Diesel Emission Production Audit Test Procedure

1. *Scope*—This SAE Recommended Practice applies to a production dynamometer test procedure which can be used to measure the smoke and gaseous emission characteristics of vehicular diesel engines. This procedure describes the smoke emission test method, smoke test cycle, gaseous emission test method, steady-state gaseous emission test cycle, equipment, instrumentation, calibration, data analysis, and correlation of results for comparison of production engine emission performance to the requirements of current or past Federal regulations.

Variations in engines, instrumentation, and test equipment may require modifications to these procedures or data reduction methods. The acceptability of this procedure is dependent upon documented statistical data appropriate to correlate all tests, data reduction techniques, and special instrumentation to the required Federal tests.

When using the audit test procedure to assess the emissions performance of production engines, considerations should be given to expected emissions deterioration factors and quality control limits should be adjusted accordingly.

1.1 Purpose—This document is intended as a guide for the measurement and assessment of transient smoke and steady-state gaseous emissions from heavy-duty vehicular diesel engines only using a shortened engine dynamometer cycle which may be applicable to production line or production quality audit conditions. Key elements of the procedure closely resemble key elements of the Federal Test Procedures used for regulatory approval by the United States Government.

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 J35—Diesel Smoke Measurement Procedure
SAE J177—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 J255—Diesel Engine Smoke Measurement
SAE J1003—Diesel Engine Emission Measurement Procedure
SAE J1349—Engine Power Test Code—Spark Ignition and Diesel

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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 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)
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 Cetane Method
ASTM D 1298—Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D 1319—Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
ASTM D 2500—Test Method for Cloud Point of Petroleum Oils
ASTM D 2622—Test Method for Sulfur in Petroleum Products (X-Ray Spectrographic Method)
ASTM D 4294—Test Method for Sulfur in Petroleum Products by Non-Dispersive X-Ray Fluorescence Spectrometry

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, Chapter I, Part 85—Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines

3. Definitions

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

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

3.3 Gaseous Emission—Substance emitted to the atmosphere from any opening downstream from the exhaust port of any engine which is gaseous in nature when being emitted.

3.4 Rated Brake Power—The maximum brake power output of an engine in kilowatts (horsepower) as stated by the manufacturer.

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

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

3.7 Intermediate Speed—The peak torque speed or 60% of rated speed, whichever is higher.

3.8 Idle SpeeD—The engine's low idle speed as specified by the manufacturer.

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

3.10 Percent Load—The fraction of the maximum available torque at that engine speed.

3.11 Opacity—That fraction of light emanating from a source which is not transmitted by a smoke-containing path, in percent (opacity=[1 - transmittance] x 100).

3.12 Opacimeter—An optical instrument designed to measure the opacity of diesel exhaust. Also called a smokemeter. Smokemeters of this type are described in SAE J35.

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

3.14 Span—The distance between zero and a known upscale set point.

3.15 Resolution—The minimum distinguishable reading increment for a given recorded trace or scale combination, expressed as a percent of the recording system's full scale.

3.16 13 Mode—A gaseous emissions cycle described in Code of Federal Regulations, Title 40, Chapter I, Part 85—Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines.

4. Abbreviations

A.P.I.- American Petroleum Institute
ASTM- American Society for Testing and Materials
bhp (kW)- Brake Horsepower (kilowatts)
BSHC- Brake Specific Hydrocarbons
$BSNO_x$- Brake Specific Nitrogen Oxides
BSCO- Brake Specific Carbon Monoxide
Bdt (Bar_t)- Dry Barometric Pressure, Pa (in Hg)
°C- Degrees Celsius
Chemi- Chemiluminescent
CO- Carbon Monoxide
Conc- Concentration
Corr- Humidity Correction Factor
dB- Decibels
DB- Dry Bulb Temperature
DIR- Dispersive Infra Red
DUV- Dispersive Ultra Violet
EP- End Point
exh- Exhaust
°F- Degrees Fahrenheit
FID- Flame Ionization Detector
FR- Federal Register
ft- Feet
g- Grams
H- Humidity (grains of water per pound of dry air)
HC- Hydrocarbons
Hg- Mercury
hp- Horsepower
h- Hour
Hz- Hertz
H_2O- Water
IBP- Initial Boiling Point
in- Inch(es)
IR- Intake Restriction, kPa (in H_2O)
IR_{max}- Manufacturer's maximum recommended Intake Restriction, kPa (in H_2O)

kPa- Kilopascal
kW (hp)- Kilowatts (horsepower)
max- Maximum
min- Minimum
m (ft)- Meter (feet)
mm (in)- millimeter (inch)
N (lb)- Newton (pound)
NDIR- Non-Dispersive Infra Red
NDUV- Non-Dispersive Ultra Violet
NO- Nitric Oxide
NO_x- Oxides of Nitrogen
obs- Observed
Pa- Pascal
ppm- Parts per million (volume)
rpm- Revolutions per minute
s- Seconds
T Nm (lb-ft)- Torque
WB- Web Bulb Temperature
WF- Weighing Factors
%- Percent
Σ- Summation

