CHAPTER 169. DIESEL SMOKE MEASUREMENT PROCEDURE

Sec.

Authority

The provisions of this Chapter 169 issued under the Vehicle Code, 75 Pa.C.S. §§ 4103 and 4532(a), unless otherwise noted.

Source

The provisions of this Chapter 169 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432, unless otherwise noted.

§ 169.1. Purpose.

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

Source

The provisions of this § 169.1 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

§ 169.2. Scope.

(a) This chapter applies to the dynamometer test procedure which can be used to assess the smoke emission characteristics of vehicular diesel engines. In particular, these procedures describe the smoke emissions test, smoke test cycle, equipment and instrumentation, instrument checks and chart reading and calculation, for evaluation of the steady-state and transient smoke emission characteristics of an engine.

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

(c) Additional or modified test conditions may be requested when this chapter is cited in a request for a smoke assessment. These modified test conditions

should be clearly stated whenever the results of the smoke assessments are reported. Similarly if the fuel is specified in the test request, this should be stated when the results are reported.

Source

The provisions of this § 169.2 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

§ 169.3. Definitions.

The following words and terms, when used in this chapter, have the following meanings, unless the context clearly indicates otherwise:

Diesel smoke—Particles, including aerosols, suspended in the engine's gaseous exhaust stream of the engine which obscure, reflect or refract light.

Full load power—The power produced, at the speed being considered, when the throttle lever is placed in the maximum fuel position.

Idle speed—The low idle speed of the engine as specified by the manufacturer.

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

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)].

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

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

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

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

Smoke opacimeter—An optical instrument designed to measure the opacity of diesel exhaust gases. The full flow of exhaust gases passes through the optical unit. A smoke opacimeter is described in SAE J255.

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

Vehicular diesel engine—A compression ignition internal combustion engine of less than 1000 horsepower, 745,700 watts, used to propel on land, nonrail, mobile equipment.

Source

The provisions of this § 169.3 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

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§ 169.4. Smoke emission test.

The following sequence of operations shall be performed during engine dynamometer testing for smoke emissions:

(1) Control the temperature of the air supplied to the engine to between 80° and 90°F (27° and 32°C). Test only when the observed barometric pressure is between 28.5 and 30.5 inches (724 and 725 millimeters) of mercury in the test area. Starting with an engine at operating temperature, operate the engine at the condition of maximum mass fuel flow, adjust the intake air restriction to within 1 inch (25.4 millimeters) of water of the maximum recommended by the manufacturer and adjust the exhaust system back pressure to within .2 inch (5.1 millimeters) of mercury of the maximum recommended by the manufacturer. Measure and record maximum observed power, fuel rate, engine speed, intake air temperature, intake air restriction and exhaust back pressure.

(2) Operate the engine at the intermediate speed. Measure and record maximum observed torque, fuel rate, engine speed, intake air temperature, intake air restriction and exhaust back pressure. Determine by experiment, if not previously determined, the preset loads required by the provisions of § 169.5 (relating to smoke test cycle).

(3) Switch on the smoke opacimeter. Allow for the meter circuit to stabilize according to the instruction of the manufacturer. Check the linearity of the meter according to the provisions of § 169.8 (a)(1) and (3) (relating to instrument checks). Mount the smoke opacimeter in accordance with the provisions of § 169.7(b) (relating to equipment and instrumentation) so that the natural flow of the exhaust stream is not disturbed by the meter, the mounting fixture or a ventilation system.

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

(5) Operate the engine at maximum power for 10 minutes or until the engine coolant, oil pressures and temperatures are stabilized.

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

(7) Operate the engine in the manner required by the provisions of § 169.5. Continuously record smoke opacity and engine speed on a strip chart recorder or other appropriate instrument. The chart speed shall be at least 1 inch (25 millimeters) per minute during the idle mode and at least 15 inches (381 millimeters) per minute during acceleration and lugging modes.

(8) Repeat the procedures as contained in the provisions of § 169.5 (a)—(d) until the entire cycle has been run three consecutive times. If the acceleration and lugging modes have been performed within the tolerances specified in the provisions of § 169.5, then the tests may be terminated at this time. If not, then the test procedure shall be rerun until data have been obtained within the specified limits.

(9) Within 1 minute after completion of the requirements of paragraph (8), recheck the calibration of the smoke opacimeter as described in paragraph (6). If either zero or span drift is in excess of 2% opacity, the test results should be considered invalid.

Source

The provisions of this § 169.4 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

Cross References

This section cited in 67 Pa. Code § 169.5 (relating to smoke test cycle); and 67 Pa. Code § 169.7 (relating to equipment and instrumentation).

