State of California
AIR RESOURCES BOARD

CALIFORNIA SMOKE TEST PROCEDURES FOR NEW 1996-1999 ~~AND LATER~~ HEAVY-DUTY OFF-ROAD DIESEL CYCLE ENGINES

PART III

Adopted: May 12, 1993
Amended: (date of amendment)

NOTE: The general provisions herein have been adapted and modified from similar provisions set forth in 40 CFR, Part 86, Subpart I - Emission Regulations for New Diesel-Fueled Heavy-Duty Engines; Smoke Exhaust Test Procedure.

This document is printed in a style to indicate changes from the existing provisions. All existing language is indicated by plain type. All additions to language are indicated by underline. All deletions to language are indicated by ~~strikeout~~.

If there is any conflict between the provisions of this document and the California Health and Safety Code, Division 26, or Title 13 of the California Code of Regulations, the Health and Safety Code and Title 13 apply.

TABLE OF CONTENTS

Section Page

California Smoke Test Procedures For New 1996-1999 ~~and Later~~ Heavy-Duty Off-Road Diesel Cycle Engines

1. General applicability.

These procedures are applicable to new heavy-duty off-road diesel-fueled and alternate-fueled diesel cycle engines beginning with the 1996 model year through the 1999 model year.

2. Definitions.

The definitions in the ~~California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines~~ 1996-1999 Heavy-Duty Test Procedures apply.

3. Abbreviations.

The abbreviations in the ~~California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines~~ 1996-1999 Heavy-Duty Test Procedures apply.

4. [Reserved].

5. Test procedures.

The procedures described in this and subsequent sections shall be the test program to determine the conformity of engines with the standards set forth in Section 11(b).

(a) The test consists of a prescribed sequence of engine operating conditions on an engine dynamometer with continuous examination of the exhaust gases. The test is applicable equally to controlled engines equipped with means for preventing, controlling, or eliminating smoke emissions and to uncontrolled engines.

(b) The test is designed to determine the opacity of smoke in exhaust emissions during those engine operating conditions which tend to promote smoke.

(c) The test procedure begins with a preconditioned engine which is then run through preloading and preconditioning operations. After an idling period, the engine is operated through acceleration and lugging modes during which smoke emission measurements are made to compare with the standards. The engine is then returned to the idle condition and the acceleration and lugging modes are repeated. Three consecutive sequences of acceleration and lugging constitutes the full set of operating conditions for smoke emission measurement.

(d) (1) Except in cases of component malfunction or failure, all emission control systems installed on, or incorporated in, a new engine shall be functioning during all procedures in this subpart.

(2) Maintenance to correct component malfunction or failure shall be authorized in accordance with Section 12 of ~~Part I of the California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines~~ the 1996-1999 Heavy-Duty Test Procedures.

6. Fuel Specifications.

The fuel specifications in the ~~California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines~~ 1996-1999 Heavy-Duty Test Procedures apply.

7. Dynamometer operation cycle for smoke emission tests.

(a) The following sequence of operations shall be performed during engine dynamometer testing of smoke emissions, starting with the dynamometer preloading determined and the engine preconditioned (Section 12(c)).

(1) Idle Mode. The engine is caused to idle for 5.0 to 5.5 minutes at the manufacturer's recommended curb idle speed. The dynamometer controls shall be set to provide the speed and load necessary to comply with the heavy-duty "curb idle" definition given in the California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines, in accordance with predominant engine application.

(2) Acceleration mode.

(i) The throttle shall be moved to cause the engine speed to increase to 200 ± 50 rpm above the measured free idle speed of the engine. The throttle shall then be moved rapidly to and held in the fully open position. The modal time duration between the point where the engine speed first begins to increase above idle speed to the point where the throttle reaches the fully open position shall be three (3) seconds, or less. The engine speed at any point during this mode shall not exceed 250 rpm above the measured free idle speed of the engine.

(ii) Upon completion of the previous mode, the inertia of the engine and the dynamometer, or a preselected dynamometer load, shall be used to control the acceleration of the engine so that the engine speed increases to 85 percent of the rated engine speed in 5 ± 1.5 seconds. This acceleration shall be linear within 100 rpm as specified in Section 13(c).