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

2. References
2.1. Applicable Documents
3. Definitions
4. Abbreviations
6. Smoke Emission Test Method
7. Smoke Emission Test Cycle
8. Smoke Measuring Equipment and Instrumentation
9. Smoke Measuring System Calibration
10. Smoke Emission Data Analysis
11. Correlation of Smoke Measurements
12. Gaseous Emission Test Method
13. Gaseous Emission Test Cycles
14. Gaseous Emission Measuring Equipment and Instrumentation
15. Gaseous Emission Measuring System Calibration
16. Gaseous Emission Data Analysis
17. Selection of N-Mode Short Cycle
18. Correlation of Gaseous Emission Measurements

6. *Smoke Emission Test Method*

6.1 Before commencing the test cycle, the engine is to have met the manufacturer's production test specifications and is to be operated at full load power for at least 1 min with coolant and oil temperatures stabilized at the recommended operating temperatures.

6.2 Intake air temperature should be controlled between 20 and 30 °C (68 and 86 °F). Higher air temperatures may be used if desired, but no allowance shall be made for possible increased smoke emissions because of such conditions. (See Appendix A.)

6.3 Fuel Specifications

6.3.1 The diesel fuels employed shall be clean and bright with pour and cloud point adequate for operability. The fuels may contain nonmetallic additives as follows: cetane improvers, metal deactivators, anti-oxidants, dehazer, antirust, pour depressant, dye, and dispersant.

6.3.2 Fuel meeting the following specifications or substantially equivalent shall be used in quality audit testing for exhaust emissions from diesel engines. The grade of fuel recommended by the engine manufacturer for the specific model shall be used for testing, commercially designated as ASTM D 975 Type 1 or Type 2. Table 1 is the ASTM D 975 specification for Type 2 fuel. This fuel shall be satisfactory for most audit testing.

TABLE 1—ASTM D 975 SPECIFICATIONS FOR TYPE 2 FUEL

Item	ASTM Test Method No.	Type 2-D
Cetane No.	D 613	40 min
Distillation Range	D 86	293–332
90% point, °C		
Gravity °API	D 287	—
Total Sulfur, %	D 129 or D 2622	0.1 max
Flash Point, °C	D 93	54 min
Viscosity, centistokes	D 445	2.0–4.3

6.3.3 In cases where the manufacturer believes the emission rate of the engine family is significantly influenced by fuel characteristics, Table 2 shows typical Type 2-D fuel blending guidelines which can be used to specify fuel for exhaust emission testing.

TABLE 2—TYPICAL TYPE 2-D FUEL BLENDING GUIDELINES

Item	ASTM Test Method No.	Type 2-D
Cetane No.	D 613	40–48
Distillation Range	D 86	
IBF °C		171–204
10% point, °C		204–238
50% point, °C		243–282
90% point, °C		293–332
EP °C		321–366
Gravity °API	D 1298	32–37
Total Sulfur Mass %	D 129 or D 2622 or D 4294	0.03–0.05
Aromatics Vol. %	D 1319	28–35
Flash Point, °C	D 93	54 min
Viscosity at 40 °C, cSt	D 445	2.5–3.1
Cloud Point, °C, Max	D 2500	+32

6.4 An exhaust back pressure of 6.75 kPa ± 3.4 kPa (2 in Hg ± 1 in Hg) should be maintained at full load rated speed. A higher back pressure may be maintained; however, no allowances for any increase in emissions shall be applied to the data.

6.5 With the engine operating at full load power, rated speed, the intake restriction is to be adjusted to the required value per Equation 1 to provide compensation for barometric and vapor pressure changes:

(Eq. 1)

$$IR = 3.38\left(B_{dt} - 29.00 + \frac{IR\ max}{13.6}\right) \text{ in kPa of water}$$

$$IR = 13.6\left(B_{dt} - 29.00 + \frac{IR\ max}{13.6}\right) \text{ in inches of water}$$

NOTE—Should IR calculate to be a negative number, then the following options are available.

