A REVIEW
OF MEASURING METHODS AND PROCEDURES
FOR ESTIMATING DIESEL SMOKE EMISSIONS
FROM MOTOR VEHICLES

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FROM MOTOR VEHICLES

Prepared by

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Smoke from diesel-fuelled motor vehicles is recognized as a major problem in many countries of the WHO Western Pacific and South-East Asian regions. Several developing countries in these regions have yet to decide on their needs in relation to control of diesel smoke emissions. At the WHO/UNEP Bi-regional Workshop on Planning for Control of Emissions from Motor Vehicles held at PEPAS in November 1980, it was requested that PEPAS review the various measurement methods and test procedures for diesel smoke emissions. This document has been prepared in response to that request.

The issue of this document does not constitute a formal publication. The author alone is responsible for views expressed in the document.

Frank C. Go
Director, PEPAS
I. INTRODUCTION

Smoke is synonymous with air pollution to many people. Apart from the nuisance problems of diesel smoke, its claimed adverse health effects mark the diesel engine as a prime target for public resentment and restrictive ordinances.

However, measurement of diesel smoke in an accurate and consistent manner has been a difficult problem for engine and vehicle manufacturers and agencies charged with enforcing smoke standards.

In this connexion, it has to be recalled that establishing a motor vehicle emission standard requires not only that a numerical value be prescribed which is characterized by a specific unit (g/km, percent opacity, etc.), but also that an exhaust emission test procedure be established by means of which the compliance of the actual quantity of emissions with the standard is determined.

Moreover, the emission test procedure consists of two parts:

1. instruments which measure the pollutants as they are emitted from the exhaust pipe; and
2. a definite, standardized way of exercising the engine while the pollutants are being measured (test cycle).

Correspondingly, several instruments and test cycles have been developed to measure diesel smoke under different test conditions.

In addition to instruments based on different physical principles and different scales, human observation and judgement are often used to relate smoke to a variety of standards.

II. PROCEDURES FOR SMOKE EVALUATION

A. Measuring Methods

As indicated above, two different methods for smoke evaluation are available, namely:

1 Diesel Smoke: black, white and blue smoke. White and blue smoke is essentially composed of colourless liquid particles (droplets) which reflect and refract the observed light. The observed colour results from the refractive index of the liquid in the droplets and the droplet size. White smoke is usually caused by condensed water vapor or liquid fuel droplets. Blue smoke is usually due to droplets resulting from the incomplete combustion of fuel or lubricating oil. Black smoke consists of carbon (soot) particles, usually less than 1 μm in size, resulting from incomplete combustion of fuel.
They are applied to evaluate smoke emissions from diesel-fuelled engines which can be subjected to two different tests, namely to:

(a) full; and
(b) short tests

Full tests generally serve to determine smoke emissions of prototype and/or assembly line diesel-fuelled engines on engine dynamometers while short tests are used to periodically control smoke emissions of in-use diesel-powered vehicles.

(1) Visual Methods

Visual methods of smoke observation and rating have been developed as simple and direct means of obtaining numerical ratings of black smoke. The smoke perceived by the observer is subjectively compared with one of the established grey scales (Ringelmann, Bacharach, photographic).

The observer must discipline himself to limit his observation to that portion of the plume immediately above the exhaust pipe exit and to compensate mentally for the factors of background colour, illumination, and ambient light level. Hence, only trained personnel are able to judge the plume density accurately without being affected by variable field conditions. To ensure uniformity of observations among different observers the officials should have successfully completed a training course consisting of a series of lectures, and slide and film presentations, in addition to the actual training to evaluate the opacity of smoke emissions.

Countries that have established smoke standards for in-use diesel engines based on the Ringelmann scale are, among others, Australia (No. 2)\(^1\), Brazil (No. 2), and Mexico (No. 3).

(2) Instrumental methods

Devices for measuring diesel smoke may be classified generally as follows:

\(^1\) Ringelmann, No. 2
a) transmittance\(^1\)-type smokemeters which measure the light extinction as a function of the smoke concentration. They are widely called opacimeters\(^2\).

Opacimeters are divided into:

(i) full-flow opacimeters that measure the opacity of the full smoke plume;

(ii) part-flow or sampling opacimeters that measure the opacity of a portion of the exhaust gas which has been extracted from the exhaust pipe and passed through a measurement chamber of standardized size.

For (i), there are basically two types of full-flow light extinction smokemeters. One meter is an end-of-line meter or one that views the full plume emitted from the exhaust pipe. The other is an in-line meter which is inserted into the exhaust system pipe. This meter views the smoke across the path-length of the tube in which the sensors are mounted.

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1 The amount of light that passes through a given length of aerosol is the difference between the amount of incident light \( I_0 (\lambda) \) and the amount scattered and absorbed by the particles \( I (\lambda) \). The BEER-LAMBERT law relates the incident and transmitted intensities of a beam of light passing through an aerosol of length \( L \) where \( K (\lambda) \) is the extinction coefficient and \( I (\lambda)/I_0 (\lambda) \) is the transmittance:

\[
\text{(1)} \quad I (\lambda) = I_0 (\lambda) \exp \left( -K (\lambda) L \right)
\]

Since the extinction coefficient is a function of the wave-length, the wave-length of light of the emitter and the detector have an important influence on the smokemeter reading (see page 5).

2 Opacity is that fraction of light transmitted from a source which is prevented from reaching the receiver due to the extinction of light over the effective path-length \( L \):

\[
\text{(2)} \quad \text{Opacity} = 1 - \exp \left[ -K (\lambda) L \right] = 1 - I (\lambda)/I_0 (\lambda) = 1 - \text{transmittance}
\]

\[
\text{(3)} \quad \text{In percent,} \quad \text{Opacity (\%)} = 100\% \left[ 1 - I (\lambda)/I_0 (\lambda) \right] = 100\% (1 - \text{transmittance})
\]

A smoke plume that does not attenuate any incident light is invisible and has a transmittance of 1 and an opacity of 0%. A plume that attenuates all the incident light is said to be 100% opaque, and therefore it has an opacity of 100% and a transmittance of 0. An instrument that measures transmittance or opacity is referred to as an opacity meter, a transmissometer or an opacimeter.
(b) reflectance-or filter-type smokemeters which measure the reflectance of the light from a filter by means of which the smoke soot has been separated from the exhaust gases;

(c) mass determination of particulate emissions. In general, the procedure is to pass a measured amount of exhaust gas through a nearly "absolute" filter, capable of retaining on its surface the particulates that were suspended in the exhaust gas. By dividing the weighed mass of the particulates by the volume of exhaust gases sampled (at a specified temperature and pressure) the mass concentration of the particulates is determined.

2.1 Full-flow opacimeter

The best known full-flow opacimeter is the U.S. PHS smokemeter, developed by the U.S. Public Health Service for measuring diesel smoke. The instrument allows the opacity of smoke to be measured continuously under transient conditions. It may be calibrated in either 0 to 100 percent light transmittance or opacity which is accomplished by blocking the light beam for 100 percent opacity and by clean air for zero opacity. Full-flow opacimeters are widely used in the U.S.A.

2.1.1 Operating procedures and precautions

(i) Since the instrument is sensitive to smoke density and length of path (L) it is important to define the location when comparing readings with other smokemeters.

The optical unit shall be positioned near the end of the exhaust pipe (12.5 cm ± 2.5 cm) so that the light beam traverses the exhaust plume at right angles to the axis of the plume. However, the unit should not be rigidly mounted on the exhaust pipe since vibrations can shake the lamp filament which may be registered as "noise" on the recorder.

(ii) The terminal 50 cm of the exhaust pipe shall be a circular cross section and be free of elbows and bends.

(iii) The end of of the pipe shall be cut off squarely.

(iv) The terminal two feet of the exhaust pipe shall have a diameter in accordance with the engine tested, as specified below:

<table>
<thead>
<tr>
<th>Maximum rated horse power</th>
<th>Exhaust pipe diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq HP \leq 101$</td>
<td>5</td>
</tr>
<tr>
<td>$101 \leq HP \leq 200$</td>
<td>7.5</td>
</tr>
<tr>
<td>$201 \leq HP \leq 300$</td>
<td>10</td>
</tr>
<tr>
<td>$301 \leq HP$</td>
<td>12.5</td>
</tr>
</tbody>
</table>

(v) The optical unit may be mounted on a movable frame (adaptor) which should not modify the unrestricted shape of the exhaust plume.
(vi) To minimize deposition of smoke particles on the light source and the detector, an air curtain across these surfaces should be used provided that it does not measurably affect the opacity of the plume.

2.1.2 Remarks

Two important optical characteristics must be specified to obtain similar performance from full-flow opacimeters:

(1) the operating wave-length; and

(2) the light collimation of the instrument.

(1) Diesel smoke is optically not neutral, i.e. it has different spectral absorptivities at different wave-lengths. Generally, diesel exhaust particle size distribution shows that 10 percent of all particles have a mean diameter of more than 1 μm and only 10 percent of less than 0.3 μm; i.e., the major fraction of the particles has mean diameters in the range of the wave-length of visual light. According to tests, for wave-lengths of light above 0.8 μm smoke becomes transparent. Consequently, opacimeters which use infrared light show less opacity than opacimeters which use light in the visible spectrum if all factors are held equal. Moreover, the photo-detector must match the emitter, i.e., the detector must provide maximum relative sensitivity for the selected wave-length of the emitter.

(2) The light collimation is important because the detector should be restricted from receiving light that has been scattered by the smoke from the measurement.

2.2 Part-flow or sampling-type opacimeter

The best known part-flow or sampling-type opacimeter is the Hartridge smokemeter. This device measures the opacity of a portion of the exhaust gas which has been extracted from the exhaust pipe and passed through a measuring chamber of standardized size. For comparison, a reference cell is filled with scavenging air. The opacity of the sample can be given in so-called Hartridge smoke units (H.S.U.) ranging from 0 (clear) to 100 (completely opaque) or in absolute units of light absorption from 0 to ∞ (m⁻¹).

This type of smokemeter is prescribed, for example in Europe for type approval in full-load tests. However, several points have to be taken into consideration:

(a) SAE¹ does not recommend this type of device for transient smoke measurements since the transient or

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¹ Society of Automotive Engineers, Inc. 400 Commonwealth Drive, Warrendale, PA. 15096, USA.
physical response is too slow. The physical response is the time that is required to fill the measurement chamber completely (transport time approximately 0.2 - 0.6 sec.) with exhaust.

The longer the physical response, the less accurate short transient smoke gusts are recorded since the sampling probe is not filled completely with smoke of high density.

(b) As a part-flow smokemeter, isokinetic sampling has been suggested. However, this suggestion is controversial since the size distribution of diesel particulate matter contains 90% of particles less than 1 μm, hence precise isokinetic sampling is actually not required.

(c) Moreover, it has been shown that pulsation can cause difficulties in part-flow sampling. In general, the flow conditions in the exhaust system of an automobile are not stationary. Due to the opening and closing of the valves, pressure variations occur which are moving with the speed of sound. At locations with changes in diameter, pressure waves are reflected in the course of which the pressures of the waves running back and forth are added. Since the chances for reflections in the sampling probe connected with the measuring unit are generally higher than at the end of the exhaust pipe behind the sampling probe, essentially higher pressures might occur in the sampling probe than in the exhaust pipe.

Since almost all part-flow opacimeters are charged by the pressure in the exhaust system, the described effect can lead to an incomplete filling of the measuring chamber resulting in false measurements. In extreme cases, no exhaust flows in the sampling probe.

(d) It has also been reported that problems arise from condensate formation specifically from vehicles of which the exhaust pipes are conducted aloft vertically.

However, according to Hartridge Ltd., most of the problems referred to above have been overcome in advanced part-flow opacimeters which meet the requirements set forth in Annex 8 of the ECE Regulation No. 24 (Annex 1).

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1 Isokinetic sampling can be defined as sampling by drawing a particulate suspension into a probe at the same linear velocity as that of the bulk of the suspension. Precise isokinetic sampling of particulate matter, however, is only necessary for particles with sizes greater than 3 μm.

2.3 Reflectance- or filter-type smokemeter

A filter-type smokemeter which has achieved wide acceptance in diesel engine smoke-metering is the Bosch smokemeter. In this instrument, the sample (330 cm$^3$) is drawn in through a controlled density paper filter disc by means of a spring-operated plunger which is held in its minimum position and released at will. Soot from the sample is deposited on the filter disc, causing it to darken in relation to the exhaust gas soot content. A separate, battery-powered photo-electric device measures the light reflected from the darkened filter. The darkening of the filter is given in Bosch smoke units (B.S.U.) in a range from 0 to 10. Calibration is accomplished with a calibrated perforated grid which corresponds to 5.0 B.S.U.s.

Variations on this type of instrument include a filter system with a roll of filter paper instead of individual discs and a remote release system. Moreover, instead of determining the darkening of the smoke stain photo-electrically, the evaluation can also be done visually by comparing the darkness of the filter with the Bacharach grey scale ranging from 0 to 10. The latter is recommended by Bosch for the free acceleration test while the photo-electric evaluation of the smoke stain is proposed for the test with the engine under constant load.

The Bosch smokemeter can be used on a chassis dynamometer or on the road under all load conditions. To perform the test on the road the spring-loaded piston is released by means of a 5 m long flexible tube from the driving cab. This causes the exhaust sample (330 cm$^3$) to be drawn in through the filter paper.

The reflectance-type smokemeter is widely used in Japan and Europe. Notwithstanding the advantages of this device it should be mentioned that:

(a) sampling under transient conditions is not recommended because of transport time lag and integration of the sample on the filter;

(b) the particle size has great influence on the measurement. Very fine particles pass through the filter which can be proved by putting two filter papers one after another. Greater soot particles are deposited on the surface while smaller particles can penetrate the paper more or less deeply depending mainly on the structure of the paper. Obviously, greater particles adhering to the surface have a greater influence on the measured result than particles which have penetrated the paper, independently of the evaluation (visual or photo-electrical) since the reflection of the light is a measure of the darkening of the filter;

(c) in contrast to the part-flow smokemeter, blue smoke cannot be evaluated by the Bosch smokemeter which is a non-continuous measuring instrument.
2.4 Mass determination of particulate emissions

The most complex method for the evaluation of particulate emissions in diesel exhaust is based on the dilution tunnel technique measuring the true mass of the particles (Annex II)\(^1\). This system applies the PDP - CVS\(^2\) or CFV - CVS\(^3\) concept. The mass of particulate emissions is determined from a proportional mass sample collected on a filter (efficiency > 98 percent) and from the total flow over the test period.

Dilution tunnels have been used extensively to collect particulate samples from spark ignition engines. In the U.S.A. the use of dilution tunnel techniques for the determination of the mass of smoke emissions is necessary since emission standards for particulates are to be based on mass concentrations for light- and heavy-duty diesel engines\(^4\). For compliance, a transient test cycle has been developed which is going to replace the current 13-mode steady-state test for heavy-duty diesel engines in the U.S. by 1985.

B. Compliance Tests

As stated above, diesel engines can be subjected to full and short tests, namely to test:

(1) at steady speeds over the full-load curve (full test)\(^5\) (Annex I);

(2) at transient conditions (full test) (only for compliance with the particulate and gaseous emission standards) (Annex II);

\(^1\) Reprinted from Federal Register/Vol. 46, No. 4/Wednesday, January 7, 1981/Proposed Rules

\(^2\) Positive Displacement Pump - Constant Volume Sampling

\(^3\) Critical Flow Venturi - Constant Volume Sampling

\(^4\) The existing smoke test and standard (CFR, § 85.874-1) are being retained along with the addition of particulate testing. The current U.S.A. diesel smoke standard exists primarily for aesthetic reasons (refer Annex II page 52)

Proposed particulate standards

a. Light-duty diesel vehicles 1985: 0.20 gm per vehicle mile
b. Light-duty diesel trucks 1985: 0.26 gm per vehicle mile
c. Heavy-duty diesel engines 1986: 0.25 gm per brake horsepower-hour

\(^5\) It is recognized that the Japanese and ECE compliance tests (full tests) for prototype and/or assembly line testing of diesel smoke emissions are only slightly different. However, the US 13-mode test for heavy-duty diesel engines differs significantly from both the Japanese and the ECE tests.
(3) at free acceleration (no-load) (short test);
(4) at Lug-Down (short test);
(5) at single steady speed (Swedish Test) (short test).

Only the short tests which are generally used to periodically control smoke emissions of in use diesel-fuelled motor vehicles are reviewed below. In Europe, however, the free acceleration short test is also applied in addition to the test at steady speeds over the full-load curve to approve the type of diesel engines (Annex I). Here, the test at free acceleration is carried out especially to provide a reference figure for authorities which use this short test later to control smoke emissions of in-use diesel-fuelled motor vehicles.

(1) Free acceleration (No-load) Test

With the free acceleration test (if the test is carried out on a vehicle the gear is in neutral position and the clutch is engaged), the engine is accelerated from idling rpm quickly, but not violently, so as to obtain maximum delivery from the injection pump. The position is maintained until maximum governed speed is reached, then the accelerator is released until the engine resumes its idling speed and the opacimeter reverts to its initial state. The free acceleration is repeated at least six times to clean the exhaust system. The test absorption coefficient is the arithmetic mean of four consecutive values which should not vary by more than $\pm 0.25 \text{ m}^{-1}$ from each other. According to ECE Regulation No. 24 the opacity of the exhaust gases shall be measured with part-flow opacimeters or instruments which have proved to be equivalent for the engine considered.

In Japan, the free acceleration test is slightly modified and evaluated differently. The engine is warmed up by idling and accelerated rapidly with no load several times and left idling for five or six seconds (Fig. 1). Then the throttle is opened fully.

![Fig. 1: No-load Acceleration test in Japan](image-url)
and sampling of diesel smoke starts simultaneously by means of a reflectance-type smokemeter. Smoke sampling should be carried out for four seconds. The rate of diesel smoke contamination is the arithmetic mean of three consecutive cycles.

The free acceleration test, however, does not allow unambiguous identification of diesel engines which emit excessive smoke under load conditions. Evidently, due to the inherent physical properties of the diesel engine, the highest smoke emission should occur under full-load. Comprehensive investigations have shown that a correlation between smoke emissions under full-load at steady-speeds and at free acceleration does not exist. Hence, in Europe, the usefulness of the free acceleration short test for providing a reference figure for authorities which use this short test for in use diesel-fuelled motor vehicles has been questioned.

The biggest difference in smoke formation measured between the two tests occurs with turbocharged engines. Due to the short acceleration time the charger does not reach its rated rpm and this results in a lack of air pressure. Possibly, the charger may even act as a throttle. With turbocharged engines the required amount of fuel at full-load is not injected since the full pressure charge is not available. Consequently, regarding the air/fuel ratio, entirely different conditions exist between free acceleration and the operation at full-load and steady-state of turbocharged engines resulting in a very poor correlation of the smoke emissions obtained from both tests.

Authorities which use a filter-type smokemeter to evaluate the smoke emitted over this short test have to take into consideration another aspect. The resulting measurement depends, among other things, on the sampling time of the filter pump and on the time required to accelerate the engine from idling to maximum governed rpm. Evidently, the acceleration time will be different for different operators. Moreover, the sampling time of the filter pump has to coincide with the acceleration time. Since the maximum opacity during acceleration can occur in a very narrow rpm range, the sampling time should at least comprise the total acceleration time. It has therefore been requested that the sampling time of filter-type smokemeters should be not less than two seconds. Moreover, different idling rpms at the free acceleration test can also affect the test result. Figure 2 shows a schematic view of the problems referred to above.

Figure 2: Conditions at the Free Acceleration Test
Due to the difficulties encountered great efforts have been made in Europe to develop a short test for periodical control of smoke emissions from in-use diesel-fuelled motor vehicles which meets the following requirements:

(a) allows identification of smoke emissions from diesel engines also under load;
(b) is economically feasible;
(c) can be conducted within a reasonable time;
(d) is sufficiently reproducible and accurate;
(e) corresponds with the opacity measured at the type approval.

Alternative short test procedures, hitherto developed, are the

(1) Lug-Down test which is used in England; and the
(2) Swedish test carried out in Sweden.

(2) Lug-Down Test

With the Lug-Down test the wheels of the driven axle are running on rollers. The gear is engaged at which a final speed of 60 km/h is reached. The driver opens the throttle completely so that the engine runs at high idling under small load. A speed recorder which is coupled with the roller is adjusted to 100 percent at the resulting speed. By means of the brakes the engine is then brought to the full-load characteristic, and within 10 seconds steadily to 40 percent of the maximum governed rpm. The speed is measured by the speed of the rollers. During this lug-down the opacity is measured continuously with a part-flow opacimeter. The opacity versus roller speed is plotted by means of an xy-plotter. The smoke emissions are judged by the plotted curve which is compared with the limiting values of the smoke emission at full-load and steady speeds (Annex I).

In contrast to the free acceleration test, the engine is driven at the full-load characteristic. In addition, the engine is only driven in the rpm range which is covered also by the full-load test at steady speeds. However, the Lug-Down test also does not fully satisfy the requirements referred to above.

Major disadvantages are:

(a) relatively high expenditure for rollers and xy-plotter;
(b) adverse effects on the brakes;

\[1\] Obviously, this is only required if the free acceleration test is used to provide a reference figure to the full-load test at steady speeds.
(c) difficulties in interpreting the plotted curve (attaching the smoke curve accurately to the recorded speed);

(d) difficulties occurring with turbocharged engines;

(e) difficulties occurring with vehicles having automatic transmission.

(3) Swedish test

Corresponding to the Lug-Down test, the engine runs under full-load in a gear which allows it to reach a final speed of 60 to 70 km/h, however, only at 50 to 70 percent of the rated rpm. The selected rpm is kept constant for a few seconds before measuring the opacity of the exhaust gases by means of a full- or part-flow opacimeter or with a filter-type smokemeter. This test can also be carried out on the road.

In principle, the Swedish test is satisfactory, however, problems also arise from:

(a) adverse effects on the brakes; and

(b) the rather arbitrary selection of the rpm at which the smoke emissions are determined.

Especially, (b) is disadvantageous since the maximum smoke formation of the engine can occur in a very narrow rpm range (for example at maximum torque) which may not be covered when selecting the rpm rather arbitrarily between 50 to 70 percent of the rated rpm. A great number of engines even generate maximum smoke emissions at rated rpm. Obviously, these engines would be excluded from being identified as emitting excessive smoke by the Swedish test.

Probably, a short test at three different rpms, namely at the

(a) smallest full-load test rpm (of the European full-load test);

(b) rpm at maximum torque; and

(c) rated rpm

would allow the smoke characteristics at full-load to be judged more accurately. However, three consecutive tests overload the brakes and can only be carried out on the road if enough time is given for the brakes to cool between the tests. This, however, substantially increases the time required for the whole test procedure. Moreover, with turbocharged engines additional problems occur due to the inertia of the charger leading to prolonged braking times, thus resulting in higher brake temperatures especially with vehicles having greater power/weight ratios.
III. SUMMARY

Presently available major visual and instrumental methods for the evaluation of smoke emissions from diesel-fuelled motor vehicles have been reviewed. In addition, different short test procedures for the control of smoke emissions under standardized conditions have been discussed.

Taking into consideration the limitations of the different measuring methods, smoke emissions can be evaluated fairly accurately. However, at present, no satisfactory short test procedure is available to control smoke emissions of in-use diesel-powered motor vehicles at full-load.

Research is presently being carried out, predominantly in Europe, to develop a suitable short test procedure.
ANNEX I

ECE REGULATION NO. 24 Uniform Provisions Concerning the Approval of Vehicles Equipped with Diesel Engines with Regard to the Emission of Pollutants by the Engine

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Annex 1 : Essential characteristics of the vehicle and the engine and information concerning the conduct of tests

Annex 2 : Communication concerning the approval (or refusal or withdrawal of approval) of a vehicle type equipped with a diesel engine with regard to the emission of pollutants by the engine, pursuant to Regulation No. 24

Annex 3 : Arrangement of the approval mark

Annex 4 : Test at steady speeds over the full-load curve

Annex 5 : Test under free acceleration

Annex 6 : Specifications of reference fuel prescribed for approval tests and to verify conformity of production

Annex 7 : Limit values applicable in the test at steady speeds

Annex 8 : Characteristics of opacimeters

Annex 9 : Installation and use of the opacimeter
1. Scope
This Regulation applies to emissions from diesel engines used for driving motor vehicles.

2. Definitions
For the purposes of this Regulation,

2.1 "Approval of a vehicle" means the approval of a vehicle type with regard to limitation of the emission of pollutants from the engine;

2.2 "Vehicle type" means a category of power-driven vehicles which do not differ in such essential respects as the vehicle and engine characteristics as defined in annex 1 to this Regulation;

2.3 "Diesel engine" means an engine which works on the compression-ignition principle;

2.4 "Cold-start device" means a device which by its operation temporarily increases the amount of fuel supplied to the engine and is intended to facilitate starting of the engine;

2.5 "Opacimeter" means an instrument for continuous measurement of the light absorption coefficients of the exhaust gases emitted by vehicles.

3. Application for approval

3.1 The application for approval of a vehicle type with regard to limitation of the emission of pollutants from the engine shall be submitted by the vehicle manufacturer or by his duly accredited representative.

3.2 It shall be accompanied by the undermentioned documents in triplicate and the following particulars:

   3.2.1 a description of the engine type comprising all the particulars referred to in annex 1;

   3.2.2 drawings of the combustion chamber and of the upper face of the piston.

3.3 An engine and the equipment prescribed in annex 1 to this Regulation for fitting it to the vehicle to be approved shall be submitted to the technical service conducting the approval tests defined in paragraph 5 of this Regulation. However, if the manufacturer so requests and the technical service conducting the approval tests agrees, a test may be carried out on a vehicle representative of the vehicle type to be approved.

4. Approval

4.1 If the vehicle type submitted for approval pursuant to this Regulation meets the requirements of paragraph 5 below, approval of that vehicle type shall be granted.
4.2 An approval number shall be assigned to each type approved. The same Contracting Party may not assign the same number to another vehicle type.

4.3 Notice of approval or of refusal of approval of a vehicle type pursuant to this Regulation shall be communicated to the Parties to the Agreement which apply this Regulation by means of a form conforming to the model in annex 2 to this Regulation and of drawings and diagrams supplied, by the applicant for approval, in a format not exceeding A4 (210 x 297 mm) or folded to that format and on an appropriate scale.

4.4 There shall be affixed, conspicuously and in a readily accessible place specified on the approval form, to every vehicle conforming to a vehicle type approved under this Regulation,

4.4.1 an international approval mark consisting of:

4.4.1.1 a circle surrounding the letter "E" followed by the distinguishing number of the country which has granted approval;

4.4.1.2 the number of this Regulation, followed by the letter "R", a dash and the approval number, below the circle;

4.4.2 the following additional symbol: a rectangle surrounding a figure expressing in m$^{-1}$ the corrected absorption coefficient obtained, at the time of approval, during the test under free acceleration, and determined at the time of approval by the procedure described in annex 5, paragraph 3.2 to this Regulation.

4.5 The approval mark and the additional symbol shall be clearly legible and indelible.

4.6 Annex 3 to this Regulation gives an example of the arrangement of the approval mark and of the additional symbol.

5. Specifications and tests

5.1 General

1 1 for the Federal Republic of Germany, 2 for France, 3 for Italy, 4 for the Netherlands, 5 for Sweden, 6 for Belgium, 7 for Hungary, 8 for Czechoslovakia, 9 for Spain, 10 for Yugoslavia, 11 for the United Kingdom and 12 for Austria. Subsequent numbers shall be assigned to other countries in the chronological order in which they ratify the Agreement concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, or in which they accede to that Agreement, and the numbers thus assigned shall be communicated by the Secretary-General of the United Nations to the Contracting Parties to the Agreement.
The components liable to affect the emission of pollutants shall be so designed, constructed and assembled as to enable the vehicle, in normal use, despite the vibration to which it may be subjected, to comply with the provisions of this Regulation.

5.2 Specifications concerning cold-start devices

5.2.1 The cold-start device shall be so designed and constructed that it cannot be brought into or kept in action when the engine is running normally.

5.2.2 The provisions of paragraph 5.2.1 above shall not apply if at least one of the following conditions is met:

5.2.2.1 the light absorption coefficient of the gases emitted by the engine at steady speeds when measured by the procedure prescribed in annex 4 to this Regulation with the cold-start device operating, is within the limits prescribed in annex 7 to this Regulation;

5.2.2.2 keeping the cold-start device in operation causes the engine to stop within a reasonable time.

5.3 Specifications concerning the emission of pollutants

5.3.1 The emission of pollutants by the vehicle type submitted for approval shall be measured by the two methods described in annexes 4 and 5 to this Regulation, relating respectively to tests at steady speeds and to tests under free acceleration.  

5.3.2 The emission of pollutants, as measured by the method described in annex 4 to this Regulations, shall not exceed the limits prescribed in annex 7 to this Regulation.