(iii) After the engine reaches the speed required in paragraph (a)(2)(ii) of this section the throttle shall be moved rapidly to, and held in, the fully closed position. Immediately after the throttle is closed, the preselected load required to perform the acceleration in paragraph (a)(2)(iv) of this section shall be applied. For electric motoring dynamometer operation in speed mode, the deceleration shall be performed in 2 ± 1.5 seconds.

(iv) When the engine decelerates to the intermediate speed (within 50 rpm), the throttle shall be moved rapidly to, and held in, the fully open position. The preselected dynamometer load which was applied during the preceding transition period shall be used to control the acceleration of the engine so that the speed increases to at least 95 percent of the rated speed in 10 ± 2 seconds.

(v) For electric dynamometer operation in speed mode, motoring assist

may be used to offset excessive dynamometer inertia load when necessary. No negative flywheel torque shall occur during any of the three acceleration modes in paragraph (a)(2) of this section except for a maximum of 10 foot-pounds for the first 0.5 second of the mode.

(3) Lugging mode.

(i) Immediately upon the completion of the preceding acceleration mode, the dynamometer controls shall be adjusted to permit the engine to develop maximum horsepower at rated speed. This transition period shall be 50 to 60 seconds in duration. During the last 10 seconds of this period, the engine speed shall be maintained within 50 rpm of the rated speed, and the power (corrected, if necessary, to rating conditions) shall be no less than 95 percent of the maximum horsepower developed during the preconditioning prior to the smoke cycle.

(ii) With the throttle remaining in the fully open position, the dynamometer controls shall be adjusted gradually so that the engine speed is reduced to the intermediate speed. This lugging operation shall be performed smoothly over a period of 35 ± 5 seconds. The rate of slowing of the engine shall be linear, within 100 rpm, as specified in Section 13(c).

(4) Engine unloading. Within 5 seconds of completing the preceding lugging mode, the dynamometer and engine controls shall be returned to the idle position described in paragraph 7 (a)(1). The engine must be at the curb idle condition within one minute after completion of the lugging mode.

(b) The procedures described in paragraphs (a)(1) through (a)(4) of this section shall be repeated until three consecutive valid cycles have been completed. If three valid cycles have not been completed after a total of six consecutive cycles have been run, the engine shall be preconditioned by operation at a maximum horsepower at rated speed for 10 minutes before the test sequence is repeated.

8. Dynamometer and engine equipment.

The following equipment shall be used for smoke emission testing of engines on engine dynamometers:

(a) An engine dynamometer with adequate characteristics to perform the test cycle described in Section 7.

(b) An engine cooling system having sufficient capacity to maintain the engine at normal operating temperatures during conduct of the prescribed engine tests.

(c) An exhaust system where the smoke meter can be placed 15 ± 5 feet from the engine exhaust outlet according to paragraph 9 (c). The smoke exhaust system shall present an exhaust backpressure within ± 0.2 inches of Hg of the upper limit at maximum rated horsepower, as established by the engine manufacturer in his sales and service literature for vehicle application.

(1) When utilizing an end-of-line smoke meter, the terminal two feet of the exhaust pipe used for smoke measurement shall be of circular cross section and be free of elbows and bends. The exit plane of the pipe where the smoke meter is mounted shall be perpendicular to the exhaust flow. The terminal two feet of the exhaust pipe shall have a nominal inside diameter in accordance with the rated power of the engine, as specified in Table 1.

