



Standard Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)¹

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1. Scope

1.1 This test method covers the evaluation of the lubricity of diesel fuels using a high-frequency reciprocating rig (HFRR).

1.2 This test method is applicable to middle distillate fuels, such as Grades Low Sulfur No. 1 D, Low Sulfur No. 2 D, No. 1 D, and No. 2 D diesel fuels, in accordance with Specification D 975; and other similar petroleum-based fuels which can be used in diesel engines

NOTE 1—It is not known that this test method will predict the performance of all additive/fuel combinations. Additional work is underway to further establish this correlation and future revisions of this test method may be necessary once this work is complete.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicable regulatory limitations prior to use.* Specific hazard statements are given in Section 7.

2. Referenced Documents

2.1 ASTM Standards:

D 975 Specification for Diesel Fuel Oils²

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products³

D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products³

D 4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination³

D 5290 Test Method for Measurement of Oil Consumption, Piston Deposits, and Wear in a Heavy-Duty High-Speed Diesel Engine—NTC-400 Procedure⁴

D 6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-On-Cylinder Lubricity Evaluator (SLBOCLE)⁵

E 18 Test Method for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials⁶

E 92 Test Method for Vickers Hardness of Metallic Materials⁶

2.2 *American Iron and Steel Institute Standard:*⁷
AISI E-52100 Chromium Alloy Steel

2.3 *American National Standards Institute Standard:*⁸
ANSI B3.12 Metal Balls

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *boundary lubrication, n*—a condition in which the friction and wear between two surfaces in relative motion are determined by the properties of the surfaces and the properties of the contacting fluid, other than bulk viscosity.

3.1.1.1 *Discussion*—Metal to metal contact occurs and the chemistry of the system is involved. Physically adsorbed or chemically reacted soft films (usually very thin) support contact loads. As a result, some wear is inevitable.

3.1.2 *lubricity, n*—a qualitative term describing the ability of a fluid to affect friction between, and wear to, surfaces in relative motion under load.

3.1.2.1 *Discussion*—In this test method, the lubricity of a fluid is evaluated by the wear scar, in millimetres, produced on an oscillating ball from contact with a stationary disc immersed in the fluid operating under defined and controlled conditions.

4. Summary of Test Method

4.1 A 2-mL test specimen of fuel is placed in the test reservoir of an HFRR and adjusted to either of the standard temperatures (25 or 60°C). The preferred test temperature is

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.E0.02 on Diesel Fuels. This test method was developed by ISO/TC22/SC7/WG6 and is a part of ISO 12156.

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² *Annual Book of ASTM Standards*, Vol 05.01.

³ *Annual Book of ASTM Standards*, Vol 05.02.

⁴ Discontinued—See 1997 *Annual Book of ASTM Standards*, Vol 05.03.

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

⁶ *Annual Book of ASTM Standards*, Vol 03.01.

⁷ Available from American Iron and Steel Institute (AISI), 1101 17th St., NW, Suite 1300, Washington, DC 20036.

⁸ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

60°C, except where there may be concerns about loss of fuel because of its volatility or degradation of the fuel because of the temperature.

4.2 When the fuel temperature has stabilized, a vibrator arm holding a nonrotating steel ball and loaded with a 200-g mass is lowered until it contacts a test disk completely submerged in the fuel. The ball is caused to rub against the disk with a 1-mm stroke at a frequency of 50 Hz for 75 min.

4.3 The ball is removed from the vibrator arm and cleaned. The dimensions of the major and minor axes of the wear scar are measured under 100× magnification and recorded.

5. Significance and Use

5.1 Diesel fuel injection equipment has some reliance on lubricating properties of the diesel fuel. Shortened life of engine components, such as diesel fuel injection pumps and injectors, has sometimes been ascribed to lack of lubricity in a diesel fuel.

5.2 The trend of HFRR test results to diesel injection system pump component distress due to wear has been demonstrated in pump rig tests for some fuel/hardware combinations where boundary lubrication is believed to be a factor in the operation of the component.⁹

5.3 The wear scar generated in the HFRR test is sensitive to contamination of the fluids and test materials and the temperature of the test. Lubricity evaluations are also sensitive to trace contaminants acquired during test fuel sampling and storage.