6.5.1 Pressurize the intake (combustion) air system.

6.5.2 Delay testing until sufficiently high barometric pressure prevails.

6.5.3 Proceed with test, but recognize that the effect will normally be to read higher or lower values than would be the case where full compliance with this section is possible.

6.6 Span smokemeter circuit to establish zero and 100% opacity values. (Allow for the meter circuit to stabilize per manufacturer's instructions.)

6.7 Operate the engine in the manner required by the Smoke Emission Test Cycle as described in Section 7.

7. Smoke Emission Test Cycle—Conduct each smoke emission test specified in Section 6 according to the following sequence. (See Appendix B for typical smoke test cycle trace.)

7.1 Lugdown Mode—When test conditions (Section 6) are fulfilled, and with the engine operating at full load power and rated speed, energize the data processing equipment and gradually change the dynamometer load to reduce engine speed from rated speed to intermediate speed within 20 to 40 s. Deceleration during this lugdown mode to be linear within ± 100 rpm.

7.2 Transitional Mode—If desired, de-energize data processing equipment after engine reaches intermediate speed.

7.2.1 Remove the load from the engine and close the fuel control lever.

7.2.2 Set preload on dynamometer as required to perform the acceleration called for in 7.3.3.

7.2.3 Time interval between closing of fuel control lever after lugdown mode and opening of fuel control lever (7.3.2) for start of acceleration mode is 30 to 90 s.

7.3 Acceleration Mode

7.3.1 Energize the data processing equipment, if needed. However, data from the first cycle will not be used for data analysis or correlation.

7.3.2 Open the fuel control lever gradually to cause the engine to accelerate smoothly from idle speed to 200 rpm ± 50 rpm above the manufacturer's recommended idle speed in 3 to 5 s, then snap the fuel control lever full open to cause the engine to accelerate against the dynamometer inertia and load (as required).

7.3.3 The acceleration rate must be controlled by load and/or inertia adjustment to ensure that the engine accelerates from 200 rpm ± 50 rpm above the manufacturer's recommended low idle speed through 85% (see note) of rated speed in 3.5 to 6.5 s, with this acceleration being linear within ± 100 rpm.

NOTE—For reasons of simplicity and ease of operation, it is allowable that 85% of rated speed be rounded off to the nearest 100 rpm; examples, for 2100 rpm rated speed, use 1800 rpm; for 1800 rpm rated speed, use 1500 rpm, and so forth.

7.4 Transitional Mode—After the acceleration mode has been completed and the engine reaches its maximum speed (the maximum speed obtained will be greater than 85% of rated speed, with exact value a function of preload applied and engine power).

7.4.1 Start closing the fuel control lever between 85 and 90% of rated speed. The fuel control lever must reach the idle speed position within 1 s.

7.4.2 Remove the dynamometer load, if any.

7.4.3 Apply the preset load or loads to perform the acceleration called for in 7.5. Allow the engine speed to drop to the intermediate speed ± 100 rpm.

7.5 Acceleration Mode—Rapidly move the fuel control lever to the full open position and accelerate the engine against a dynamometer load schedule such that engine speed reaches 95 to 100% of rated speed in 8 to 12 s.

7.6 Repeat 7.1 to 7.5 to obtain data for analysis. Additional cycles may be performed at the option of the manufacturer, if there is any question as to cycle to cycle variation. Sections of previous cycle may be omitted if they are not needed for correlation under Section 11.

8. Smoke Measuring Equipment and Instrumentation—The following equipment and instrumentation is required to conduct the smoke emission test:

8.1 An engine dynamometer with adequate characteristics to perform the tests required by the test method.

8.2 An intake system of proper diameter and suitable length for the engine being tested, with provisions for adjusting restriction to enable compliance with 6.5.

8.3 An exhaust system of the proper diameter and suitable length for the engine being tested with provision for mounting the smoke opacimeter. (See Appendix C, Appendix D, and Appendix E.) The system must be adequate to impose a back pressure within the limits specified under 6.4.

A muffler or collector system may be used if it does not raise the back pressure limits beyond those specified in 6.4.

[Editor's Note—Section 8.4 and Section 8.5 contain specifications for the smokemeter and data recording instrumentation. These specifications were established to support the specific engine smoke test cycle described in this document. These specifications should not be taken out of context and applied to other engine smoke test procedures which exercise the engine in significantly different manner, unless testing has demonstrated their applicability.]

