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Diesel Smoke Measurement Procedure

- 1. Scope**—This SAE Recommended Practice applies to the dynamometer test procedure which can be used to assess the smoke emission characteristics of vehicular diesel engines. In particular, this procedure describes the smoke test cycle, equipment and instrumentation, instrument checks, chart reading, and calculation for evaluation of an engine's transient smoke emission characteristic. In addition, this procedure offers guidelines to be used in establishing correlation between full flow in-line and end-of-line opacimeters.

Since the type of test described here is transient in nature, a fast responding full flow opacimeter is required for the smoke measurements. Slow responding or sampling, or both, type instruments must not be used since they typically have excessive and variable response delays and do not provide an accurate measurement of an engine's transient smoke characteristics.

NOTE— It is recommended that whenever this procedure is cited, any additional or modified test conditions must be clearly reported.

- 1.1 Purpose**—This document provides a procedure for the assessment of transient smoke emissions from vehicular diesel engines using an engine dynamometer cycle which simulates on-highway operating conditions. While intended for engine development and evaluation, it is similar to the procedure which has been used for regulatory approval by the United States Government. In many areas, additional recommendations to improve test precision are offered.

2. References

- 2.1 Applicable Publications**—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

- 2.1.1 SAE PUBLICATIONS**—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J255—Diesel Engine Smoke Measurement

SAE 690492—Steady-State Correlation of Diesel Smokemeters—An SAE Task Force Report. A.W. Carey, Jr., Cummins Engine Co., Inc.

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2.1.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 86—Method for Distillation of Petroleum Products

ASTM D 93—Test Methods for Flash Point by Pensky-Martens Closed Tester

ASTM D 120—Specification for Rubber Insulating Gloves

ASTMD287—Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)

ASTMD445—Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)

ASTM D 613—Test Method for Ignition Quality of Diesel Fuels by the Cetane Method

ASTM D 2622—Test Method for Sulfur in Petroleum Products (X-Ray Spectrographic Method)

2.1.3 FEDERAL PUBLICATION—Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Code of Federal Regulations, Title 40, Part 86

3. Definitions

3.1 Vehicular Diesel Engine—Any compression ignition internal combustion engine used to propel onland, nonrail, mobile equipment.

3.2 Diesel Smoke—Particles, including aerosols, suspended in the engine's gaseous exhaust stream which obscure, reflect or refract, or both, visible light.

3.3 Rated Brake Power—The maximum brake power output of an engine in kilowatts as measured at rated speed.

3.4 Rated Speed—The speed at which the manufacturer specifies the rated brake power of an engine.

3.5 Peak Torque Speed—The speed at which the engine develops maximum torque as measured by the manufacturer.

3.6 Intermediate Speed—The peak torque speed, provided that speed occurs between 60 and 75% of rated speed. If the peak torque speed is less than 60% of rated speed, intermediate speed means 60% of rated speed. If the peak torque speed is greater than 75% of rated speed, intermediate speed means 75% of rated speed.

3.7 Curb Idle Speed—The engine's low idle speed as specified by the manufacturer (with tolerances) depending on the predominant transmission application.

a. Manual Transmission—The manufacturer's recommended speed with transmission in neutral or clutch disengaged.

b. Automatic Transmission—The manufacturer's recommended speed with transmission in gear.

3.8 High Idle Speed—The engine's governed maximum speed that occurs during wide-open throttle and no-load conditions.

3.9 Full Load Power—The power produced, at the speed being considered, when the throttle control is placed in the maximum fuel position.

3.10 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)].

3.11 Smoke Opacimeter—An optical instrument designed to measure opacity of diesel exhaust gases. The full flow of exhaust gases passes through the optical path. Opacimeters, including in-line and end-of-line types, are described in SAE J255.

(The term opacimeter will be used throughout this document in reference to smoke opacity measurement devices. Similarly, EOL and IL will be used to denote end-of-line and in-line types of opacimeters.)

3.12 Transmittance—That fraction of light transmitted from a source, through a smoke-obscured path, which reaches the observer or instrument receiver.

4. **Abbreviations Used**

bhp - brake horsepower
 dB - decibels
 °C - degrees Celsius
 cS - centistokes
 EOL - end of line
 °F - degrees Fahrenheit
 Hg - Mercury
 Hz - Hertz
 I.D. - inside diameter
 IL - in-line
 in - inch
 LSR - least squares regression
 m - meter
 min - minimum, minute
 mm - millimeter
 N - percent opacity
 NA - naturally aspirated
 NIST - National Institute of Standards and Technology
 Pa - pascal, kPa - kilopascals
 rpm - revolutions per minute
 s - second
 T - transmittance
 TC - turbocharged
 W - Watts, kW - kilowatts
 % - percent

5. Sections—The document is divided into the following sections:

Section 2, References
 Section 3, Definitions
 Section 4, Abbreviations Used
 Section 6, Fuel Specification
 Section 7, Smoke Emission Test
 Section 8, Smoke Test Cycle
 Section 9, Information to be Recorded
 Section 10, Equipment and Smoke Measurement Instrumentation
 Section 11, Instrument Checks
 Section 12, Data Analysis
 Section 13, Correlation Procedure for Full-Flow Opacimeters

6. Fuel Specification

- 6.1** The diesel fuels employed shall be clean and bright, with pour and cloud point adequate for operability. The fuels may contain nonmetal additives as follows: Cetane improver, metal de-activator, anti-oxidant, dehazer, anti-rust, pour depressant, dye, and dispersant.
- 6.2** Since fuel properties can affect diesel smoke emissions, it is recommended for good comparability with other tests that fuel specifications comply with those in the current Code of Federal Regulations, Title 40, Part 86. Those specifications at the publishing date of this procedure are listed in Table 1. Any deviations of the test fuel properties from these specifications should be reported along with the test results.