TABLE 1

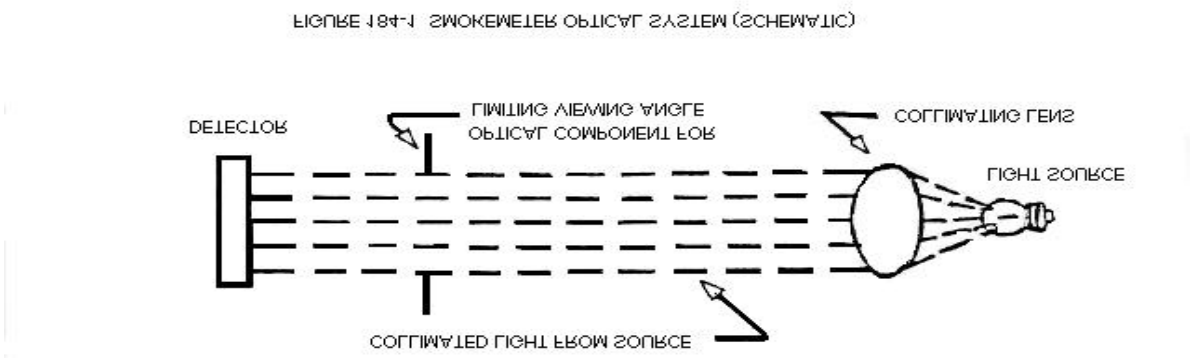
Maximum-Rated Horsepower	Exhaust Pipe Diameter Standard Optical Path Length
Less than 101	2 in 0.0508 m
101 to 200	3 in. 0.0762 m
201 to 300	4 in 0.1016 m
301 to 500	5 in. 0.1270 m
501 or more	6 in. 0.1524 m

(2) When utilizing an inline smoke meter, there shall be no change in the exhaust pipe diameter within 3 exhaust pipe diameters before or after the smoke meter. Within 6 exhaust pipe diameters upstream of the smoke meter, no change in exhaust pipe diameter may exceed a 12 half-angle.

(d) An engine air inlet system presenting an air inlet restriction within one inch of water of the upper limit for the engine operating condition which results in maximum air flow, as established by the engine manufacturer in his sales and service literature, for the engine being tested.

9. Smoke measurement system.

(a) Schematic drawing. The figure 184-1 is a schematic drawing of the optical system of the light extinction meter.



(b) Equipment. The following equipment shall be used in the system.

(1) Adapter - The optical unit of end-of-line smoke meters may be mounted on a fixed or movable frame. The normal unrestricted shape of the exhaust plume shall not be modified by the adaptor, the meter, or any ventilatory system used to remove the exhaust from the

test site.

(2) Smoke meter (light extinction meter) - The smoke meter used must be of the full-flow light obscuration type with continuous measurement and recording capability.

(i) It is positioned in such a manner that the smoke meter light beam traverses the exhaust smoke plume at right angles to the axis of the exhaust flow.

(ii) The smoke meter light source shall be an incandescent lamp with a color temperature in the range of 2800 to 3250 K, or a green light emitting diode (LED) with a spectral peak between 550 - 570 nanometers.

(iii) The light output is collimated to a beam with a minimum diameter of 0.5 inches and a maximum diameter of 1.13 inches. The angle of divergence shall be within a 4 included angle.

(iv) The light detector shall be a photocell or a photodiode. If the light source is an incandescent lamp, the detector shall have a spectral response similar to the photopic curve of the human eye (a maximum response in the range of 550 to 570 nanometers, to less than 4 percent of that maximum response below 430 nanometers and above 680 nanometers).

(v) A collimating tube with apertures equal to the beam diameter is attached to the detector to restrict the viewing angle of the detector to within a 16 included angle.

(vi) An amplified signal corresponding to the amount of light blocked is recorded continuously on a remote recorder.

(vii) An air curtain across the light source and detector window assemblies may be used to minimize deposition of smoke particles on those surfaces provided that it does not measurably affect the opacity of the plume.

(viii) The smoke meter consists of two units: an optical unit and a remote control unit.

(ix) Light extinction meters employing substantially identical measurement principles and producing substantially equivalent results, but which employ other electronic and optical techniques, may be used only after having been approved in advance by the Executive Officer.

(3) Recorder - a continuous recorder, with variable chart speed over a minimal range of 0.5 to 8.0 inches per minute (or equivalent) and an automatic marker indicating 1-second intervals continuously records the exhaust gas opacity, engine rpm and throttle position.

(i) The recorder is equipped to indicate only when the throttle is in the fully open or fully closed position.