8.4 A full flow light extinction opacimeter meeting the recommended requirements of 8.4.1 is to be mounted in the exhaust system. SAE J35 contains methods for running engine tests and guidelines for the correlation of readings between opacimeters.

8.4.1 The smoke opacimeter must be of the continuous reading full flow type with the following minimum recommended performance characteristics. (See Appendix F.)

8.4.1.1 Calibration accuracy ± 1%.

8.4.1.2 Linearity ±1% (from 0 to 50% opacity).

8.4.1.3 Drift ±1% within the temperature range specified by the manufacturer.

8.4.1.4 Response time 0.140 s max for a change from 0 to 95% of full scale.

8.4.1.5 Range 0 to 100% opacity.

8.5 Smoke opacity and engine speed are to be monitored continually using either a strip chart recorder or other data collection/processing equipment that is calibrated to provide the following minimum performance requirements:

8.5.1 Minimum speed range of 13 to 508 mm/min (0.5 to 20.0 in/min).

8.5.2 Maximum full-scale response time for smoke opacity of 0.5 s.

8.5.3 An automatic marker indicating 1.0 s intervals to verify chart speed is desirable.

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

8.5.4.1 The smoke opacity trace is to be linear when calibrated or corrected to read from 0 to 50% opacity. The trace should have a resolution within 1% of full-scale running.

8.5.4.2 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 30 rpm of rated engine speed.

8.5.4.3 The chart speed used to record smoke opacity during the lugdown and acceleration modes must provide a time resolution of 0.50 s.

8.5.5 The use of general instrumentation for measuring engine speed, power, inlet air restriction, exhaust back pressure, inlet air temperature and humidity, barometric pressure, pressure, and temperature measurements while performing tests required in this subpart should be of sufficient accuracy to ensure that the smoke test results are not affected by these components (SAE J1349, defines instrument accuracy).

8.5.6 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.

8.5.6.1 Three decibels point—10 Hz.

8.5.6.2 Insertion loss—0 dB ± 0.5 dB.

8.5.6.3 Selectivity—12 dB per octave above 10 Hz.

8.5.6.4 Attenuation—27 dB down at 40 Hz min.

9. Smoke Measuring System Calibration

9.1 The 0 and 100% settings of the output from the data processing equipment should be verified at the beginning and conclusion of each complete cycle. A span or zero shift of the smokemeter output up to 2% opacity between readings is acceptable, but greater shifts in output than this require correction and rerunning of the test. (If the shift in output of less than 2% is known to be linear with time, the output may be corrected.)

9.2 Periodic or as required checks for linearity between 0 and 100% opacity should be conducted using calibrated neutral density filters at specified opacity levels. Any deviation in excess of 1% opacity should be corrected in the range from 0 to 50% opacity. (See Appendix G and Appendix H.)

9.3 If an alternative data processing system per 8.5 is utilized, periodic checks for correlation with a conventional strip chart recorder should be made as experience seems necessary to ensure and record the accuracy of the entire system.

10. Smoke Emission Data Analysis—The following procedure is for use with data recorded by a strip chart recorder or equivalent. It is permissible to utilize an integrating recorder or data processing equipment that can be demonstrated to yield equivalent results.

10.1 Locate the start of the lugdown mode (7.1) on the speed trace. The lugdown mode starts when the engine speed is 50 rpm below rated speed and ends when the engine speed is at the intermediate speed. Divide the lugdown mode into 0.5 s intervals and determine the average smoke reading during each 0.5 s intervals.

10.1.1 Locate and record the five highest 0.5 s intervals during the lugdown mode. The average of these five readings is the lugdown smoke value.

10.2 Locate the start of the second acceleration cycle (7.3) on the speed trace. The first acceleration mode starts when the engine speed is raised above the idle speed (7.3.2). Divide the acceleration modes (7.3 and 7.5) into 0.5 s intervals and determine the average smoke reading during each 0.5 s interval.

10.2.1 Locate and record the fifteen highest 0.5 s intervals during the acceleration modes. The average of these fifteen readings is the acceleration smoke value. (An alternate number of intervals may be used for correlation with the Federal Procedure, see Section 11.)

10.2.2 If a third acceleration cycle (7.5) was run, repeat 10.2 and 10.2.1 for the third acceleration mode. The average of the acceleration smoke values for the two cycles is the acceleration smoke value.