5.3.3 In the case of engines with an exhaust-driven supercharger the absorption coefficient measured under free acceleration shall not exceed the limit prescribed in annex 7 for the nominal flow value corresponding to the maximum absorption coefficient measured during the tests at steady speeds, plus 0.5 m⁻¹.

5.4 Equivalent measuring instruments shall be allowed. If an instrument other than those described in annex 8 to this Regulation is used, its equivalence for the engine considered shall be required to be proved.

2 A test under free acceleration shall be carried out, especially in order to provide a reference figure for administrations which use this method to check vehicles in use.
6. Modification of the vehicle type

6.1 Every modification of the vehicle type shall be notified to the administrative department which approved the vehicle type. The department may then either:

6.1.1 consider that the modifications made are unlikely to have an appreciable adverse effect and that in any case the vehicle still complies with the requirements; or

6.1.2 require a further test report from the technical service conducting the tests.

6.2 Confirmation of approval, specifying the alterations, or refusal of approval shall be communicated by the procedure specified in paragraph 4.3 above to the Parties to the Agreement which apply this Regulation.

7. Conformity of production

7.1 Every vehicle bearing an approval mark as prescribed under this Regulation shall conform, with regard to components affecting the emission of pollutants by the engine, to the vehicle type approved.

7.2 In order to verify conformity as prescribed in paragraph 7.1, a vehicle bearing the approval mark required by this Regulation shall be taken from the series.

7.3 Conformity of the vehicle with the approved type shall be verified on the basis of the description given in the approval form. In addition, verifying tests shall be carried out in the following conditions.

7.3.1 A vehicle which has not been run in shall be subjected to the test under free acceleration prescribed in annex 5 to this Regulation. The vehicle shall be deemed to conform to the approved type if the absorption coefficient determined does not exceed by more than 0.5 m\(^{-1}\) the figure shown in the approval mark.

7.3.2 If the figure determined in the test referred to in paragraph 7.3.1 above exceeds by more than 0.5 m\(^{-1}\) the figure shown in the approval mark, a vehicle of the type considered or its engine shall be subjected to the test at steady speeds over the full-load curve, as prescribed in annex 4 to this Regulation. The emission levels shall not exceed the limits prescribed in annex 7 to this Regulation.

8. Penalties for non-conformity of production

8.1 The approval granted in respect of a vehicle type pursuant to this Regulation may be withdrawn if the requirements laid down in paragraph 7.1 are not complied with or if the vehicle or vehicles taken fail to pass the tests prescribed in paragraph 7.3 above.
8.2 If a Party to the Agreement which applies this Regulation withdraws an approval it has previously granted, it shall forthwith notify the other Contracting Parties applying this Regulation thereof, by means of a copy of the approval form bearing at the end, in large letters, the signed and dated annotation "APPROVAL WITHDRAWN".

9. Names and addresses of technical services conducting approval tests, and of administrative departments

The Parties to the Agreement which apply this Regulation shall communicate to the Secretariat of the United Nations the names and addresses of the technical services conducting approval tests and of the administrative departments which grant approval and to which forms certifying approval or refusal or withdrawal of approval, issued in other countries, are to be sent.
ANNEX 1

Essential Characteristics of the Vehicle and the Engine and Information Concerning the Conduct of Tests

1. Description of engine
   1.1 Make ..........................................................
   1.2 Type ..........................................................
   1.3 Cycle: four-stroke/two-stroke
   1.4 Bore ......................................................... mm
   1.5 Stroke ........................................................ mm
   1.6 Number of cylinders ..............................
   1.7 Cylinder capacity ................................. cm³
   1.8 Compression ratio ..............................
   1.9 System of cooling .................................
   1.10 Supercharger with/without description of the system
   1.11 Air filter: drawings, or makes and types ..............

2. Additional anti-smoke devices (if any, and if not covered by another heading)
   Description and diagrams .................

3. Air intake and fuel feed
   3.1 Description and diagrams of air intakes and their accessories (heating device, intake silencer, etc.)

   1 In the case of non-conventional engines and systems, particulars equivalent to those referred to here shall be supplied by the manufacturer.

   2 Strike out what does not apply.

   3 Specify the tolerance.
### Fuel Feed

#### Feed Pump
- Pressure\(^3\) ...................................... or characteristic
diagram \(^3\) ........................................

#### Injector System ..............................

### Injection Piping ...........................

#### Length .....................................

#### Internal Diameter .........................

#### Injector(s) .................................

#### Starting Pressure bars\(^3\) ..............
or characteristic diagram\(^2\), \(^3\) ...........

### Governor .................................

#### Make(s) .....................................

#### Type(s) .....................................

---

2 Strike out what does not apply.

3 Specify the tolerance.
3.2.2.4.3 Speed at which cut-off starts under load: .......... r.p.m.
3.2.2.4.4 Maximum no-load speed .................... r.p.m.
3.2.2.4.5 Idling speed: ......................... r.p.m.

3.3 Cold-start system
3.3.1 Make(s) ........................................
3.3.2 Type(s) ........................................
3.3.3 Description .................................

4. Valve timing
4.1 Maximum lift of valves and angles of opening and closing
   in relation to dead centres
   ........................................................................................................
   ........................................................................................................

4.2 Reference and/or setting ranges\(^2\) .........................

5. Exhaust system
5.1 Description and diagrams .............................
5.2 Mean back-pressure at maximum power: ......... mm water

6. Transmission
6.1 Moment of inertia of engine flywheel .................
6.2 Additional moment of inertia with no gear engaged
   ........................................................................................................

\(^2\) Strike out what does not apply.
7. Additional information on test conditions
7.1 Lubricant used
7.1.1 Make ........................................
7.1.2 Type ........................................................
(State percentage of oil in mixture if lubricant and fuel mixed)

8. Engine performances
8.1 Idling speed ......................... r.p.m. 3
8.2 Engine speed at maximum power ...... r.p.m. 3
8.3 Power at the six points of measurement referred to in paragraph 2.1 of annex 4 to this Regulation

8.3.1 Power of the engine measured on the test bench: indicate the standard followed (BSI - CUNA - DIN - GOST - IGM - ISO - SAE, etc. 2)
8.3.2 Power measured on the wheels of the vehicle

<table>
<thead>
<tr>
<th>Engine speed (n) r.p.m.</th>
<th>Measured power HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

2 Strike out what does not apply.
3 Specify the tolerance.
ANNEX 2

(Maximum format: A4 (210 x 297 mm))

Communication concerning the approval (or refusal or withdrawal of approval) of a vehicle type equipped with a diesel engine with regard to the emission of pollutants by the engine, pursuant to Regulation No. 24

Approval No............................

1. Trade name or mark of the vehicle .........................

2. Vehicle type ........................................

3. Manufacturer's name and address ........................

4. If applicable, name and address of manufacturer's representative

5. Emission levels

5.1 at steady speeds .................................

<table>
<thead>
<tr>
<th>Engine speed (r.p.m.)</th>
<th>Nominal flow G (litres/second)</th>
<th>Limit absorption values (m⁻¹)</th>
<th>Measured absorption values (m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td></td>
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<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 under free acceleration

5.2.1 measured absorption value ........................................ m\(^{-1}\)

5.2.2 corrected absorption value ........................................ m\(^{-1}\)

6. Make and type of the opacimeter ........................................

7. Engine submitted for approval tests on .........................

8. Technical service conducting approval tests ....................

9. Date of test report issued by that service .......................

10. Number of test report issued by that service .................

11. Approval granted/refused\(^1\)

12. Site of approval mark on the vehicle ............................... 

13. Place ...........................................................................

14. Date ...........................................................................

15. Signature ......................................................................

16. The following documents, bearing the approval number shown above, are annexed to this communication:

   1 copy of annex 1 to this Regulation, duly completed and with the drawings and diagrams referred to attached;

   .... photograph(s) of the engine and its compartment.

\(^1\) Strike out what does not apply.
The above approval mark affixed to a vehicle shows that, pursuant to Regulation No. 24, the vehicle type concerned has, with regard to the emission of pollutants by the engine, been approved in the Netherlands (E 4) under approval number 2439. The corrected absorption coefficient is 1.30 m⁻¹.
ANNEX 4

Test at Steady Speeds over the Full-Load Curve

1. Introduction

This annex describes the method of determining emissions of pollutants at different steady speeds over the full-load curve.

1.2 The test may be carried out either on an engine or on a vehicle.

2. Measurement principle

2.1 The opacity of the exhaust gases produced by the engine shall be measured with the engine running under full load and at steady speed. Six measurements shall be made at engine speeds spaced out uniformly between that corresponding to maximum power and the higher of the following two engine speeds:

45 per cent of the engine speed corresponding to maximum power; and
1000 r.p.m.

The extreme points of measurement shall be situated at the limits of the interval defined above.

2.2 In the case of diesel engines fitted with an air supercharger which can be engaged at will, and where the entry into operation of the air supercharger automatically brings about an increase in the quantity of fuel injected, the measurements shall be made both with and without the supercharger working. For each engine speed, the higher of the two figures obtained shall be the result of the measurement.

3. Test conditions

3.1 Vehicle or engine

3.1.1 The engine or the vehicle shall be submitted in good mechanical conditions. The engine shall have been run in.

3.1.2 The engine shall be tested with the equipment prescribed in annex 1 to this Regulation.

3.1.3 The settings of the engine shall be those prescribed by the manufacturer and shown in annex 1 to this Regulation.

3.1.4 The exhaust device shall not have any orifice through which the gases emitted by the engine might be diluted.

3.1.5 The engine shall be in the normal working condition prescribed by the manufacturer. In particular, the cooling water and the oil shall each be at the normal temperature prescribed by the manufacturer.
3.2 Fuel

The fuel shall be the reference fuel whose specifications are given in annex 6 to this Regulation.

3.3 Test laboratory

3.3.1 The absolute temperature $T$ of the laboratory, expressed in degrees Kelvin, and the atmospheric pressure $H$, expressed in torr, shall be measured, and the factor $F$ shall be determined by the formula

$$F = \left( \frac{750}{H} \right)^{0.65} \times \left( \frac{T}{298} \right)^{0.5}$$

3.3.2 For a test to be recognized as valid, the factor $F$ shall be such that $0.98 \leq F \leq 1.02$.

3.4 Sampling and measuring apparatus

The light-absorption coefficient of the exhaust gases shall be measured with an opacimeter satisfying the conditions laid down in annex 8 and installed in conformity with annex 9 to this Regulation.

4. Limit values

4.1 For each of the six engine speeds at which the absorption coefficient is measured pursuant to paragraph 2.1 above, the nominal gas flow $G$, expressed in litres per second, shall be calculated by means of the following formulae:

- for two-stroke engines \[ G = \frac{V \cdot n}{60} \]
- for four-stroke engines \[ G = \frac{V \cdot n}{120} \]

in which:

$V$ is the cylinder capacity of the engine expressed in litres; and

$n$ is the engine speed in revolutions per minute.

4.2 For each engine speed the absorption coefficient of the exhaust gases shall not exceed the limit value given in the table in annex 7. Where the value of the nominal flow is not one of those given in that table, the limit value applicable shall be obtained by interpolation on the principle of proportional parts.
ANNEX 5

Test Under Free Acceleration

1. Test conditions

1.1 The test shall be carried out on the vehicle or engine which has undergone the test at steady speeds described in annex 4 to this Regulation.

1.1.1 If the engine test is a bench test it shall be carried out as soon as possible after the test for measurement of opacity under full load at steady speed. In particular, the cooling water and the oil shall be at the normal temperatures stated by the manufacturer.

1.1.2 If the test is carried out on a stationary vehicle the engine shall first be brought to normal operating condition during a road run. The test shall be carried out as soon as possible after completion of the road run.

1.2 The combustion chamber shall not have been cooled or fouled by a prolonged period of idling preceding the test.

1.3 The test conditions prescribed in annex 4, paragraphs 3.1, 3.2 and 3.3, shall apply.

1.4 The conditions prescribed in annex 4, paragraph 3.4, with regard to the sampling and measuring apparatus shall apply.

2. Test methods

2.1 If the test is a bench test the engine shall be disconnected from the brake, the latter being replaced either by the rotating parts driven when no gear is engaged or by an inertia substantially equivalent to that of the said parts.

2.2 If the test is carried out on a vehicle the gear-change control shall be set in the neutral position and the drive between engine and gearbox engaged.

2.3 With the engine idling, the accelerator control shall be operated quickly, but not violently, so as to obtain maximum delivery from the injection pump. This position shall be maintained until maximum engine speed is reached and the governor comes into action. As soon as this speed is reached the accelerator shall be released until the engine resumes its idling speed and the opacimeter reverts to the corresponding conditions.

2.4 The operation described in paragraph 2.3 above shall be repeated not less than six times in order to clear the exhaust system and to allow for any necessary adjustment of the apparatus. The maximum opacity values read
in each successive acceleration shall be noted until stabilized values are obtained. No account shall be taken of the values read while, after each acceleration, the engine is idling. The values read shall be regarded as stabilized when four of them consecutively are situated within a band width of 0.25 m⁻¹ and do not form a decreasing sequence. The absorption coefficient $X_M$ to be recorded shall be the arithmetical mean of these four values.

2.5 Engines fitted with an air supercharger shall be subject, where appropriate, to the following special requirements:

2.5.1 in the case of engines with an air supercharger which is coupled or driven mechanically by the engine and is capable of being disengaged, two complete measurement cycles with preliminary accelerations shall be carried out, the air supercharger being engaged in one case and disengaged in the other. The measurement result recorded shall be the higher of the two results obtained; and

2.5.2 in the case of engines with an air supercharger which can be cut out by means of a driver-operated by-pass, the test shall be carried out with and without the by-pass. The measurement result recorded shall be the higher of the results obtained.

3. Determination of the corrected value of the absorption coefficient

3.1 Notation

- $X_M$: value of the absorption coefficient under free acceleration measured as prescribed in paragraph 2.4 of this annex;
- $X_L$: corrected value of the absorption coefficient under free acceleration;
- $S_M$: value of the absorption coefficient measured at steady speed (annex 4, paragraph 2.1) which is closest to the prescribed limit value corresponding to the same nominal flow;
- $S_L$: value of the absorption coefficient prescribed in annex 4, paragraph 4.2, for the nominal flow corresponding to the point of measurement which gave the value $S_M$;
- $L$: effective length of the light path in the opacimeter.

3.2 The absorption coefficients being expressed in m⁻¹ and the effective length of the light path being expressed in metres, the corrected value $X_L$, is given by the smaller of the following two expressions:

$$X'_L = \frac{S_L}{S_M} X_M$$

or

$$X''_L = X_M + 0.5$$
### ANNEX 6

**Specifications of Reference Fuel Prescribed for Approval Tests and to Verify Conformity of Production**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Limits and units</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density 15/40°C</td>
<td>0.830 ± 0.005</td>
<td>ASTM¹ D 1298-67</td>
</tr>
<tr>
<td>Distillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>Min. 2450°C</td>
<td>ASTM D 86-67</td>
</tr>
<tr>
<td>90%</td>
<td>330 ± 10°C</td>
<td></td>
</tr>
<tr>
<td>Final boiling point</td>
<td>Max. 370°C</td>
<td></td>
</tr>
<tr>
<td>Cetane index</td>
<td>54 ± 3</td>
<td>ASTM D 976-66</td>
</tr>
<tr>
<td>Kinematic viscosity at 100°F</td>
<td>3 ± 0.5 cst</td>
<td>ASTM D 445-65</td>
</tr>
<tr>
<td>Sulphur content</td>
<td>0.4 ± 0.1% by weight</td>
<td>ASTM D 129-64</td>
</tr>
<tr>
<td>Flash-point</td>
<td>min. 550°C</td>
<td>ASTM D 99-66</td>
</tr>
<tr>
<td>Cloud point</td>
<td>max. - 70°C</td>
<td>ASTM D 97-66</td>
</tr>
<tr>
<td>Aniline point</td>
<td>69 ± 50°C</td>
<td>ASTM D 611-64</td>
</tr>
<tr>
<td>Carbon residue on 10% bottoms</td>
<td>max. 0.2% by weight</td>
<td>ASTM D 524-64</td>
</tr>
<tr>
<td>Ash content</td>
<td>max. 0.01% by weight</td>
<td>ASTM D 482-63</td>
</tr>
<tr>
<td>Water content</td>
<td>max. 0.05% by weight</td>
<td>ASTM D 95-62</td>
</tr>
<tr>
<td>Copper - corrosion test at 100°C</td>
<td>max. 1</td>
<td>ASTM D 130-68</td>
</tr>
<tr>
<td>Net calorific value</td>
<td>10,250 ± 100 kcal/Kg</td>
<td>ASTM D 2-68 (Ap.VI)</td>
</tr>
<tr>
<td></td>
<td>18,450 ± 180 BTU/lb</td>
<td></td>
</tr>
<tr>
<td>Strong acid number</td>
<td>nil mg KOH/g</td>
<td>ASTM D 974-64</td>
</tr>
</tbody>
</table>

**Note:** The fuel must be based only on straight-run distillates, hydrodesulphurized or not, and must contain no additives.

---

¹ Initials of the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pennsylvania 19103, U.S.A. The figures after the dash denote the year when a standard was adopted or revised. Should any ASTM standards be amended, the standards adopted in the years quoted above will remain applicable unless all Parties to the 1958 Agreement which apply this Regulation agree to replace them by later standards.
ANNEX 7

Limit Values Applicable in the Tests at Steady Speeds

<table>
<thead>
<tr>
<th>Nominal flow G litres/second</th>
<th>Absorption coefficient K m⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 42</td>
<td>2.26</td>
</tr>
<tr>
<td>45</td>
<td>2.19</td>
</tr>
<tr>
<td>50</td>
<td>2.08</td>
</tr>
<tr>
<td>55</td>
<td>1.985</td>
</tr>
<tr>
<td>60</td>
<td>1.90</td>
</tr>
<tr>
<td>65</td>
<td>1.84</td>
</tr>
<tr>
<td>70</td>
<td>1.775</td>
</tr>
<tr>
<td>75</td>
<td>1.72</td>
</tr>
<tr>
<td>80</td>
<td>1.665</td>
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<tr>
<td>85</td>
<td>1.62</td>
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<td>105</td>
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<td>125</td>
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<td>130</td>
<td>1.32</td>
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<td>135</td>
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<td>140</td>
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<td>145</td>
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<td>150</td>
<td>1.225</td>
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<td>155</td>
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<td>160</td>
<td>1.19</td>
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<tr>
<td>165</td>
<td>1.17</td>
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<tr>
<td>170</td>
<td>1.155</td>
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<tr>
<td>175</td>
<td>1.14</td>
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<tr>
<td>180</td>
<td>1.125</td>
</tr>
<tr>
<td>185</td>
<td>1.11</td>
</tr>
<tr>
<td>190</td>
<td>1.095</td>
</tr>
<tr>
<td>195</td>
<td>1.08</td>
</tr>
<tr>
<td>≥ 200</td>
<td>1.065</td>
</tr>
</tbody>
</table>

Note: Although the above values are rounded to the nearest 0.01 or 0.005, this does not mean that the measurements need to be made to this degree of accuracy.
ANNEX 8

Characteristics of Opacimeters

1. Scope

This annex defines the conditions to be met by opacimeters used in the tests described in annexes 4 and 5 to this Regulation.

2. Basic specification for opacimeters

2.1 The gas to be measured shall be confined in an enclosure having a non-reflecting internal surface.

2.2 In determining the effective length of the light path through the gas, account shall be taken of the possible influence of devices protecting the light source and the photoelectric cell. This effective length shall be indicated on the instrument.

2.3 The indicating dial of the opacimeter shall have two measuring scales, one in absolute units of light absorption from 0 to \( \infty \) (m\(^{-1}\)) and the other linear from 0 to 100; both scales shall range from 0 at total light flux to full scale at complete obscuration.

3. Construction specifications

3.1 General

The design shall be such that under steady-speed operating conditions the smoke chamber is filled with smoke of uniform opacity.

3.2 Smoke chamber and opacimeter casing

3.2.1 The impingement on the photoelectric cell of stray light due to internal reflections or diffusion effects shall be reduced to a minimum (e.g. by finishing internal surfaces in matt black and by a suitable general layout).

3.2.2 The optical characteristics shall be such that the combined effect of diffusion and reflection does not exceed one unit on the linear scale when the smoke chamber is filled with smoke having an absorption coefficient near 1.7 m\(^{-1}\).

3.3 Light source

The light source shall be an incandescent lamp with a colour temperature in the range 2,800 to 3,250° K.
3.4 Receiver

3.4.1 The receiver shall consist of a photoelectric cell with a spectral response curve similar to the photopic curve of the human eye (maximum response in the range 550/570 nm; less than 4 per cent of that maximum response below 430 nm and above 680 nm).

3.4.2 The construction of the electrical circuit, including the indicating dial, shall be such that the current output from the photoelectric cell is a linear function of the intensity of the light received over the operating-temperature range of the photoelectric cell.

3.5 Measuring scales

3.5.1 The light-absorption coefficient \( k \) shall be calculated by the formula \( \Phi = \Phi_0 \cdot e^{-kL} \), where \( L \) is the effective length of the light path through the gas to be measured, \( \Phi_0 \) the incident flux and \( \Phi \) the emergent flux. When the effective length \( L \) of a type of opacimeter cannot be assessed directly from its geometry, the effective length \( L \) shall be determined

- either by the method described in paragraph 4. of this annex; or
- through correlation with another type of opacimeter for which the effective length is known.

3.5.2 The relationship between the 0-100 linear scale and the light-absorption coefficient \( k \) is given by the formula

\[
k = \frac{1}{L} \log_e \left( 1 - \frac{N}{100} \right)
\]

where \( N \) is a reading on the linear scale and \( k \) the corresponding value of the absorption coefficient.

3.5.3 The indicating dial of the opacimeter shall enable an absorption coefficient of 1.7 m\(^{-1}\) to be read with an accuracy of 0.025 m\(^{-1}\).

3.6 Adjustment and calibration of the measuring apparatus

3.6.1 The electrical circuit of the photoelectric cell and of the indicating dial shall be adjustable so that the pointer can be reset at zero when the light flux passes through the smoke chamber filled with clean air or through a chamber having identical characteristics.
3.6.2 With the lamp switched off and the electrical measuring circuit open or short-circuited, the reading on the absorption-coefficient scale shall be $\infty$, and it shall remain at $\infty$ with the measuring circuit reconnected.

3.6.3 An intermediate check shall be carried out by placing in the smoke chamber a screen representing a gas whose known light-absorption coefficient $k$, measured as described in paragraph 3.5.1, is between $1.6 \text{ m}^{-1}$ and $1.8 \text{ m}^{-1}$. The value of $k$ must be known to within $0.025 \text{ m}^{-1}$. The check consists in verifying that this value does not differ by more than $0.05 \text{ m}^{-1}$ from that read on the opacimeter indicating dial when the screen is introduced between the source of light and the photoelectric cell.

3.7 Opacimeter response

3.7.1 The response time of the electrical measuring circuit, being the time necessary for the indicating dial to reach 90 per cent of full-scale deflection on insertion of a screen fully obscuring the photoelectric cell, shall be 0.9 to 1.1 second.

3.7.2 The damping of the electrical measuring circuit shall be such that the initial overswing beyond the final steady reading after any momentary variation in input (e.g. the calibration screen) does not exceed 4 per cent of that reading in linear scale units.

3.7.3 The response time of the opacimeter which is due to physical phenomena in the smoke chamber is the time taken from the start of the gas entering the chamber to complete filling of the smoke chamber; it shall not exceed 0.4 second.

3.7.4 These provisions shall apply solely to opacimeters used to measure opacity under free acceleration.

3.8 Pressure of the gas to be measured and of scavenging air

3.8.1 The pressure of the exhaust gas in the smoke chamber shall not differ by more than 75 mm (water gauge) from the atmospheric pressure.

3.8.2 The variations in the pressure of the gas to be measured and of the scavenging air shall not cause the absorption coefficient to vary by more than $0.05 \text{ m}^{-1}$ in the case of a gas having an absorption coefficient of $1.7 \text{ m}^{-1}$.

3.8.3 The opacimeter shall be equipped with appropriate devices for measuring the pressure in the smoke chamber.

3.8.4 The limits of pressure variation of gas and scavenging air in the smoke chamber shall be stated by the manufacturer of the apparatus.
3.9 Temperature of the gas to be measured

3.9.1 At every point in the smoke chamber the gas temperature at the instant of measurement shall be between 700°C and a maximum temperature specified by the opacimeter manufacturer such that the readings over the temperature range do not vary by more than 0.1 m⁻¹ when the chamber is filled with a gas having an absorption coefficient of 1.7 m⁻¹.

3.9.2 The opacimeter shall be equipped with appropriate devices for measuring the temperature in the smoke chamber.

4. Effective length "L" of the opacimeter

4.1 General

4.1.1 In some types of opacimeter the gas between the light source and the photoelectric cell, or between transparent parts protecting the source and the photoelectric cell, is not of constant opacity. In such cases the effective length L shall be that of a column of gas of uniform opacity which gives the same absorption of light as that obtained when the gas is normally admitted into the opacimeter.

4.1.2 The effective length of the light path is obtained by comparing the reading N of the opacimeter operating normally with the reading N₀ obtained with the opacimeter modified so that the test gas fills a well defined length L₀.

4.1.3 It will be necessary to take comparative readings in quick succession to determine the correction to be made for shifts of zero.

4.2 Method of assessment of L

4.2.1 The test gas shall be exhaust gas of constant opacity or a light-absorptive gas of a gravimetric density similar to that of exhaust gas.

4.2.2 A column of length L₀ of the opacimeter, which can be filled uniformly with the test gas, and the ends of which are substantially at right angles to the light path, shall be accurately determined. This length L₀ shall be close to the effective length of the opacimeter.

4.2.3 The mean temperature of the test gas in the smoke chamber shall be measured.
4.2.4 If necessary, an expansion tank of sufficient capacity to damp the pulsations and of compact design may be incorporated in the sampling line as near to the probe as possible. A cooler may also be fitted. The addition of the expansion tank and of the cooler should not unduly disturb the composition of the exhaust gas.

4.2.5 The test for determining the effective length shall consist in passing a sample of test gas alternately through the opacimeter operating normally and through the same apparatus modified as indicated in paragraph 4.1.2.

4.2.5.1 The opacimeter readings shall be recorded continuously during the test with a recorder whose response time is equal to or shorter than that of the opacimeter.

4.2.5.2 With the opacimeter operating normally, the reading on the linear scale of opacity is \( N \) and that of the mean gas temperature expressed in Kelvin degrees is \( T \).

4.2.5.3 With the known length \( L_O \) filled with the same test gas, the reading on the linear scale of opacity is \( N_O \) and that of the mean gas temperature expressed in Kelvin degrees is \( T_O \).

4.2.6 The effective length will be

\[
L = L_O \frac{T}{T_O} \cdot \frac{\log(1 - \frac{N}{100})}{\log(1 - \frac{N_O}{100})}
\]

4.2.7 The test shall be repeated with at least four test gases giving readings evenly spaced between the readings 20 and 80 on the linear scale.

4.2.8 The effective length \( L \) of the opacimeter will be the arithmetic average of the effective lengths obtained as stated in paragraph 4.2.6 for each of the gases.
ANNEX 9

Installation and Use of the Opacimeter

1. Scope

This annex specifies the installation and use of opacimeters for the tests described in annexes 4 and 5 to this Regulation.

2. Sampling opacimeter

2.1 Installation for steady-speed tests

2.1.1 The ratio of the cross-sectional area of the probe to that of the exhaust pipe shall not be less than 0.05. The back pressure measured in the exhaust pipe at the opening of the probe shall not exceed 75 mm (water gauge).

2.1.2 The probe shall be a tube with an open end facing forwards in the axis of the exhaust pipe, or of the extension pipe if one is required. It shall be situated in a section where the distribution of smoke is approximately uniform. To achieve this, the probe shall be placed as far downstream in the exhaust pipe as possible, or, if necessary, in an extension pipe so that, if D is the diameter of the exhaust pipe at the opening, the end of the probe is situated in a straight portion at least 6 D in length upstream of the sampling point and 3 D in length downstream. If an extension pipe is used, no air shall be allowed to enter the joint.

2.1.3 The pressure in the exhaust pipe and the characteristics of the pressure drop in the sampling line shall be such that the probe collects a sample sensibly equivalent to that which would be obtained by isokinetic sampling.

2.1.4 If necessary, an expansion tank of compact design and of sufficient capacity to damp the pulsations may be incorporated in the sampling line as near to the probe as possible. A cooler may also be fitted.

The design of the expansion tank and cooler shall not unduly disturb the composition of the exhaust gas.

