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LAND SEA AIR SPACE

TECHNICAL REPORT J35

DIESEL SMOKE MEASUREMENT PROCEDURE—SAE J35

SAE Recommended Practice

Report of Automotive Emissions Committee approved January 1973.

Purpose—This SAE Recommended Practice provides a procedure for the assessment of transient and steady-state smoke emissions from vehicular diesel engines using an engine dynamometer cycle which simulates normal operating conditions. While intended for engine development and evaluation, it is similar to a procedure which has been used for regulatory approval by the United States government.

Scope—The recommended practice applies to the dynamometer test procedure which can be used to assess the smoke emission characteristics of vehicular diesel engines. In particular, these procedures describe the smoke emissions test, smoke test cycle, equipment and instrumentation, instrument checks, and chart reading and calculation, for evaluation of an engine's steady-state and transient smoke emission characteristics.

A full-flow smoke opacimeter as opposed to other types of smokemeters is required because the test is designed to monitor transient smoke. Sampling type instruments have an excessive and variable delay and do not provide an accurate measurement of the engine's transient smoke output. An Appendix shows that the Beer-Lambert law can be used to correlate opacity measurements with different meter path lengths.

Additional or modified test conditions may be requested when this recommended practice is cited in a request for a smoke assessment. These modified test conditions should be clearly stated whenever the results of the smoke assessments are reported. Similarly if the fuel is specified in the test request, this should be stated when the results are reported.

Sections—The procedure is divided into the following sections:

1. Definition of Terms and Abbreviations
2. Smoke Emission Test
3. Smoke Test Cycle
4. Information to be Recorded
5. Equipment and Instrumentation
6. Instrument Checks
7. Chart Reading
8. Appendix

1. Definition of Terms and Abbreviations

1.1 Terms Used

1.1.1 VEHICULAR DIESEL ENGINE—Any compression ignition internal combustion engine of less than 1000 hp (745,700 W) used to propel on-land, nonrail, mobile equipment.

1.1.2 DIESEL SMOKE—Particles, including aerosols, suspended in the engine's gaseous exhaust stream which obscure, reflect, and/or refract light.

1.1.3 RATED BRAKE POWER—The maximum brake power output of an engine in horsepower (watts) as stated by the manufacturer (in accordance with SAE J270).

1.1.4 RATED SPEED—The speed at which the manufacturer specifies the rated brake power of an engine.

1.1.5 PEAK TORQUE SPEED—The speed at which the engine develops maximum torque as stated by the manufacturer.

1.1.6 INTERMEDIATE SPEED—The peak torque speed or 60% of rated speed, whichever is higher.

1.1.7 IDLE SPEED—The engine's low idle speed as specified by the manufacturer.

1.1.8 FULL LOAD POWER—The power produced, at the speed being considered, when the throttle lever is placed in the maximum fuel position.

1.1.9 OPACITY—That fraction of light transmitted from a source which is prevented from reaching the observer or instrument receiver expressed in percent [opacity = 100% (1 − transmittance)].

1.1.10 SMOKE OPACIMETER—An optical instrument designed to measure the opacity of diesel exhaust gases. The full flow of exhaust gases passes through the optical unit. One such smoke opacimeter is described in SAE J255.

1.1.11 SPAN—The distance between zero and full-scale deflection of the readout device used with the smoke opacimeter.

1.1.12 RESOLUTION—The minimum distinguishable reading, for a given trace width and scale combination, expressed as a percent of full-scale.

1.2 Abbreviations Used

dB—decibels
°C—degrees Celsius
°F—degrees Fahrenheit
Hg—Mercury
hp—Horsepower
Hz—Hertz
in—inch(es)
min—Minimum, minute
mm—Millimetre
rpm—Revolutions per minute
s—second
%—Percent

2. Smoke Emission Test—Perform the following sequence of operations during engine dynamometer testing for smoke emissions:

2.1 Control the temperature of the air supplied to the engine to between 80 and 90°F (27 and 32°C). Test only when the observed barometric pressure is between 28.5 and 30.5 in (724 and 775 mm) of Hg in the test area.

Starting with an engine at operating temperature, operate the engine at the condition of maximum mass fuel flow, adjust the intake air restriction to within 1 in (25.4 mm) of water of the maximum recommended by the manufacturer and adjust the exhaust system back pressure to within 0.2 in (5.1 mm) of Hg of the maximum recommended by the manufacturer. Measure and record maximum observed power, fuel rate, engine speed, intake air temperature, intake air restriction, and exhaust back pressure.

2.2 Operate the engine at the intermediate speed. Measure and record maximum observed torque, fuel rate, engine speed, intake air temperature, intake air restriction, and exhaust back pressure. Determine by experiment, if not previously determined, the preset loads required by the Smoke Test Cycle (paragraph 3).