10.3 Re-examine the 0.5 s intervals of 10.1 and 10.2. The average of the three highest 0.5 s intervals represents the peak smoke value.

11. Correlation of Smoke Measurements—The successful application of this procedure implies confidence that values obtained will correlate well with results obtained from the Federal Test Procedure using the prescribed smokemeter. In order to achieve such a confidence level, it is necessary that the manufacturer conduct such tests as may be required, with freedom to apply correction factors as needed to obtain good correlation. Specific recommendations in this regard are as follows:

11.1 The number of 0.5 s intervals analyzed under 7.2 of this procedure may be modified to assist in acceptable correlation depending upon the particular manufacturer's needs.

11.2 Correction for stack size difference and spectral response difference between equipment used in this procedure and in the method prescribed by the United States Government for certification purposes must be determined by the manufacturers. SAE J35 contains methods under Section 10 for correlation tests.

11.3 The use of regression analysis, based upon test data, is recommended for establishing satisfactory correlation between the manufacturer's smoke emission test procedure and the Federal Smoke Test Procedure.

11.4 Correlation of Smoke Cycle Opacity Measurements

11.4.1 Back-to-back short cycle and Federal test results (on the same engine) should agree within:

a. ±2.0% opacity a smoke (acceleration)
b. ±1.5% opacity b smoke (lug)
c. ±5.0% opacity c smoke (peak)

A correction factor between the two types of tests may be applied to the data prior to correlation calculations.

11.4.2 Acceptable short cycle schedules will have correlation coefficients of 0.9 or better. If the average emission level of the population with 90% confidence lies three standard deviations below the applicable standard, a correlation coefficient of 0.75 or greater is acceptable.

11.4.3 Acceptable short cycle schedules will identify deviant engines as well as nominal engines.

12. Gaseous Emission Test Method

12.1 Before commencing the test cycle, the engine is to have met the manufacturer's production test specifications. All test instruments shall be warmed up and readied (per manufacturer's recommendations) including, but not limited to:

a. Zero checks
b. Span checks on all ranges scheduled
c. Flow checks/pressure checks for zero, span, and sample gases

12.2 Intake air temperature between 20 and 30 °C (68 and 86 °F) is recommended. Higher air temperatures may be used. (Refer to 16.5.)

12.3 The fuel specifications of 6.3 apply.

12.4 The exhaust back-pressure requirements of 6.4 apply.

12.5 The intake air restriction requirements of 6.5 apply.

12.6 Span the instruments. With the engine warmed up and all the test equipment readied and at the proper operating temperatures, zero and span the instruments. The span gas(es) should be selected in accordance with the manufacturer's recommendations and the full scale value of the instrument range(s) to be utilized. Full scale values shall be selected so that the expected emission values shall fall in the 15 to 100% range of the instruments. The analyzer's response may be less than 15% of full scale if:

a. The full scale value is 155 ppm or less.
b. The full scale value is 5500 ppm or less for CO analysis.
c. The emissions from the engine are erratic and the average chart-deflection value is greater than 15% of full scale.
d. The contribution of all modes read below the 15% level is less than 10% by mass of the final test results. In no case shall expected values exceed 100% full scale.
e. Additional calibration values have been obtained to help define the lower portion of the calibration curve. At least 4 non-zero, nominally equally spaced, calibration points below 15% of full-scale range should be utilized.

12.7 Operate the engine in accordance with either the 13-Mode emissions cycle (Section 13) and/or the manufacturer's short cycle emissions schedule (Section 13).

13. Gaseous Emissions Test Cycles

13.1 The gaseous emissions test cycle shall consist of 1 to 13 steady-state modes of engine operation run at various revolutions per minute and percents of full load torque.

13.2 The 13-Mode cycle shall be run to the schedules in Table 3:

TABLE 3—13-MODE CYCLE SCHEDULE

Mode Number	Engine Speed ± 50 rpm	Percent Load ± 2%
1	Idle Speed	0 (Residual Load Only)
2	Intermediate Speed	2.0
3	Intermediate Speed	25.0
4	Intermediate Speed	50.0
5	Intermediate Speed	75.0
6	Intermediate Speed	100.0
7	Idle Speed	0 (Residual Load Only)
8	Rated Speed	100.0
9	Rated Speed	75.0
10	Rated Speed	50.0
11	Rated Speed	25.0
12	Rated Speed	2.0
13	Idle Speed	0 (Residual Load Only)

13.3 The N-Mode, short cycle test shall consist of those modes (selected from the 13-Mode schedule) that enables an estimation of 13-Mode test values in accordance with the limits specified in Section 18.

