification, report the non-reference oil test results on the same standardization report form set and data dictionary as used for reference oil test results.

15.2 Attach the temperature recording trace, including heat-up time.

15.3 For non-reference tests with a value of zero for viscosity increase, pentane insolubles, or toluene insolubles, report a value of zero as the test result and report *NA* for the transformed results. For tests with viscosity results that are too viscous to measure, report a value of *NA* as the test result and the transformed result. For test results where viscosity is too viscous to measure or have a value of zero for viscosity increase, pentane insolubles, or toluene insolubles, do not apply any severity adjustment.

15.4 Report reference oil test results to the TMC within five days of test completion. Use the report form package shown in Annex A5.

15.5 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits of Form 4 of Annex A5 under Other Comments.

15.6 *Electronic Transmission of Test Results*—Electronic transfer of reference and non-reference oil test report data can be done utilizing the ASTM Data Communications Committee Test Report Transmission Model (see Section 2—Flat File Transmission Format) available from the ASTM TMC.

15.7 Attach the operational recording traces for all parameters in Table 1 as part of the test report.

16. Precision and Bias

16.1 Test precision is established on the basis of reference oil test results (for operationally valid tests) monitored by the ASTM TMC. The data are reviewed semi-annually by the L-60-1 Surveillance Panel. Contact the ASTM TMC for current industry data. Table 2 summarizes reference oil precision of the test as of June 30, 1997.

16.1.1 *Intermediate Precision Conditions*—Conditions where test results are obtained with the same test method using the same test oil, with changing conditions, such as operators, measuring equipment, test stands, test engines, and time.

NOTE 5—"Intermediate precision" is the more appropriate term for this test method rather than "repeatability," which defines more rigorous within-laboratory conditions.

16.1.1.1 *Intermediate Precision Limit* (i.p.)—The difference between two results obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 2 in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

16.1.2 *Reproducibility Conditions*—Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

16.1.2.1 *Reproducibility Limit* (R)—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 2 in only one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result ± Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.