5.4 The HFRR and Scuffing Load Ball on Cylinder Lubricity Evaluator (SLBOCLE, Test Method D 6078) are two methods for evaluating diesel fuel lubricity. No absolute correlation has been developed between the two test methods.

5.5 The HFRR may be used to evaluate the relative effectiveness of diesel fuels for preventing wear under the prescribed test conditions. Correlation of HFRR test results with field performance of diesel fuel injection systems has not yet been determined.

5.6 This test method is designed to evaluate boundary lubrication properties. While viscosity effects on lubricity in this test method are not totally eliminated, they are minimized.

6. Apparatus

6.1 *High-Frequency Reciprocating Rig (HFRR)*¹⁰, (see Fig. 1) capable of rubbing a steel ball loaded with a 200-g mass against a stationary steel disk completely submerged in a test fuel. The apparatus uses a 1-mm stroke length at a frequency of 50 Hz for 75 min. Complete operating conditions are listed in Table 1.

6.2 *Test Reservoir*, capable of holding a test disk in a rigid manner beneath the test fuel. The temperature of this reservoir, and consequently the test fuel contained in it, is maintained by means of a closely attached electrically controlled heater pad.

6.3 *Control Unit*, for controlling stroke length, frequency, test reservoir temperature, friction force, electrical contact

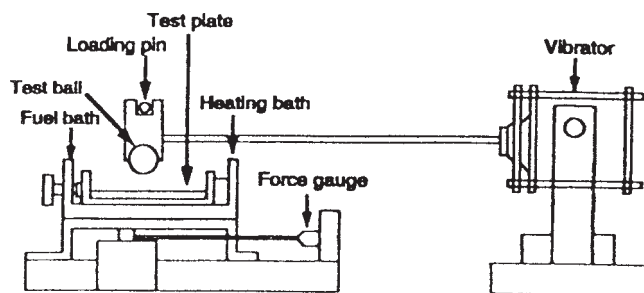


FIG. 1 Schematic Diagram of HFRR (not including instrumentation)

TABLE 1 Test Conditions

Fluid volume	2 ± 0.20 mL
Stroke length	1 ± 0.02 mm
Frequency	50 ± 1 Hz
Fluid temperature	25 ± 2°C
	or
	60 ± 2°C
Relative humidity	> 30 %
Applied load	200 ± 1 g
Test duration	75 ± 0.1 min
Bath surface area	6 ± 1 cm ²

potential, and test duration, with an electronic data acquisition and control system.¹⁰

6.4 *Microscope*, capable of 100× magnification in graduations of 0.1 mm and incremented in divisions of 0.01 mm.

6.4.1 *Glass Slide Micrometer*, with a scale ruled in 0.01 mm divisions.¹¹

6.5 *Cleaning Bath*, ultrasonic seamless stainless steel tank with adequate capacity and a cleaning power of 40 W or greater.

6.6 *Desiccator*, containing a drying agent, capable of storing test disks, balls, and hardware.

7. Reagents and Materials

7.1 *Acetone*, reagent grade (**Warning**—Extremely flammable. Vapors may cause flash fire).

7.2 *Compressed Air*, containing less than 0.1 ppmv hydrocarbons and 50 ppmv water. (**Warning**—Compressed gas under high pressure. Use with extreme caution in the presence of combustible material.)

7.3 *Gloves*, clean, lint-free, cotton, disposable

7.4 *Reference Fluids*:

7.4.1 *Fluid A*—High lubricity reference¹² (**Warning**—Flammable). Store in clean, borosilicate glass with an aluminum foil-lined insert cap. Store in dark area.

7.4.2 *Fluid B*—Low lubricity reference¹² (**Warning**—Flammable. Vapor harmful). Store in clean, borosilicate glass with an aluminum foil-lined insert cap. Store in dark area.

7.5 *Test Ball*, (Grade 24 per ANSI B3.12) of AISI E-52100 steel, with a diameter of 6.00 mm, having a Rockwell hardness

⁹ Nikanjam, M., Crosby, T., Henderson, P., Gray, C., Meyer, K., and Davenport, N., "ISO Diesel Fuel Lubricity Round Robin Program," SAE, Paper No. 952372, SAE Fuels and Lubricants Meeting, Oct. 16-19, 1995, Toronto, Canada.