(ii) The recorder scale for opacity is linear and calibrated to read from 0 to 100 percent opacity full scale.

(iii) The opacity trace has a resolution within one percent opacity.

(iv) The recorder scale for engine rpm is linear and has a resolution of 30 rpm.

(v) The throttle position trace clearly indicates when the throttle is in the fully open and fully closed positions.

(vi) Any means other than a stripchart recorder may be used provided it produces a permanent visual data record of quality equal to or better than that described above (e.g., tabulated data, traces, or plots).

(4) The recorder used with the smoke meter shall be capable of full-scale deflection in 0.5 second or less. The smoke meter-recorder combination may be damped so that signals with a frequency higher than 10 cycles per second are attenuated. A separate low-pass electronic filter with the following performance characteristics may be installed between the smoke meter and the recorder to achieve the high-frequency attenuation:

(i) Three decibel point - 10 cycles per second.

(ii) Insertion loss - zero ± 0.5 decibel.

(iii) Selectivity - 12 decibels per octave above 10 cycles per second.

(iv) Attenuation - 27 decibels down at 40 cycles per second minimum.

(5) In lieu of the use of chart recorders, automatic data collection equipment may be used to record all required data. Automatic data processing equipment may then be used to perform the data analysis specified in Section 13. The automatic data collection equipment must be capable of sampling at least two records per second.

(c) Smoke Meter Location.

(1) The smoke meter(s) shall be installed in the exhaust system at a location according to the following criteria.

(i) For engines with a single exhaust outlet: Install the smoke meter 15 ± 5 feet downstream from the exhaust manifold or turbocharger outlet.

(ii) For engines with multiple exhaust outlets: Join the exhaust outlets together into a single exhaust system and install the smoke meter 15 ± 5 feet downstream from the junction of the individual exhaust outlets.

OR

(iii) For engines with multiple exhaust outlets: Install a smoke meter in each of the exhaust pipes 15 ± 5 feet downstream from each exhaust manifold or turbocharger outlet.

OR

(iv) For engines with multiple exhaust outlets: Install a smoke meter on the exhaust pipe which produces the highest smoke levels 15 ± 5 feet downstream from the exhaust manifold or turbocharger outlet. The Executive Officer may require smoke measurements from the other exhaust outlets, if deemed appropriate.

(2) Install the smoke meter(s) so that the full flow of the exhaust stream shall be centered between the light source and the detector apertures. The measurement shall be made at right angles to the axis of the exhaust flow.

(3) End-of-line smoke meter(s) shall be installed so that the center of the light beam axis is located 1 ± 0.25 inches from the exhaust pipe outlet.

(4) Power shall be supplied to the control unit of the smoke meter in time to allow at least 15 minutes for stabilization prior to testing.

10. Information.

The following information, as applicable, shall be recorded for each test:

(a) Engine description and specifications. A copy of the information specified in this paragraph must accompany each engine sent to the Executive Officer for compliance testing. If the engine is submitted to the Executive Officer for testing under the California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines, only the information specified therein need accompany the engine. The manufacturer need not record the information specified in this paragraph for each test if the information, with exception of paragraphs (a)(3), (a)(12), and (a)(13) of this section, is included in the manufacturer's application for certification.

(1) Engine-system combination.

(2) Engine identification numbers.

(3) Number of hours of operation accumulated on engine.

(4) Rated maximum horsepower and torque.

(5) Maximum horsepower and torque speeds.

(6) Engine displacement.

(7) Governed speed.

(8) Curb-idle rpm.

(9) Fuel consumption at maximum power and torque.

(10) Maximum air flow.

(11) Maximum and test air inlet restriction.

(12) Exhaust pipe diameter(s).

(13) Maximum exhaust system backpressure.

(b) Test data; general. This information may be recorded at any time between four hours prior to the test and four hours after the test.

(1) Engine-system combination.

(2) Engine identification numbers.

(3) Instrument operator.

(4) Engine operator.

(5) Number of hours of operation accumulated on the engine prior to beginning the warm-up portion of the test.