13.4 Time of Test

13.4.1 The engine stabilization time in each mode shall be 2 to 10 min. The sampling time for the gaseous emissions shall be recorded for a minimum of 30 s near the end of each mode.

13.4.2 Mode 1, mode 7, and mode 8 (if preceded by mode 7) shall have a minimum duration of 5 min.

14. Gaseous Emissions Measuring Equipment and Instrumentation—The following equipment and instrumentation is required to conduct the gaseous emission test:

14.1 An engine dynamometer with adequate characteristics to perform the tests required by the test method.

14.2 An air intake system of proper diameter and suitable length for the engine being tested, with provisions for adjusting restriction to enable compliance with 6.5.

14.3 An exhaust system of the proper diameter and suitable length for the engine being tested. The system must be adequate to impose a back-pressure within the limits specified under 6.4.

14.4 An instrument for the continuous measurement of the hydrocarbon concentration in diesel exhaust.

14.4.1 The instrument(s) should meet those specifications presented in SAE J215.

14.4.2 Alternate instruments may be used if correlation is available with those instruments already recognized as meeting the proper specifications.

14.5 Instrument(s) for the continuous measurement of carbon monoxide (CO) and oxides of nitrogen (NO_x) in diesel exhaust.

14.5.1 The instrument(s) should meet those specifications presented in SAE J177.

14.5.2 Alternate instruments may be used if correlation is available with those instruments already recognized as meeting the proper specifications.

14.6 HC, CO, and NO emission values are to be monitored during each mode of an emission test, using either a strip chart recorder or other data collection/processing equipment that is calibrated to provide equivalent results.

The following are minimum performance requirements for a strip chart recorder:

14.6.1 Minimum speed range of 13 to 508 mm/min (0.5 to 20 in/min).

14.6.2 Maximum full-scale response time of 0.5 s.

14.6.3 Accuracy of ±0.25%.

14.6.4 Linearity of 0.1%.

14.7 The use of general instrumentation for measuring engine speed, power, inlet air restriction, exhaust back pressure, inlet air temperature and humidity, barometric pressure, pressure, and temperature measurements while performing tests required in this part should be of sufficient accuracy to ensure that the gaseous emission test results are not affected by these components. (SAE J1349 defines instrument accuracy.)

15. Gaseous Emission Measuring System Calibration

15.1 Check each day for leaks in the sample line connections.

15.2 A zero and span check of the HC, CO, and NO analyzers should be done as often as necessary to ensure that drift is less than ±2%.

15.3 Check the sample gas flow rate during each mode to ensure proper flow.

15.4 Monthly check of analyzers as outlined in SAE J177a and J215, to ensure that the equipment is meeting specifications.

15.5 Monthly check of all equipment related to Section 14 to ensure that the emissions test is not adversely affected by these components.

16. Gaseous Emission Data Analysis

16.1 Locate or record the last 30 s of each mode and determine the average reading for HC, CO, and NO_x.

16.2 Determine the concentration of HC, CO, and NO_x during each mode from the average reading and corresponding calibration data.

16.3 Determine the exhaust gas mass-flow rate for each mode according to SAE J244.

16.4 Convert the measured CO and NO_x concentrations to a wet basis according to Section 4 and 5.4 of SAE J177a.

16.5 Multiply the wet NO_x values by the following humidity correction factor:

(Eq. 2)

$$\frac{1}{1+A(H-75)+B(T-85)}$$

where:

A = 0.044 (F/A) – 0.0038
B = –0.116 (F/A) + 0.0053
H = Humidity (grains of water per pound of dry air)
T = Temperature of air in °F (temperature range of 68 to 115 °F)
F/A = Fuel-Air Ratio (dry air basis)

16.6 Calculate the mass emissions and brake specific emissions according to Section 4 of SAE J1003.

17. Selection of N-Mode Short Cycle

17.1 The N-Mode short cycle should be mode(s) selected from 13-Mode test data for minimum error or prediction of 13-Mode cycle results. Analysis of 13-Mode test data will produce several N-Mode combinations with similar standard deviation of error of prediction values, therefore, the lowest standard deviation criteria should be supplemented with test experience and judgment to enable the final combination to be the best predictor of 13-Mode results in accordance with Section 18. Each engine model in a manufacturer's line should be evaluated individually. As the emission characteristics vary with engine model, it may be found that the best N-Mode cycle for one model may not be the best predictor for another.