2.1.5 A butterfly valve or other means of increasing the sampling pressure may be placed in the exhaust pipe at least three 3D downstream from the sampling probe.
2.1.6 The connecting pipes between the probe, the cooling device, the expansion tank (if required) and the opacimeter shall be as short as is possible while satisfying the pressure and temperature requirements prescribed in annex 8, paragraphs 3.8 and 3.9. The pipe shall be inclined upwards from the sampling point to the opacimeter, and sharp bends where soot might accumulate shall be avoided. If not embodied in the opacimeter, a by-pass valve shall be provided upstream.

2.1.7 A check shall be carried out during the test to ensure that the requirements of annex 8, paragraph 3.8, concerning pressure and those of annex 8, paragraph 3.9, concerning the temperature in the measuring chamber are observed.

2.2 Installation for tests under free acceleration

2.2.1 The ratio of the cross-sectional area of the probe to that of the exhaust pipe shall not be less than 0.05. The back pressure measured in the exhaust pipe at the opening of the probe shall not exceed 75 mm (water gauge).

2.2.2 The probe shall be a tube with an open end facing forwards in the axis of the exhaust pipe, or of the extension pipe if one is required. It shall be situated in a section where the distribution of smoke is approximately uniform. To achieve this, the probe shall be placed as far downstream in the exhaust pipe as possible or, if necessary, in an extension pipe so that, if D is the diameter of the exhaust pipe at the opening, the end of the probe is situated in a straight portion at least 6 D in length upstream of the sampling point and 3 D in length downstream. If an extension pipe is used, no air shall be allowed to enter the joint.

2.2.3 The sampling system shall be such that at all engine speeds the pressure of the sample at the opacimeter is within the limits specified in annex 8, paragraph 3.8.2. This may be checked by noting the sample pressure at engine idling and maximum no-load speeds. Depending on the characteristics of the opacimeter, control of sample pressure can be achieved by a fixed restriction or butterfly valve, in the exhaust pipe or extension pipe. Whichever method is used, the back pressure measured in the exhaust pipe at the opening of the probe shall not exceed 75 mm (water gauge).

2.2.4 The pipes connecting with the opacimeter shall also be as short as possible. The pipe shall be inclined upwards from the sampling point to the opacimeter, and sharp bends where soot might accumulate shall be avoided. A by-pass valve may be provided upstream of the opacimeter to isolate it from the exhaust-gas flow when no measurement is being made.
3. Full-flow opacimeter

The only general precautions to be observed in steady-speed and free-acceleration tests are the following:

3.1 Joints in the connecting pipes between the exhaust pipe and the opacimeter shall not allow air to enter from outside.

3.2 The pipes connecting with the opacimeter shall be as short as possible, as prescribed in the case of sampling opacimeters. The pipe system shall be inclined upwards from the exhaust pipe to the opacimeter, and sharp bends where soot might accumulate shall be avoided. A by-pass valve may be provided upstream of the opacimeter to isolate it from the exhaust-gas flow when no measurement is being made.

3.3 A cooling system may also be required upstream of the opacimeter.
Additional Useful Reference Material


Verlag TÜV Rheinland, Köln 1979 (only in German)
ANNEX II

Wednesday
7 January 1981

FEDERAL REGISTER

Part III

Environmental Protection Agency

Control of Air Pollution From
New Motor Vehicles and New
Motor Vehicle Engines; Particulate
Regulation for Heavy-Duty Diesel
Engines
ENVIROMMENTAL PROTECTION
AGENCY

40 CFR Part 86
(Docket No. A-80-18; AMS-FRL-1628-7)

Control of Air Pollution From New
Motor Vehicles and New Motor Vehicle
Engines; Particulate Regulation for
Heavy-Duty Diesel Engines

AGENCY: Environmental Protection
Agency.

ACTION: Proposed rule.

SUMMARY: The proposed regulation
would establish a standard for the
emission of particulate matter from
heavy-duty diesel engines. Beginning
with the 1988 model year, this standard
would be 0.25 gram per brake
horsepower-hour of particulate carbon
per megapascal (g/[BHP·hr] / [MPa]). Although
this standard represents about a twothirds reduction in particulate emissions from
uncontrolled levels, it is judged feasible
without increasing emissions of nitrogen
oxides (NOx). The proposed regulation
would also amend the emission testing
regulations at 40 CFR Part 86 to
establish procedures for the
measurement of particulate emissions from
new heavy-duty diesel engines to
determine compliance with the
particulate emission standard. In
addition, this regulation would
incorporate compliance testing of
production heavy-duty engines for
particulate emissions under the
Selective Enforcement Auditing (SEA)
program beginning with the 1986 model
year.

In a related rulemaking action, EPA
would also propose a revised NOx
emission standard for these same
heavy-duty diesel engines, along with revised
NOx emission standards for light-duty
trucks and heavy-duty gasoline engines
for 1986 and later model years. In order
to ensure that these two proposals are
mutually compatible, EPA would restrict
the degree of NOx emission reduction
required from heavy-duty diesel engines to
that which is attainable with the proposed
particulate standard in effect. This
relationship between the two
rulemaking actions affecting heavy-duty
diesel engines is outlined in greater detail
later in the section entitled Technology.

DATES: Public Hearing: There will be a
public hearing on the provisions of this
proposed regulation approximately 45
days after publication of this document.
The time and place will be
announced at a later date in a
subsequent Federal Register notice.

EPA will consider all written
comments received on or before the 30th
day following the public hearing. EPA
requests that, to the extent possible,
comments be submitted prior to the
hearing.

ADDRESS: Interested persons may
submit written comments to the Central
Docket Section A-130, West Tower
Lobby Gallery I. U.S. Environmental
Protection Agency, Attn: Docket No. A-
80-18, 401 M Street SW, Washington,
D.C. 20460.

Copies of materials relevant to this
rulemaking action can be obtained from
Public Docket No. A-80-18 at the U.S.
Environmental Protection Agency.
Central Docket Section, West Tower
Lobby Gallery, 401 M Street, S.W.,
Washington, D.C. 20460. The Central
Docket Section is open to visitors
Monday through Friday, 8:30 10:00 a.m., to
4:00 p.m. (As provided in 40 CFR Part 5,
The Agency may charge a reasonable fee
for copying services.)

FOR FURTHER INFORMATION CONTACT:
Richard A. Rykowski, Environmental
Protection Agency, 2565 Plymouth Road,
Ann Arbor, MI 48105. Telephone: (313)
668-4339 (7 P.M.) 347-9516.

SUPPLEMENTARY INFORMATION:
Comments and the Public Docket:
During final rulemaking EPA will
consider all written comments received
on or before the 30th day following the
public hearing. EPA requests that, to the
extent possible, comments be submitted
prior to the hearing. EPA will keep the
record of the public hearing open for
submission of rebuttal and other
information, following the close of the
hearing until the above mentioned date.

It is EPA's intention to assure all
interested parties an opportunity to
study all information which may become
the basis for EPA's final action in this
proceeding. Accordingly, the Agency
will not consider in this rulemaking any
material which cannot be made publicly
available. Parties who wish to submit
information in response to this Notice of
Proposed Rulemaking are cautioned that
EPA will not consider, but will return to
the commenter, any comments which
are claimed, in whole or in part, to be
confidential.

Authority: Statutory authority and mandate
for this action are found under Sections
202, 203(a) and 301(a) of the Clean Air Act (42
U.S.C. 7521, 7522 and 7501). Section
202(a)(3)(A)(iii) of the Act provides
that, "The Administrator shall prescribe
regulations under paragraph (1) of this
subsubsection applicable to emissions of particulate matter from
diesel engines categories of vehicles
manufactured during and after model year
1984 (or during any earlier model year, if
practicable)." Section 202(a)(1) provides,
in part, that the Administrator shall test, or
require such tests be performed, at
appropriate emissions testing facilities,
apparatus to new motor vehicle
to determine whether such vehicle
comforms with the regulations
prescribed under Section 202 of this Act." Section 201(a)
provides, in part, that the Administrator is
authorized to describe such regulations as
are necessary to carry out his functions under the Act.

Background: Despite significant gains
made in the control of total suspended
particulate (TSP) emissions from
dieil engines, there are still many non-road
quality regions which are not able to
meet the national Ambient Air Quality
Standard (NAAQS) for TSP of 0.15
micrograms per cubic meter. As
diesel engines continue to time to
even greater portion of the
diesel engine trucks and buses whose
good vehicle weight rating exceeds 8,500
pounds, their contribution to ambient
levels of total suspended particulate (TSP)
will increase over levels that are
already significant. Current heavy-duty
diesel engines emit more than twice the
particulate per mile emitted by heavy-duty
gasoline engines operated on
unleaded gasoline. Beginning with the 1984
model year, heavy-duty gasoline engines
will for the most part be equipped with catalytic
converters to comply with existing standards for
hydrocarbons and carbon monoxide. These engines
will then be operating on cleaner
burning unleaded gasoline and their
dieil emissions are predicted to decrease by
55-65 percent. Thus, without regulation,
heavy-duty diesels will emit 40-100
times the particulate emitted by these
1984 and later model year gasoline
e quipments. Also, due to the extremely low
levels of particulate emissions expected
from future heavy-duty gasoline engines,
EPA does not plan to propose a
particulate emission standard for these
e quipments. Table 1 lists particulate
emission levels from some heavy-duty
diesel engines currently being used.

If current trends continue, EPA
expects the use of diesel engines in
heavy-duty vehicles to increase
dramatically over the next 15 years.

While diesel engines currently
produce about one-third of all new
heavy-duty vehicles sold in this country.
As production increases, this
percentage to increase to 57-69
percent by 1995. This move toward
to diesel vehicles will increase
pariculate emissions from heavy-duty
diesel to an estimated 216,000-286,000.
metric tons per year by 1988. Urban areas would be the most heavily affected by these emissions. Ambient particulate levels from heavy-duty diesel engines alone would reach 3-9 micrograms per cubic meter (annual geometric mean) in cities such as Chicago, Los Angeles, New York, and Dallas. Somewhat lower levels of 2-5 micrograms per cubic meter (annual geometric mean) would occur in smaller cities such as St. Louis, Denver, and Phoenix. These levels would occur over large-scale areas within these cities. Additional particulate levels of 5-6 micrograms per cubic meter (annual geometric mean) would be expected in localized areas within 90 miles of very busy roadways.

Table 1

<table>
<thead>
<tr>
<th>Engine</th>
<th>Particulate emissions (g/kWh)</th>
<th>Year of test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976 Caterpillar 330B</td>
<td>0.79</td>
<td>1977</td>
</tr>
<tr>
<td>1976 Caterpillar 340B (Family 16)</td>
<td>0.81</td>
<td>1977</td>
</tr>
<tr>
<td>1977 Caterpillar 340B (Family 16)</td>
<td>0.82</td>
<td>1977</td>
</tr>
<tr>
<td>1976 Container NTC-360 (Big Cam)</td>
<td>0.60</td>
<td>1977</td>
</tr>
<tr>
<td>1976 Container NTC-360</td>
<td>0.65</td>
<td>1977</td>
</tr>
<tr>
<td>1974 Container NTC-290</td>
<td>0.58</td>
<td>1974</td>
</tr>
<tr>
<td>1974 Container VT-2B</td>
<td>0.86</td>
<td>1974</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>3.1</td>
<td>1974</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>3.7</td>
<td>1974</td>
</tr>
<tr>
<td>No 83 Fuel</td>
<td>9.4</td>
<td>1974</td>
</tr>
<tr>
<td>1975 Deere V-1114</td>
<td>0.36</td>
<td>1975</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>0.36</td>
<td>1975</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>0.75</td>
<td>1975</td>
</tr>
<tr>
<td>1976 Deere V-1114</td>
<td>0.54</td>
<td>1976</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>0.54</td>
<td>1976</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>0.90</td>
<td>1976</td>
</tr>
<tr>
<td>1976 Deere V-1114</td>
<td>0.54</td>
<td>1976</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>0.54</td>
<td>1976</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>0.90</td>
<td>1976</td>
</tr>
<tr>
<td>1977 Deere V-1114</td>
<td>0.54</td>
<td>1977</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>0.54</td>
<td>1977</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>0.90</td>
<td>1977</td>
</tr>
<tr>
<td>1978 Deere V-1114</td>
<td>0.54</td>
<td>1978</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>0.54</td>
<td>1978</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>0.90</td>
<td>1978</td>
</tr>
<tr>
<td>1979 Deere V-1114</td>
<td>0.54</td>
<td>1979</td>
</tr>
<tr>
<td>No 1 Fuel</td>
<td>0.54</td>
<td>1979</td>
</tr>
<tr>
<td>No 2 Fuel</td>
<td>0.90</td>
<td>1979</td>
</tr>
</tbody>
</table>

*Engines operated on No. 2 fuel except where noted*

A description of the standard being proposed follows together with a description of the technological, environmental and economic impacts of this regulation. Following these topics are discussions of 1) the alternatives examined by EPA, 2) the major areas of the current Federal Test Procedure that would be changed by the proposed particulate test procedures, 3) the alternative particulate measurement techniques considered for the Federal Test Procedure, and 4) the major differences between the proposed test procedure and that contained in EPA's Draft Recommended Practice of April 1977.

Proposed Standard: The proposed particulate standard for heavy-duty diesel engines is 0.25 gram per brake horsepower-hour (g/BHP-hr) (0.093 gram per megawatt (g/MW)) beginning with the 1988 model year. Heavy-duty diesel engines must also continue to meet the appropriate gaseous emission standards for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) and smoke standards.

The proposing of the particulate standard will not affect the current certification or selective enforcement audit (SEA) processes. It does, however, modify test procedures to provide for particulate measurement. As manufacturers of heavy-duty diesels must currently follow these procedures to demonstrate compliance with gaseous emission and smoke standards, the same will hold true for this particulate standard. The use of a full useful-life deterioration factor, the use of a 10 percent acceptable quality level for SEA and the certification engine selection criteria will all apply to this particulate standard as they will for the HC, CO, NOx, and smoke standards. However, because the proposed test procedure will provide both particulate and gaseous emission values simultaneously, EPA does not expect this proposed particulate standard to increase the number of engines requiring testing for either certification or SEA.

Technology: The Clean Air Act as amended in August 1977 requires heavy-duty diesel particulate emission control based upon control technology which the Administrator determines will be available for the model year to which such standards apply. Due consideration must also be given to cost, noise, energy, and safety. The 0.25 g/BHP-hr (0.093 g/MJ) standard being proposed today fulfills these requirements.

EPA has in the course of developing this proposal, tested heavy-duty diesel engines from each of the 5 major manufacturers to determine their particulate emission levels; the transient test procedure as described in the "Draft Recommended Practice for Measurement of Gaseous and Particulate Emissions from Heavy-Duty Diesel Engines Under Transient Conditions," April 1977, was used. Together, the engines produced by these five manufacturers account for approximately 97 percent of the heavy-duty diesel engines sold in this country. The particular engines tested by EPA represent the complete range of engine sizes and applications found in today's fleet and account for roughly 70 percent of U.S. sales. To date, this test program is approximately 80 percent complete. EPA does not believe that delaying this proposal until the completion of this testing is necessary since 1) testing has already been completed on 3 of the 5 major manufacturers' engines, 2) given the representativeness of the tested engines of the other 2 manufacturers and the methodology used to determine the technologically feasible engine-out particulate level (discussed below), it is unlikely that the level of the proposed standard would be significantly affected by the remaining few engines, and 3) the test program will be completed before promulgation of the final standard. If changes to the standard are warranted based on this new data, the comment period will be reopened.

EPA based the level of this proposed standard on:

1. An engine-out particulate emission level of 0.41 g/BHP-hr (0.153 g/MJ).
2. A 60 percent reduction in engine-out particulate emissions from the application of trap-oxidizers.
3. Over the full useful life, an increase in particulate emissions of up to 20 percent due to engine and trap-oxidizer deterioration; and
4. A 24 percent allowance based on 12 percent variability in the particulate emissions of production engines and a 10 percent acceptable quality limit for a Selective Enforcement Audit. These four points are discussed below.

1. Engine-Out Emission Level

The 0.41 g/BHP-hr engine-out emission level represents the level of particulate emissions which EPA has determined to be technologically feasible by 1986 without the use of aftertreatment devices (i.e., trap-oxidizers) and without taking into consideration in-use deterioration or production variability. This level represents the average of the set of engines made up of each manufacturer's lowest particulate emitting model tested by EPA on No. 2 diesel fuel [see Table 1]. This approach was chosen from among several alternatives because it best satisfies the Clean Air Act requirements that the standard reflect the greatest degree of emission reduction achievable...giving appropriate consideration to the cost...and to noise, energy, and safety factors...EPA considered three other approaches in determining the technologically achievable level of engine-out particulate emissions. They were: 1) the worst baseline engine (highest particulate emission level), 2) the lowest particulate emission level among the tested engines, and 3) the highest single emission level among each manufacturer's best engines.

The first option would set the feasible level of engine-out particulate emissions of 0.79 g/BHP-hr (0.28 g/MJ) [see Table 1]. Using the engine-out particulate emissions of the "worst" baseline engine or vehicle as the starting point for setting the particulate standard may be an appropriate approach when vehicle parameters, such as engine size or...
vehicle weight, are a significant factor in the resulting level of emissions. The approach was followed to some extent in setting the particulate emission standards for light-duty vehicles and light-duty trucks (45 FR 14496, March 5, 1980). Particulate emissions from light-duty vehicles and trucks are directly affected by such parameters as vehicle weight and engine size. EPA found that the differences in particulate emissions of baseline light-duty vehicles were not so much the result of different design features leading to lower particulate levels that could be readily incorporated into other vehicles, but rather the fact that generally heavier vehicles tend to emit greater levels of particulate emissions. In order to avoid setting standards based on the level achievable by the “best” or smallest vehicle, EPA has prevented all light-duty diesels from meeting the standards except compacts and small pick-ups with small engines. The Agency based the standards on the lowest particulate level achievable by the “worst” (or largest) diesel-powered baseline vehicle.

However, using the engine-out particulate emissions of the “worst” heavy-duty engine as the starting point for setting the heavy-duty particulate standard would be inappropriate because EPA could find no significant correlation between emissions and such parameters as engine size or type. In fact, EPA found a baseline engine with much lower emissions that was comparable in terms of horsepower and in use application to the baseline engine which had the highest particulate emissions. The results of EPA’s investigation suggest that at least some engine design features leading to lower particulate emissions (from the worst baseline engine) are available.

Given these findings, EPA could not determine that 0.73 g/BHP-hr represented the “greatest reduction achievable...” and Option 1 had to be rejected. To do otherwise would have ignored the reduction potential already demonstrated by every other engine tested to date.

Option 2 would require all engines to reach an engine-out particulate level demonstrated by the best of the baseline engines tested. This level is 0.31 g/BHP-hr (0.12 g/Mile). Implicit in the choice of this option would be the judgment that (1) there are no engine design features that have an effect on particulate emissions which cannot be readily incorporated on all other heavy-duty diesels, regardless of their size, application (truck or bus), or manufacturer, and that (2) the features would produce exactly the same low particulate emission level on all engines.

EPA has examined the relationship between particulate emissions and engine size or application and has found no significant correlation. Differences were found in the emissions of engines produced by various manufacturers, but no evidence was found to indicate that the designs used to obtain low emissions on some engines were not available to all manufacturers. However, EPA could not find evidence that these design features would have exactly the same effect on every manufacturer’s engines, unless each manufacturer would produce an exact replica of the lowest-emitting baseline engine. For example, the primary cause of the low particulate emissions produced by this engine may have been an improved fuel injection technique which is available to all manufacturers. However, because the fuel injection system is an integral part of the engine and its efficiency would depend on many other engine parameters (whose effect on particulate emissions are not at this time fully understood), the only way to determine the effect of a modification on a given engine would be to test it on that engine. While EPA could have theoretically performed enough tests on a sufficiently large sample of engines in an attempt to demonstrate that all engines could achieve the emissions of the best baseline engine, the cost of such a program would be enormous and the implementation of this particulate standard would have been postponed by at least 1-2 years. The delay would be unacceptable given the mandate of the Clean Air Act. Given the available data, a standard based on Option 2 might well require a major redesign of virtually all engine families for compliance to be assured. EPA has no basis for expecting that such a major redesign effort would even be possible.

Thus, if EPA chose this approach, it would be possible that a large number of engines might not be able to meet the particulate standard in 1980. In this case, the affected manufacturers could only introduce these engines into commerce if they elected to pay a nonconformance penalty on each engine. While EPA believes that nonconformance penalties have a definite role to play in the regulation of heavy-duty vehicles, we do not believe that Congress intended for nonconformance penalties to be paid in order for most engines to be sold. Yet this situation could arise under Option 2.

Option 3 would use as the starting point for setting the standard the highest engine-out particulate level from the set of engines made up of each of the four major manufacturer’s lowest emitting engines. In other words, Option 3 would set the engine-out particulate level at 1.9% of BHP-hr (0.22 g/Mile) (see Table 1). The record of Table 1 shows that all two-thirds of the engines tested are already emitting less particulate than this level. Thus, this option would face the same problem as discussed above with Option 1: it does not give adequate consideration to the control potential already demonstrated by the vast majority of the engines being produced today. Thus, while Option 3 might appear to solve the problem of Option 2, it is simply getting manufacturers to manufacture different engines than the same engines associated with Option 1 and EPA had to reject it from further consideration.

The option chosen by EPA, which bases the feasible level of engine-out particulate emissions on the average of the engine emissions of the lowest-emitting engine from each of the five major manufacturers, addresses the problem presented by each of the previous three options and best fulfills the congressional mandate to develop a particulate standard which reflects “the greatest degree of emission reduction achievable...” giving appropriate consideration to the cost... and to noise, energy, and safety factors...” It takes into consideration, for example, the inability of several manufacturers to build engines which emit relatively low levels of particulate from each of the five major manufacturers, addresses the problem presented by each of the previous three options and best fulfills the congressional mandate to develop a particulate standard which reflects “the greatest degree of emission reduction achievable...” giving appropriate consideration to the cost... and to noise, energy, and safety factors...” It takes into consideration, for example, the inability of several manufacturers to build engines which emit relatively low levels of particulate from each of the five major manufacturers, addresses the problem presented by each of the previous three options and best fulfills the congressional mandate to develop a particulate standard which reflects “the greatest degree of emission reduction achievable...” giving appropriate consideration to the cost... and to noise, energy, and safety factors...” for the average of Table 1. Implicit in the choice of this option would be the judgment that (1) there are no engine design features that have an effect on particulate emissions which cannot be readily incorporated on all other heavy-duty diesels, regardless of their size, application (truck or bus), or manufactured. Option 3 would use as the starting point for setting the standard the highest engine-out particulate level from the set of engines made up of each of the four major manufacturer’s lowest emitting engines. In other words, Option 3 would set the engine-out particulate level at 1.9% of BHP-hr (0.22 g/Mile) (see Table 1). The record of Table 1 shows that all two-thirds of the engines tested are already emitting less particulate than this level. Thus, this option would face the same problem as discussed above with Option 1: it does not give adequate consideration to the control potential already demonstrated by the vast majority of the engines being produced today. Thus, while Option 3 might appear to solve the problem of Option 2, it is simply getting manufacturers to manufacture different engines than the same engines associated with Option 1 and EPA had to reject it from further consideration.

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the loadtime available should be sufficient to allow it to incorporate design features of other manufacturers' engines which have already been demonstrated to lower particulate emissions.

By averaging the particulate emission levels of the best engines, the chosen approach recognizes basic manufacturer-to-manufacturer design differences and reflects a more representative range of performance capabilities than other options based on the performance of single engines. Level of 0.41 g/BHP-hr (0.15 g/MJ) is thus a stringent level to use as a starting point, requiring the higher-polluting engines to incorporate, to a great degree, the demonstrated technology of the best engines of a given manufacturer. Yet at the same time it takes into consideration the uncertainties that would be involved in forcing a manufacturer to adopt almost completely the designs employed by its competitors.

While it is possible that a more stringent engine-out level could be identified that would be technologically feasible, EPA does not have sufficient data at this point to support the utilization of such a level. Further study would be required before a more stringent level could be identified and adequately supported. This would only serve to further delay implementation of the standard. Therefore, EPA believes that it is more appropriate to utilize the engine-out level that is supported by the available data. EPA will continue its research in this area and if it becomes evident that a more stringent engine-out level is technologically feasible, EPA will commence the work to revise the standard accordingly.

Up until this point, we have restricted the discussion of engine-related technology to that already present on existing engines and avoided discussing additional engine modifications which could also reduce particulate emissions. One promising long-term technique in this latter category is to modify the engine to burn methanol. Methanol is an attractive alternative fuel since it (1) can be readily producible from plentiful domestic sources such as coal and biomass; (2) can possibly be produced by more thermally efficient and environmentally acceptable processes than processes which yield synthetic crude; (3) can be produced with readily available, commercially proven technology which appears to require less capital investment than Syncrude production processes; and (4) appears to have the potential for very low particulate, hydrocarbon and biologically active organic emissions. The potential for reduced particulate emissions makes methanol a promising alternative fuel with regard to this level. Particulate controls that actually increase NOX emissions would only aggravate this situation. Thus, EPA will not factor the particulate reductions available from these techniques into its determination of the greatest particulate reduction achievable from heavy-duty diesels.

However, there are some techniques available which can reduce engine-out particulate emissions with increasing NOX emissions. Data available to EPA has shown that modifications made to a Cummins engine and different modifications made to a Caterpillar engine both resulted in lower particulate emissions and lower NOX emissions. In addition, the latter engine was already a relatively low particulate emitter. These results, plus the general fact that particulate emissions have yet to be directly controlled and consequently, have yet to be factored into design decisions, support the conclusion that engine-out particulate emissions could be reduced below the 0.41 g/BHP-hr level without increasing NOX emissions.

Before applying these reductions to the 0.41 g/BHP-hr particulate level, however, the Congressional mandate to reduce NOX emissions must be considered once again. This mandate is very specific, requiring reductions to a specified level. The Congressional mandate to reduce particulate emissions is somewhat less specific, calling only for the greatest reduction achievable without specifying a level. It appears that if diesel cars are to meet or even approach a NOX level of 1.7 g/BHP-hr, some increase in particulate emissions may have to result. If the particulate reductions mentioned above were left to offset increases in particulate emissions due to NOX controls, a lower NOX level could be achieved. This would increase the likelihood of achieving the Congressional mandate to reduce NOX emissions. As will be described in the next section, significant reductions in particulate emissions are available from aftertreatment techniques, such as trap-oxidizers. Therefore given (1) that there are other technologies which provide significantly lower particulate emissions and (2) the specificity of the NOX mandate, EPA has decided that the two Congressional mandates would best be met by reserving the engine-out particulate reductions achievable below 0.41 g/BHP-hr to offset the effects of NOX control. In this way, the degree of NOX reduction available to diesels will be enhanced, while significant particulate reductions still occur via use of trap-oxidizers. Thus, 0.41 g/BHP-hr will be used as the lowest engine-out

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particulate level achievable by all heavy-duty diesels.

While this decision enhances the feasibility of the light-duty NOx standard it does not insure that net increases in particulate emissions will still not occur due to the implementation of NOx controls. Any such increases could make the 0.41 g/BHP- hr particulate level infeasible. To prevent this from occurring, EPA, in its proposal of the NOx standard will restrict the required NOx reduction from diesels to that achievable with a 0.41 g/ BHP-hr engine-out particulate emission level. In this way, the feasibility of the NOx standard can be enhanced without affecting the feasibility of the particulate standard being proposed today.

2. Trap-Oxidizers

In addition to reducing particulate emissions formed in the combustion process, additional reductions are available from the application of after-treatment devices, particularly trap-oxidizers. A trap-oxidizer basically consists of a high-temperature trapping material housed in a stainless steel shell. Placed in the exhaust, it collects particulate and periodically (or continually) incinerates (oxidizes) it. The incineration process usually requires an initial minimum exhaust temperature of 450-500°C. Because such temperatures may not normally occur in heavy-duty diesel exhaust, exhaust temperatures may need to be artificially raised to the necessary level to permit regeneration (i.e., incineration).

The particulate collection efficiencies of many trap materials have already been demonstrated. Many materials, such as alumina coated wire mesh and metal wool, have shown efficiencies of up to 65 percent. Slightly modified ceramic monolithic substrates (similar to those used in automotive catalysis) have shown collection efficiencies of up to 84 percent. In determining the technologically achievable level of particulate emissions with after-treatment, EPA has used a 80 percent collection efficiency as an upper limit.3 This is the same efficiency which EPA used to determine the technologically feasible level for the light-duty diesel particulate standard (45 FR 14449).