2.3 Switch on the smoke opacimeter. Allow for the meter circuit to stabilize per manufacturer's instruction. Check the linearity of the meter per paragraphs 6.1.2 and 6.1.3.

Mount the smoke opacimeter in accordance with paragraph 5.2 so that the natural flow of the exhaust stream is not disturbed by the meter, the mounting fixture, or any ventilation system.

2.4 Pass the exhaust flow through the smoke opacimeter so that the opacity of the exhaust plume may be measured.

2.5 Operate the engine at maximum power for 10 min or until the engine coolant, oil pressures, and temperatures are stabilized.

2.6 Discontinue passing the exhaust gas stream through the meter. Set the zero and span of the smoke opacimeter recorder.

2.7 Operate the engine in the manner required by the Smoke Test Cycle (paragraph 3). Continuously record smoke opacity and engine speed on a strip chart recorder or other appropriate instrument. The chart speed shall be at least 1 in (25 mm)/min during the idle mode and at least 15 in (381 mm)/min during acceleration and lugging modes.

2.8 Repeat the procedures as contained in paragraphs 3.1-3.4 until the entire cycle has been run three consecutive times. If the acceleration and lugging modes have been performed within the tolerances specified in paragraph 3, then the tests may be terminated at this time. If not, then the test procedure should be rerun until data have been obtained within the specified limits.

2.9 Within 1 min after completion of paragraph 2.8, recheck the calibration of the smoke opacimeter as described in paragraph 2.6. If

either zero or span drift is in excess of 2% opacity, the test results should be considered invalid.

3. Smoke Test Cycle—Conduct each smoke emissions test specified in paragraph 2 according to the following sequence:

3.1 Idle Mode—Idle the engine for 1.5-2.0 min at the manufacturer's recommended low idle speed with the dynamometer controls set to provide minimum load by turning the load switch to the "off" position or by adjusting the controls to the minimum load position.

3.2 Acceleration Mode

3.2.1 Accelerate the engine at full throttle against inertia or alternately against a preprogrammed dynamometer load such that the engine speed increases to 85-90% of rated speed in 3.5-5.5 s.[1] The acceleration should be kept linear within ±100 rpm.

3.2.2 When the engine reaches 85-90% of rated speed, rapidly close the throttle and remove the dynamometer load, if any. Apply the preset load required to perform the acceleration in paragraph 3.2.3. Allow the engine speed to drop to the intermediate speed within ±100 rpm.

3.2.3 Rapidly move the throttle to the full throttle position and accelerate the engine against a dynamometer load schedule such that the engine speed reaches 95-100% of rated speed in 10 ±2 s.

3.3 Rated Speed Mode

3.3.1 Proceeding from the acceleration mode, adjust the dynamometer controls to permit the engine to develop full load power at rated speed.

3.3.2 Allow the engine to operate for 1 min after the load and speed have stabilized at full load power at rated speed.

3.4 Lugging Mode—Adjust the dynamometer controls without changing the throttle position to slow the engine gradually to the intermediate speed. Perform this engine lugging operation smoothly over a period of 35 ±5.0 s. The slowing rate of the engine should be kept linear within ±100 rpm.

3.5 Intermediate Speed Mode—Allow the engine to operate at full load power at the intermediate speed for 1 min after the load and speed have stabilized.

3.6 Engine Unloading—After completion of the lugging and intermediate speed modes, the dynamometer and engine shall be returned to the idle condition described in paragraph 3.1. The zero and span of the smoke opacimeter may be checked and reset if necessary. If either zero or span drift is in excess of 2%, the test results should be considered invalid.

4. Information to be Recorded—Record the following information in a test log for each smoke emissions test conducted:

4.1 Performance data, including:

4.1.1 Date, time of day, number of engine hours, and observers.

4.1.2 Barometric pressure and standard dry and wet bulb temperature readings.

4.1.3 Maximum observed power, fuel rate, engine speed, intake air restriction, exhaust restriction, and intake air temperature at rated speed.

4.1.4 Maximum observed torque, fuel rate, engine speed, intake air restriction, and intake air temperature at the intermediate speed.

4.1.5 Smoke opacimeter type and identifying number.

4.1.6 Exhaust pipe diameter.

4.1.7 Calibrated and observed values of calibration filter(s).

4.1.8 Other desired information.

4.2 Record the following information on the recorder sheet at the time of each smoke emission test:

4.2.1 Test number.

4.2.2 Engine model and serial number.

4.2.3 Engine hours.

4.2.4 Test date, time.

4.2.5 Smoke opacimeter type and number.

4.2.6 Identify calibration traces and note the value of calibration filter(s).

4.2.7 Identify smoke and speed traces.

5. Equipment and Instrumentation—Use the following equipment and instruments for smoke emissions and service simulation tests:

5.1 An engine dynamometer with adequate characteristics to perform the tests required by the Smoke Test Cycle (paragraph 3).