§ 169.5. Smoke test cycle.

A smoke emissions test specified in the provisions of § 169.4 (relating to smoke emission test) is conducted according to the following sequence:

(1) *Idle mode.* Idle the engine for 1.5 to 2 minutes at the recommended low idle speed of the manufacturer with the dynamometer controls set to provide minimum load by turning the load switch to the ''off'' position or by adjusting the controls to the minimum load position.

(2) *Acceleration mode.* Test procedures shall be as follows:

(i) Accelerate the engine at full throttle against inertia or alternately against a preprogrammed dynamometer load such that the engine speed increases to 85—90% of rated speed in 3.5 to 5.5 seconds. For maximum repeatability on turbocharged engines with more than 1.5 pressure ratio, this should be held to closer limits. The acceleration should be kept linear within plus or minus 100 revolutions per minute.

(ii) When the engine reaches 85—90% of rated speed, rapidly close the throttle and remove the dynamometer load, if any. Apply the preset load required to perform the acceleration in subparagraph (iii). Allow the engine speed to drop to the intermediate speed within plus or minus 100 revolutions per minute.

(iii) Rapidly move the throttle to the full throttle position and accelerate the engine against a dynamometer load schedule such that the engine speed reaches 95—100% of rated speed in 10, plus or minus 2, seconds.

(3) *Rated speed mode.* Test procedures shall be as follows:

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

(ii) Allow the engine to operate for 1 minute after the load and speed have stabilized at full load power at rated speed.

(4) *Lugging mode.* Adjust the dynamometer controls without changing the throttle position to slow the engine gradually to the intermediate speed. Perform this engine lugging operation smoothly over a period of 35, plus or minus

5, seconds. The slowing rate of the engine should be kept linear within plus or minus 100 revolutions per minute.

(5) *Intermediate speed mode.* Allow the engine to operate at full load power at the intermediate speed for one minute after the load and speed have stabilized.

(6) *Engine unloading.* After completion of the lugging and intermediate speed modes, the dynamometer and engine shall be returned to the idle condition described in paragraph (1). The zero and span of the smoke opacimeter may be checked and reset if necessary. If either zero or span drift is in excess of 2%, the test results should be considered invalid.

Source

The provisions of this § 169.5 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

Cross References

This section cited in 67 Pa. Code § 169.4 (relating to smoke emission test); 67 Pa. Code § 169.7 (relating to equipment and instrumentation); and 67 Pa. Code § 169.9 (relating to chart reading—general engine applications).

§ 169.6. Information to be recorded.

The following information shall be recorded in a test log for each smoke emissions test conducted:

(1) *Performance data.* The following information shall be included:

(i) Date, time of day, number of engine hours and observers.

(ii) Barometric pressure and standard dry and wet bulb temperature readings.

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

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

(v) Smoke opacimeter type and identifying number.

(vi) Exhaust pipe diameter.

(vii) Calibrated and observed values of calibration filter.

(viii) Other desired information.

(2) *Records.* The following information shall be recorded on the recorder sheet at the time of each smoke emission test:

(i) Test number.

(ii) Engine model and serial number.

(iii) Engine hours.

(iv) Test date and time.

(v) Smoke opacimeter type and number.

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

(vii) Identify smoke and speed traces.

Source

The provisions of this § 169.6 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

§ 169.7. Equipment and instrumentation.

The following equipment and instruments shall be used for smoke emissions and service simulation tests:

(1) An engine dynamometer with adequate characteristics to perform the tests required by the provisions of § 169.5 (relating to smoke test cycle).

(2) Provide an exhaust system of proper diameter and suitable length for the engine being tested, with provisions for mounting the smoke opacimeter. Test data show that a range of length 4 to 20 feet (1.2 to 6.1 meters) does not change the meter reading. In the case of short exhaust systems, the opacimeter may be affected by the high temperature. The system shall be capable of being adjusted to meet the exhaust back pressure required to comply with the provisions of § 169.4 (relating to smoke emission test). Install a 2 foot (610 millimeters) section of smooth circular pipe, free of elbows and bends, prior to the smoke opacimeter location. If an opacimeter which mounts at the end of the exhaust system is used, the optical unit of the opacimeter shall be mounted radially to the exhaust pipe so that the measurement will be made at right angles to the axis of the exhaust plume. The opacimeter shall be located at the termination of the exhaust stack with the light beam of the opacimeter just clearing the stack termination point. The full flow of the exhaust stream shall be centered between the source and detector apertures, or windows and lenses, and on the axis of the light beam. If a muffler is needed, a conventional automotive muffler of a size and type commonly used with the engine may be installed in this system.