Several trap-oxidizer regeneration approaches have been investigated. The simplest solution would be to continuously (or near-continuously) oxidize the particulate, in which case the trap-oxidizer would function much like a diesel catalytic converter. The problem with this approach is simply in maintaining the high-temperature conditions that ensure continual oxidation. Much effort is being expended on producing converters which would function on diesels, and designs have been attempted by EPA that are close to what is needed. An alternative is to oxidize the particulate only occasionally, when enough organic material has been collected by the trap to aid the process and when the exhaust temperature is high enough to initiate oxidation. Many approaches have been suggested to initiate the oxidation process. The most promising is the addition of an inlet air throttle, which would limit the intake air into the combustion chambers and raise the temperature of the exhaust. The throttling would be periodic, and could be achieved by raising the engine speed, by raising the engine load, by utilizing throttling to initiate oxidation, the trap collection efficiency actually increased slightly. There appear to be no technical problems with utilizing throttling to initiate oxidation, and there is evidence that throttling may possibly reduce engine-out particulate and NOx emissions slightly.

Collection efficiencies and regeneration techniques have progressed to the point where the most critical issue is whether the efficiency and regeneration mechanism can be maintained over the useful life of the vehicle. At this time, EPA has only limited trap-oxidizer durability data, as researchers have been reluctant to fund durability testing until other more basic questions such as burn-off control were solved. The problems of durability are problems which lend themselves to engineering solutions; no major new technology is needed. Under controlled conditions, existing traps have already been shown to retain their trapping capability over many burn-off cycles. The trapping media and engine controls already appear to exist for a full useful life trap. The major problem remaining is one of characterizing the in-use operating conditions of the engine, so that regeneration may be controlled to always insure that the burn-off temperature stays below that which could damage the trap. As this is primarily a problem of optimizing the trap position in the exhaust and the logic used by the burn-off control device, we are confident that the durability questions will be resolved in the near future.

One aspect of heavy-duty diesel operation which might appear to cause a durability problem is a longer useful life (in terms of miles) relative to light-duty diesels. Indeed, the average useful life of a heavy-duty diesel is currently 475,000 miles, while that of a light-duty diesel is only 100,000 miles. In terms of years, however, the average heavy-duty diesel is used only nine years, as opposed to ten years for light-duty diesels. This provides some indication of the difference in the types of driving characteristic of the two types of vehicles. Heavy-duty diesels may accumulate large amounts of mileage, but they also do it in a short period of time under relatively steady conditions. This type of driving should be much less damaging to a trap than the shorter trip driving of a light-duty vehicle, where the temperature transients, which can structurally stress the trap, should be much greater. Thus, the useful lives in terms of time, rather than mileage, should be the better indicator of durability requirements of the trap. As heavy-duty diesel engines capture more of the lighter truck market now dominated by gasoline engines, their operation will begin to approach that of light-duty vehicles in at least some aspects. However, EPA expects the useful life of these former gasoline-fueled vehicles to remain the same after dieselization as before. This useful life is only 114,000 miles, which is very close to that of light-duty diesels. Thus, EPA expects that heavy-duty diesels will experience no greater trap durability problems than light-duty diesels.

EPA recognizes that trap-oxidizers are not currently available to permit compliance with the proposed 1985 heavy-duty diesel standard, but given sufficient good faith effort by the manufacturers, 60 percent efficient trap-oxidizers should be available in time to be incorporated on the 1986 model year fleet. As discussed above, the basic concept of the trap-oxidizer is well understood. The improvements that are necessary are engineering problems, such as trap placement and the optimization of the regeneration control. The solution to these problems is more a function of the resources allocated to the problem than any scientific or technical breakthrough, which would be the case if an entirely new trapping media were required.

The recently promulgated light-duty diesel particulate standards (45 FR 14449) call for a final level of control in 1985 based on trap-oxidizer technology. Information gained from the study of...
trap-oxidizers on light-duty diesels to date has centered on areas such as 1) development of a durable, efficient trapping material, 2) understanding the burn-off process, and 3) development of engine control techniques to ensure proper burn-off. Knowledge gained in these areas should be especially applicable to heavy-duty diesels. However, heavy-duty diesels can often operate under different conditions than their light-duty counterparts. For example, they are at times left to idle for periods of several hours (due to inherent cold-start difficulties and to prevent starter wear). This operating characteristic is important to trap-oxidizer regeneration since exhaust temperatures are very cool at idle; high exhaust temperatures are needed to incinerate collected particulate. Thus, means must be devised to allow for trap-oxidizer regeneration while engines are in this mode. While this problem and others do not appear to be insurmountable they do indicate that some additional design effort will be necessary to incorporate trap-oxidizers onto heavy-duty diesels. To facilitate the application and optimization of these devices onto heavy-duty diesels, an additional year is being provided in this proposal beyond the 1986 date of trap-oxidizer introduction for light-duty diesels.

As mentioned earlier, 1986 is also the year that the forthcoming NO₃ proposal will apply for these same engines. Many engine design and operational features of heavy-duty diesels affect both these pollutants (see the Regulatory Analysis for further details). As mentioned earlier, some can cause decreased emissions of one pollutant while causing emission levels of the other to increase. As manufacturers will have to design their engines for particulate control while considering the impact on NO₃ emissions (and vice versa) it would be most reasonable to have the two standards apply in the same year, allowing design to occur in parallel. Thus, 1986 appears to be a reasonable date to implement the 0.25 g/BHP-hr particulate standard in light of the design and engineering efforts necessary and because of the close relationship between particulate and NO₃ emissions.

Left to the marketplace, it is extremely unlikely that sufficient pressure would be brought to bear on the industry to aggressively pursue trap-oxidizer development. Experience has shown the greatest emission control development work to have taken place when direct regulatory incentives were in place. Since most trap-oxidizer designs are not now available to successfully comply with the proposed 1986 standard, to the extent that the standard motivates the industry to aggressively pursue research and development it is a "technology-forcing" standard. The term "technology-forcing" often implies that the sought-after technology is completely unknown or unforeseeable, but such is not the case here. The basic concept of the trap-oxidizer is very well understood, and, as explained above, much development has already occurred. Thus, this rulemaking is technology forcing only in the respect that it will encourage a feasible control strategy that might otherwise be ignored.

3. Deterioration of Engine and Trap-Oxidizer

Data indicating the degree of deterioration of heavy-duty diesel engines, with regard to particulate emission, over their useful lives are not available since 1) particulate emissions from heavy-duty diesels have not been regulated before and 2) an adequate test procedure was only recently become available; manufacturers will be required to certify using the transient test procedure beginning with the 1985 model year. However, EPA tests of in-use light-duty diesels having accumulated an average 48,000 miles (77,280 kilometers) indicate that little if any increase in engine-out particulate emissions occurs. With the stability of heavy-duty diesel emissions of other pollutants, the use of similar fuel systems, and the similarity of the general emissions stability of light- and heavy-duty diesels, it is reasonable to project that the engine-out particulate emissions of heavy-duty diesels will deteriorate very little. Heavy-duty diesels were not included in this in-use survey since 1) no zero-mile certification data are available because heavy-duty diesel particulate is not currently regulated and 2) the only available test site has been occupied with the baseline emissions program.

Information on the deterioration of trap-oxidizer efficiency is even more scarce, as none are currently commercially available and durability tests of available prototypes have been waiting for engine production and burn-off techniques were perfected. EPA therefore solicits comments in the areas of anticipated engine and particularly trap-oxidizer deterioration as they relate to particulate emissions. For the purposes of this proposed rulemaking EPA has assumed that the combined engine and trap-oxidizer deterioration will be no more than 20 percent.

4. Selective Enforcement Auditing and Production-Line Variability

In addition to complying with EPA's certification process for new engines, heavy-duty diesel manufacturers are also subject to a Selective Enforcement Audit (SEA) of their production engines, the fourth point mentioned above. As is the case for other regulated pollutants, at least 90 percent of a manufacturer's production engines must meet the proposed particulate standard to keep the probability of failing an SEA below 5 percent. This means that manufacturers must achieve excellent quality control or else design their emission control systems to reach levels below the standard on the average. Otherwise, if the control system were designed to just meet the standard, only about half the engines would pass.

To determine how far a manufacturer would have to design below the standard, two factors must be taken into account: 1) the variability of the particulate emissions of the production engines of a given engine family, and 2) the small number of prototypes upon which the design decision is made. The 10 percent acceptable quality level (AQL) could lead manufacturers to design their engines (on the average) to meet a particulate level 12.88 times the existing standard deviation lower than the standard (assuming a normal distribution of emissions) or manufacturers could improve quality control to reduce variability, which would allow them to design closer to the standard. While EPA believes that the production variability of particulate emissions could be reduced from existing levels, the lack of data on the existing variability of production engines, plus the lack of data on the ability to reduce variability, prevents a reliable judgment to be made concerning this ability. The absence of reliable test facilities also prevents any effort by EPA to obtain such data on its own. Since EPA cannot determine in the case of this regulation that reductions in variability will be sufficient to deal with the effect of a 10 percent AQL, it is reasonable to allow for a reduction in the design target for the average vehicle to account for the presence of a 10 percent AQL. As indicated above, this allowance should be 1.26 times the standard deviation of particulate emissions from production engines. While no actual data on the particulate emission variability of production engines are available, EPA assumed that this variability would be similar to that for gaseous emissions, or 12 percent of...
mean emissions. Given this, the effect of the 10 percent AQI would be to increase the technologically feasible level by 15.4 percent, or a factor of 1.154. Including the effect of base design decisions on only a small number of prototype engines (assumed to be three in this case) raises this factor to 1.24.

EPA requests data on the actual production line variability of particulate emissions, the degree to which production line variability can be reduced, and also on the methodology used by manufacturers to determine their design targets.

Derivation of Standard: All the above mentioned factors were combined to yield the proposed 0.25 g/BHP-hr standard. First, there is the engine-out particulate level of 0.41 g/BHP-hr which is reduced by 0.35 metric tons via trap-oxidizer technology to 0.104 g/BHP-hr. Then, taking into account the effect of emission variability and the 10 percent AQI, increases this value by a factor of 1.24 to 0.203 g/BHP-hr. Finally, the deterioration factor is 1.2 increases the technologically feasible level to just under 0.25 g/BHP-hr, which is the level being proposed.

Environmental Impact: The proposed standard will reduce particulate emissions from heavy-duty diesels by 64 percent in 1995 with respect to what would be expected without regulation. Nationwide particulate emissions in 1995 from heavy-duty diesels will be reduced from approximately 218,000-260,000 metric tons per year to 78,000-95,000 metric tons per year. Urban particulate levels from these vehicles will also decrease 64 percent in 1995 from 79,000-97,000 metric tons per year to 28,000-35,000 metric tons per year. This emission reduction will reduce ambient heavy-duty diesel particulate levels in large cities (e.g., New York, Chicago, Los Angeles) from 1.7-7.2 to 0.6-2.6 micrograms per cubic meter (annual means). Heavy-duty diesel particulate levels in smaller cities (e.g., St. Louis, Pittsburgh, Phoenix) will also decrease from 1.6-4.9 to 0.6-1.6 micrograms per cubic meter (annual means). Localized levels which occur over and above these larger scale impacts will also decrease from 4.6-5.6 micrograms per cubic meter to 1.6-2.0 micrograms per cubic meter (annual means). These latter impacts could occur as far as 90 meters from very busy roadways.

The above impacts clearly show the significant reductions in ambient particulate emission levels expected from these regulations. It should be noted, however, that until such time as particulate matter have the same level of impact on human health. Small particles, which are much more likely to be deposited in the alveolar region and which require much longer periods of time to be cleared from the respiratory tract, are believed to be much more deleterious to human health on an equal mass basis than larger particles. Thus, control of diesel particulate (100 percent is less than 15 micrometers in diameter and approximately 97 percent is less than 2.5 micrometers in diameter) is especially important with respect to human health. There is also particular concern over the chemical composition of diesel particulate emissions, as the extractable organic fraction of diesel particulate is known to be mutagenic in short-term biosays. EPA is currently performing a health assessment to determine the carcinogenic risk (if any) to human milk.

However, EPA has not based the level of the proposed standard on any presumption of a carcinogenic effect being associated with diesel particulate. Should future results from the diesel health effects studies indicate that further action is necessary to control particulate emissions, EPA will exercise its authority under Title I of the Clean Air Act to do so.

Economic Impact (All Costs are in Terms of 1980 Dollars): EPA estimates the retail price of heavy-duty diesel vehicles to increase by approximately $527-$550 in 1980 due to the engine and vehicle modifications necessitated by this regulation. The retail price increase of a new vehicle mentioned above is about 0.5-3.0 percent of the total cost of a new heavy-duty diesel vehicle. The range of costs is due to possible differences in trap-oxidizer systems which may be used on different models. The trap-oxidizer system is also expected to require maintenance costs about $30 when it is five years old. However, the vehicle modifications involved in adding the trap-oxidizer will eliminate the need to replace the exhaust pipe and muffler throughout the vehicle's life. This will save about $400 in maintenance costs (discounted) during the vehicle's life. In all, vehicle maintenance costs should decrease by $178 due to the 1986 standard (discounted to year of vehicle purchase). Overall, then, this regulation will cost $349-$472 per vehicle. All of these estimates include profit at both the manufacturer and dealer level. All, the increased cost of owning and operating a heavy-duty diesel due to this regulation will be less than 0.3 percent.

Due to cost and future increases in the price of gasoline-fueled vehicles due to emission controls and the negligible impact of this regulation on the cost of converting goods by heavy-duty diesel, EPA expects no decrease in demand relative to the sales of gasoline-fueled vehicles in this segment. This regulation is expected to have a minor impact on the cost effectiveness of particulate control strategies implemented in the past. This is important to emphasize that in some respects the mobile and stationary.
source strategies for particulate control have certain differences in their primary purposes. Therefore, reduction of a measure of effectiveness for comparison purposes has inherent limitations. In spite of these, however, the comparison may still be useful to the degree that it focuses on one of these common purposes, protection of public health and welfare.

There is another step which own be taken to improve the measure of cost effectiveness and that is to relate effectiveness to reductions in ambient pollutant concentrations instead of emission reductions. People's exposure to pollutants is directly related to the ambient pollutant concentration of the air they breathe, but only indirectly related to the emissions from various sources. However, the data necessary to perform such calculations are very difficult to obtain and generally not available. Still, to indicate the potential differences between the air quality impacts of different sources, a rudimentary air quality analysis was performed. ¹ Using indicators of a source's impact on air quality relative to its emissions, EPA found that both heavy- and light-duty diesel engines produce between 45 and 168 times the ambient particulate concentration as the largest power plants (4.520 megawatt heat input) based on equivalent emission rates. Similarly, both heavy- and light-duty diesel engines produce between 1.1 and 4.7 times the ambient particulate concentration as the largest power plants (1.5 megawatt heat input) based on equivalent emission rates. No localized impacts from other source were examined, only large-scale impacts. If localized impacts had been examined, the results would be different. The results from other stationary sources could also be quite different.

Just considering differences in the relationship between emissions and air quality, the results of any comparison of cost effectiveness could be changed drastically. Indeed, there are many other factors which should also be considered. As mentioned earlier, the above ratios are only an extremely rough estimate of the relative air quality impacts of diesels and power plants. Many simplifications were necessary in order to make this comparison at all. Overall, however, the results do indicate clearly that control of diesel particulate is not less cost effective than other cost-effective control measures adopted by EPA using the measures of effectiveness discussed above.

Alternative Actions: Control of particulate emissions from heavy-duty diesel vehicles is required by the Clean Air Act. Thus, EPA does not have the discretion to forego control of heavy-duty diesel particulate emissions in favor of other control strategies. However, alternative individual engine standards and/or implementation dates for this heavy-duty diesel particulate standard were examined.

The Clean Air Act requires this particulate standard to "reflect the greatest degree of emission control achievable through the application of technology which the Administrator determines will be available for the model year to which such standards apply." EPA must also give due consideration to cost, energy, and safety. The main goal of our analysis of alternative levels and dates, then, was to determine the level(s) and timing of the standard which best complied with the requirements of the Act.

First, EPA considered implementing a one-step versus a two-step standard. A one-step standard set at the final level of technology (trap-oxidizers) would be available in the same year (1988) as the revised heavy-duty diesels. As alluded to earlier, manufacturers will be required to certify their engines using the transient test procedure beginning in 1985. This essentially precludes an interim standard earlier than 1986 since it would have to use the transient test procedure, which would not be as representative of in-use particulate emissions as the transient cycle. An interim standard for 1985 would apply for only 1 model year and provide only modest reductions in particulate emissions at a time when more significant increasements would be expected, since the NOx standard would not come into effect until 1988. A standard in 1985 would also divert valuable Agency and industry resources from implementing and meeting the 1980 standards (NOx and particulate) and shifting them toward a less effective interim particulate standard. In 1985, with the coming of the revised NOx standard, a particulate standard will be needed to prevent potential increases in particulate emissions. However, by then a standard based on trap-oxidizers could be implemented.

EPA specifically considered a two-step standard with the first standard taking effect in 1988. Under this scenario, the 1988 standard would be based on improved engine design, while the later standard (in this case, 1988) would be based on the use of trap-oxidizers. This alternative would have the advantage of allowing manufacturers more time to develop trap-oxidizers and also separate this work from that related to engine development. Its disadvantages were the added cost of certifying all engines in 1988 and delaying the primary air quality benefit of the regulation for two more years. EPA also examined the effect of delay on capital and trap-oxidizer costs, but found no substantial advantage resulting from this approach.

In all, EPA found that the leadtime advantages of postponing the final level of control did not outweigh the delay of the air quality benefits of a standard which could be implemented in 1986 based on technology and leadtime considerations. This was particularly true given that there appeared to be no great cost benefit involved with delay.

For these reasons, EPA chose a one-step standard in 1988. However, EPA would reconsider a two-step standard approach if additional data warranted such action.

Second, EPA considered the possible choices for the level of this standard. These alternative levels have already been discussed in the section on technology and will not be repeated here. In summary, EPA examined the various levels in light of the Clean Air Act requirement that the standard reflect the greatest reduction potential achievable considering the leadtime available and other specified factors and concluded that the standard which is being proposed was appropriate. The issue of cost has already been discussed previously, so no further mention of it will be made here. Since the proposed standard will not affect the fuel economy of heavy-duty diesels, it is reasonable with respect to energy impacts. Based on numerous successful regenerations of prototype trap-oxidizers, EPA also expects that the application of trap-oxidizer technology can and will be made in such a way as to ensure the safe operation of the vehicle. ² Thus, in consideration of all these factors, we chose the level of 0.25 gram per brake horsepower-hour in 1988 proposed today.

The use of an averaging approach upon which to base the actual particulate standard is not planned for this rulemaking. However, EPA is actively exploring the feasibility of emissions averaging and will be proposing an averaging scheme for controlling NOx emissions from light- and heavy-duty trucks. The results of this analysis of averaging will in part determine if EPA will consider emissions averaging for this heavy-duty

¹ Consult the Regulatory Analysis for further details.

² Consult the Regulatory Analysis for further details.
diesel particulate standard and other existing mobile source emissions standards through future rulemaking actions.

**Major Revisions to the Existing Heavy-Duty Test Procedure:** The recently promulgated gaseous emissions regulations for 1988 and later model year heavy-duty engines included a new test procedure for determining gaseous exhaust emissions from heavy-duty engines. The test procedure specifically for diesel engines was very similar to that specified for gasoline engines and applied to the same gaseous pollutants (HC, CO, NOx). With the mandate to regulate particulate emissions, EPA has proposed additions to the heavy-duty diesel test procedure that include the measurement of particulate emissions from diesel engines. These additions will not affect the basic heavy-duty test procedure nor the stringency of the test with respect to gaseous emissions, but merely specify the additional equipment and steps necessary for the measurement of diesel particulate.

Because EPA just recently revamped the heavy-duty engine test procedures and foresaw at that time the need to propose these modifications, we took steps then to ensure that no unnecessary equipment expenses would be incurred by manufacturers and others interested in testing diesel engines. The test procedure modifications being proposed today do require certain pieces of equipment to be used which are not required for gaseous emission testing (e.g., the dilution tunnel). To prevent the need for replacing equipment for measuring gaseous emissions which had been used for only a short period of time (e.g., the dilution tunnel replacing the baffled box) with new equipment to allow measurement of particulate emissions, EPA originally designed the gaseous emission test procedure to allow for the addition of equipment associated with particulate testing without making obsolete any of the equipment used for measuring gaseous emissions. In this way, manufacturers could design their transient test cells to allow for future particulate testing, even though the particulate standards had not yet been proposed, and none of their effort would have been wasted.

**Additions and changes to the current Federal Test Procedure (FTP) for diesels that would be brought about by the incorporation of particulate testing are discussed below:**

1. **Measuring particulate matter:** The particulate measurement procedure would require a dilution tunnel and a constant mass sampler (i.e., a train of tubes which must precede the critical flow venturi or the positive displacement pump). The dilution tunnel would have to be sufficiently long to assure thorough mixing at the sampling probes. The use of a mixing box with extensive baffling was rejected because of suspected particulate loss on its surfaces. A constant mass sampler, as opposed to a constant volume sampler, is necessary for particulate testing to insure that the particulate sample taken is proportional to the entire emissions of particulate from the engine at any given time.

2. **Measuring particulate emissions simultaneously with gaseous emissions:** The first was particulate matter, after dilution and mixing with ambient air in a dilution tunnel, would be collected on filter media (fluorocarbon or fluorocarbon-coated glass fiber) over both the cold and hot start portions of the test. The temperature of the exhaust at the location of particulate sampling would have to be kept below 125°F (51.7°C) at all times. This could be accomplished by either of two methods, single or double dilution. With single dilution, the constant mass sampler would have to be of sufficient capacity to maintain the temperature of the entire diluted exhaust below 125°F (51.7°C) at the particulate probe tip. With double dilution, the temperature of the diluted exhaust in the primary tunnel would be allowed to be well above 125°F (51.7°C), but a second dilution of a fraction of the exhaust in the secondary tunnel would have to maintain the temperature of this smaller sample below 125°F (51.7°C) at all times during the test. This 125°F (51.7°C) temperature restriction is necessary to insure that heavy hydrocarbons and other organic compounds, which would become associated with the particles upon ambient dilution in real life, are also measured by EPA's test procedure. This temperature requirement also causes some of these heavy organics to be measured twice, once as particulate and once as hydrocarbons. Before the level of exhaust hydrocarbons is measured under EPA's test procedure, the sample is heated to 375°F (191°C) to drive some of these hydrocarbons off of the particulate. These hydrocarbons on the particulate at 125°F (51.7°C) and in the gas phase at 375°F (191°C) may participate in oxidant-forming reactions and therefore should be measured as hydrocarbons. These same hydrocarbons may also remain on the particulate and be inhaled as such and therefore should also be measured as particulate.

As can be seen from an examination of the test procedure amendments being proposed today, EPA has republished the entire Subpart N, which contains the transient test procedure for heavy-duty vehicles, gasoline-fueled and diesel, for the 1980 model year. We did this for a number of reasons. First, we hoped that it would provide the user with a single, comprehensive document containing the heavy-duty test procedure for both gaseous and particulate emissions. This would avoid the need to piece this proposal together with past publications in order to obtain a complete test procedure. Two, while the number of substantive changes to the test procedure is limited, the large amount of internal referencing done in Subpart N for descriptive purposes (e.g., see 40 CFR 80.1310-54) requires many sections to be revised because the references will change (to "Sec."). Thus, the majority of the sections in Subpart N would have needed to be revised regardless. While the republication of Subpart N for the 1980 model year makes it easier to use the test procedure in practice, it also makes it more difficult to identify the revisions being proposed today. To aid those interested in finding these revisions, EPA has listed below the sections of Subpart N which contain proposed substantive revisions. Any revisions contained in other sections should only be revised references or the addition of "particulate" to descriptive sentences which currently describe the test procedure as applying only to the measurement of gaseous emissions.

Sections in Subpart N containing proposed substantive revisions are:

- 80.1300-00
- 80.1337-00
- 80.1315-00
- 80.1310-00
- 80.1320-00
- 80.1344-00
- 80.1327-00

**Test Procedure Alternatives:** EPA considered and rejected two alternative techniques for estimating on-the-road particulate emissions. The first was the smoke measurement. EPA rejected this technique because 1) smoke does not correlate well with particulate emissions across engine lines, 2) smoke measurements are very inaccurate at the levels encountered over most of the transient cycle.

In spite of this, the presence of the smoke standard has helped to prevent particulate emissions from increasing while no particulate standards were in effect. There is a strong correlation between smoke and particulate and a worst case test always has some effect on other-than-worst case conditions. However, a smoke standard is not a viable long-term alternative to a particulate emission standard.
The existing smoke test and standard are being retained along with the addition of particulate testing. The smoke test measures smoke under worst case conditions which are not often encountered over the transient cycle. Therefore, it is unlikely that the particulate standard alone would insure continued compliance with the existing smoke standards. Also, the current smoke standard is primarily for aesthetic reasons which do not disappear with the addition of particulate testing.

The second technique EPA considered was opto-acoustical measurement. This technique uses a laser beam to heat the particles in the exhaust and measures the resulting pressure waves with a microphone. EPA also rejected this technique because (1) it is as yet unproven and (2) it appears to have many of the same correlation problems as smoke measurement, primarily that the acoustical response varies with the chemical composition of the particulate.

Changes from Previous Draft Test Procedure: EPA published the "Draft Recommended Practice for Measurement of Gasous and Particulate Emissions from Heavy-Duty Diesel Engines Under Transient Conditions" in April 1979 and distributed it on May 8, 1979. Two manufacturers—Caterpillar Tractor Company and Cummins Engine Company—responded to the request for comments on the Draft Recommended Practice. One of the more significant responses was Cummins' comment that substantial errors in the instantaneous proportionality of the sample taken from the primary tunnel (up to 25 percent) might result with the double-dilation sampling technique due to the second residence time in the secondary tunnel. The effect of such an error on particulate measurements would depend on the particle concentrations at the time the sampling errors occurred. However, these instantaneous concentrations cannot be measured at this time.

In its studies of the two systems to date, EPA has found no evidence that any such sampling error actually affects the mass of particulate collected. Rather, the evidence indicated that the two systems produced very comparable results. However, EPA made one modification to the draft recommended practice which should substantially reduce any instantaneous sampling errors and further ensure that no such errors would affect the mass of particulate collected. EPA has reduced the required residence time of the diluted exhaust in the secondary tunnel from 2 to 0.25 seconds. The latter residence time was derived from confirmable light-duty diesel testing using the single dilution technique. It represents the total time necessary after dilution to ensure that the gaseous and particulate phases come to equilibrium before the particulate is collected.

The remainder of the comments from both manufacturers related to very detailed aspects of the test procedure. EPA has incorporated those comments, where possible, into the test procedure being proposed today. Some suggested revisions were not made, however, due to the fact that no data were presented to support the viability of the revision. A detailed analysis of the comments is contained in the docket and can also be obtained by calling or writing the contact person for this regulation (shown above).

Selective Enforcement Auditing (SEA): SEA will be performed on production heavy-duty diesel engines beginning in the 1984 model year to determine whether they conform to the regulations under which their respective certificates of conformity were issued. Subpart K of Part 80, SEA of New Gasoline-Fueled and Diesel Heavy-Duty Engines (45 FR 41311, Jan. 21, 1980), describes the program for the testing of these engines. Paragraph § 80.1008-84(a) of Subpart K provides that these engines will be tested in accordance with Subpart N. With the establishment of a new particulate emission standard and the addition of particulate testing procedures to Subpart N, EPA would require SEA testing of heavy-duty diesel engines for compliance with this standard beginning in the 1986 model year.

Nonconformity Penalties: Section 203(g) of the Clean Air Act provides for nonconformity penalties (NCPs) in the case of any class or category of heavy-duty vehicles or engines to which a standard promulgated under section 202(a) of this Act applies. . . As discussed elsewhere in this preamble, EPA believes that all heavy-duty diesel engines will be capable of complying with the proposed standard. However, whenever a manufacturer must do substantial development work and/or make substantial modifications of existing emission control techniques in order to both certify and produce heavy-duty diesel engines capable of complying with all regulatory requirements, there is some risk that unforeseen circumstances could result in "technological laggards," i.e., manufacturers whose heavy-duty diesel engines are incapable of complying with the regulation. Therefore, the heavy-duty diesel engines affected by this regulation may be subject to NCPs.

The proposed particulate emission standard for heavy-duty diesel engines is initially based on the application of trap-oxidizer exhaust treatment devices. As discussed in the "Technology" section, the basic trap-oxidizer concept is well understood. However, these devices are not currently available to permit compliance with the proposed standard; various engineering improvements still have to be made. Therefore, trap-oxidizers represent a basically new emission control technique for which substantial development work for heavy-duty diesel particulate emissions usage is still required. Manufacturers may experience unforeseen problems in the development and application of successful trap-oxidizers, and it for this reason that EPA intends to make NCPs available for heavy-duty diesel particulate emissions.