17.2 Definitions of N-Mode Short Cycle

17.2.1 PREDICTED 13-MODE CYCLE RESULT—The Predicted 13-Mode Cycle Result is defined as the N-Mode cycle result multiplied by an average scaling factor.

17.2.2 ERROR OF PREDICTION—The Error of Prediction is defined as the 13-Mode cycle result minus the predicted 13-Mode cycle result.

17.2.3 BEST N-MODE SHORT CYCLE—The Best N-Mode Short Cycle is defined as the combination of modes with the smallest standard deviation of the error of prediction, that when multiplied by an average scaling factor produces the most accurate predicted 13-Mode result.

17.3 Analysis of 13-Mode Data

17.3.1 This analysis of 13-Mode data is recommended as a means to determine which combination of N-Modes in the 13-Mode cycle contains the least variation and, therefore, offers the best basis from which to predict. The model data should be reduced to a form such that a number or a pair of numbers represents the contribution of that mode to the 13-Mode emissions sum. A single number should be used if HC + NO_x is to be treated as a sum and two numbers if treated separately. In the case of separate analysis, it is understood that calculations are to be run in parallel. This number will be referred to as Mode X emissions, where X represents the mode under consideration.

17.3.2 It is recommended that analysis be done on at least fifteen 13-Mode tests on the same engine model, and should proceed as follows:

17.3.2.1 For each test, divide the 13-Mode brake specific emissions by the Mode X emissions. The resultant is defined as the scaling factor. Calculate the average scaling factor for each mode for each emission constituent.

17.3.2.2 Multiply each Mode X emissions by the average scaling factor. The resultant is the predicted Mode X emissions.

17.3.2.3 For each 13-Mode test, subtract the predicted Mode X emissions from the 13-Mode emissions result. The resultant is defined as the error of prediction.

17.3.2.4 Calculate the standard deviation of the error of prediction for all 13-Modes for each emission constituent CO, HC, NO_X, HC + NO_X). The mode with the smallest standard deviation for all constituents is defined as the best single mode predictor.

17.3.2.5 Repeat the previous calculations except combine the best single mode predictor with each of the remaining modes to form X + Y Emissions. Calculate the best double mode predictor for each constituent. Repeat for three and four modes, but little improvement is usually seen beyond four.

17.3.2.6 Select and test the N-Mode Short Cycle that most accurately predicts the 13-Mode result for all constituents.

17.4 The results of the 13-Mode analysis should be used to guide development of the N-Mode Short Cycle. To test its accuracy, run a series of 13-Mode and N-Mode Short Cycle tests back-to-back. It may be found that the scaling factor calculated by dividing the 13-Mode test by the N-Mode test may be slightly different from that calculated by the 13-Mode analysis.

18. Correlation of Gaseous Emission Measurements

18.1 Back-to-back Federal and Short Cycle results on the same engine should agree within:

- **a.** ±0.25 g/bhp-h for HC
- **b.** ±0.75 g/bhp-h for NO
- **c.** ±0.8 g/bhp-h for HC + NO_X
- **d.** ±0.3 g/bhp-h for CO

A correction factor between the two types of tests may be applied to the data prior to the back-to-back calculations.

18.2 Acceptable short cycle schedules will have correlation coefficients (Modern Elementary Statistics, Freund, John E.) of 0.9 or better. If the average emission level of the population with 90% confidence lies three standard deviations below the applicable standard, a correlation coefficient of 0.75 or better is acceptable.

The correlation coefficient (r) is equal to:

(Eq. 3)

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\left[n(\Sigma x^2) - (\Sigma x)^2\right]^{1/2}\left[n(\Sigma y^2) - (\Sigma y)^2\right]^{1/2}}$$

where:

x = 13-Mode cycle result in g/bhp-h
y = Predicted 13-Mode result from N-Mode short cycle in g/bhp-h
n = Sample size of 16 (15 tests, plus 0, 0 to direct linear regression through origin)

(Eq. 4)

$$\Sigma_{xy} = \sum_{i=i}^{16} x_i y_i$$

$$\Sigma_x = \sum_{i=1}^{16} x_i$$

$$\Sigma_y = \sum_{i=1}^{16} y_i$$

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APPENDIX A

A.1 Retesting—Upon completion of the prescribed test(s), the test results should provide data for accept or reject decision. Under certain conditions, a retest of a rejected sample may be permitted. These conditions are:

a. Inlet air temperature higher than specified
b. Fuel does not meet specifications
c. Exhaust back pressure greater than specified
d. Inlet air restriction greater than specified
e. Barometric pressure abnormally low
f. Abnormal emissions level
g. After engine repairs or adjustments