¹⁰ Available from PCS Instruments, 5 Warple Mews, London W3 0RF, England.

¹¹ Catalog No. 31-16-99 from Bausch and Lomb, Inc. has been found satisfactory. A certificate of traceability from the National Institute of Standards and Technology is available.

¹² Reference Fluids A and B are available from ASTM Test Monitoring Ctr., 6555 Penn Ave., Pittsburgh, PA 15026-4489.

“C” scale (HRC) number of 58 - 66, in accordance with Test Method E 18, and a surface finish of less than $0.05 \mu\text{m} R_a$.¹²

7.6 *Test Disk*, 10 mm disk of AISI E-52100 steel machined from annealed rod, having a Vickers hardness “HV 30”, in accordance with Specification E 92, a scale number of 190-210, turned, lapped, and polished to a surface finish of less than $0.02 \mu\text{m} R_a$.¹²

7.7 *Toluene*, reagent grade (**Warning**—Flammable. Harmful if inhaled).

7.8 *Wiper*, wiping tissue, light-duty, lint-free, hydrocarbon-free, disposable.

8. Sampling and Sample Containers

8.1 Unless otherwise specified, samples shall be taken by the procedure described in Practice D 4057 or Practice D 4177.

8.2 Because of the sensitivity of lubricity measurements to trace materials, sample containers shall be only fully epoxy-lined metal, amber borosilicate glass, or polytetrafluorethylene (PTFE), cleaned and rinsed thoroughly at least three times with the product to be sampled before use, as specified under Containers for Lubricity Testing in Practice D 4306.

8.3 New sample containers are preferred, but if not available, the Containers for Lubricity Testing section of Practice D 4306 gives guidance on suitable cleaning procedures for each type of container.

9. Preparation of Apparatus

9.1 *Test Disks*, (as received):

9.1.1 Upon receipt, new discs must be stored under toluene for at least 12 h before cleaning, as described in 9.1.2 through 9.1.5.

9.1.2 Remove disks from toluene and place discs in a clean beaker. Transfer a sufficient volume of toluene into the beaker to completely cover the test disks.

9.1.3 Place beaker in ultrasonic cleaner and turn on for 7 min.

9.1.4 Handle all clean test pieces with clean forceps. Remove the test discs and repeat the above cleaning procedure from 9.1.2 with acetone for 2 min.

9.1.5 Dry and store in desiccator.

NOTE 2—Drying operations can be accomplished using compressed air jet at 140 to 210 kPa-pressure.

9.2 *Test Balls*, (as received)—The test balls are to be cleaned following the same procedure, 9.1.1 to 9.1.5, as for the test disks.

9.3 *Hardware*—All hardware and utensils that come into contact with the test disks, test balls, or test fuel, shall be cleaned by washing thoroughly with toluene, dried, and rinsed with acetone. Dry and store in a desiccator.

10. Test Apparatus Inspection and Verification

10.1 *Temperature*—Check the temperature control of the test reservoir using a calibrated temperature measuring device.

10.2 *Frequency*—Check the frequency of the vibrator unit with a calibrated frequency meter.

10.3 *Stroke Length*—Check the stroke length by measuring the wear scar on the test disk, using a calibrated microscope, after running a test on reference Fluid B. Subtract the width of the wear scar from the length of the wear scar to give the actual stroke length.

10.4 *Run Time*—Check the run time with a calibrated stopwatch (optional).

10.5 *Test Apparatus*—Verify test apparatus performance and accuracy at least every 20 tests by testing each reference fluid in accordance with this section. Perform two tests with each reference fluid at the test temperature to which the test apparatus is being verified. If the difference between the two wear scar diameters (WSDs) for either fluid is greater than 0.08 mm, then further tests or corrective action to verify the test apparatus performance and accuracy will be required. Further tests or corrective action to verify the test apparatus performance and accuracy is also required if the average of the two tests differs by more than 0.08 mm from the average WSD values provided with Fluid A and Fluid B at 25°C and 60°C.

11. Procedure

11.1 Table 1 summarizes the test conditions.

11.2 Strict adherence to cleanliness requirements and to the specified cleaning procedures is required. During handling and installation procedures, protect cleaned test parts (disks, balls, reservoir, and fixtures) from contamination by using clean forces and wearing clean cotton gloves.