The Agency is not proposing the specific penalty rate or the "upper limit" on allowable particulate emissions in this NPRM. These will be proposed at a later date through separate rulemaking, with full opportunity for public comment. EPA's intention to offer NCPs does not affect leadtime considerations for meeting the proposed particulate standard. The availability of NCPs should not be viewed as a mechanism allowing manufacturers to design to a higher emission standard, but rather as a "safety valve" for those who have made good faith efforts, but are experiencing unforeseen problems in compliance. EPA intends to structure the NCPs, as required by the Act, to remove any competitive disadvantage to manufacturers complying with the standard. The penalty will also increase periodically to provide a further incentive to bring nonconformers into compliance or to develop new replacement engines as expeditiously as possible.

Evaluation Plan: EPA intends to review the effectiveness and need for continuation of the provisions contained in this action no more than five years after initial implementation of the final regulation. In particular, EPA will solicit comments from affected parties with regard to costs and other burdens associated with compliance and will also review data on the particulate emissions from heavy-duty diesel vehicles built before and after the promulgation of the regulation to determine how effective this measure has been.

Reporting and Recordkeeping Requirements: This regulation does not require any new signs, reporting or recordkeeping burden. However, it does
add particulate matter to the list of exhaust pollutants which are currently regulated from heavy-duty diesels. As such it will have some impact on the current load of reporting and recordkeeping requirements. Specifically, it will require: 1) submission of the design of all new emission control systems added solely for the purpose of particulate control as part of the manufacturer's application for certification; and 2) inclusion of the rule of particulate emission from affected vehicles along with other test results. Both of these additions are quite minor when compared to the current reporting requirements. Detailed designs of the diesel engine are already required and the only device likely to come under 1) above is the trap-oxidizer. Similarly, results from gaseous emission tests are already required and this regulation will only require the addition of a few numbers to whole pages of values.

Given that the reporting requirements of this regulation only involve minor additions to existing requirements, EPA does not find it reasonable to automatically delete these requirements if affirmative action is not taken within five years. Rather, EPA believes that it is in the public's best interest to perform a review of the reporting requirements of this regulation along with the review of all of the reporting requirements of mobile source air pollution regulation. This review of reporting requirements will be part of an overall review of the regulations themselves which will take place within the next five years.

Note.—The Administrator has determined that this action is a "Significant" regulation. We have prepared a document entitled "Heavy Duty Diesel Particulate Regulation: Regulatory Analysis" detailing the Regulatory Analysis and other analyses required by Executive Order 12044 and the Economic Impact Assessment required by Section 317 of the amended Clean Air Act. Anyone may review and reproduce this document in the EPA Central Docket Section. Copies are also available upon request. Dated December 23, 1980.

Douglas M. Coyle, Administrator.

EPA proposes to amend Subparts A and N of 40 CFR Part 86 as set forth below:
1. Section 86.086-11 is revised to read as follows:

§ 86.086-11 Emission standards for 1988 and later model year diesel heavy-duty engines.

(a) Exhaust emissions from new 1989 and later model year diesel heavy-duty engines shall not exceed the following:
(i) Hydrocarbons: 1.3 grams per brake horsepower hour, as measured under transient operating conditions (Subpart N).
(ii) Carbon monoxide: 15.5 grams per brake horsepower hour as measured under transient operating conditions (Subpart N).
(iii) Oxides of nitrogen: 10.7 grams per brake horsepower hour, as measured under transient operating conditions (Subpart N).
(iv) Particulate matter: 0.25 grams per brake horsepower hour, as measured under transient operating conditions (Subpart N).

2. The standards set forth in paragraph (a) of this section refer to the exhaust emissions generated over operating schedules as set forth in Subpart N and measured and calculated in accordance with those procedures. (b) The opacity of smoke emissions from new 1986 and later model year diesel heavy-duty engines shall exceed the following:
(i) 20 percent during the engine acceleration mode.
(ii) 15 percent during the engine idling mode.
(iii) 50 percent during the engine lugging mode.

3. The standards set forth in paragraph (b) of this section refer to exhaust smoke emissions generated under the conditions set forth in Subpart I of this part and measured and calculated in accordance with those procedures. (c) No crankcase emissions shall be discharged into the ambient atmosphere from any new 1986 model year naturally aspirated diesel heavy-duty engine. This provision does not apply to turbocharged engines. (d) Every manufacturer of new motor vehicle engines subject to the standards prescribed in this section shall, prior to taking any of the actions specified in section 203(a)(1) of the Act, test or cause to be tested motor vehicle engines in accordance with applicable procedures in Subparts I or N of this part to ascertain that each such test engines meet the requirements of paragraphs (a), (b), and (c) of this section.

2. A new § 86.086-28 is proposed to read as follows:

§ 86.086-28 Compliance with emission standards.

[a](1) Paragraph (a) of this section applies to light-duty vehicles.

(b) The applicable exhaust and fuel evaporative emission standards of this subpart apply to the emissions of vehicles for their useful life.

(c) Since it is expected that emission control efficiency will change with mileage accumulation on the vehicle, the emission levels of a vehicle which has accumulated 50,000 miles will be used as the basis for determining compliance with the standards.

4. The procedure for determining compliance of a new motor vehicle with exhaust emission standards is as follows:

(i) Separate emission deterioration factors shall be determined from the exhaust emission results of the durability data vehicle(s) for each engine-system combination. A separate factor shall be established for exhaust HC, exhaust CO, exhaust NOx, and exhaust particulate (diesel vehicles only) for each engine-system combination. A separate evaporation emission deterioration factor shall be determined for each evaporative emission family-evaporative emission control system combination from the testing conducted by the manufacturer (gasoline-fueled vehicles only).

(b) The applicable results to be used in determining the exhaust emission deterioration factors for each engine-system combination shall be:

(1) All valid exhaust emission data from the tests conducted under § 86.086-28(a)(4) except the zero-mile tests. This shall include the official test results, as determined in § 86.086-29 for all tests conducted on all durability-data vehicles of the combination selected under § 86.086-24(c) (including all vehicles elected to be operated by the manufacturer under § 86.086-24(c)(1)(ii)).

(2) All exhaust emission data from the tests conducted before and after the scheduled maintenance provided in § 86.086-25.

(3) All exhaust emission data from tests required by maintenance approved under § 86.086-25, in those cases where the Administrator conditioned his approval for the performance of such maintenance on the inclusion of such data in the deterioration factor calculation.

(d) All applicable exhaust emission results shall be plotted as a function of the mileage on the system, rounded to the nearest mile, and the best fit straight lines, fitted by the method of least squares, shall be drawn through all these data points. The interpolated 4,000- and 50,000-mile points on this line must be within the low altitude standards provided in § 86.085-8 or § 86.085-9, as applicable, or the data will not be acceptable for use in calculation of a deterioration factor, unless no applicable data point exceeded the standard. An exhaust emission deterioration factor shall be calculated for each engine-system combination as follows:
These interpolated values shall be carried out to a minimum of four places to the right of the decimal point before dividing one by the other to determine the deterioration factor. The results shall be rounded to three places to the right of the decimal point in accordance with ASTM E 29-67.

An evaporative emissions deterioration factor (gasoline-fueled vehicles only) shall be determined from the testing conducted as described in §60.688-31(a)[4][i], for each evaporative emission family-evaporative emission control system combination to indicate the evaporative emission level at 50,000 miles relative to the evaporative emission level at 4,000 miles as follows:

Factor = Evaporative emission level at 50,000 miles minus the evaporative emission level at 4,000 miles.

The factor shall be established to a minimum of two places to the right of the decimal.

(i) A. The official exhaust-emission test results for each emission-data vehicle at the 4,000-mile test point shall be multiplied by the appropriate deterioration factor: Provided That if a deterioration factor as computed in paragraph [a][4][i][B] of this section is less than one, that deterioration factor shall be one for the purposes of this paragraph.

(ii) The official evaporative emission test results (gasoline-fueled vehicles only) for each evaporative emission-data vehicle at the 4,000-mile test point shall be adjusted by addition of the appropriate deterioration factor: Provided That if a deterioration factor as computed in paragraph [a][4][i][C] of this section is less than one, that deterioration factor shall be zero for the purposes of this paragraph.

(iii) The emissions to compare with the standard shall be the adjusted emissions of paragraphs [a][4][ii][A] and [B] of this section for each emission-data vehicle. Before any emission value is compared with the standard, it shall be rounded, in accordance with ASTM E 29-67, to two significant figures. The rounded emission values may not exceed the standard.

(iv) Every test vehicle of an engine family must comply with the exhaust emission standards, as determined in paragraph [a][4][iii] of this section, before any vehicle in that family may be certified.

A. Every test vehicle of an evaporative emission family must comply with the evaporative emission standard, as determined in paragraph [a][4][iii] of this section before any vehicle in that family may be certified.

(b) (1) The exhaust and fuel evaporative emission standards of §60.685-9, §60.686-10, and §60.686-11, as applicable, apply to the emissions of vehicles or engine for their useful life.

(2) Since emission control efficiency generally decreases with the accumulation of mileage on the vehicle or engine, deterioration factors will be used in combination with emission-data test results as the basis for determining compliance with the standards.

(3) Separate preliminary exhaust emission deterioration factors, determined from tests of vehicles, engines, subsystems, or components conducted by the manufacturer, shall be supplied for each engine family-control system combination. Separate factors shall also be established for the acceleration mode (designated as "A"), the lugging mode (designated as "B"), and the peak opacity (designated as "C").

(A) The applicable results to be used in determining the deterioration factors for each combination shall be:

(i) The results of the emission tests conducted on light-duty vehicles during durability data vehicle after accumulating 4,000-mile according to the Durability Driving Schedule, or on new heavy-duty vehicles after accumulating 125 hours manufacturer's duty cycles, conforming to the schedule. The mileage point for these results shall be taken to be 4,000 miles for the purpose of this section.

(ii) The results of all emission tests conducted on durability-data vehicles and engines during in-use mileage accumulation, as required or permitted by §60.688-26(b)(5)(v) (light-duty trucks) or §60.688-26(c)(5)(v) (heavy-duty engines), except those excluded under §60.688-26(b)(1)(i) or §60.688-26(b)(1)(ii) for light-duty trucks, or §60.688-26(b)(1)(i) or §60.688-26(c)(5)(v) for heavy-duty engines. The mileage points for heavy-duty engine results shall be adjusted by the addition of 4,000 miles at the time of deterioration factor calculation.

(B) All applicable exhaust emission results shall be determined as a function of accumulated in-use mileage. Separate plots shall be made for each durability data vehicle or engine. Least squares regression lines plus high mileage values
and low mileage values resulting from the procedure of paragraph (b)(1) shall be determined from those plots.

(C)(1) Deterioration factors for each vehicle or engine for transient HC, CO, and NOx for idle CO (gasoline-fueled vehicles and engines only), and exhaust particulate (light-duty diesel trucks and heavy-duty diesel engines only) shall be calculated by dividing the high mileage value of paragraph (b)(5)(ii)(E) by the low mileage value of paragraph (b)(5)(ii)(D). A factor less than one shall be set equal to one.

(C) The high mileage value shall be calculated as follows:

(1) Prior to the actual change for any external aftertreatment device, the high mileage value shall be the larger of the values resulting from the following two methods.

(a) The best fit straight line fitted by the method of least squares to the applicable data and extrapolated (or interpolated if the in-use mileage accumulation is complete) to the high mileage point. The high mileage point shall be either the useful life or a mileage which represents a point 50 percent of the useful life past the current mileage, whichever is smaller.

(b) The highest of any data points (or average of results if the manufacturer conducted multiple tests at each point) which exceed two standard errors of the estimate from the best fit straight line fitted by the method of least squares to the applicable data.

(2) After the actual change of any external aftertreatment device, in the case where only one applicable mileage point exists after the change, the value (or average of values) shall be compared to the value of the best fit straight line of paragraph (b)(5)(ii)(D) extrapolated to that mileage. If the value for examination (or average) falls below the line it shall not be used in the calculations, and the high mileage value shall be as determined in subparagraph (1) above. If the value (or average of values) falls on or above the line, the data for the test point after the change of the external aftertreatment device shall be added to the data used in subparagraph (1) above and the high mileage value recomputed by the procedure of subparagraph (1). In this case, the low mileage value of paragraph (b)(5)(ii)(E) shall also be recalculated based upon inclusion of the additional data.

(3) After the actual change of any external aftertreatment device, in the case where two or more applicable data points shall be divided into two sets. The first set shall include all data for mileage points prior to the change point. The second set shall include all data for mileage points after the change point. The procedure of subsection (1) above shall be performed separately for each set of data. The actual high mileage value shall be that from whichever data set yields the higher value.

(D) The single in-use deterioration factor for each engine family-control system combination for each of transient HC, CO, and NOx, idle CO (gasoline vehicles and engines only), exhaust particulate (diesel light-duty trucks and diesel heavy-duty engines only) and the acceleration, luggage, and peak capacity smoke modes (heavy-duty diesel engines), shall be the arithmetic mean of the corresponding factors for each engine as determined in paragraph (b)(5)(ii)(C) of this section.

(E) [(A) For transient HC, CO, and NOx, idle CO (gasoline vehicles and engines only), and exhaust particulate (diesel light-duty trucks and diesel heavy-duty engines only), the official emission test results for each emission-data vehicle or engine at the 4,000-mile or 125 hour test point shall be adjusted by multiplication by the appropriate deterioration factor.

(F) [For acceleration smoke ("A"), luggage smoke ("B"), and peak smoke ("C"), the official emission test results for each emission-data vehicle at the 12-hour test point shall be adjusted by multiplication by the appropriate deterioration factor.

(iv) The emission values to compare with the standards shall be the adjusted emission values of paragraph (b)(4)(iii) of this section rounded to two significant figures in accordance with ASTM E 29-67 for each emission-data vehicle or engine.

(G) (H) Paragraph (b)(6) of this section describes the procedure for determining compliance of a new light-duty truck with fuel evaporative emission standards. The procedure described here shall be used for all vehicles in all model years.

(H) The manufacturer shall determine, based on testing described in § 60.605-621(b)(4)(iii), and annually an evaporative emission deterioration factor for each evaporative emission family-evaporative emission control system combination. The factor shall be calculated by subtracting the emission level at 4,000 miles from the emission level at the useful life point.

(iii) The official evaporative emission test results for each evaporative emission-data vehicle at the 4,000-mile test point shall be adjusted by the addition of the appropriate deterioration factor. However, if the deterioration factor supplied by the manufacturer is less than zero, it shall be zero for the purposes of this paragraph.

(iv) The emission value to compare with the standards shall be the adjusted emission values of paragraph (b)(8)(iii) of this section rounded to two significant figures in accordance with ASTM E 29-67 for each evaporative emission-data vehicle.

(7) Every test vehicle or engine of an engine family must satisfy all applicable standards, as determined in paragraph (b)(4)(iv) or (b)(5)(iv) and paragraph (b)(6) of this section, before any vehicle or engine in that family will be certified.

(C) [Reserved]

(3) The following sections are added to the table of contents under Subpart N.

Subpart N—Emission Regulations for New Gasoline-Fueled and Diesel Heavy-Duty Engines; Gaseous and Particulate (Diesel Only) Exhaust Test Procedures

1808-83 Equipment required and specifications; overview.
1808-84 Equipment and engine specifications.
1808-85 Emission sampling systems, gasoline-fueled engines.
1808-86 Exhaust gas sampling system, diesel engines.
1808-87 Exhaust gas sampling and analytical systems; diesel engines.
1808-88 Exhaust gas sampling and analytical systems; CVS bag sample.
1808-89 Weighing chamber (or room) and microgram balance specifications.
1808-90 Fuel specifications.
1808-91 Analytical glassware.
§ 111.1302-88 Scope; application.

This subpart contains test procedures for engine emissions tests on gasoline-fueled and diesel heavy-duty engines. Equipment required and specifications are as follows:

(a) Exhaust emission tests. All engines subject to this subpart are tested for exhaust emissions. Diesel and gasoline-fueled engines are tested identically with the exception of hydrocarbon measurements; diesel engines require a heated hydrocarbon detector, § 111.3206-88. Necessary equipment and specifications appear in sections 111.1308-88 through 111.1314-88.

(b) Fuel, analytical gas, and engine cycle specifications. Fuel specifications for exhaust emission testing are specified in § 111.1313-88. Analytical gases are specified in § 111.1314-88. The EPA heavy-duty transient engines cycles for use in exhaust testing are described in § 111.1333-80 and specified in Appendix I.

A new § 111.1307-88 is added and reserved as follows:

§ 111.1307-88 (Reserved)

A new § 111.1308-88 is added and reads as follows:

§ 111.1308-88 Dynamometer and engine equipment specifications.

(a) Engine dynamometer. The engine dynamometer system must be capable of detecting torque and rpm simultaneously over transient cycles. The transient torque and rpm schedules described in § 111.1333-86 and specified Appendix I (f and g) must be followed within the accuracy requirements specified in § 111.1341-86. In addition to these general requirements, the dynamometer read out and read out signals for speed and torque shall meet the following accuracy specifications:

(1) Engine speed shall be accurate to within 2 percent of point at all speeds.

(2) Engine torque at the flywheel shall be accurate to within 3 percent of point at all torque settings above 10 percent of full scale of the torque measuring device. Below 10 percent of full-scale, the torque measuring device shall have an accuracy of ±0.5 ft-lbs, if the full scale value is 50 ft-lbs, or less.

(3) ±10 ft-lbs, if the full scale value is greater than 50 ft-lbs, or less.

(b) Cycle verification equipment. In order to verify that the test engine has followed the test cycle correctly, the dynamometer read out signals for speed and torque must be collected in a manner that allows a statistical correlation between the actual engine performance and the test cycle (See § 111.1341-86). Normally, this collection process would involve conversion of analog dynamometer signals into digital values for storage in a computer. The conversion of dynamometer read out values into values (computer or other)
that are used to evaluate the validity of engine performance in relation to the test cycle shall be performed in a manner such that:

1. Speed values used for cycle evaluation are accurate to within 2 percent of the dynamometer speed read-out values.

2. Engine flywheel torque values used for cycle evaluation are accurate to within 3 percent of the dynamometer torque read-out value.

(c) Option. For some systems it may be more convenient to combine the tolerances in paragraphs (a) and (b). This is permitted if the root mean square method (RMS) is used. The RMS values would then refer to accuracy in relationship to true value.

1. Speed values used for cycle evaluation shall be accurate to within 2.8 percent of true value.

2. Engine flywheel torque values used for cycle evaluation shall be accurate to within 4.2 percent of true value.

(d) Speed calibration equipment. A 60-throw (or greater) wheel in combination with a common mode rejection frequency counter is considered an absolute standard for engine or dynamometer speed.

(e) Torque calibration equipment. Two techniques are allowed for torque calibration. Alternate techniques may be used if shown to be equivalent, and if prior approval is obtained from the Administrator.

1. The lever-arm dead-weight technique involves the placement of known weights a known distance from the center of rotation of the torque measuring device. The equipment required is:

   (i) Calibration weights. A minimum of calibration weights for each range of torque measuring device used are required. The weights must be approximately equally spaced and each must be accurate to 0.5 percent of National Bureau of Standard weights. Laboratories located in foreign countries may certify calibration weights to local government bureau standards.

   (ii) Determination of accuracy by state government Bureau of Weights and Measures is acceptable. Effects of changes in gravitational constant at the test site may be accounted for if desired.

2. A lever arm with a minimum length of 24 inches. The distance from the center of the engine torque measurement device to the point of weight application shall be accurate to within 0.010 inches. The arm must be balanced, or the hanging torque of the arm must be known within ±0.1 ft-lbs.

3. The lever technique involves the use of a master load cell with a method of loading (usually hydraulic) the torque measuring device, or master unit that applies a known force to the torque measuring device based on piston area and pressure. The equipment required is:

   (i) A master load cell or force application unit that must be calibrated at each test weight specified in paragraph (c)(1)(i) of this section with known weights traceable to within 0.1 percent of NBS weights. The provision on traceability in paragraph (c)(1)(i) apply to this section. The overall accuracy of the calibration curve of torque applied to the engine torque sensor is determined by the master unit(s) shall be within 0.3 percent of true value. Below 10 percent of full scale of the master unit the calibration curve of torque applied to the engine torque sensor shall be accurate to:

   (A) ±0.5 ft-lbs. of true value if full scale value is 550 ft-lbs. or less.

   (B) ±1.0 ft-lbs. of true value if full scale value is 1050 ft-lbs. or less.

   (C) ±2.0 ft-lbs. of true value if full scale value is greater than 1050 ft-lbs.

4. A lever arm with a minimum length of 24 inches. The distance from the center of the engine torque measuring device to the point of force application shall be accurate to within 0.010 inches. The arm must be balanced, or the hanging torque of the arm must be known within ±0.1 ft-lbs.

5. Transfer of calibration or span from a dynamometer "case" torque value to the engine flywheel torque measuring device is permitted only under static or steady state conditions.

6. Other techniques may be used if shown to be equivalent if approved by the Administrator.
(SEE FIG. N86-7 FOR SYMBOL LEGEND)

FIGURE N86-1 — EXHAUST GAS SAMPLING SYSTEM PDP-CVS
FOR GASOLINE FUELED ENGINES
Critical Flow venturi. The operation of the critical flow venturi—constant volume sampler (CFV-CVS). Figure 90-2, is based upon the principles of fluid dynamics associated with critical flow. The CVF system is commonly called a constant volume system (CVS) even though the flow varies. It would be more proper to call the critical flow venturi (CFV) system a constant proportion sampling system since proportional sampling throughout temperature excursions is maintained by use of a small CFV in the sample line. The variable mixture flow rate is maintained at sonic velocity, which is inversely proportional to the square root of the gas temperature, and is computed continuously. Since the pressure and temperature are the same at both venturi inlets, the sample volume is proportional to the total volume.
FIGURE N86-2 — EXHAUST GAS SAMPLING SYSTEM (CFV-CVS)
FOR GASOLINE FUELED ENGINES

(SEE FIG. N86-7 FOR SYMBOL LEGEND)
(4) Other systems. Other sampling and/or analytical systems including the systems described in § 86.1310-86 for diesel engines may be used if shown to yield equivalent results, and if approved in advance by the Administrator.

(b) Component description. PDP-CVS. The PDP-CVS, Figure N86-1, consists of a dilution air filter and mixing assembly, heat exchanger, positive displacement pump, sampling system, and associated valves, pressure and temperature sensors. The PDP-CVS shall conform to the following requirements:

(1) Static pressure variations at the tailpipe(s) of the engine shall remain within ±5 inches of water (1.2 kPa) of the static pressure variations measured during a dynamometer engine cycle with no connection to the tailpipe(s).

(Sampling systems capable of maintaining the static pressure to within ±1 inch of water (0.25 kPa) will be used by the Administrator if a written request substantiates the need for this closer tolerance.)

(2) The temperature measuring system shall have an accuracy and precision of ±2°F (1.1°C) and a response time of 0.100 seconds to 0.25 percent of a temperature change (as measured in hot silicone oil).

(3) The pressure measuring system shall have an accuracy and precision of ±3 mm Hg (0.4 kPa).

(4) The flow capacity of the CVS shall be large enough to prevent water condensation in the system.

(5) Sample collection bags for dilution air and exhaust samples shall be of sufficient size so as not to impede sample flow.

13. A new § 86.1310-86 is added and reads as follows:

§ 86.1310-86 Exhaust gas sampling and analytical system; diesel engines.

(a) General. The exhaust gas sampling system described in this paragraph is designed to measure the true mass of both gaseous and particulate emissions in the exhaust of heavy-duty diesel engines. This system utilizes the CVS concept (described in § 86.1330-86) of measuring mass emissions of NOx, CO, CO2, and particulate. A continuously integrated system is required for HC measurement, and is allowed for NOx, CO, and CO2. The mass of gaseous emissions is determined from the sample concentration and total flow over the test period. The mass of particulate emissions is determined from a proportional mass sample collected on a filter and from the total flow over the test period. General requirements are as follows:

(1) This sampling system requires the use of a PDP-CVS, or a CFV-CVS with heat exchanger or with electronic flow compensation. Figure N86-1 is a schematic drawing of the PDP system. Figure N86-2 is a schematic drawing of the CFV system.

§§ 86.1300-86 / Proposed Rules
FIGURE N86-3
GASEOUS AND PARTICULATE EMISSIONS SAMPLING SYSTEM (PDP-CVS)
FOR DIESEL ENGINES ONLY
(SEE FIGURE N86-7 FOR SYMBOL LEGEND)
FIGURE N86-4
GASEOUS AND PARTICULATE EMISSIONS SAMPLING SYSTEM (CFV-CVS)
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N86-7 FOR SYMBOL LEGEND)
(2) The HIC analytical system for diesel engines requires a heated flame ionization detector (HFD) and heated sample system.

(i) The HFD sample must be taken directly from the diluted exhaust stream through a heated probe and integrated continuously over the test cycle. Unless compensation for varying flow is made, the HFD must be used with a constant flow system to insure a representative sample.

(ii) The heated probe shall be located downstream of a mixing chamber that provides a uniform sample distribution across the CVS duct.

(iii) The dilution tunnel similar to those used for diesel particulate sampling may be used as a mixing chamber for gaseous emissions also.

(i) Option: Continuously integrated measurement of diluted NOx, CO, and CO2 is permitted; however, prior approval of the Administrator is required. Test results will be required as well as engineering data and detailed system specifications to gain this approval. Minimum requirements and technical specifications are given in (h)(5) of this section.

(4) Bag sampling (§ 86.1309-38) and analytical (§ 86.1311-80) capabilities as shown in N86-3 (or Figure N86-4) are required to provide both gaseous and particulate emissions sampling capabilities from a single system if NOx, CO, or CO2 are not measured continuously.

(b) Since various configurations can produce equivalent results, exact conformance with these drawings is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems.

(6) Other sampling and/or analytical systems may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(b) Component description. The components necessary for diesel exhaust sampling shall meet the following requirements:

(1) The PDP-CVS shall conform to all of the requirements listed for the exhaust gas PDP-CVS (§ 86.1309-01). The UTV-CVS shall conform to all of the requirements listed for the exhaust gas UTV-CVS (§ 86.1309-06). In addition, the CVS must conform to the following requirements:

(i) The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream at a temperature that will satisfactorily measure particulate and/or hydrocarbon measurements.

This may be achieved by either of the following methods:

(A) Single-dilution method. A CVS of sufficient flow capacity to maintain a temperature of 125 °F (51.7 °C) or less at the sampling zone may be used with the primary-dilution tunnel. Direct sampling of the particulate material may then take place (Figure N86-5).
FIGURE N86-5
SINGLE DILUTION PARTICULATE MEASUREMENT SYSTEM
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N86-7 FOR SYMBOL LEGEND)
(B) Double-dilution method. A smaller size CVS may be used with a smaller primary-dilution tunnel (i.e., smaller than the dilution tunnel or CVS described in § 60.1310-86(b)(1)(A)), and a secondary-dilution tunnel system (Figure N86-6). The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream in the primary-dilution tunnel at a temperature of 375°F (191°C) or less at the sampling zone. The secondary dilution tunnel system must be designed to provide sufficient secondary dilution air to maintain the double-diluted exhaust stream at a temperature of 125°F (51.7°C) or less immediately before the particulate filter.
FIGURE N86-6
DOUBLE DILUTION PARTICULATE MEASUREMENT SYSTEM
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N86-7 FOR SYMBOL LEGEND)
(ii) For the CFV-CVS, a heat exchanger or electronic flow compensation (which includes the particulate sample flows) is required.

(iii) For the CFV-CVS, the gas mixture temperature, measured at a point immediately ahead of the critical flow venturi, shall be within ±20°F (11°C) of the designed operating temperature at the start of the test. The gas mixture temperature variation from its value at the start of the test shall be limited to ±20°F (11°C) during the entire test. The temperature measuring system shall have an accuracy and precision of ±2°F (1°C).

(2) The transfer of heat from the engine exhaust gas shall be minimized between the point where it leaves the chassis exhaust system and the point where it enters the primary-dilution tunnel airstream. To accomplish this, a short length (not more than 12 feet (3.66 m) if uninsulated, or not more than 20 feet (6.1 m), if insulated) of smooth stainless steel tubing rom the muffler to the primary-dilution tunnel is required. This tubing shall have a maximum inside diameter of 6.0 inches (15.2 cm). Short sections (altogether not to exceed 20 percent of the entire tube length) of flexible tubing at connection points are allowed. If insulated, the radial thickness of the insulation must be at least R inches, where:

\[ R = \frac{k}{c} - 2 \text{t} \]

where k = Thermal conductivity of the insulating material (Btu/hr ft °F), and
t = Thickness of uninsulated tubing (inches).

(3) The engine exhaust shall be directed downstream at the point where it is introduced into the primary-dilution tunnel.

(4) The primary-dilution tunnel shall be:

(i) Sufficiently distant (radially) from the point where the exhaust enters the primary-dilution tunnel.

(ii) Filtered at the dilution air inlet.

(iii) The primary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the primary-dilution tunnel.