(3) Mount a full-flow, light-extinction, smoke opacimeter in or on the exhaust system at the location specified in paragraph (2). When dual exhaust systems are used, both systems shall be equipped with a smoke opacimeter measuring an exhaust stream of (127 millimeters) diameter or larger.

(4) Smoke opacity and engine speed shall be monitored continuously, using a strip chart recorder or equivalent, with a minimum speed range of .5—15 inches per minute (13—381 millimeters per minute), and a maximum full-scale response time for smoke opacity of .5 second. (Response time for 95% to 100% of full-scale within .5 second). The reading shall stabilize at 100% within 1 second. An automatic marker indicating 1 second intervals to verify chart speed is desirable.

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

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

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

(iii) The chart speed used to record smoke opacity shall provide a time resolution of at least .25 second.

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

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

(i) Three decibels point—10 hertz.

(ii) Insertion loss—zero, plus or minus .5 decibel.

(iii) Selectivity—12 decibels per octave above 10 hertz.

(iii) Attenuation—27 decibels down at 40 hertz minimum.

Source

The provisions of this § 169.7 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

Cross References

This section cited in 67 Pa. Code § 169.4 (relating to smoke emission test).

§ 169.8. Instrument checks.

(a) *Smoke opacimeter.* The smoke opacimeter shall be checked according to the following procedure prior to each test:

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

(2) Adjust the zero control under conditions of ''no smoke'' to give a recorder trace of zero.

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

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

(ii) For maximum correlation of results, the calibration of the neutral density filters should be traceable to the United States National Bureau of Standards.

(b) *Other instruments.* The instruments for measuring engine speed, torque, air inlet restrictions, exhaust system back pressure, fuel rate and so forth, and for

recording engine speed and smoke opacity used in the tests prescribed herein shall be calibrated periodically in accordance with good technical practice.

Source

The provisions of this § 169.8 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

Cross References

This section cited in 67 Pa. Code § 169.4 (relating to smoke emission test).

§ 169.9. Chart reading—general engine applications.

The following procedure shall be used in reading the smoke opacimeter recorder chart:

(1) Locate the start of the acceleration modes tested under the provisions of § 169.5(2)(i) and (iii) (relating to smoke test cycle) and the start of the lugging mode tested under the provisions of § 169.5(3) on the speed trace.

(i) Divide both of the acceleration modes into .5 second intervals beginning at the start of the first acceleration of each test. Determine the average smoke reading during each .5 second interval.

(ii) Locate and record the 15 highest .5 second readings during both acceleration modes of each smoke cycle. Average the 45 readings from the three cycles. Record and designate this value as (a), which shall represent the acceleration smoke characteristic of the engine.

(2) Locate the lugging mode tested under the provisions of § 169.5(4).

(i) Divide the lugging mode into .5 second intervals and determine the average smoke readings during each .5 second interval.

(ii) Locate and record the five highest .5 second intervals during the lugging mode. Average the 15 readings from the three cycles. Record and designate this value as (b), which shall represent the lugdown smoke characteristics of the engine.

(3) Reexamine the average .5 second intervals of paragraphs (1)(ii)—(2)(ii) and locate the highest .5 second reading during each dynamometer cycle. Average these three readings from the three cycles. Record and designate as (c), which shall represent the peak smoke opacity characteristic of the engine.

(4) Locate the last 15 seconds of the rated speed mode of each cycle tested under the provisions of § 169.5 (3)(ii). Determine the average smoke reading during this period. Average the three values and record and designate as (d), which shall represent the full load, rated speed smoke characteristic of the engine.

(5) Locate the last 15 seconds of the intermediate speed mode run of each cycle tested under the provisions of § 169.5(5). Determine the average smoke reading during this period. Average the three values and record and designate as (e), which shall represent the full load, intermediate speed smoke characteristic of the engine.

Source

The provisions of this § 169.9 adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

APPENDIX A

VALIDITY OF BEER-LAMBERT RELATIONSHIP

In November 1967, the SAE Diesel Smoke Measurement Task Force conducted a test program to establish the correlation between a number of diesel smoke measurement systems. A secondary goal of this task force was to establish the validity of the Beer-Lambert relationship for the transmission of light through various diameter plumes:

$$T = e^{-naQ1} = e^{-K1}$$

Where:

T = transmission.

n = number of particles per unit volume.

a = mean particle projected area.

Q = particle extinction coefficient.

l = length of light path.

e = base of natural logarithms.

