

Diesel Engine Emission Measurement Procedure

1. **Scope**—This SAE Recommended Practice is intended for use as a test procedure to determine the gaseous emission levels of diesel engines. Its purpose is to provide a map of an engine's emissions characteristics which, through use of the proper weighting factors, can be used as a measure of that engine's emission levels under various applications. The emission results for hydrocarbons, nitrogen oxides, carbon monoxide, and carbon dioxide are expressed in units of grams per kilowatt hour (grams/brake horsepower hour) and represent the mass rate of emissions per unit of work accomplished.

The emissions are measured in accordance with SAE Recommended Practices J177, J215, and J244 using nondispersive infrared equipment for CO and CO₂, a heated flame ionization analyzer for HC, and a high performance NDIR or a chemiluminescence analyzer for NO_x. All emissions are measured during steady-state engine operation. The mass rate of emissions is calculated (a) from the concentration in the exhaust gas and the exhaust flow for each mode or (b) alternately, using a carbon balance method, from the concentration in the exhaust gas and the mass flow rate of fuel for each mode. If method (a) is used, CO₂ should be measured for data validation. The final emissions are calculated by dividing the summation of the weighted emission mass rates by the summation of the weighted brake power values for a cycle.

2. **References**

- 2.1 **Applicable Publications**

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

SAEJ177—Measurement of Carbon Dioxide, Carbon Monoxide, and Oxides of Nitrogen in Diesel Exhaust
SAE J215—Continuous Hydrocarbon Analysis of Diesel Emissions
SAE J244—Measurement of Intake Air or Exhaust Gas Flow of Diesel Engines
SAE J1349—Engine Power Test Code—Spark Ignition and Diesel

- 2.1.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Dr., 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 129—Test Method for Sulfur in Petroleum Products (General Bomb Method)
ASTM D 287—Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)

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SAE WEB ADDRESS:

ASTM D 445—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 Octane Method
 ASTM D 1319—Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption

3. Definitions

- 3.1 Diesel Engine**—Any compression ignition engine.
- 3.2 Exhaust Emission**—Any substance (but normally limited to pollutants) emitted to the atmosphere from any opening downstream from the exhaust port of the combustion chamber of an engine.
- 3.3 Rated Power**—The maximum power output of an engine as stated by the manufacturer (in accordance with SAE J1349).
- 3.4 Rated Speed**—The engine speed at which the manufacturer specifies the rated power of an engine.
- 3.5 Intermediate Speed For U.S. On-Highway Applications**—The peak torque speed, when that speed occurs between 60 and 75% of rated speed. If 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.
- 3.6 Peak Torque Speed**—The speed at which the engine develops maximum torque as stated by the manufacturer.
- 3.7 Curb Idle Speed**—For heavy-duty diesel engines equipped with manual transmissions, curb idle means the manufacturer's recommended engine speed with the transmission in neutral or with the clutch disengaged. For heavy-duty diesel engines equipped with automatic transmissions, curb idle means the manufacturer's recommended engine speed with the automatic transmission in gear and the output shaft stalled.
- 3.8 Dynamometer Idle**—For heavy-duty diesel engines equipped with automatic transmissions, dynamometer idle means the manufacturer's recommended engine speed without a transmission that simulates the manufacturer's recommended engine speed with a transmission and with the transmission in neutral.
- 3.9 Rated Torque**—The maximum torque produced by an engine, as stated by the manufacturer.
- 3.10 Percent Load**—The fraction of the maximum available torque at that engine speed.

4. Abbreviations—The abbreviations used in the document have the following meanings in both capital and lower case:

API	= American Petroleum Institute
ASTM	= American Society for Testing and Materials
α	= Atomic hydrogen/carbon ratio of the fuel (approximately 1.8 for No. 2 diesel fuel)
ϕ	= Equivalence ratio (dry), that is, dry fuel air ratio (measured)/fuel-air ratio (stoichiometric)
BARO	= Absolute barometric pressure, kPa (in Hg)
BHP	= Brake power (horsepower)
BSCO	= Brake specific carbon monoxide emissions, g/kW·h (g/bhp·h)
BSFC	= Brake specific fuel consumption, g/kW·h (g/bhp·h)
BSHC	= Brake specific hydrocarbon emissions, g/kW·h (g/bhp·h)
BSNO _x	= Brake specific oxides of nitrogen emissions, g/kW·h (g/bhp·h)
DCO	= CO volume concentration in exhaust, PPM (dry)
DCO ₂	= CO ₂ volume concentration in exhaust, percent (dry)