(b) The particulate sample probes shall be located sufficiently distant from the dilution tunnel so that the inlet gas temperature is maintained at a constant temperature (±0.5°F (3°C)).

(c) The gas meter or flow instrumentation shall be located sufficiently distant from the tunnel so that the inlet gas temperature remains constant (±0.5°F (2.8°C)).

(d) The particulate sample probes shall be located sufficiently distant from the dilution tunnel so that the inlet gas temperature remains constant (±0.5°F (2.8°C)).

(e) The secondary-dilution tunnel shall be:

(i) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(ii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(iii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(iv) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(v) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(vi) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(vii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(viii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(ix) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(x) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xi) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xiii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xiv) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xv) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xvi) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xvii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xviii) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xix) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(xx) The secondary-dilution tunnel shall be:

(a) Sufficiently distant (radially) from the point where the exhaust enters the secondary-dilution tunnel.

(2) The exit faces downstream in the secondary-dilution tunnel.

(3) The single-dilution sample exists on the centerline of the secondary tunnel.

(B) The particulate sample transfer tube shall be:

(i) Sufficiently distant (radially) from other sampling probes (in the primary-dilution tunnel) so as to be free from the influence of any wakes or eddies produced by the other probes.

(ii) 0.5 inches (1.27 cm) minimum inside diameter.

(iii) No longer than 35 inches (91.4 cm) from inlet plane to exit plane.

(d) Designed to minimize the deposition of particulate during transfer (e.g., bends should be gradual as possible protrusions (due to sensors, etc.) should be smooth and not sudden, etc.).

(5) Constructed of electrically or electrically conductive material which does not react with the exhaust components.

(B) The secondary-dilution air shall be at a temperature of 77 ±9°F (25 ±5°C).

(D) The secondary-dilution tunnel shall be:

(1) 3.0 inches (7.62 cm) minimum inside diameter.

(2) Of sufficient length so as to provide a residence time of at least 0.25 seconds for the double-diluted sample.

(3) Constructed of electrically conductive material which does not react with the exhaust components.

(E) Additional dilution air must be provided so as to maintain temperature of 125°F (51.7°C) immediately before the sample filter. The gas meter or flow instrumentation shall be located at a constant mass flow rate in order to maintain proportional sampling. Determination of the mass of air entering the secondary dilution tunnel is required. Introduction and measurement can be achieved by either of the following methods.

(1) A Doppler-type pump, flowing filtered dilution air at a constant temperature (77 ±9°F (25 ±5°C)) and pressure (atmospheric is acceptable) along with a gas meter or flow instrumentation for mass determination. (See § 86.1320-96 for calibration specifications.)

(C) The gas meter or flow instrumentation shall be located sufficiently distant from the tunnel so that the inlet gas temperature remains constant (77 ±9°F (25 ±5°C)).

(2) A choked critical flow orifice flowing filtered dilution air. For mass determination a gas meter or other flow instrumentation is acceptable. (See § 86.1320-96 for calibration specifications.)

The gas meter or flow instrumentation shall be located so that the inlet gas temperature remains constant (77 ±9°F (25 ±5°C)).
(F) The primary filter holder shall be located within 12.0 inches (7.5 cm) of the exit of the secondary-dilution tunnel.

(C) The particulate sample probe shall be located sufficiently distant from the dilution tunnel so that the inlet gas temperature is maintained constant (± 5°F (± 2.8°C)).

(H) The gas meter or flow instrumentation (if double-dilution this means the downstream device) shall be located sufficiently distant from the tunnel (either primary or secondary) so that the inlet gas temperature remains constant (± 5°F (± 2.8°C)).

2 Continuous HC measurement system (1) The continuous HC sample system (as shown in Figure N60-3 or N60-4) shall be an "overflow calibration (or span) gas" type system. In this type of system, excess span or calibration gas spills out of the probe during calibration of the analyzer.

(ii) No other analyzers may draw a sample from the continuous HC sample probe line or system.

(iii) The span, calibration, or background sample flow rates into the sample line shall be between 190 and 210 percent of the HFID analyzer flow rate.

(iv) The span, calibration or background gases shall enter the heated sample line no farther than 4 inches from the CVS duct or dilution tunnel outside surface.

(v) The continuous hydrocarbon probe shall be:

(A) Installed in the primary dilution tunnel facing upstream at a point where the dilution air and exhaust are well mixed (i.e., approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel).

(B) Sufficiently distant (radially) from other probes so as to be free from the influence of any wakes or eddies produced by the other probes.

(C) Heated and insulated over the entire length to maintain a 375°F (191°C) wall temperature. The radial thickness of the insulation must be at least 8 inches, where

\[ R = \frac{k}{\text{Thermal conductivity of insulating material}} \times \text{flue/ht ft} \times \text{F/ºF}, \]

and

\[ r = \text{Outer radius of uninsulated probe} \]

(Both 4).

(vi) It is intended that the total hydrocarbon probe be free from cold spots (i.e., free from spots where the probe wall temperature is less than 355°F (180°C)).

(vii) The dilute exhaust gas flowing in the total hydrocarbon sample system shall be:

(A) At 375°F ± 10°F (191°C ± 6°C) immediately before the heated filter. This gas temperature will be determined by a temperature sensor located at the exit of the heated sample line. The sensor shall have an accuracy and precision of ± 2°F (1.1°C).

(B) at 375°F ± 10°F (191°C ± 6°C) immediately before HFID. This gas temperature will be determined by a temperature sensor located at the exit of the heated sample line. The sensor shall have an accuracy and precision of ± 2°F (1.1°C).

(viii) It is intended that the dilute exhaust gas flowing in the total hydrocarbon sample system be between 365°F and 385°F (185°C and 197°C) gas temperature.

(ix) The response time of the continuous measurement system shall be:

(A) 1.5 seconds from an instantaneous step change at the probe entrance to the analyzer to within 95 percent of the step change.

(B) 5.5 seconds from an instantaneous step change at the entrance to the sample probe or overflow span gas port to within 95 percent of the step change.

(C) For the purpose of verification of response time, the step change shall be at least 80 percent of full-scale chart deflection.

(9) Optional continuously integrated NO, CO, and CO2 measurement system

(i) The sample probe shall:

(A) Be in the same plane as the continuous HC probe, but shall be sufficiently distant (radially) from other probes so as to be free from the influence of any wakes or eddies produced by other probes.

(B) Shall face upstream.

(C) Heated and insulated over the entire length to prevent water condensation. Minimum temperature is 55°C (131°F). Sample gas temperature immediately before the first filter in the system shall be at least 55°C (131°F).

(ii) The continuous NO, CO, or CO2 sampling and analysis system shall conform to the specifications of 40 CFR 86, Subpart D with the following exceptions and revisions:

(A) The system components required to be heated by Subpart D need only be heated to prevent water condensation, the minimum temperature allowed is 55°C (131°F).

(B) The system response defined in § 86329-79 shall be no greater than 5.5 seconds. Longer response time may be allowed if an analysis system response time is coordinated with CVS flow fluctuations, is shown to be equivalent to the 5.5 second system, and if prior approval is granted by the Administrator.

(C) Alternative NO, measurement techniques outlined in § 86346-79 are not permitted for NO measurement in this Subpart.

(D) All analytical gases shall conform to the specifications of § 861314-86.

(ii) The chart deflections of analyzers with non-linear calibration curves shall be converted to concentration values by the calibration curve(s) specified in Subpart D (86330-79) before flow correction (if used) and subsequent integration takes place.

(c) Filters, particulate sampling — 

(1) Filter acceptance criteria. Valid diesel particulate net filter weights shall be accepted according to the following criteria:

(i) During the cold start phase of the heavy-duty transient cycle and again during the hot start phase of the heavy-duty transient cycle dilute exhaust will be simultaneously sampled by paired primary test and back-up test filters.

(ii) The back-up filter holder shall be located 3 to 4 inches downstream of the primary filter holder.

(iii) The net weight of particulate material collected on each primary test filter and each back-up test filter shall be determined by the procedure outlined in § 861339-85.

(2) A total of test weights will be determined by the following formula:

\[
\text{Mass Particulate) Test filter} = \text{(Mass Particulate) Test filter} - \text{(Mass Particulate) Back-up filter}
\]
(v) If the ratio is greater than 0.95, then particulate emissions calculations are based on the net weight of the primary filter only.

(vi) If the ratio is less than 0.95, then particulate emissions calculations are based on the combined net weights of the back-up filter and the primary test filter.

(2) The particulate filter must have a minimum 70 mm diameter (60 mm stain area). Larger diameter filters are also acceptable. (Larger diameter filters may be desirable in order to reduce the pressure drop across the filter when testing vehicles which produce large amounts of particulate.)

(3) The recommended minimum loading on the 70 mm filter is 5.3 milligrams. Equivalent loadings (i.e., mass/stain area) are recommended for larger filters. For equivalency calculations assume the 70 mm loading has a 60 mm stain diameter.

(4) Fluorocarbon coated glass fiber filters or fluorocarbon based (membrane) filters are required for particulate collection.

14. A new § 86.1311-86 is added and reads:

§ 86.1311-86 Exhaust gas analytical system. CVS bag sample.

(a) Schematic drawings. Figure N86-7 is a schematic drawing of the exhaust gas analytical system used for analyzing CVS bag samples from either gasoline-fueled or diesel engines. The schematic of the hydrocarbon analysis train for diesel engines is shown as part of Figure N86-3 or N86-4. Since various configurations can produce accurate results, exact conformance with the drawing is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems.

BILLING CODE 2500-20-M
FOR DIESEL HC ANALYSIS
SEE FIGURE N86-3 or N86-4

OPEN TO ATMOSPHERE

FUEL AIR

ZERO AIR

HC

R

HC SPAN GASES

ZERO GAS

CONDITIONING COLUMNS

HIGH CO

R

LOW CO

CO2

R

CO2 SPAN GASES

ZERO GAS

NO.

R

NO2 OR CO2

TO OUTSIDE VENT

SYMBOl LEGEND

FLOW CONTROL VALVE
SELECTION VALVE
PARTICULATE FILTER
PUMP
FLOWMETER
PRESSURE GAUGE
RECORDER

FIGURE N86-7 EXHAUST GAS ANALYTICAL SYSTEM
[b] Major component description. The analytical system, Figure N86-7, consists of a flame ionization detector (FID) for the detection & quantification of hydrocarbons, nondispersive infrared analyzers (NDIR) for the determination of carbon monoxide and carbon dioxide and a chemiluminescence analyzer (CL) for the determination of oxides of nitrogen. A heated flame ionization detector (HFID) is used for the continuous determination of hydrocarbons from diesel engines, Figure N86-3 or N86-4.

The exhaust gas analytical system shall conform to the following requirements:

(1) The CL requires that the nitrogen dioxide present in the sample be converted to nitric oxide before analysis. Other types of analyzers may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(2) The carbon monoxide (NDIR) analyzer may require a sample conditioning column containing CASO₄, or indicating silica gel to remove water vapor and containing ascarite to remove carbon dioxide from the CO analysis stream.

(i) If CO Instruments are used which are essentially free of CO₂ and water vapor interference, the use of the conditioning column may be deleted. (See §6.1323-80 and §6.1342-80.)

(ii) A CO instrument will be considered to be essentially free of CO₂ and water vapor interference if its response to a mixture of 4 percent CO₂ in N₂, which has been bubbled through water at room temperature produces an equivalent CO response, as measured on the most sensitive CO range, which is less than 1 percent of full scale CO concentration on ranges above 300 ppm full scale or less than 3 ppm on ranges below 300 ppm full scale. (See §6.1323-80).

[c] Alternate analytical systems. Analysis systems meeting the specifications of 40 CFR 80, Subpart D may be used for testing this Subpart (N) with the exception of §§ 86.346-86 and 86.347-86, provided that the Subpart D systems meet the specifications of this Subpart. Hetero analyzers may be used in their heated configuration.

(d) Other analyzers and equipment. Other types of analyzers and equipment may be used if shown to yield equivalent results and if approved in advance by the Administrator.

15. A new §86.1313-86 is added and reads as follows:

§86.1313-86 Fuel specifications.

(a) Gasoline. [1] Gasoline having the following specifications will be used by the Administrator in exhaust emission testing. Gasoline having the following specifications or substantially equivalent specifications approved by the Administrator, shall be used by the manufacturer in exhaust testing, except that the lead and octane specifications do not apply.

(b) Diesel fuel. (1) The diesel fuels employed for testing shall be clean and bright, with pour and cloud points adequate for operability. The diesel fuel may contain nonmetallic additives as follows: Cetane improver, metal deactivator, antioxidant, dehazer, antitrust, pour depressant, dye and dispersant.

(2) Diesel fuel meeting the following specifications, or substantially equivalent specifications approved by the Administrator, shall be used in exhaust emissions testing. The grade of diesel fuel recommended by the engine manufacturer commercially designated as "Type 1-D" or "Type 2-D" grade diesel fuel shall be used.

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(b) Gases for the hydrocarbon analyzer shall be single blends of propane using air as the diluent.
(c) Gases for the NO analyzer shall be single blends of NO named as NO, with a maximum NO concentration of 5 percent of the nominal value using nitrogen as the diluent.
(d) Fuel for the FID shall be a blend of 40±2 percent hydrogen with the balance being helium. The mixture shall contain less than 1 ppm equivalent carbon concentration. 98 to 100 percent hydrogen fuel may be used with advance approval of the Administrator.

(e) The allowable zero gas (air or nitrogen) impurity concentrations shall not exceed 1 ppm equivalent carbon for nitrogen and oxygen with oxygen concentrations between 18 and 21 mole percent.

(2) Calibration gases shall be traceable to within 1 percent of NBS gas standards, or other gas standards which have been approved by the Administrator.

(3) Span gases shall be accurate to within 2 percent of true concentration, where the span concentration refers to NBS gas standards, or other gas standards which have been approved by the Administrator.

(g) The use of proportioning and precision blending devices to obtain the required gas concentrations is allowable provided the use has been approved in advance by the Administrator.

18. A new § 86.1315-86 is added and reserved as follows:

§ 86.1315-86 [Reserved]

21. A new § 86.1316-86 is added and reads as follows:

§ 86.1316-86 Engine dynamometer system calibration.

(a) The engine flywheel torque and engine speed measurement transducers shall be calibrated at least once each month with the calibration equipment described in § 86.1316-86.

(b) The engine flywheel torque and speed feedback signal shall be calibrated at least once each month.

(c) Other engine dynamometer system calibrations shall be performed as dictated by good engineering practice and manufacturer's recommendations.

(d) When calibrating the engine, flywheel torque transducer, any lever arm used to convert a weight or a force through a distance into a torque shall be used in a horizontal position (±5 degrees).

(e) Calibrated transducers may not be used for engine flywheel torque transducer calibration, but may be used to span the transducer prior to engine testing.

22. A new § 86.1316-86 is added and reads as follows:

§ 86.1316-86 CVS calibration.

(a) The CVS is calibrated using an accurate flowmeter and restrictor valve. The calibrated accuracy of the flowmeter shall be traceable to the National Bureau of Standards to within 1 percent of the true flow value. (Note: In no case should an upstream screen or other restriction which can effect the flow be used ahead of the flowmeter unless calibrated throughout the flow range with such a device.) The CVS calibration procedures are designed for use with a "metering venturi type" flowmeter. Properly calibrated large radius or ASME flow nozzles are considered equivalent if traceable to

<table>
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<tr>
<th>Item</th>
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<th>Type 2-0</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.4-6.0</td>
</tr>
<tr>
<td>Flash point</td>
<td>D92</td>
<td>80-110</td>
</tr>
<tr>
<td>Density, API</td>
<td>D129</td>
<td>42-46</td>
</tr>
<tr>
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<td>20.0-40.0</td>
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<tr>
<td>Percentage</td>
<td>D113</td>
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</tr>
<tr>
<td>Maximum</td>
<td>D129</td>
<td>1.0</td>
</tr>
</tbody>
</table>

(4) Other petroleum distillate fuels may be used for testing and service accumulation provided they are:

(1) Commercially available;
(2) Information, acceptable to the Administrator, is provided to show that only the designated fuel would be used in customer service;
(3) Use of a fuel listed under paragraphs (b)(2), (b)(3), and (b)(4) of this section would have a detrimental effect on emissions or durability;
(4) Written approval from the Administrator of the fuel specifications must be provided prior to the start of testing.

(5) The specification range of the fuels to be used under paragraphs (b)(2), (b)(3), and (b)(4) of this section shall be reported in accordance with § 86.004-86(a).

17. A new § 86.1314-86 is added and reads as follows:

§ 86.1314-86 Analytical gases.

(a) Gases for the CO and CO2 analyzers shall be single blends of CO and CO2, respectively using nitrogen as the diluent.
NBS measurements. Other measurement systems may be used if shown to be equivalent under the test conditions in this action and if approved by the Administrator. Measurements of the various flowmeter parameters are recorded and related to flow through the CVS. Procedures used by EPA for both PDP- and CFV-CVS's are outlined below. Other procedures yielding equivalent results may be used if approved in advance by the Administrator.

(b) After the calibration curve has been obtained, verification of the entire system may be performed by injecting a known mass of gas into the system and comparing the mass indicated by the system to the true mass injected. An indicated error does not necessarily mean that the calibration is wrong, since other factors can influence the accuracy of the system, e.g., analyzer calibration or HC hangup. A verification procedure is found in paragraph (e) of this section.

(c) PDP calibration. (1) The following calibration procedure outlines the equipment, the test configuration, and the various parameters which must be measured to establish the flow rate of the CVS pump.

(i) All the parameters related to the pump are simultaneously measured with the parameters related to a flowmeter which is connected in series with the pump.

(ii) The calculated flow rate ft³/min., (at pump inlet absolute pressure and temperature) can then be plotted versus a correlation function which is the value of a specific combination of pump parameters.

(iii) The linear equation which relates the pump flow and the correlation function is then determined.

(iv) In the event that a CVS has a multiple speed drive, a calibration for each range used must be performed.

(2) This calibration procedure is based on the measurement of the absolute values of the pump and flowmeter parameters that relate the flow rate at each point. Three conditions must be maintained to assure the accuracy and integrity of the calibration curve:

(i) The pump pressures should be measured at taps on the pump rather than at the external piping on the pump inlet and outlet. (Pressure taps that are mounted at the top center and bottom center of the pump drive headplate are exposed to the actual pump cavity pressure, and therefore reflect the absolute pressure differentials.)

(ii) The temperature stability must be maintained during calibration. (Flowmeters are sensitive to inlet temperature oscillations which cause the data points to be scattered. Gradual changes in temperature are acceptable as long as they occur over a period of several minutes.)

(iii) All connections between the flowmeter and the CVS pump must be absolutely void of any leakage.

(3) During an exhaust emission test the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

(4) Connect a system as shown in Figure N88-8. Although particular types of equipment are shown, other configurations that yield equivalent results may be used if approved in advance by the Administrator. For the system indicated, the following data with given accuracy are required:
FIGURE N86-8 — PDP-CVS CALIBRATION CONFIGURATION
(5) After the system has been connected as shown in Figure N88-8, set the variable restrictor in the wide open position and run the CVS pump for 20 minutes. Record the calibration data.

(ii) Reset the restrictor valve to a more restricted condition in an increment of pump inlet depression that will yield a minimum of six data points for the total calibration. Allow the system to stabilize for 3 minutes and repeat the data acquisition.

(7) Data analysis: (i) The air flow rate, Qa, at each test point is calculated in standard cubic feet per minute (60° F. 29.92' Hg) from the flowmeter data using the manufacturer's prescribed method.

(ii) The air flow rate is then converted to pump flow, Qp, in cubic feet per revolution at absolute pump inlet temperature and pressure.

\[ V = \frac{Q_a}{n} = \frac{328}{P} \]

Where:
- \( V \) = Pump flow. ft³/revolution (m³/revolution) at \( T_r, P_r \)
- \( Q_a \) = Meter air flow rate in standard cubic feet per minute, standard conditions are 60° F. 29.92 in. Hg (20° C. 101.3 kPa).

\[ \Delta P_r = \text{the pressure differential from pump inlet to pump outlet, in. Hg (kPa)} \]
\[ = P_r - P_f \]
\[ P_r = \text{Absolute pump outlet pressure, in. Hg (kPa)} \]
\[ = P_f + PPO \text{ (Sp. Gr./13.57 for SI units, } P_r = P_f + PPO) \]

(d) CFV calibration: (1) Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature:

\[ Q_s = \sqrt{\frac{K_v}{T}} \]

Where:
- \( Q_s \) = flow
- \( K_v \) = calibration constant
- \( P \) = absolute pressure
- \( T \) = absolute temperature

The calibration procedure described below establishes the value of the calibration constant at measured values of pressure, temperature and air flow.

(2) The manufacturer's recommended procedure shall be followed for calibrating electronic portions of the CFV.

(3) Measurements necessary for flow calibration are as follows:

\[ \Delta P = \text{the pressure differential from pump inlet to pump outlet, in. Hg (kPa)} \]
\[ = P_r - P_f \]
\[ P_r = \text{Absolute pump outlet pressure, in. Hg (kPa)} \]
\[ = P_f + PPO \text{ (Sp. Gr./13.57 for SI units, } P_r = P_f + PPO) \]

(4) Set up equipment as shown in Figure N88-9 and check for leaks. Any leaks between the flow measuring devices and the critical flow venturi will seriously affect the accuracy of the calibration.

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FIGURE N86-9 — CFV-CVS CALIBRATION CONFIGURATION
(5) Set the variable flow restrictor to the open position, start the blower, and allow the system to stabilize. Record data from all instruments.

(6) Vary the flow restrictor and make at least 8 readings across the critical flow range of the venturi.

(7) Data analysis. The data recorded during the calibration are to be used in the following calculations:

(i) The air flow rate, Q, at each test point is calculated in standard cubic feet per minute from the flow meter data using the manufacturer's prescribed method.

(ii) Calculate values of the calibration coefficient for each test point:

\[ K_v = \frac{Q_s}{\sqrt{\frac{T_v}{P_v}}} \]

Where:

- \( Q_s \) = Flow rate in standard cubic feet per minute, standard conditions are 60°F, 29.92 in. Hg (20°C, 101.3 kPa).
- \( T_v \) = Temperature at venturi inlet, R(K).
- \( P_v \) = Pressure at venturi inlet, mm Hg (kPa).
- \( P_r \) = Pressure upstream of venturi from flow meter data.
- \( P_w \) = Water pressure.
- \( P_m \) = Pressure upstream of venturi from manometer.
- \( K_v \) = Venturi coefficient.

(iii) Plot \( K_v \) as a function of venturi inlet pressure. For sonic flow, \( K_v \) will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and \( K_v \) decreases. See Figures N86-9.
The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric mass to determine the percent accuracy of the system.

(6) Cost engineering practice requires that the cause for any discrepancy greater than ±2 percent must be found and corrected.

23 A new § 80.1320-86 is added and reads as follows:

§ 80.1320-86 Gas meter or flow instrumentation calibration, particulate measurement.

Sampling for particulate emissions requires the use of gas meters or flow instrumentation to determine flow through the particulate filters. This instrument shall receive initial and periodic calibrations as follows:

(a) Install a standard air flow measurement device (such as a laminar flow element) upstream of the instrument: This standard device shall measure air flow at standard conditions. Standard conditions are defined as 760°F (20°C) and 29.92 inches of mercury (101.3 kPa). A critical flow orifice, a bellmouth nozzle, or a laminar flow element is recommended as the standard device.

(b) Flow air through the calibration system at the sample flow rate used for particulate testing and at the back pressure which occurs during the sample test.

(3) When the temperature and pressure in the system have stabilized, measure the gas meter indicated volume of the instrument over a time period of at least 5 minutes and until a flow volume of at least ±1 percent accuracy can be determined by the standard device. Record the stabilized air temperature and pressure upstream of the instrument and as required for the standard device.

(4) Calculate air flow at standard conditions as measured by both the standard device and the instrument.

(5) Repeat the procedures of paragraphs (b) through (d) above using flow rates which are 10 percent above the nominal sampling flow rate and 10 percent below the nominal sampling flow rate.

(6) If the air flow at standard conditions measured by the instrument differs by more than ±0.5 percent from the standard measurement at any of the three measured flow rates, then a correction shall be made by either of the following two methods:

(i) Mechanically adjust the instrument so that it agrees within 1 percent of the standard measurement at the three specified flow rates, or

(ii) Develop a continuous best fit calibration curve for the instrument (as a function of the standard device flow measurement) from the three calibration points that represents the data to within 1 percent at all points to determine corrected flow.

(b) If the air flow at standard conditions measured by the instrument differs by more than ±3 percent from the standard measurement at any of the three measured flow rates, then a correction shall be made by either of the following two methods:

(i) Mechanically adjust the instrument so that it agrees within 1 percent of the standard measurement at the three specified flow rates, or

(ii) Develop a continuous best fit calibration curve for the instrument (as a function of the standard device flow measurement) from the three calibration points that represents the data to within 1 percent at all points to determine corrected flow.

(c) If the air flow at standard conditions measured by the instrument differs by more than ±5 percent from the standard measurement at any of the three measured flow rates, then a correction shall be made by either of the following two methods:

(i) Mechanically adjust the instrument so that it agrees within 1 percent of the standard measurement at the three specified flow rates, or

(ii) Develop a continuous best fit calibration curve for the instrument (as a function of the standard device flow measurement) from the three calibration points that represents the data to within 1 percent at all points to determine corrected flow.
smoothly thereafter the NDIR carbon monoxide analyzer shall be calibrated.

1. Adjust the analyzer to optimize performance.

2. Zero the carbon monoxide analyzer with either zero-grade air or zero-grade nitrogen.

3. Calibrate on each used operating range with carbon monoxide in N\textsubscript{i} calibration gases having nominal concentrations of 15, 30, 45, 60, 75, and 90 percent of that range. Additional calibration points may be generated. For each range calibrated, if the deviation from a least-squares best-fit straight line is 2 percent or less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2 percent at any point, the best-fit non-linear equation which represents the data to within 2 percent of each test point shall be used to determine concentration.

(c) The initial and periodic interference, system check, and calibration test procedures specified in 40 CFR 66, Subpart D may be used in lieu of the procedures specified in this section.

26. A new § 86.1323-86 is added and reads as follows:

§ 86.1323-86 Oxides of nitrogen analyzer calibration.

The chemiluminescent oxides of nitrogen analyzer shall receive the following initial and periodic calibration.

(a) Prior to its introduction into service and weekly thereafter the chemiluminescent oxides of nitrogen analyzer shall be checked for NO\textsubscript{x} to NO converter efficiency. Figure N86-11 is a reference for the following steps:

1. Follow the manufacturer's instructions for instrument start-up and operation. Adjust the analyzer to optimize performance.

2. Zero the oxides of nitrogen analyzer with zero-grade air or zero-grade nitrogen.

3. Connect the outlet of the NO\textsubscript{x} generator to the sample inlet of the oxides of nitrogen analyzer which has been set to the most common operating range.

4. Introduce into the NO\textsubscript{x} analyzer-system an NO in nitrogen (N\textsubscript{i}) mixture with a NO concentration equal to approximately 80 percent of the most common operating range. The NO\textsubscript{x} content of the gas mixture shall be less than 5 percent of the NO concentration.

5. With the oxides of nitrogen analyzer in the NO mode, record the connection of NO indicated by the analyzer.

6. Turn on the NO\textsubscript{y} generator (or air) supply and adjust the (or air) flow rate so that the NO indicated by the analyzer is about 10 percent less than indicated in step (5). Record the concentration of NO in this NO + O\textsubscript{y} mixture.

7. Switch the NO\textsubscript{y} generator to the generation mode and adjust the generation rate so that the NO measured on the analyzer is 20 percent of that measured in step (6). There must be at least 10 percent unreacted NO at this point. Record the concentration of residual NO.

8. Switch the oxides of nitrogen analyzer to the NO\textsubscript{y} mode and measure total NO\textsubscript{y}. Record this value.

9. Switch off the NO\textsubscript{y} generator but maintain gas flow through the system. The oxides of nitrogen analyzer will indicate the NO\textsubscript{y} in the NO + O\textsubscript{y} mixture. Record this value.

10. Turn off the NO\textsubscript{y} generator (or air) supply. The analyzer will now indicate the NO\textsubscript{y} in the original NO in N\textsubscript{i} mixture. This value should be no more than 5 percent above the value indicated in step (4).

11. Calculate the efficiency of the NO\textsubscript{y} converter by substituting the concentrations obtained into the following equation:

\[
\text{Percent Efficiency} = \frac{1 + \frac{a-b}{c-d}}{1} \times 100
\]

Where:

\( a \) = concentration obtained in step (9).

\( b \) = concentration obtained in step (9).

\( c \) = concentration obtained in step (6).

\( d \) = concentration obtained in step (7).