The n, a, and Q variables are often referred to as the turbidity on attenuation coefficient (k); and are constant for a given soot density.

In the final published report, the SAE Task Force concluded that the Beer-Lambert relationship was usable for transmission predictions.

Figure 5 of the Task Force report (A.W. Carey Jr., ''Steady-State Correlation of Diesel Smoke Meters.'' Paper 690492 presented at SAE Mid-Year Meeting, Chicago, May 1969) is reproduced in this appendix as Figure A-1. The following is noted in the report:

''Fig. 5 presents the results obtained when the stack size was varied. The effect of stack size as shown in Fig. 5 clearly demonstrates the powerful influence this variable has on the apparent opacity of the smoke column. It is entirely reasonable to expect that the greater optical path length through the smoke column issuing from the 6 inch diameter stack will produce greater extinction of the light than would that from a 3 inch stack. The effect is predicted quite accurately by the Beer-Lambert relationship, as evidenced by the Beer-Lambert prediction points which have been placed along the 6 inch diameter and 3 inch diameter correlation lines. These Beer-Lambert predictions are based on the observed opacity correlation obtained with the 4 inch diameter stack and accuracy of the prediction is excellent.''

The results of this test are included in SAE J255.

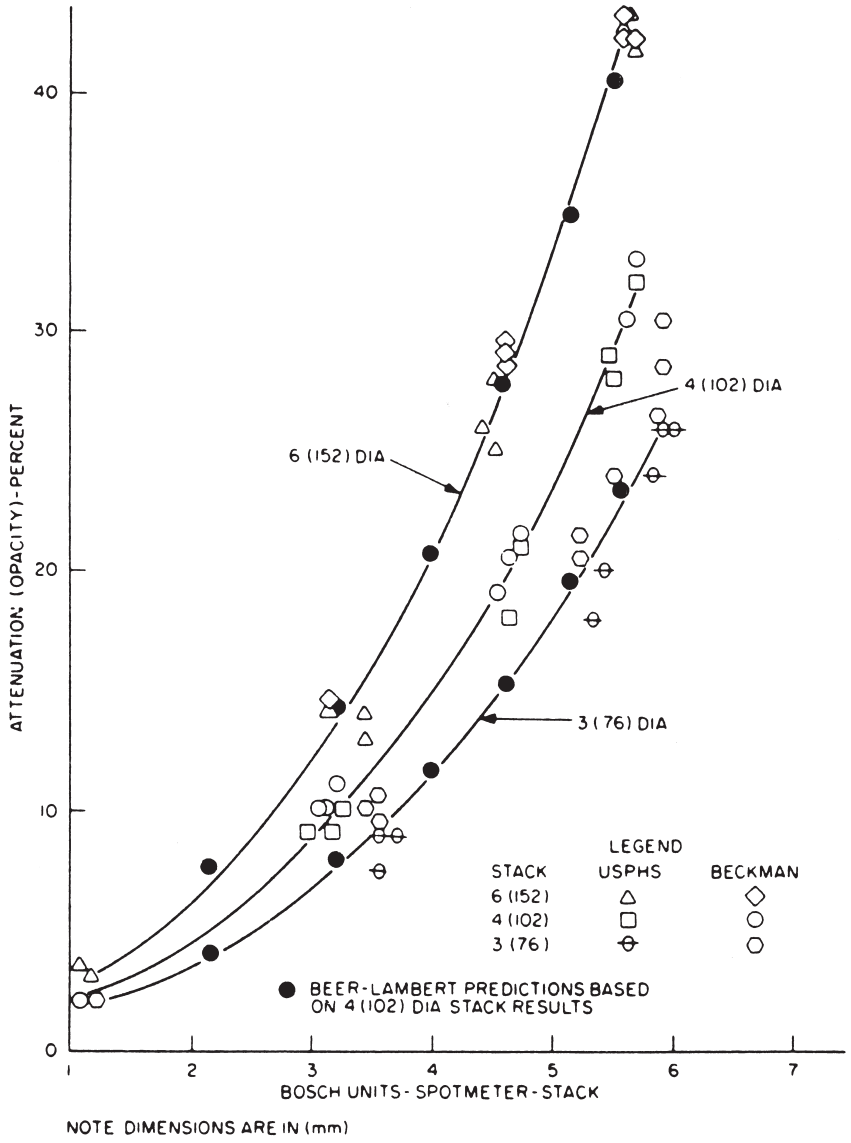

Figure A-1—EFFECT OF STACK SIZE

Source

The provisions of this Appendix A adopted August 26, 1977, effective August 27, 1977, 7 Pa.B. 2432.

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