(6) Calibration date(s) of neutral density filters used to calibrate the smoke meter.

(c) Test data; pre-test.

(1) Date and time of day.

(2) Test number.

(3) Barometric pressure.

(4) [Reserved]

(5) Intake air humidity and temperature:

(i) Humidity-conditioned air supply. Air that has had its absolute humidity altered is considered humidity-conditioned air. For this type of intake air supply, the humidity measurement must be made within the intake air supply system, and after the humidity conditioning has taken place.

(ii) Non-conditioned air supply. Humidity measurements in

non-conditioned intake air supply systems must be in the air stream entering the supply system and within 18 inches of the inlet for supply system. Alternatively, the humidity measurements can be measured within the intake air supply stream.

(iii) Engine intake air temperature measurement must be made within 48 inches of the engine. The measurement location must be made either in the supply system or in the air stream entering the supply system.

(d) Test data; modal.

(1) Observed engine torque and speed during the steady-state test conditions specified in Section 7(a)(3)(i).

(2) On the recorder or automatic data collection equipment: Identify zero traces - calibration traces - idle traces (or printout of the zero and calibration values) - closed-throttle trace - open throttle trace - acceleration and lugdown test traces - start and finish of each test.

11. Instrument Checks.

(a) The smoke meter shall be checked according to the following procedure prior to each test:

(1) [Reserved]

(2) The zero control shall be adjusted under conditions of "no smoke" to give a recorder or data collection equipment response of zero;

(3) Calibrated neutral density filters having approximately 10, 20 and 40 percent opacity shall be employed to check the linearity of the instrument. The filter(s) shall be inserted 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 the recorder response shall be noted. Filters with exposed filtering media should be checked for opacity every six months; all other filters shall be checked every year, using NBS or equivalent reference filters. Deviations in excess of one percent of the nominal opacity shall be corrected.

(b) The instruments for measuring and recording engine rpm, engine torque, air inlet restrictions, exhaust system backpressure, throttle position, etc., which are used in the test prescribed herein, shall be calibrated in accordance with good engineering practice.

12. Test Run.

(a) The temperature of the air supplied to the engine shall be between 68° F and 86° F. The engine fuel inlet shall be 100° F ± 10° F and shall be measured at a point specified by the manufacturer. The observed barometric pressure shall be between 28.5 inches and 31 inches of mercury. Higher air temperature or lower barometric pressure may be used, if desired, but no allowance will be made for possible increased smoke emissions because of such conditions.

(b) The governor and fuel system shall have been adjusted to provide engine performance at the levels in the application for certification required under Section 8 of Part I of the California Exhaust Emission Standards and Test Procedures for New 1996 and Later Heavy-Duty Off-Road Diesel Cycle Engines.

(c) The following steps shall be taken for each test:

(1) Start cooling system;

(2) Warm up the engine.

(i) If the engine is cold, start and operate at free idle for 2 to 3 minutes.

(ii) Operate the engine at approximately 50 percent power at the peak torque speed for 5 to 7 minutes.

(iii) Operate the engine at rated speed and wide open throttle for 25 to 30 minutes.

(iv) **Option.** The engine may be preconditioned by operating at rated speed and maximum horsepower until the oil and water temperatures are stabilized. The temperatures are defined as stabilized if they are maintained within 2 percent of point for 2 minutes. This optional procedure may be substituted for paragraph (c)(2)(iii) of this section.

(v) Unload the engine and operate at the curb idle speed.

(3) Determine by experimentation the dynamometer inertia and dynamometer load required to perform the acceleration in the dynamometer cycle for smoke emission tests (Section 7(a)(2)). In a manner appropriate for the dynamometer and controls being used, arrange to conduct the acceleration mode;

(4) Install smoke meter optical unit and connect it to the recorder/data collection system. Connect the engine rpm and throttle position sensing devices to the recorder/data collection system;

(5) Turn on purge air to the optical unit of the smoke meter, if purge air is used;

(6) Check and record zero and span settings of the smoke meter. (If a recorder is used, a chart speed of approximately one inch per minute shall be used.) The optical unit shall be retracted from its position about the exhaust stream if the engine is left running;

(7) Precondition the engine by operating it for 10 minutes at maximum rated horsepower;

(8) Proceed with the sequence of smoke emission measurement on the engine dynamometer as prescribed in Section 7;

(9) (i) During the test sequence of Section 7 continuously record smoke measurements, engine rpm, and throttle position.