If converter efficiency is not greater than 90 percent corrective action will be required.
FLOW CONTROL
SOLENOID VALVE

O₂ OR AIR
SUPPLY

O₂ OR AIR
SUPPLY

VARIAC

115 V.A.C.

OZONATOR

ANALYZER
INLET
CONNECTOR

NO/N₂
SUPPLY

(SEE FIG. N86-7 FOR SYMBOL LEGEND)

FIGURE N86-11 — NOₓ CONVERTER EFFICIENCY DETECTOR
(b) Initial and periodic calibration. Prior to its introduction into service and monthly thereafter the chemiluminescent oxides of nitrogen analyzer shall be calibrated on all normally used instrument ranges. Use the same flow rates as when analyzing samples. Proceed as follows:

1. Adjust analyzer to optimize performance.
2. Zero the oxides of nitrogen analyzer with zero-grade air or zero-grade nitrogen.
3. Calibrate on each normally used operating range with NO in N₂ calibration gases having nominal concentrations of 15, 30, 45, 60, 75 and 90 percent of that range. For each range, calibrated, if the deviation from a least-squares best-fit straight line is 2 percent or less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2 percent at any point, the best-fit non-linear equation which represents the data to within 2 percent of each test point shall be used to determine concentration.

(c) The initial and periodic interferences, system check, and calibration test procedures specified in 40 CFR 86. Subpart D may be used in lieu of the procedures described in this section. A new § 86.1324-86 is added and reserved as follows:

§ 86.1324-86 Carbon dioxide analyzer calibration.

Prior to its introduction into service and monthly thereafter the NDIR carbon dioxide analyzer shall be calibrated as follows:

(a) Follow the manufacturer's instructions for instrument start-up and operation. Adjust the analyzer to optimize performance.

(b) Zero the carbon dioxide analyzer with either zero-grade air or zero-grade nitrogen.

(c) Calibrate on each normally used operating range with carbon dioxide in N₂ calibration gases having nominal concentrations of 15, 30, 45, 60, 75, and 90 percent of that range. Additional calibration points may be generated. For each range, calibrated, if the deviation from a least-squares best-fit straight line is 2 percent or less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2 percent at any point, the best-fit non-linear equation which represents the data to within 2 percent of each test point shall be used to determine concentration.

(d) The initial and periodic interferences, system check, and calibration test procedures specified in 40 CFR 86. Subpart D may be used in lieu of the procedures in this section. A new § 86.1325-86 is added and reserved as follows:

§ 86.1325-86 Calibration of other equipment.

Other test equipment used for testing shall be calibrated as often as required by the manufacturer or necessary according to good practice.

2. A new § 86.1327-86 is added and reserved as follows:

§ 86.1327-86 Engine dynamometer test procedure overview.

(a) The engine dynamometer test procedure is designed to determine the brake-specific emission of hydrocarbons, carbon monoxide, oxides of nitrogen, and particulate (diesels only). The test procedure consists of a "cold" start test following either natural or forced cool-down periods described in §§ 86.1335-86 and 86.1336-86, respectively. A "hot" start test follows the "cold" start test after a hot soak of 20 minutes. The idle test of Subpart P may be run after the "hot start" test. The exhaust emissions are diluted with ambient air and a continuous proportional sample is collected for analysis during both the cold and hot start tests. The composite samples collected are analyzed either in bags or continuously for hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂), and oxides of nitrogen (NOₓ). In addition, for diesels only, particulates are collected on a fluorocarbon coated glass fiber filters or fluorocarbon based (membrane) filters and the dilution air is prefilted.

(b) Engine torque and rpm shall be recorded continuously during both the cold and hot start tests. Data points shall be recorded at least once every second.

(c) Using the torque and rpm feedback signals the brake horsepower is integrated with respect to time for the cold and hot cycles. This produces a brake horsepower-hour value that enables the brake-specific emissions to be determined (see § 86.1344-86). Calculations: exhaust emissions.

(d)(1) When an engine is tested for exhaust emissions or is operated for service accommodation on an engine dynamometer, the complete engine shall be tested with all emission control devices installed and functioning.

(2) Evaporative emission controls need not be connected if data are provided to show that normal operating conditions are maintained in the engine induction system.

(3) On air cooled engines, the fan shall be installed.

(4) Additional accessories (e.g., oil cooler, alternators, air compressors, etc.) may be installed with advance approval by the Administrator.

(5) The engine must be equipped with a production type starter.

(e) Means of engine cooling which will maintain the engine operating temperatures (e.g., intake air, oil, water, etc.) at approximately the same temperature as specified by the manufacturer shall be used. Auxiliary fan(s) may be used to maintain engine cooling during operation on the dynamometer. Only water is allowed as an engine-coolant medium. Rust inhibitors and lubrication additives may be used. Up to the levels recommended by the additive manufacturer. Antifreeze mixtures (e.g., ethylene glycol, alcohols) and other coolants that would enhance heat transfer are specifically prohibited.

(f) Exhaust systems. A chassis-type exhaust system shall be used which is assembled with respect to emissions. The exhaust system shall meet the following requirements:

1. For all catalyst and trap-oxidizer systems, the distance from the exhaust manifold flange(s) to the catalyst or trap-oxidizer shall be the same as in the vehicle configuration unless the manufacturer provides data showing equivalent performance at another location.

2. The exhaust back pressure or restriction shall be typical of those seen in the actual vehicle exhaust system configuration or the back pressure shall be the manufacturer's recommended maximum exhaust back pressure limit.

3. For all diesel engines, the distance from the exhaust manifold flange to the exit of the chassis-type exhaust system shall be a maximum of 12 feet.

31. A new § 86.1328-86 is added and reserved as follows:

§ 86.1328-86 (Reserved)
START

GENERATE MAXIMUM TORQUE CURVE

PRACTICE CYCLE RUNS}

COLD SOAK OR COOL DOWN}

80 HR. MAX

COLD START EXHAUST EMISSION TEST

HOT SOAK}

HOT START EXHAUST EMISSION TEST

END

FIGURE N86-12 — TEST SEQUENCE
(b) The average temperature of the engine intake air and CVS dilution air shall be maintained at 25°C ± 5°C (77°F ± 9°F) throughout the test sequence. Engines with auxiliary emission control devices which are temperature dependent (e.g., checkers, air cleaner, hot air doors, etc.) shall be tested at an average ambient test cell temperature 25°C ± 5°C throughout the test sequence, except as noted in § 60.1335-86.

(c) No control of ambient or CVS dilution air humidity is required. Engine intake air humidity shall not exceed 30 grams of water per pound of dry air.

(d) The idle test of Subpart P may be run after completion of the hot start exhaust emission test, if applicable.

(e) The barometric pressure observed during the generation of the maximum torque curve shall not deviate more than 1 in. Hg from the value measured at the beginning of the map. The barometric pressure observed during the exhaust emission test shall not deviate more than 1 in. Hg from the value measured at the beginning of the emission test. The average barometric pressure observed during the exhaust emission test must be within 1 in. Hg of the average observed during the maximum torque curve generation.

(f) Diesel engines only. Air inlet and exhaust restrictions shall be set to represent the average restrictions which would be seen in use in a representative application. Inlet depression and exhaust backpressure shall be set with the engine operating at maximum horsepower.

(g) A new § 60.1331-86 is added and reserved as follows:

§ 60.1331-86 [Reserved]

.35 A new § 60.1332-86 is added and reads as follows:

§ 60.1332-86 Engine mapping procedures.

(a) Mount test engine on the engine dynamometer.

(b) Determine minimum mapping speed.

(1) Gasoline-fueled engines. The minimum mapping speed shall be calculated from the following equations:

\[
\text{Minimum Speed} = \text{Curb Idle RPM} - \frac{280 \text{ RPM}}{\text{engine size} + 70} 
\]

(ii) Diesel engines. The minimum mapping speed shall be calculated from the following equations:

(1) Minimum Speed = Low Idle RPM - 280 RPM + 70 RPM, whichever is greater.

(2) Minimum Speed = 400 RPM, whichever is greater.

(c) Determine maximum mapping speed.

(1) Gasoline-fueled engines. The maximum speed during the engine operating test shall be limited to 100 RPM below the maximum speed at which the engine can be run at wide open throttle without smoke or other emissions that exceed the acceptable levels.

(2) Diesel engines. The maximum speed during the engine operating test shall be limited to 100 RPM below the maximum speed at which the engine can be run at wide open throttle without smoke or other emissions that exceed the acceptable levels.

(3) Mapping curve generation.

(iii) For governed engines the maximum mapping speed shall be at least 100 RPM above the maximum speed at which the engine can be run at wide open throttle without smoke or other emissions that exceed the acceptable levels.

(iv) For ungoverned engines, the maximum mapping speed shall be calculated from the following equations:

\[
\text{Maximum Speed} = \text{Curb Idle RPM} + \frac{115 \text{ (Measured) \times Curb Idle RPM}}{\text{(Raced RPM – Curb Idle RPM)}} - 100
\]

or (ii) of this section using the measured rated speed derived from the new maximum torque curve. If either of the new minimum or maximum speeds lay outside the range of speeds encompassed by the actual map, then the map shall be considered void. The entire mapping procedures shall be repeated, using the newly derived measured rated speed in all calculations.

(3) Diesel engines. (i) Start the engine and operate at 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. It is permitted to precondition the engine 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 the minimum value for 2 minutes. The engine must be operated a minimum of 10 minutes for this option. This optional procedure may be substituted for step (iii).

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

(vi) Operate the engine at wide open throttle and minimum engine speed. Increase the engine speed at a constant rate of 5 RPM/second (± 1 RPM/second) from minimum to maximum speed. Engine speed and torque points shall be recorded at a sample rate of at least one point per second.

(vii) Recalculate minimum and maximum speeds per (b)(2) and (c)(3)(i) or (ii) of this section using the measured rated speed derived from the new maximum torque curve. If either of the new minimum or maximum speeds lay outside the range of speeds encompassed by the actual map, then the map shall be considered void. The entire mapping procedure shall be repeated, using the newly derived measured rated speed in all calculations.

(viii) Mapping curve generation.
[1] Gasoline-fueled engines. (i) Fit all data points recorded under (d)(2)(vi) and (vii) of this section (100 RPM increments) with a cubic spline technique.

(ii) All points generated under the continuous RPM sweep by step (d)(2)(vi) and (viii) shall be connected by linear interpolation between points.

(iii) For governed engines, all points above the maximum speed (see (c)(1)(ii) of this section) shall be assigned maximum torque values of zero for purposes of cycle generation.

(iv) For all engines, all speed points below 400 RPM shall be assigned a maximum torque value equal to that observed at 400 RPM for purposes of cycle generation.

(v) The torque curve resulting from step (i) through (iv) is the mapping curve and will be used to convert the normalized torque values in the engine cycle (see Appendix 1, f) to actual torque values for the test cycle.

[2] Diesel-engines. (i) Connect all data points recorded under (d)(3)(vi) and (vii) of this section using linear interpolation between points.

(ii) For governed engines, all points above the maximum speed (see (c)(2)(ii) of this section) shall be assigned maximum torque values of zero for purposes of cycle generation.

(iii) For all engines, all speed points below 400 RPM shall be assigned a maximum torque value equal to that observed at 400 RPM for purposes of cycle generation.

(iv) The torque curve resulting from step (i) through (iii) is the mapping curve and will be used to convert the normalized torque values in the engine cycle (see Appendix 1, g) into actual torque values for the test cycle.

(f) Alternate mapping and mapping curve generation techniques. If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine or engine family, alternate mapping techniques may be used. Alternate techniques may be used only if approved in advance by the Administrator, and only if the Administrator judges that change to be justified and the alternate procedure to be technically correct.

36. A new § 86.1333-86 is added and reads as follows:

§ 86.1333-86 Transient test cycle generation.

(a) The heavy-duty transient engine cycle for gasoline- and diesel-fueled engines are listed in Appendix 1 (f and g). These second-by-second listings are designed to represent transient torque and RPM maneuvers characteristic of heavy-duty vehicles. Both RPM and torque are normalized in these listings.

(b) To unnormalize RPM use the following equation:

\[
\text{Actual RPM} = \frac{\text{Rated RPM} - \text{Curb Idle RPM}}{100} \times \text{Curb Idle RPM}
\]

(Curb idle for diesel engines is defined as the low idle RPM.)

(2) Torque is normalized to the maximum torque at the RPM listed with it. Therefore, to unnormalize the torque values in the cycle, the maximum torque curve for the engine in question must be used. The generation of the maximum torque curve is described in § 86.1332-86.

(b) Example of the unnormalization procedure. The following test point shall be unnormalized:

<table>
<thead>
<tr>
<th>Percent RPM</th>
<th>Torque Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>82</td>
</tr>
</tbody>
</table>

The test engines have these values:

- Measured Idle RPM = 800 (Does not appear on given torque curve.)
- Curb Idle RPM = 800.
- Maximum torque curve as illustrated in Figure N86-13.

Calculate actual RPM:

- Actual RPM = \(43(800-600)/100 + 600\)
- Actual RPM = 1978

Determine actual torque:

- Determine the maximum torque at 1978 RPM from Figure N86-13. Then multiply this value (458 ft-lb) by 0.82. This results in an actual torque of 384 ft-lbs.
FIGURE N86-13 — SAMPLE MAXIMUM TORQUE CURVE FOR A GASOLINE-FUELED ENGINE.
(c) Engine speed and torque shall be recorded at least once every second during the cold start test and hot start test. The torque and RPM feedback signals may be electrically filtered.

(d) Gasoline-fueled engines. The zero percent speed specified in the gasoline-fueled engine cycle (Appendix I (f)) shall be supplantied by proper operation of the engine's automatic choke.

(1) During automatic choke operation a manual transmission engine shall be allowed to idle at whatever speed is required to produce a feedback torque of 0 ft-lbs ± 10 ft-lbs (using for example clutch disengagement, speed to torque control switching, software overrides, etc.) at those points in Appendix I where both reference speed and reference torque are zero percent values.

(2) During automatic choke operation an automatic transmission engine shall be allowed to idle at whatever speed is required to produce a feedback torque of 0 ft-lbs ± 10 ft-lbs (see (a)(2) of this section for definition of CITT) at those points in Appendix I where both reference speed and reference torque are zero percent values.

(3) This automatic choke high idle allowance is permitted only for the first 150 seconds of the cold cycle and the first 30 seconds of the hot cycle, after which the cycles shall be run as specified in Appendix I (f). (See 86.1341-86 for allowances in the cycle validation criteria.)

(e) Automatic Transmissions. The reference cycles in Appendix I (f) and (g) shall be altered for engines intended for use with automatic transmissions.

(1) Zero percent speed for automatic transmission engines is defined as curb idle RPM, i.e., in-vehicle, coupled with automatic transmission in gear.

(2) All zero-percent speed, zero-percent torque points (idle points) shall be modified to zero percent speed, percent torque. Using the manufacturers' specified curb idle transmission torque (CITT), the maximum torque available at the curb idle (i.e., with transmission) RPM as determined from the maximum torque curve generated in 86.1332-86, x percent torque is defined per the following equation:

\[
\text{CITT} = 100
\]

\[
\text{Maximum Torque at Curb Idle RPM}
\]

37 A new § 86.1334-86 is added and reads as follows:

§ 86.1334-86 Pre-test engine and dynamometer preparation.

Control system calibration. (a) Before the cold start or cool down, final calibration of the dynamometer and throttle control systems may be performed. These calibrations may consist of steady-state operation and/or actual practice cycle runs, but emissions may not be measured.

(b) Following any practice runs or calibration procedures, the engine shall be turned off and allowed to either cool down at 80° to 86°F for a minimum of 12 hours, or be cooled per § 86.1335-86.

38 A new § 86.1335-86 is added and reads as follows:

§ 86.1335-86 Optional forced cool-down procedure.

(a) This forced cool-down procedure applies to both gasoline and diesel-fueled engines.

(b) No substances or fluids may be applied to the engine internal or external surfaces except for water and air, and only as prescribed in (c) and (d) of this section.

(c) For water-cooled engines two types of cooling are permitted.

(1) Water may be circulated through the engine's water coolant system.

(2) The coolant may be blown in either direction and at any desired flow rate. The thermostats may be removed or blocked open during the cool down but must be restored before the exhaust emissions test begins.

(ii) The temperature of the circulated or injected water shall be between 10°C (50°F) and 30°C (86°F).

(iii) No fluid except water and no fluid or substance in solution with water is permitted. This does not preclude the use of a building's standard water supply for forced cool-down purposes.

(2) Flow of air may be directed at the exterior of the engine.

(i) Air shall be directed uniformly over the entire exterior surface of the engine at any desired flow rate.

(ii) The temperature of the cooling air shall not exceed 30°C (86°F). This is the only occasion when test cell ambient air temperature may deviate from the general specifications set forth in § 86.1330-86(b), i.e., may be less than 20°C (68°F).

(d) For air-cooled engines only cooling as prescribed in (c)(2) of this section is permitted.

(e) The cold cycle exhaust emission test may begin after a forced cool down only, when the engine oil temperature as measured at the dipstick is between 20°C and 24°C (68°F and 75°F). No oil engine oil change is permitted during the test sequence, nor is any direct or indirect cooling of the oil permitted except by natural conduction and convection associated with the procedures in (c) and (d) of this section.

(i) If the engine does not start after 15 seconds of cranking, cranking shall cease and the reason for failure to start
shall be determined. The gas flow measuring device (or revolution counter) on the constant volume sampler (and the hydrocarbon integrator and particulate sample pump(s) when testing diesel vehicles, see § 86.1337, Engine dynamometer test run) shall be turned off during this diagnostic period. In addition, either the CVS should be turned off or the exhaust tube disconnected from the tailpipe during the diagnostic period. If failure to start is an operational error, the engine shall be rescheduled for testing from a cold start.

(2) If longer cranking times are recommended to the ultimate purchaser, such cranking times may be used provided the owner's manual and the service repair manual indicate the longer cranking times are normal, and if the use of the longer cranking times is approved in advance by the Administrator.  

(3) If a failure to start occurs during the cold portion of the test and is caused by an engine malfunction, corrective action of less than 30 minutes duration may be taken (according to § 86.084-25), and the test continued. The sampling system shall be reactivated at the same time cranking begins. When the engine starts, the timing sequence shall begin. If failure to start is caused by engine malfunction and the engine cannot be started, the test shall be voided and corrective action may be taken according to § 86.084-25. The reasons for the malfunction (if determined) and the corrective action taken shall be reported to the Administrator.

(4) If a failure to start occurs during the hot start portion of the test and is caused by engine malfunction, the engine must not be started within one minute of key on. The sampling system shall be reactivated at the same time cranking begins. When the engine starts, the transient engine cycle timing sequence shall begin. If the engine cannot be started within one minute of key on, the test shall be voided.

(5) Follow the manufacturer's choke and throttle instructions for cold starting. Simultaneously start the engine and begin exhaust and dilution air sampling. For diesel engines, turn on the hydrocarbon, carbon monoxide (CO), CO₂ or NOₓ (if used) analyzers system integrator(s) and particulate sample pumps and indicate the start of the test on the data collection medium (i.e., mark the chart on a chart recorder, set a byte on a computer or data logger, etc.).  

(6) As soon as it is determined that the engine is started, start a "free idle" timer.  

(7) Allow the engine to idle freely with no load for 24 ± 1 seconds. This idle period for automatic transmission engines may be interpreted as an idle speed in neutral or park. All other idle conditions shall be interpreted as an idle speed in gear. It is permissible to lug the engine down to curb idle speed during the last 8 seconds of the free idle period for the purpose of engaging dynamometer control loops.

(8) Begin the transient engine cycles such that the first non-idle record of the cycle occurs at 25 ± 1 seconds. The free idle time is included in the 25 ± 1 seconds.

Note—During diesel testing, adjust the sample pump(s) so that the flow rate through the particulate probe or transfer tube is maintained at a constant value within ±3 percent of the set flow rate. Record the average temperature and pressure at the gas meter(s) or flow instrumentation inlet. If the set flow rate cannot be maintained because of high particulate loading on the filter, the test shall be terminated. The test shall be rerun using lower flow rate and/or a larger diameter filter.

(9) Allow the engine to idle freely with no load for 24 ± 1 seconds. This idle period for automatic transmission engines may be interpreted as an idle speed in neutral or park. All other idle conditions shall be interpreted as an idle speed in gear. It is permissible to lug the engine down to curb idle speed during the last 8 seconds of the free idle period for the purpose of engaging dynamometer control loops.

(10) On the last record of the cycle cease sampling, immediately turn the engine off, and start a hot soak timer. For diesel engines immediately after the engine stops running, simultaneously turn off the gas flow measuring device(s) and the diesel hydrocarbon and particulate sample pumps and mark the hydrocarbon recorder chart, and turn off the particulate sample pump(s).  

(11) Immediately after the engine is turned off, turn off the engine cooling fan(s) if used, and the CVS blower. As soon as possible transfer the "cold start cycle" exhaust and dilution air bag samples to the analytical system and process the samples according to § 83.1304-88 obtaining a stabilized reading of the exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the test. For diesel engines carefully remove each particulate sample filter from its holder and place each in a petri dish, and cover.

(12) Allow the engine to soak for 20 ± 1 minutes.

(13) Prepare the engine and dynamometer for the hot start test.

(14) Connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems.

(15) Start the CVS (if not already on), the sample pumps (except the diesel particulate sample pump(s), if applicable), the temperature recorder.
the engine cooling fan(s) and any data collection system (i.e., chart recorders, computers, data loggers, etc.). The heat exchanger of the constant volume sample(s) and the heated components of any continuous sampling system(s) shall be preheated to their respective operating temperatures before the test begins. See § 80.1340-86(c) for continuous sampling procedures.

(17) Adjust the sample flow rates to the desired flow rate and set the CVS gas flow measuring devices to zero.

Note.—CVS-CVS sample flow rate is fixed by the venturi design.

(18) Carefully install a clean particulate filter into each of the filter holders for diesel tests. The filters must be handled only with forceps or tongs. Rough or abrasive filter handling will result in erroneous weight determination.

(19) Follow the manufacturer's choke and throttle instructions for hot starting. Simultaneously start the engine and begin exhaust and dilution air sampling. For diesel engines, turn on the hydrocarbon analyzer system integrator, mark the recorder chart, and turn on the particulate sample pump(s).

(20) As soon as it is determined that the engine is started, start a "Idle" recording.

(21) Allow the engine to idle freely with no-load for 24 ± 1 seconds. The provisions and interpretations of step (18) of this section apply.

(22) Begin the transient engine cycle such that the first non-idle record of the cycle must be between 25 ± 1 seconds. The free idle is included in the 25 ± 1 seconds.

(23) On the last record of the cycle close sampling. For diesel engines, simultaneously turn off gas flow measuring device(s) and the diesel hydrocarbon recorder chart, and turn off the particulate sample pump(s).

(24) As soon as possible transfer the "hot start cycle" exhaust and dilution air bag samples to the analytical system and process the samples according to § 80.1340-86. Obtain a stabilized reading of the exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the cycle.

For diesel engines, carefully remove each particulate sample filter from its holder and place each in a clean petri dish and cover as soon as possible. Within one hour after the end of the hot start phase of the test, transfer the four particulate filters to the weighing chamber for post test conditioning.

(25) The CVS and the engine may be turned off if desired.

(b) The procedure in paragraph (a) of this section is designed for one sample bag for the cold start portion and one for the hot start portion. It is permissible to use 4 sample bag per test portion. The bias shall be for the portion of the cycle as indicated below:

<table>
<thead>
<tr>
<th>Bag No.</th>
<th>Gasoline-based</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>276</td>
<td>297</td>
</tr>
<tr>
<td>2</td>
<td>868</td>
<td>922</td>
</tr>
<tr>
<td>3</td>
<td>1,111</td>
<td>1,150</td>
</tr>
<tr>
<td>4</td>
<td>1,141</td>
<td>1,182</td>
</tr>
</tbody>
</table>

41. A new § 80.1338-86 is added and reads as follows:

§ 80.1338-86 Emission measurement accuracy.

(a) Measurement accuracy for analysis systems used for bag measurements.

(1) Good engineering practice would dictate that analyzer readings below 15 percent of full scale chart deflection should generally not be used.

(2) Some high resolution real-time systems such as computers, data loggers, etc., can provide sufficient accuracy and resolution below 15 percent of full scale. Such systems may be used provided that additional calibration techniques are added to ensure that the calibration curves below 15 percent of full scale, in the region of the sample measurements, conforms to the accuracy specifications in § 80.1316-86 through § 80.1328-86.

(b) Measurement accuracy for continuous analysis systems used for continuous measurement systems.

(1) Analyzers used for continuous analysis must be operated such that the integrated concentration value over the test cycle falls between 15 and 100 percent of full scale chart deflection. Exceptions to these limits are:

(i) The analyzer's response may be less than 15 percent or more than 100 percent of full scale if automatic range change circuitry is used and the limits for range changes are between 15 and 100 percent of full-scale chart deflection;

(ii) The analyzer's response may be less than 15 percent of full scale if:

(A) Alternative [2] of this section is used to insure that the accuracy of the calibration curve is maintained below 15 percent; or

(B) The full-scale value is 155 ppmC or less:

(C) The emissions from the engine are erratic and the integrated chart deflection value is greater than 15 percent of full scale; or

(D) The contribution of all data read below the 15 percent level is less than 10 percent by mass of the final test results.

(iii) During engine start-up the HC analyzer is allowed to "spike" on/off for a maximum of 5 seconds.

42. A new § 80.1339-86 is added and reads as follows:

§ 80.1339-86 Diesel particulate filter handling and weighing.

(a) At least 1 hour, but not more than 80 hours before the test, place each filter in an open, but protected, petri dish and place in the weighing chamber which meets the humidity and temperature specifications of § 80.1312-86.

(b) At the end of the 1 to 80 hour stabilization period, weigh the filter on a balance having a precision of one microgram. Record this weight. This reading is the tare weight.

(c) The filter shall then be stored in a covered petri dish which shall remain in the weighing chamber until needed for testing.

(d) If the filter is not used within one hour of its removal from the weighing chamber, it shall be re-weighed.

(e) After the test, and after the sample filter is returned to the weighing room, condition it for at least 1 hour but not more than 80 hours. Then weigh a second time. This latter reading is the gross weight of the filter. Record this weight.

(f) The net weight (Mw) is the gross weight minus the tare weight.

Note.—Should the sample on the filter contact the petri dish or any other surface, the test is void and must be re-run.

43. A new § 80.1340-86 is added and reads as follows:

§ 80.1340-86 Emission sample analysis.

(a) The analyzer response may be read by automatic data collection (ADC) equipment such as computers, data loggers, etc. If ADC equipment is used the following is required.

(1) For bag analysis the analyzer response must be stable at greater than 99 percent of final reading. A single value representing the average chart deflection over a 10 second stabilized period may be stored.

(2) For continuous analysis systems, the ADC system must store at least 5 chart deflection readings per second.

(3) The chart deflections in (a) and (b) of this section may be stored on long term computer storage devices such as computer tapes, storage discs, punch cards, or they may be printed in a listing for storage. In either case a chart recorder is not required and records from a chart recorder, if they exist, need not be stored.
(4) If the data from ADC equipment is used as permanent records, the ADC equipment and the analyzer values as interpreted by the ADC equipment are subject to the calibration specifications in §§ 80.1116–66 through §80.1320–66, as if the ADC equipment were part of the analyzer.

(b) Data records from any one or a combination of analyzers may be stored as chart recorder records.

(c) Software zero and span. (1) The use of “software” zero and span is permitted. The process of software zero and span refers to the technique of initially adjusting the analyzer zero and span responses to the calibration curve values, but for subsequent zero and span checks the analyzer response is simply recorded without adjusting the analyzer gain. The observed analyzer response recorded from the subsequent check is mathematically corrected back to the calibration curve values for zero and span. The same mathematical correction is then applied to the analyzer’s response to a sample of exhaust gas in order to compute the true sample concentration.

(2) A maximum amount of software zero and span must be used. The observed change in deflection before and after zero and span checks may be 10 percent of full scale chart deflection.

(3) Software zero and span may be used to switch between ranges without adjusting the gain of the analyzer.

(4) The software zero and span technique may not be used to mask analyzer drift. The observed change in deflection before and after a given time period or event shall be used for computing the drift. Software zero and span may be used after the drift has been computed to mathematically adjust any span drift so that the “after” span check may be transformed into the “before” span check for the next segment.

(d) For bag sample analysis perform the following sequence:

(1) Warm-up and stabilize the analyzers.

(2) Clean and/or replace filter elements, conditioning column (if used), etc. as necessary.

(3) The order of steps (1) and (2) may be interchanged.

(4) Obtain a stable zero reading.

(5) Zero and span the analyzers with water and air sampled. The span gases shall have concentrations between 75 and 100 percent of full scale chart deflection. The flow rates and system pressures during sampling shall be approximately the same as those encountered during sampling.