APPENDIX B

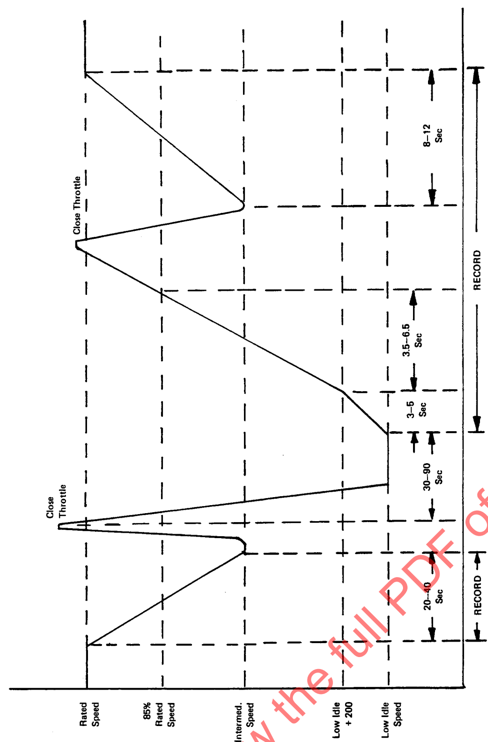

FIGURE B1—SMOKE TEST CYCLE

APPENDIX C

C.1 Smoke Opacimeter Installation—End of Line—The smoke opacimeter installation should be as follows:

C.1.1 The engine exhaust system shall be of circular cross section and be free of elbows and bends in the terminal 610 mm (2 ft). The end of the exhaust pipe shall be cut off square and have a diameter in accordance with the engine being tested, as specified in Table C1:

TABLE C1—EXHAUST TAILPIPE SIZE

Maximum Rated Kilowatts (hp)	Exhaust Pipe Size
Less than 75 (101)	51 mm (2 in)
75–149 (101–200)	76 mm (3 in)
150–224 (201–300)	102 mm (4 in)
225 (301) to more	127 mm (5 in)

C.1.2 The opacimeter optical unit may be mounted on a fixed or movable frame. The normal unrestricted shape of the exhaust plume shall not be modified by the adapter, the meter, or any ventilation system used to remove the exhaust from the test site.

C.1.3 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.

C.1.4 The opacimeter should be located at the termination of the exhaust stack with the light beam of the opacimeter 127 mm ± 25 mm (5 in ± 1 in) from the stack termination point.

C.1.5 The full flow of the exhaust stream shall be centered between the source and detector apertures and on the axis of the light beam.

C.1.6 In the case of multiple exhaust outlets, such as dual exhaust systems, the tailpipe size selection must still be based upon the full rated power of the engine, as shown in Table C1.

APPENDIX D

D.1 Smoke Opacimeter Installation—Inline Type—The smoke opacimeter may be installed as follows:

D.1.1 The sensor may be installed in any position in the exhaust system and should be located 4.5 m ± 3 m (15 ft ± 10 ft) from the engine.

D.1.2 Exhaust gas temperatures and ambient temperatures should not exceed manufacturer's specifications.

D.1.3 Temperature of cooling water (if used) for stabilization of the electronics should be as per manufacturer's recommendations.

D.1.4 Opacimeter to be installed with a minimum of two pipe diameters straight section upstream from the meter.

D.1.5 Inlet pipe to opacimeter to be same inside diameter as opacimeter for a minimum length of two pipe diameters.

D.1.6 Provide a source of clean dry laboratory air at the opacimeter which is free of dust and oil and at the pressure of flow rate scheduled by the manufacturer of the opacimeter.

D.1.7 The exhaust system must be capable of being adjusted to meet the exhaust back pressure required for the smoke test. A butterfly valve or other means of increasing the exhaust system back pressure may be placed on the exhaust pipe but at least the 3 diameters from the opacimeter.

APPENDIX E

E.1 Dual Exhaust Systems—If dual exhaust systems are used for production testing of Vee engines:

E.1.1 Exhaust stack diameter shall be determined as in Appendix C.

E.1.2 Smoke levels should be measured from both exhaust systems. If this is not practical, place the opacimeter on the exhaust system expected to produce the highest smoke levels.