(ii) If a chart recorder is used for data collection, it shall be run at a minimum chart speed of one inch per minute during the idle mode and transitional periods, and eight inches per lugging modes.

(iii) Automatic data collection equipment, if used, shall sample at least two records per second.

(iv) The smoke meter zero and full scale response may be rechecked and reset during the idle mode of each test sequence.

(v) If either zero or full-scale drift is in excess of 2 percent opacity, the smoke meter controls must be readjusted and the test must be repeated;

(10) Turn off engine;

(11) (i) Check zero and reset if necessary.

(ii) Check span response (linearity) of the smoke meter by inserting neutral density filters.

(iii) If either zero drift or the linearity check is in excess of two percent

opacity, the results shall be invalidated.

13. **Data analysis.** .

The following procedure shall be used to analyze the test data:

(a) Locate the modes specified in Section 7(a)(1) through (a)(4) by applying the following starting and ending criteria:

(1) The idle mode specified in Section 7(a)(1) starts when engine preconditioning or the lugging mode of a preceding cycle has been completed and ends when the engine speed is raised above the idle speed.

(2) The acceleration mode specified in Section 7(a)(2)(i) starts when the preceding idle mode has been completed and ends when the throttle is in the fully open position, as indicated by the throttle position trace as specified in Section 7(a)(2)(ii).

(3) The acceleration mode specified in Section 7(a)(2)(ii) starts when the preceding acceleration mode has been completed and ends when the engine speed reaches 85 percent of the rated speed.

(4) The transition period specified in Section 7(a)(2)(iii) starts when the preceding acceleration mode has been completed and ends when the throttle is in the fully open position trace, as specified in Section 7(a)(2)(iv).

(5) The acceleration mode specified in Section 7(a)(2)(iv) starts when the preceding transition period has been completed and ends when the engine speed reaches 95 percent of the rated speed.

(6) The transition period specified in Section 7 (a)(3)(i) starts when the preceding acceleration mode has been completed and ends when the engine speed is 50 rpm below the rated speed and the provisions of Section 7(a)(3)(i) are met.

(7) The lugging mode specified in Section 7(a)(3)(ii) starts when the preceding transition period has been completed and ends when the engine speed is at the intermediate speed.

(b) Determine if the test requirements of Section 7 are met by applying the following modal criteria:

(1) Idle mode as specified in Section 7(a)(1):

(i) Duration: 5 to 5.5 minutes.

(ii) Speed: within specification during the last four minutes of the mode.

(2) Acceleration mode as specified in Section 7(a)(2)(i).

(i) Duration: three seconds or less.

(ii) Speed increase: 200 ± 50 rpm.

(3) Acceleration mode as specified in Section 7(a)(2)(ii);

(i) Linearity: ± 100 rpm as specified in paragraph (c) of this section.

(ii) Duration: 3.5 to 6.5 seconds.

(iii) Throttle position: fully open until speed is at least 85 percent of the rated speed.

(4) Transition period as specified in Section 7(a)(2)(iii):

(i) Throttle position: moved rapidly to, and held in, the fully closed position.

(5) Acceleration mode as specified in Section 7(a)(2)(iv):

(i) Duration: 8 to 12 seconds.

(ii) Throttle position: fully open when speed is at intermediate speed.

(6) Transition period as specified in Section 7(a)(3)(i):

(i) Duration: 50 to 60 seconds.

(ii) Average speed during last 10 seconds within ± 50 rpm of rated speed.

(iii) Average observed power during last 10 seconds: At least 95 percent of the observed horsepower developed during preconditioning mode (paragraph 12(c)).

(7) Lugging mode as specified in Section 7(a)(3)(ii):

(i) Linearity: ± 100 rpm as specified in paragraph (c) of this section.