TABLE 1—TEST FUEL SPECIFICATIONS

Item	ASTM No.	Range No. 1	Range No. 2
Cetane	D-613	48–54	40–48
Distillation	D-86		
IBP C(F)		166–199 (330–390)	171–204 (340–400)
10%		188–221 (370–430)	204–238 (400–460)
50%		210–249 (410–480)	243–282 (470–540)
90%		238–271 (460–520)	293–332 (560–630)
EP		260–293 (500–560)	321–366 (610–690)
Sulfur, %	D-120, D-2622	0.03–0.05	0.03–0.05
Gravity, API	D-287	40–44	32–37
Hydrocarbon composition			
Aromatics, %		8 min	27 min
Saturates, Olefins		Remainder	Remainder
Flash Point C(F)	D-93	49 (120) min	54 (130) min
Viscosity, cS	D-445	1.6–2.0	2.0–3.2

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

- 7.1** Control the temperatures of (a) the air supplied to the engine to $25\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ and (b) the fuel pump inlet to $38\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$. It is recommended to test only when the observed barometric pressure is between 725 (96.7) and 785 (104.7) mm of Hg (kPa) in the test area. Note that smoke emissions are affected by the dry barometric pressure of the combustion air.

For TC engines at operating temperature, and at rated speed and full load-power conditions, adjust the intake air restriction to within 25 mm of water of the maximum recommended by the manufacturer and the exhaust system back pressure to within 5 mm of Hg of the maximum recommended by the manufacturer. The measurement locations for intake and exhaust pressures should be as defined by the manufacturer. Measure and record observed power, fuel rate, engine speed, intake air temperature, fuel pump inlet temperature, inlet air restriction, and exhaust back pressure.

For NA engines, the intake adjustment and measurement should be made at high idle conditions.

- 7.2 Optional**—In addition to 7.1, operate the engine at the intermediate speed. Measure and record maximum observed torque, fuel rate, engine speed, intake air temperature, fuel pump inlet temperature, intake air restriction, and exhaust back pressure. Determine by experiment, if not previously determined, the preset loads required by the smoke test cycle (Section 8).

- 7.3** Switch on the opacimeter. Allow for the meter circuit to stabilize per the manufacturer's instructions. Set the zero and span of the meter per 11.2 and 11.3.

The opacimeter should be mounted in accordance with 10.2 so that the natural flow of the exhaust gas stream is not disturbed by the meter, the mounting fixture, or any ventilation system.

- 7.4** Pass the exhaust flow through the opacimeter so that the opacity of the exhaust plume may be measured.
- 7.5** Operate the engine at rated brake power for 10 min or until the engine coolant, oil pressures, and temperatures are stabilized.
- 7.6** Discontinue passing the exhaust gas stream through the meter. Check and reset the meter zero and span per 11.2 and 11.3. Check the linearity of the meter per 11.4.
- 7.7** Operate the engine in a manner required by the smoke test cycle (Section 8). Continuously record smoke opacity and engine speed on a strip chart recorder or other appropriate instrument. The chart speed shall be at least 25 mm/min (1 in/min) during the idle mode and at least 200 mm/min (8 in/min) during the acceleration and lugging modes. If readings are taken by an automatic data acquisition system, readings shall be taken at least at 0.1 Hz at idle and 10 Hz during other modes.
- 7.8** Repeat the procedures as contained in 8.1 through 8.4 until the entire cycle has been run three consecutive times. If the acceleration and lugging modes have been performed within the tolerances specified in Section 8, then the tests may be terminated at this time. If not, then the test procedure, beginning with the 10-min preconditioning described in 7.5, should be rerun until data has been obtained within the specified limits.
- 7.9** Within 1 min after completion of 7.8, recheck the zero and span of the smoke meter as described in 7.6. If either zero or span drift is in excess of 2% opacity, the test results should be considered invalid.
- 8. *Smoke Test Cycle***—Conduct each smoke emission test in accordance with the procedure specified in Section 7. Follow the engine operating sequence per 8.1 through 8.4. Refer to the “Smoke Test Cycle” (Figure 1) for locating real time events that indicate the beginning or ending, or both, of the elements of each mode and appear as letters A through J.

Note that if a motoring-absorbing dynamometer is used, motoring assist to overcome the dynamometer inertia is acceptable, but motoring in excess of $-13.6 \text{ N}\cdot\text{m}$ ($-10 \text{ lb}\cdot\text{ft}$) (negative net torque) for more than 0.5 s to achieve speed targets is not permitted.

- 8.1 *Idle Mode***—Idle the engine for 5 to 5.5 min at the manufacturer's recommended curb idle speed. Dynamometer load may be applied to simulate an automatic transmission to achieve curb idle speed. Any other adjustments that cause idle speed to be altered for the purpose of simulating accessories are not allowed.

Idle mode begins following the preconditioning mode (7.5), or the lugging mode (8.4) designated J in Figure 1 and ends at point A, the beginning of the acceleration mode. Idle speed should be held within specifications during the last 4 min.