DHC	= Hydrocarbon volume concentration in exhaust, PPM (dry)
DKNO _x	= NO volume concentration in exhaust, in PPM (dry and humidity corrected)
EIP	= Absolute engine intake pressure, kPa (in Hg) = BARO-inlet restriction

$$f/a = \text{Dry fuel air ratio(measured)} = (f/a)_{\text{wet}} + \frac{G}{1000} \quad (\text{Eq. 1})$$

G	= Humidity of the inlet air in grams of water per kilogram of dry air
K	= Water-gas equilibrium constant = 3.5
Kno _x	= Humidity correction factor for oxides of nitrogen
K _w	= Wet to dry correction factor
kW	= Brake power (kilowatts)
M _c	= Atomic weight of carbon (12.011)
(M _c + αM _H)	= Mean molecular weight of fuel per carbon atom
M _{CO}	= Molecular weight of CO (28.01)
M _F	= Mass flow rate of fuel used in engine in grams/h
M _H	= Atomic weight of hydrogen (1.008)
Mno ₂	= Molecular weight of nitrogen dioxide (NO ₂) (46.01)
P _v	= Partial pressure of water vapor, kPa (in Hg)
T	= Temperature of inlet air, °C (°F)
W _{CO}	= Mass rate of CO in exhaust, grams/h
W _F	= Weighting factor of U.S. on-highway applications (0.067 for modes 1, 7, and 13 and 0.08 for all other modes)
Whc	= HC volume concentration in exhaust, PPMC (wet)
W _{HC}	= Mass rate of HC in exhaust, grams/h
W _{NO_x}	= Mass rate of NO _x in exhaust, grams/h
Y	= H ₂ O volume concentration in intake air

where:

$$Y = \frac{P_v}{\text{BARO} - P_v} \quad (\text{Eq. 2})$$

5. Engine Dynamometer Test Procedure

5.1 Introduction—The test procedure consists of a prescribed sequence of engine operating conditions on an engine dynamometer with measurements of HC, NO_x, CO, and CO₂ during 13 steady-state modes with five modes at rated engine speed, five modes at an intermediate speed, and three modes at an idle speed.

5.2 Fuel Specification

- 5.2.1 The diesel fuels employed shall be clean and bright, with pour point and cloud point adequate for operability. The fuels may contain nonmetal additives as follows: Cetane improver, metal deactivator, antioxidant, dehazer, antirust, pour depressant, dye, and dispersant.
- 5.2.2 Fuel meeting the specifications in Table 1 is currently recommended in the U.S. Highway regulations. Other fuels may be used, realizing that some fuel properties affect exhaust emissions results.

TABLE 1—TEST FUEL SPECIFICATIONS

Item	ASTM Test No.	Range
Cetane number	D 613	42–50
Distillation range	D 86	
IBP, °C (°F)		171–204 (340–400)
10 % Point, °C (°F)		174–238 (400–460)
50% Point, °C (°F)		243–282 (470–540)
90% Point, °C (°F)		288–321 (550–610)
EP, °C (°F)		304–349 (580–660)
Gravity, °API	D 287	33–37
Total sulfur, %	D 129	0.2–0.5
Hydrocarbon composition	D 1319	
Aromatics, % min		27
Paraffins, naphthenes, olefins		Remainder
Flash point, °C (°F) min	D 93	54 (130)
Viscosity, m ² /s (cst)	D 445	2–3.2 x 10 ⁻⁶ (2–3.2)

5.3 Instrumentation

5.3.1 Instrumentation shall be provided to measure the following engine operating data:

- a. Engine speed—rpm
- b. Torque—N·m (lb·ft)
- c. Mass fuel consumption—kg/min (lb/min)
- d. Observed barometer—kPa (in Hg)
- e. Water vapor pressure—kPa (in Hg)
- f. Intake air restriction—kPa (in H₂O)
- g. Exhaust back pressure—kPa (in Hg)
- h. Intake air temperature—°C (°F)
- i. Fuel temperature at pump inlet—°C (°F)

5.3.2 Instrumentation shall be provided to measure the engine intake air flow or exhaust flow and the concentration of CO, CO₂, NO_x, and HC in the exhaust as follows:

5.3.2.1 The determination of CO, CO₂, and NO_x concentrations shall be accomplished using sampling and analysis according to SAE J177.

5.3.2.2 The determination of HC concentration shall be accomplished using sampling and analysis by a heated flame ionization detector method using SAE J215.

5.3.2.3 The determination of intake air or exhaust flow shall be accomplished using SAE J244.

5.4 Test Conditions

5.4.1 The following ranges of test conditions shall be maintained during exhaust emission testing:

5.4.1.1 *Intake Air Temperature*—25 °C ± 5 °C (77 °F ± 9 °F)

5.4.1.2 *Barometric Pressure*—100 kPa ± 3 kPa (29.6 in Hg ± 1 in Hg)