5.2 Provide an exhaust system of proper diameter and suitable length[2] for the engine being tested, with provisions for mounting the smoke opacimeter. The system must be capable of being adjusted to meet the exhaust back pressure required for the Smoke Emission Test (paragraph 2). Install a 2 ft (610 mm) section of smooth circular pipe, free of elbows and bends, prior to the smoke opacimeter location.[3] If a muffler is needed, a conventional automotive muffler of a size and type commonly used with the engine may be installed in this system.

5.3 Mount a full-flow, light-extinction, smoke opacimeter in or on the exhaust system at the location specified in paragraph 5.2. When dual exhaust systems are used, both systems should be equipped with a smoke opacimeter measuring an exhaust stream of 5 in (127 mm) diameter or larger.

5.4 Smoke opacity and engine speed is to be monitored continuously, using a strip chart recorder or equivalent, with a minimum speed range of 0.5-15.0 in/min (13-381 mm/min), and a maximum full-scale response time for smoke opacity of 0.5 s.[4] An automatic marker indicating 1.0 s intervals to verify chart speed is desirable.

5.5 The various components, opacimeter, electronic filters, and recorder, should comprise a system capable of data output within the following limits:

5.5.1 The smoke opacity trace is to be linear when calibrated to read from 0 to 100% (full-scale). The trace should have a resolution within 1% of full-scale reading.

5.5.2 The engine speed trace is to be linear when calibrated to read from the low idle speed to rated engine speed. The trace should have a resolution within 1% of rated engine speed.

5.5.3 The chart speed used to record smoke opacity is to provide a time resolution of at least 0.25 s.

5.6 The use of general instrumentation for measuring engine speed, power, fuel rate, inlet air restriction, exhaust back pressure, inlet air temperature and humidity, barometric pressures, and such pressures and temperatures while performing tests required in this part should not affect the recorded smoke opacity.

5.7 A separate low-pass electronic filter with the following performance characteristics may be installed between the smoke opacimeter and the recorder to achieve high frequency attenuations.

5.6.1 Three decibels point—10 Hz.

5.6.2 Insertion loss—0 ±0.5 dB.

5.6.3 Selectivity—12 dB per octave above 10 Hz.

5.6.4 Attenuation—27 dB down at 40 Hz min.

6. Instrument Checks

6.1 Check the smoke opacimeter according to the following procedure prior to each test.

6.1.1 Check the surfaces of the optical section to verify that they are clean and free from foreign material and fingerprints.

6.1.2 Adjust the zero control under conditions of "no smoke" to give a recorder trace of zero.

6.1.3 Use calibrated neutral density filters having approximately 10, 20, and 40% opacity to check the linearity of the instrument. Any deviations in excess of 1% of the calibrated value of a filter should be corrected.

6.1.3.1 Insert the filter(s) in the light path perpendicular to the axis of the beam and adjacent to the opening from which the beam of light from the light source emanates and note the recorder response.

6.1.3.2 For maximum correlation of results, the calibration of the neutral density filters should be traceable to the U.S. National Bureau of Standards.

6.2 Calibrate the instruments for measuring engine speed, torque, air inlet restrictions, exhaust system back pressure, fuel rate, etc., and for recording engine speed and smoke opacity used in the tests prescribed herein periodically in accordance with good technical practice.

7. Chart Reading—General Engine Applications—Use the following procedure in reading the smoke opacimeter recorder chart:

7.1 Locate the start of the acceleration modes (paragraphs 3.2.1 and 3.2.3) and the start of the lugging mode (paragraph 3.3) on the speed trace.

7.1.1 Divide both of the acceleration modes into ½ s intervals beginning at the start of the first acceleration of each test. Determine the average smoke reading during each ½ s interval.

7.1.2 Locate and record the 15 highest ½ s readings during both acceleration modes of each smoke cycle. Average the 45 readings from the three cycles. Record and designate this value as (a). ((a) represents the acceleration smoke characteristic of the engine.)

7.2 Locate the lugging mode (paragraph 3.4).

7.2.1 Divide the lugging mode into ½ s intervals and determine the average smoke readings during each ½ s interval.

[1]For maximum repeatability on turbocharged engines with more than 1.5 pressure ratio, this should be held to closer limits.

[2]Test data show that a range of length 4-20 ft (1.2-6.1 m) does not change the meter reading. In the case of short exhaust systems, the opacimeter may be affected by the high temperature.

[3]If an opacimeter which mounts at the end of the exhaust system is used, the optical unit of the opacimeter shall be mounted radially to the exhaust pipe so that the measurement will be made at right angles to the axis of the exhaust plume. The opacimeter should be located at the termination of the exhaust stack with the light beam of the opacimeter just clearing the stack termination point. The full flow of the exhaust stream shall be centered between the source and detector apertures (or windows and lenses) and on the axis of the light beam.

[4]Response time for 95-105% of full-scale within 0.5 s. Reading to stabilize at 100% within 1.0 s.