11.3 Using forceps, place the test disk into the test reservoir, shiny side up. Secure the test disk to the test reservoir and the test reservoir to the test apparatus. Ensure the unit’s thermocouple is properly placed in the reservoir. Ensure the relative humidity in the test laboratory is greater than 30 %.

11.4 Using forceps, place the test ball into the holder and attach the holder to the end of the vibrator arm. Ensure the holder is horizontal before fully securing the unit.

11.5 Using a pipette, place 2 ± 0.2 mL of the test fuel into the bath.

11.6 Set the temperature controller to the desired test temperature (25°C or 60°C, preferably 60°C, see 4.1) and switch on the heater. Set the stroke length to 1 mm. Set the vibration frequency to 50 Hz.

11.7 When the temperature has stabilized, lower the vibrator arm and suspend a 200-g weight from the arm. Start the vibrator unit.

11.8 Operate the test for 75 min. At the completion of the test, switch off the vibrator unit and the heater. Lift up the vibrator arm and remove the test ball holder.

11.9 Rinse the test ball (still in the holder) in cleaning solvents and dry with a tissue. Using a permanent marker, circle the wear scar on the ball.

11.10 Remove the test reservoir and properly dispose of the fuel. Remove the test disk and wipe it clean. Place the disk in a storage receptacle (plastic bag) marked with the unique test reference.

11.11 Place the test ball holder under the microscope and measure the wear scar diameter in accordance with Section 12

11.12 Upon completion of the wear scar measurement, remove the test ball from the holder and place the ball together in storage with the test disk.

12. Measure of the Wear Scar

12.1 Turn on the microscope light and position the test ball under microscope at 100× magnification.

12.2 Focus the microscope and adjust the stage such that the wear scar is centered within the field of view.

12.3 Align the wear scar to a divisional point of reference on the numerical scale with the mechanical stage controls. Measure the major axis to the nearest 0.01 mm. Record the readings on the data sheet.

12.4 Align the wear scar to a divisional point of reference on the numerical scale with the mechanical stage controls. Measure the minor axis to the nearest 0.01 mm. Record the readings on the data sheet.

12.5 Record the condition of the wear area if different from the reference standard test, that is, debris color, unusual particles or wear pattern, visible galling, and so forth, and presence of particles in the test reservoir.

13. Calculation

13.1 Calculate the wear scar diameter as follows:

$$WSD = (M + N)/2$$

where:

WSD = wear scar diameter, mm,

M = major axis, mm, and

N = minor axis, mm.

14. Report

14.1 Report the following information:

14.1.1 Major axis, minor axis, and wear scar diameter to the nearest 0.01 mm.

14.1.2 Description of the wear scar area.

14.1.3 Fuel temperature.

14.1.4 Description of the test fuel and date sample taken.

14.1.5 Identification of test specimens.

14.1.6 Date of testing.

14.1.7 Any deviations from the test conditions given in Table 1.

15. Precision and Bias ¹³

15.1 *Precision*—The precision was developed for fuels with wear scar diameters between 0.143 and 0.772 mm at 25°C (0.175 and 1.00 mm at 60°C). The precision data were developed in a 1995 cooperative testing program involving both United States and European testing laboratories. There were nine distinct fluids and each laboratory was given 18 fluids to test. The fluids were blind coded so that replicate samples were not known to the operator. A randomized test sequence was provided and each laboratory was requested to use the same operator and equipment for all 18 samples. Nine laboratories tested the HFRR at 25°C and ten laboratories tested the HFRR at 60°C.

15.1.1 The difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following value in only one case in twenty:

Repeatability at 25°C = 0.062 mm

Repeatability at 60°C = 0.080 mm

15.1.2 The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following value in only one case in twenty:

Reproducibility at 25°C = 0.127 mm

Reproducibility at 60°C = 0.136 mm

15.2 *Bias*—The procedure in this test method has no bias because lubricity is not a fundamental and measurable fluid property and thus is evaluated in terms of this test method.

16. Keywords

16.1 boundary lubrication; diesel fuel; friction; lubricity; wear

¹³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02-1411.

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