(ii) Duration: 30 to 40 seconds.

(iii) Speed at end: intermediate speed.

(c) Determine if the linearity requirement of Section 7 were met by means of the following procedure:

(1) For the acceleration mode specified in Section 7(a)(2)(ii), note the maximum deflection of the rpm trace from a straight line drawn between and starting and ending points specified in paragraph (a)(3) of this section.

(2) For the lugging mode specified in Section 7(a)(3)(ii), note the maximum deflection of the rpm trace from a straight line drawn from the starting and ending points specified in paragraph (a)(7) of this section.

(3) The test results will be invalid if any deflection is greater than 100 rpm.

(4) This linearity check may be performed by direct analysis of the recorder traces, or by computer analysis of data collected by automatic data collection equipment.

(d) Analyze the smoke trace by means of the following procedure:

Note: If multiple smoke meters were used for smoke measurements, according to paragraph 9(c)(1)(iii), follow this smoke analysis procedure to analyze the smoke data from each of the smoke meters.

(1) Starting at the beginning of the first acceleration, as defined in paragraph (a)(2) of this section, and stopping at the end of the second acceleration as defined in paragraph (a)(3) of this section, divide the smoke trace into half-second intervals. Similarly, subdivide into half-second intervals the third acceleration mode and the lugging mode as defined by paragraphs (a)(5) and (7) respectively, of this section.

(2) Determine the average smoke reading during each half-second interval.

(3) Locate and record the 15 highest half-second readings during the acceleration mode of each dynamometer cycle.

(4) Locate and record the five highest half-second readings during the lugging mode of each dynamometer cycle.

(5) Examine the average half-second values which were determined in paragraphs (d)(3) and (d)(4) of this section and record the three highest values for each dynamometer cycle.

(6) This smoke trace analysis may be performed by direct analysis of the recorder traces, or by computer analysis of data collected by automatic data collection equipment.

14. Calculations.

(a) If the measured half-second opacity values were obtained with a smoke meter(s) with an optical path length different than shown in table 1 for the corresponding rated power of the engine, the measured half-second values for all modes and dynamometer cycles shall be converted to equivalent standard opacity values of the proper optical path length. Convert the as measured opacity values to standard opacity values by using either equations 1 and 2, or by using equation 3, below.

$$K_m = (-1/L_m) * \ln[1 - (N_m /100)] \qquad \text{(equation 1)}$$

$$N_s = (1 - e^{-Km*Ls}) * 100 \qquad \text{(equation 2)}$$

OR

$$N_s = 100 * (1 - \{1 - [N_m /100]\}^{(Ls/Lm)}) \qquad \text{(equation 3)}$$

Where:

N_m = Measured half-second value to be converted, in percent opacity;

L_m = Measuring smoke meter optical path length, in meters;

L_s = Standard optical path length corresponding to engine power, in meters (see table 1);

K_m = Calculated light extinction coefficient value (K in per meter basis);

N_s = Standard half-second value equivalent to standard tailpipe size, in percent opacity.

Note: With equations 1 and 2, L_m and L_s must be in meters. With equation 3, it is only necessary that L_m and L_s be in the same units.

(b) Average the 45 readings in Section 13(d)(3), or the equivalent converted values from 14(a) above, whichever case is applicable, and designate the value as "A". This is the value for the engine acceleration mode.

(c) Average the 15 readings in Section 13(d)(4), or the equivalent converted values from 14(a) above, whichever case is applicable, and designate the value as "B". This is the value for the engine lugging mode.

(d) Average the 9 readings in Section 13(d)(5), or the equivalent converted values from 14(a) above, whichever case is applicable, and designate the value as "C". This is the value for

the engine peaks in either mode.

Note: If multiple smoke meters were used according to paragraph 9(c)(1)(iii), the half-second values for each mode from each smoke meter shall be combined and the calculated average based upon the total number combined values.

For example, if two smoke meters were used, for acceleration mode data, 45 half-second values in each data set from each smoke meter (and if necessary converted to standard optical path lengths) would be combined to form a data set of 90 values, and then averaged.