(6) The order of steps (4) and (5) may be interchanged.

(7) Obtain a stable zero reading.

(8) Zero and span each range to be used on each analyzer used prior to the beginning of the cold cycle. The span gases shall have a concentration between 75 and 100 percent of full scale chart deflection. The flow rates and system pressures shall be approximately the same as those encountered during sampling.

(9) Re-check zero response, repeat steps (7) and (8) or use software zero and span if necessary.

(10) If a chart recorder is used, identify the most recent zero and span response as the pre-analysis values.

(11) If ADC equipment is used, electronically record the most recent zero and span response as the pre-analysis values.

(9) Measure HC (except diesels). CO, CO₂, and NO₅ concentrations in the sample bag(s) with approximately the same flow rates and pressures used in paragraph (d)(5) of this section. Constituents measured continuously do not require bag analysis.

(10) Rechecking of the zero and span point after the analysis of the bag is permitted. The number of bags that may be analyzed after pre-analysis values for zero and span have been determined is not specified. The limiting criteria on the time span or the number of events that may occur between the pre-analysis and post-analysis zero span checks are the following:

(i) A pre-analysis zero and span check for each range used must be performed and the values recorded. The time interval or the number of events that may occur between the pre and post checks is not specified. However, the difference between pre-analysis zero and span checks recorded in step (7) and (8) versus those recorded for the post-analysis check may not exceed the zero drift limit or the span drift limit of 2 percent of full scale chart deflection for any range used.

(ii) The time span between the pre and post checks may be no longer than the time period that was used to evaluate the analyzer drift performance.

(11) Analyze the remaining sample and background bags as outlined in steps (4) through (10).

(12) For continuous sample analysis perform the following sequence:

(1) Warm-up and stabilize the analyzers.

(2) Clean and/or replace filter elements, conditioning column (if used), etc. as necessary.

(3) The order of steps (1) and (2) may be interchanged.

(4) Leak check portions of the sampling system that operate under a vacuum when sampling.

(5) At the beginning of each sample line, filters, pumps, etc., to stabilize at operating temperature.

(6) The order of steps (4) and (5) may be interchanged.

(7) Obtain a stable zero reading.

(8) Zero and span each range to be used on each analyzer used prior to the beginning of the cold cycle. The span gases shall have a concentration between 75 and 100 percent of full scale chart deflection. The flow rates and system pressures shall be approximately the same as those encountered during sampling.

(9) Re-check zero response, repeat steps (7) and (8) or use software zero and span if necessary.

(10) If a chart recorder is used, identify the most recent zero and span response as the pre-analysis values.

(11) If ADC equipment is used, electronically record the most recent zero and span response as the pre-analysis values.

(12) Measure the emissions (HC required for diesels. NO₅, CO, CO₅, optional) continuously during the cold start cycle. Indicate the start of the test, the range(s) used, and the end of the test on the recording medium (chart paper or ADC equipment). Use approximately the same flow rates and system pressures used in step (8).

(13) Collect background HC, CO, CO₂, and NO₅ in a sample bag.

(14) Perform a post-analysis zero and span check for each range at the conditions specified in step (8).

(15) Neither the zero drift nor the span drift between the pre-analysis and post-analysis checks on any range used may exceed 3 percent for HC or 2 percent for NO₅, CO, and CO₂ of full scale chart deflection, or the values recorded in paragraphs (d) and (e).

(16) Determine HC background levels for the cold start cycle by introducing a sample from the background bag into the overflow HC span system.

(17) Determine background levels of NO₅, CO, or CO₂ (if necessary) by the technique outlined in paragraph (e) of this section. The continuous analyzers may be used for analysis under paragraph (a).

Note.—For a quality control check on diesel HC, compare an analysis of a background bag to a continuous analysis of background air sampled through the total hydrocarbon probe. For best results, the difference should be less than 1 percent on the average (time integrated) dilute hydrocarbon emission level during the test.

(18) Repeat steps (7) through (17) for the hot cycle. The post-analysis zero and span check for the cold start (or previous hot start) cycle may be used for the pre-analysis zero and span for the following hot start cycle.

(19) If the HC drift is greater than 3 percent of full scale chart deflection, hydrocarbon hang-up is suspected.
(f) 1C hang-up. If the 1C hang-up is suspected, the following sequence may be performed.

1. Fill a clean sample bag with zero gas.
2. Zero and span the HPID with the overflow system.
3. Analyze the sample bag through the overflow sample system.
4. Analyze the sample bag on another FID or HPID meeting the specification of this Subpart or 40 CFR, Subpart D, that does not have a hang-up problem.
5. If the difference between the readings obtained is 3 percent or more of the HPID full scale, disconnect probe and clean same. (Soaking with sulfuric acid has proven effective.) Clean sample line also. (Holding to 450°F and flow nitrogen gas continuously for 12 hours has proven useful.)
6. Reassemble the sample system. Heat to specified temperature, and repeat the procedure in (1) through (6) above.

44. A new § 86.1341-86 is added and reads as follows:

§ 86.1341-86 Test cycle validation criteria.
(a) For a valid test the criteria in Figure N85-14 must be met for both cycles (cold start and hot start) individually. Deviations from the regression analysis are permitted where allowed in Figure N85-14.

Rolling code 0000-00-00

[e] For a valid test the criteria in Figure N85-14 must be met for both cycles (cold start and hot start) individually. Deviations from the regression analysis are permitted where allowed in Figure N85-14.
### REGRESSION LINE TOLERANCES

<table>
<thead>
<tr>
<th></th>
<th>SPEED</th>
<th>TORQUE</th>
<th>BRAKE HORSEPOWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>STANDARD ERROR OF ESTIMATE (SE) OF $Y$ ON $X$</td>
<td>100 RPM</td>
<td>$13%$ OF MAXIMUM ENGINE TORQUE</td>
<td>$8%$ OF MAXIMUM BRAKE HORSEPOWER</td>
</tr>
<tr>
<td>SLOPE OF THE REGRESSION LINE, $m$</td>
<td>0.970-1.030</td>
<td>0.923-1.03 HOT</td>
<td>0.88-1.03 (HOT)</td>
</tr>
<tr>
<td>COEFFICIENT OF DETERMINATION, $R^2$</td>
<td>$0.9700,y$</td>
<td>0.8600 (HOT), $y$</td>
<td>0.87-1.03 (COLD)</td>
</tr>
<tr>
<td>$Y$ INTERCEPT OF THE REGRESSION LINE, $b$</td>
<td>$\pm 50$ RPM</td>
<td>$\pm 15$ FT. LBS.</td>
<td>$\pm 5.0$ OF BRAKE HORSEPOWER</td>
</tr>
</tbody>
</table>

### PERMITTED POINT DELETIONS FROM REGRESSION ANALYSIS

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>POINTS TO BE DELETED</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIRST 24 SECONDS ($\leq 1$) OF FREE IDLE</td>
<td>SPEED, TORQUE, BRAKE HORSEPOWER</td>
</tr>
<tr>
<td>OF HOT AND COLD CYCLES</td>
<td></td>
</tr>
<tr>
<td>WIDE OPEN THROTTLE, SPEED CONTROL:</td>
<td>TORQUE, BRAKE HORSEPOWER</td>
</tr>
<tr>
<td>SPEED CONTROL:</td>
<td>SPEED, BRAKE HORSEPOWER</td>
</tr>
<tr>
<td>TORQUE FEEDBACK $&lt;$ TORQUE REFERENCE</td>
<td></td>
</tr>
<tr>
<td>SLOW FEEDBACK $&lt;$ SPEED REFERENCE</td>
<td></td>
</tr>
<tr>
<td>SPEED CONTROL, CLOSED THROTTLE, TORQUE REFERENCE $&lt;$ ZERO</td>
<td>TORQUE, BRAKE HORSEPOWER</td>
</tr>
<tr>
<td>GASOLINE FUELED ENGINES EQUIPPED WITH AUTOMATIC CHOKEs, FIRST 180 SECONDS</td>
<td>SPEED, BRAKE HORSEPOWER</td>
</tr>
<tr>
<td>OF COLD CYCLE OR FIRST 30 SECONDS OF HOT CYCLE, CLOSED THROTTLE AND:</td>
<td></td>
</tr>
<tr>
<td>MANUAL TRANSMISSION, IF TORQUE FEEDBACK</td>
<td></td>
</tr>
<tr>
<td>A. IS EQUAL TO ZERO ($\leq 10$ FT. LBS.) OR:</td>
<td></td>
</tr>
<tr>
<td>B. AUTOMATIC TRANSMISSION, IF TORQUE FEEDBACK IS EQUAL TO CURB IDLE</td>
<td></td>
</tr>
<tr>
<td>TRANSMISSION TORQUE ($\leq 10$ FT. LBS.)</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE N86-14
The integrated brake horsepower-hour for each cycle (cold and hot start) shall be between -15 percent and +5 percent of the integrated brake horsepower-hour for the reference cycle or the test is void. All torque and speed data points must be used to calculate the integrated brake horsepower-hour. For the purposes of this calculation, negative torque values (i.e., motoring brake) shall be set equal to zero and included.

If a dynamometer test run is determined to be statistically or experimentally void, corrective action shall be taken. The engine shall then be allowed to cool (naturally or forced) and the dynamometer test rerun per § 86.1337-60. New § 86.1342-60 is added and reads as follows:

§ 86.1342-60 Calculations; exhaust emissions.

The final reported transient emission test results shall be computed by use of the following formula:

\[ A_{\text{em}} = \frac{1/7(g_C) + 6/7(g_R)}{1/7(BHP-HC) + 6/7(BHP-HR)} \]

Where:

- \( A_{\text{em}} \) = Weighted mass emission level (HC, CO, CO\(_2\), NO\(_x\) or particulate (diesel only)) in grams per brake horsepower hour.
- \( g_x \) = Mass emission level in grams, measured during the cold start test.
- \( R_x \) = Mass emissions level in grams, measured during the hot start test.
- BHP-HR = Total brake horsepower-hour (brake horsepower integrated with respect to time) for the cold start test.
- BHP-HR = Total brake horsepower-hour (brake horsepower integrated with respect to time) for the hot start test.

(1) The mass of each pollutant for the cold start test and the hot start test for bag measurements and diesel heat exchanger sample system measurements is determined from the following equations:

(i) Hydrocarbon mass:

\[ HC_{\text{mass}} = V_{\text{mix}} \times \text{Density}_{HC} \times \frac{(HC_{\text{conc}}/1,000,000)}{\text{mix}} \]

(ii) Oxides of nitrogen mass:

\[ NOx_{\text{mass}} = V_{\text{mix}} \times \text{Density}_{NOx} \times \text{H} \times \frac{(NOx_{\text{conc}}/1,000,000)}{\text{mix}} \]

(iii) Carbon monoxide mass:

\[ CO_{\text{mass}} = V_{\text{mix}} \times \text{Density}_{CO} \times \frac{(CO_{\text{conc}}/1,000,000)}{\text{mix}} \]

(iv) Carbon dioxide mass:

\[ CO_{2\text{mass}} = V_{\text{mix}} \times \text{Density}_{CO_2} \times \frac{(CO_2_{\text{conc}}/100)}{\text{mix}} \]

(v) Diesel particulate mass:

\[ PMass = \left( V_{\text{mix}} + V_{\text{St}} \right) \times \frac{PF}{V_{\text{St}}} \]
(2) The mass of each pollutant for the cold start test and the hot start test for flow compensated sample systems is determined from the following equations:

(i) \( HC_{mass} = \frac{1}{10^6} \sum \left\{ (HC_i) \times (V_{mix,i} \times (Density\ HC) \times 4T) \right\} \)

(ii) \( NOx_{mass} = \frac{1}{10^6} \sum \left\{ (NOx_i) \times (V_{mix,i} \times (Density\ NO) \times 4T) \right\} \)

(iii) \( CO_{mass} = \frac{1}{10^6} \sum \left\{ (CO_i) \times (V_{mix,i} \times (Density\ CO) \times 4T) \right\} \)

(iv) \( CO2_{mass} = \frac{1}{10^6} \sum \left\{ (CO2_i) \times (V_{mix,i} \times (Density\ CO2) \times 4T) \right\} \)

(3) Meaning of symbols:

(i) \( HC_{mass} \) = Hydrocarbon emissions, in grams per test phase.

\( HC \) = Hydrocarbon concentration of the dilution air as measured, in ppm carbon equivalent.

\( NOx_{mass} \) = Oxides of nitrogen emissions, in grams per test phase.

\( CO_{mass} \) = Carbon monoxide concentration of the dilute exhaust sample corrected for background, in ppm carbon equivalent.

\( CO2_{mass} \) = Carbon dioxide concentration of the dilute exhaust sample corrected for background, in ppm.

Where:

\( HC \) = Hydrocarbon concentration of the dilute exhaust bag sample or, for diesel heat exchanger systems, average hydrocarbon concentration of the dilute exhaust sample as calculated from the integrated HC traces, in ppm carbon equivalent. For flow compensated sample systems \( HC_{mass} \) is the instantaneous concentration.

\( NOx_{mass} \) = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( CO_{mass} \) = Carbon monoxide concentration of the dilute exhaust bag sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( CO2_{mass} \) = Carbon dioxide concentration of the dilute exhaust bag sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( HC \), \( NOx_{mass} \), \( CO_{mass} \), \( CO2_{mass} \) = Concentration of the respective pollutant, in ppm.

Density \( HC \) = Density of carbon monoxide is 32.97 g/lbf \( \times 1.144 \text{ kg/m}^3 \), assuming an average carbon to hydrogen ratio of 1.145, at 68°F [20°C] and 760 mm Hg [101.3 kPa] pressure.

\( HC \) = Hydrocarbon concentration of the dilute exhaust sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( NOx_{mass} \) = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( CO_{mass} \) = Carbon monoxide concentration of the dilute exhaust sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( CO2_{mass} \) = Carbon dioxide concentration of the dilute exhaust sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( NOx_{mass} \) = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( CO_{mass} \) = Carbon monoxide concentration of the dilute exhaust sample corrected for water vapor and carbon dioxide extraction, in ppm. For flow compensated sample systems \( NOx_{mass} \) is the instantaneous concentration. The calculation assumes the carbon to hydrogen ratio of the fuel is 1.145.

\( CO \) = [1 - 0.01825CO] - 0.000332R[CO2]

Where:

\( CO \) = Carbon monoxide concentration of the dilute exhaust bag sample measured, in ppm.

\( CO2 \) = Carbon dioxide concentration of the dilute exhaust bag sample, in percent.

\( NOx_{mass} \) = Oxides of nitrogen concentration of the dilute exhaust bag sample, in ppm. For flow compensated sample systems \( NOx_{mass} \) is the instantaneous concentration. The calculation assumes the carbon to hydrogen ratio of the fuel is 1.145.

\( CO2_{mass} \) = Carbon dioxide concentration of the dilute exhaust bag sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

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\( CO2_{mass} \) = Carbon dioxide concentration of the dilute exhaust bag sample corrected for background, water vapor, and \( CO \) extraction, in ppm.

\( NOx_{mass} \) = Oxides of nitrogen concentration of the dilute exhaust bag sample corrected for background, water vapor, and \( CO \) extraction, in ppm.
$V_{nf} = V_{nf} \times (P_1 + P_2) \times 528.8^* \\
V_{nf} \times 760 \text{ mmHg}$

Where:
$V_{nf} = \text{actual volume of dilute sample removed from the primary-dilution tunnel, cubic feet.}$
$P_n = \text{barometric pressure, mmHg.}$
$P_1 = \text{pressure elevation above ambient measured at the inlet to the dilute exhaust sample gas meter or flow instrumented, mmHg.}$
$P_2 = \text{pressure elevation above ambient measured at the inlet to the dilute exhaust sample gas meter or flow instrumented, mmHg.}$
$P_n = \text{barometric pressure, mmHg.}$

For gasoline engines:
$K_n = 1/[(1 - 0.00471[H - 75]) \text{ or for SI units } 1/[(1 - 0.032) (H - 10.71)]]$

For diesel engines:
$K_n = 1.$

Where:
$H = \text{Absolute humidity in grains (grams) of water per pound (kilogram) of dry air.}$
$H = [(43.478R) \times x_{P}/(P_2 = (P_2 x P_1)/(100)) \text{ for SI units, } H = [(6.211R) x P_1/T]/(P_2 = (P_2 x P_1)/(100))]$
$R_n = \text{Relative humidity of the ambient air, in percent.}$
$P_2 = \text{Barometric pressure, in mm Hg (kPa).}$
$T_n = \text{Average temperature of the dilute exhaust sample at the inlet to the gas meter or flow instrumented.}$
$V_{nf} = \text{actual volume of dilute sample removed from the primary-dilution tunnel, cubic feet.}$
$P_1 = \text{Barometric pressure, mmHg.}$
$P_2 = \text{Barometric pressure, mmHg.}$
$V_{nf} = \text{actual volume of dilute sample removed from the primary-dilution tunnel, cubic feet.}$
$P_n = \text{pressure elevation above ambient measured at the inlet to the sample gas meter located at the exit side of the secondary dilution tunnel, mmHg.}$
$V_{nf} = \text{Total dilute exhaust sample volume in cubic feet per test phase corrected to standard conditions (528.8'R [293.15K]) and 760 mm Hg (101.3 kPa).}$
$V_{nf} = \text{Total dilute exhaust sample volume in cubic feet per test phase corrected to standard conditions (528.8'R [293.15K]) and 760 mm Hg (101.3 kPa).}$
$V_{nf} = \text{Instantaneous dilute exhaust volumetric flow rate [for compensated flow systems], in cubic feet per second.}$
$P_1 = \text{Pressure of a sample pumping system.}$
$V_{nf} = \text{actual volume of secondary dilution air, cubic feet.}$
$P_2 = \text{Barometric pressure, mmHg.}$
$P_n = \text{pressure elevation above ambient measured at the inlet to the sample gas meter or flow instrumented located at the exit side of the secondary dilution tunnel, mmHg.}$
$V_{nf} = \text{Actual temperature of the dilute exhaust sample at the inlet to the exit side gas meter or flow instrumentation.}$
$P_1 = \text{Barometric pressure, mmHg.}$

Note—Both $V_{nf}$ and $V_{nf}$ may require correction according to § 96.1320-86(f). (b) For a double-dilution system:

$V_{nf} = V_{nf} \times (P_1 + P_2) \times 528.8' \\
760 \text{ mmHg}$

Where:
$V_{nf} = \text{actual volume of double diluted sample which passed through the particulate filter, cubic feet.}$
$P_{nf} = \text{Barometric pressure, mmHg.}$
$P_1 = \text{pressure elevation above ambient measured at the inlet to the sample gas meter located at the exit side of the secondary dilution tunnel, mmHg.}$
$V_{nf} = \text{Actual temperature of the dilute exhaust sample at the inlet to the exit side gas meter or flow instrumentation.}$
$P_1 = \text{Barometric pressure, mmHg.}$
$P_2 = \text{Barometric pressure, mmHg.}$
$V_{nf} = \text{actual volume of secondary dilution air, cubic feet.}$
$P_n = \text{Barometric pressure, mmHg.}$
$P_1 = \text{pressure elevation above ambient measured at the inlet to the sample gas meter or flow instrumented located at the exit side of the secondary dilution tunnel, mmHg.}$
$V_{nf} = \text{Actual temperature of the dilute exhaust sample at the inlet to the exit side gas meter or flow instrumentation.}$

Note—The background particulate level inside the dilution air filter box at EPA is very low. This particulate level will be assumed 0, and background particulate samples will not be taken with each exhaust sample. It is recommended that background particulate checks be made periodically to verify the low level. Any manufacturer may make the same assumption without prior EPA approval.

(vi) $DF = 13.5 \times (CO_2 + \text{[H}_2\text{O} + \text{CO}) \times 10^4$ $K_n + \text{Humidity correction factor.}$

For gasoline engines:
$K_n = 1/[(1 - 0.00471[H - 75]) \text{ or for SI units } 1/[(1 - 0.032) (H - 10.71)]]$

For diesel engines:
$K_n = 1.$

Where:
$H = \text{Absolute humidity in grains (grams) of water per pound (kilogram) of dry air.}$
$H = [(43.478R) \times x_{P}/(P_2 = (P_2 x P_1)/(100)) \text{ for SI units, } H = [(6.211R) x P_1/T]/(P_2 = (P_2 x P_1)/(100))]$
$R_n = \text{Relative humidity of the ambient air, in percent.}$
$P_2 = \text{Barometric pressure, in mm Hg (kPa).}$
$T_n = \text{Average temperature of the dilute exhaust sample at the inlet to the exit side gas meter or flow instrumentation.}$
$R_n = \text{Relative humidity of the ambient air, in percent.}$
$P_2 = \text{Barometric pressure, in mm Hg (kPa).}$
$D_T = \text{Time interval (in seconds) between samples in flow compensated systems (0.2 seconds maximum).}$
$V_{nf} = \text{Total dilute exhaust sample volume in cubic feet per test phase corrected to standard conditions (528.8'R [293.15K]) and 760 mm Hg (101.3 kPa).}$
$V_{nf} = \text{Total dilute exhaust sample volume in cubic feet per test phase corrected to standard conditions (528.8'R [293.15K]) and 760 mm Hg (101.3 kPa).}$
$V_{nf} = \text{Instantaneous dilute exhaust volumetric flow rate [for compensated flow systems], in cubic feet per second.}$

For PDP-CVS, $V_{nf} = 16:

$W = (P_1 + P_2) \times 528.8' \\
760 \text{ mm Hg} \times \text{mg}$

for SI units,

Where:
$V_{nf} = \text{Volume of gas pumped by the positive displacement pump, in cubic feet (cubic feet per revolution) per revolution. This volume is dependent on the pressure differential across the positive displacement pump.}$
$N = \text{Number of revolutions of the positive displacement pump during the test phase while samples are being collected.}$
$P_1 = \text{Barometric pressure, in mm Hg (kPa).}$
$P_1 = \text{Pressure depression below atmospheric measured at the inlet to the positive displacement pump, in mm Hg (kPa) during an idle mode.}$
$T_n = \text{Average temperature of dilute exhaust entering positive displacement pump during test, } R (K).$

(b) Sample calculation of mass values of exhaust emissions:

(1) Assume the following test results for a gasoline engine:

<table>
<thead>
<tr>
<th>Component</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>8924</td>
</tr>
<tr>
<td>CO_2</td>
<td>1771</td>
</tr>
<tr>
<td>NO</td>
<td>3,843</td>
</tr>
<tr>
<td>NO_2</td>
<td>187.0</td>
</tr>
<tr>
<td>HC</td>
<td>221.8</td>
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<td>HC</td>
<td>1771</td>
</tr>
</tbody>
</table>

These:

Cold Start Test

$H = [(43.478R) \times x_{P}/(P_2 = (P_2 x P_1)/(100)) \text{ for SI units, } H = [(6.211R) x P_1/T]/(P_2 = (P_2 x P_1)/(100))]$

$P_2 = \text{Barometric pressure, in mm Hg (kPa).}$
$T_n = \text{Average temperature of the dilute exhaust sample at the inlet to the exit side gas meter or flow instrumentation.}$
$R_n = \text{Relative humidity of the ambient air, in percent.}$
$P_2 = \text{Barometric pressure, in mm Hg (kPa).}$
$D_T = \text{Time interval (in seconds) between samples in flow compensated systems (0.2 seconds maximum).}$
$V_{nf} = \text{Total dilute exhaust sample volume in cubic feet per test phase corrected to standard conditions (528.8'R [293.15K]) and 760 mm Hg (101.3 kPa).}$
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For PDP-CVS, $V_{nf} = 16:

$W = (P_1 + P_2) \times 528.8' \\
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Where:
$V_{nf} = \text{Volume of gas pumped by the positive displacement pump, in cubic feet (cubic feet per revolution) per revolution. This volume is dependent on the pressure differential across the positive displacement pump.}$
$N = \text{Number of revolutions of the positive displacement pump during the test phase while samples are being collected.}$
$P_1 = \text{Barometric pressure, in mm Hg (kPa).}$
$P_1 = \text{Pressure depression below atmospheric measured at the inlet to the positive displacement pump, in mm Hg (kPa) during an idle mode.}$
$T_n = \text{Average temperature of dilute exhaust entering positive displacement pump during test, } R (K).$

(b) Sample calculation of mass values of exhaust emissions:

(1) Assume the following test results for a gasoline engine:
[1] The final reported brake-specific fuel consumption (BSFC) shall be computed by use of the following formula:

\[
BSFC = \frac{1/7(M_1) + 4/7(M_2)}{1/7(BHP-IR_1) + 4/7(BHP-IR_2)}
\]

Where:

BSFC = brake specific fuel consumption in pounds of fuel per brake horsepower-hour (lbs/BHP-1HR)

\( M_i \) = mass of fuel, in pounds, used by the engine during the cold start test.

\( M_{2i} \) = mass of fuel, in pounds, used by the engine during the hot start test.

BHP-IR = total brake horsepower-hours (brake horsepower integrated with respect to time) for the cold start test.

BHP-IR_2 = total brake horsepower-hours (brake horsepower integrated with respect to time) for the hot start test.

(1) The mass of fuel for the cold start and hot start test is determined from the following equation:

\[
M = \frac{(G_0/R_k) + (1/453.6)}{(C_0 + 4.29C_{mass} + 0.27 CO_{mass})}
\]

(2) Meaning of symbols:

\( M \) = mass of fuel, in pounds, used by the engine during the cold or hot start test.

\( G_0 \) = grams of carbon measured during the cold or hot start test.

\( C_0 \) = grams of carbon in the fuel per gram of fuel.

\( R_k \) = measured hydrogen to carbon ratio of the fuel.

\( H_{mass} \) = Hydrocarbon emissions, in grams for cold or hot start test.

\( CO_{mass} \) = Carbon monoxide emissions, in grams for cold or hot start test.

\( CO_{mass} \) = Carbon dioxide emissions, in grams for cold or hot start test.

\( a \) = The measured hydrogen to carbon ratio of the fuel.

(1) Assume the following test results:

(d) Sample calculation of brake-specific fuel consumption:

\[
BSFC = \frac{1/7(M_1) + 4/7(M_2)}{1/7(BHP-IR_1) + 4/7(BHP-IR_2)}
\]
Cold Start Cycle Test Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP-HR</td>
<td>6.945</td>
</tr>
<tr>
<td>C</td>
<td>1.85</td>
</tr>
<tr>
<td>HC&lt;sub&gt;mass&lt;/sub&gt;</td>
<td>37.08 grams</td>
</tr>
<tr>
<td>CO&lt;sub&gt;mass&lt;/sub&gt;</td>
<td>357.69 grams</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2mass&lt;/sub&gt;</td>
<td>5419.62 grams</td>
</tr>
</tbody>
</table>

Then:

\[ G_s \text{ for cold start test} = \frac{[12.011/(12.011 + (1.85)(1.008))](37.08) + 0.429(357.69)}{0.273(5419.62)} \times \frac{1}{453.6} = 4.24 \text{ lbs.} \]

\[ R_2 = \frac{12.011}{12.011 + 1.85(1.008)} = .866 \]

\[ M_C = \frac{(1665.10/.866)(1/453.6)}{4.24} = 4.24 \text{ lbs.} \]

\[ M_R = \frac{(1638.88/.866)(1/453.6)}{4.17} = 4.17 \text{ lbs.} \]

(2) Brake-specific fuel consumption results:

\[ BSFC = \frac{1/7(4.24) + 6/7(4.17)}{1/7(6.945) + 6/7(7.078)} = .592 \text{ lbs of fuel/BHP-HR} \]
§ 80.1343-86 is added and reserved as follows:

80.1343-86 (Reserved)

47. A new § 80.1344-86 is added and reads as follows:

80.1344-86 Required information.

(a) The required test data shall be grouped into the following three general categories:

(1) Engine setup and descriptive data. This data must be provided to the EPA supervisor of engine testing for each engine sent to the Administrator for confirmatory testing prior to the initiation of engine setup. This data is necessary to insure that EPA test personnel have the correct data in order to set up and test the engine in a timely and proper manner. This data is not required for tests performed by the manufacturer.

(2) Per test data. This data is general test data that must be recorded for each test. The data is of a more descriptive nature such as identification of the test engine, test setup, etc. As such, this data can be recorded at any time within 24 hours of the test.

(3) Test data. This data is physical test data that must be recorded at the time of testing.

(b) All data may be supplied to the Administrator by punch cards, magnetic tape, or other electronic data processing means. Acceptable data formats and transmission techniques will be provided in the Application Format for Certification of the applicable Model Year.

(c) Engine setup data. Because the specific test facilities may change somewhat with time, the specific data parameters and number of items may vary slightly. The Application Format for Certification for the applicable Model Year will specify the exact requirements. In general, the following type of data will be required:

(1) Engine manufacturer.
(2) Engine system combination.
(3) Engine code and CID.
(4) Engine identification number.
(5) Applicable engine model year.
(6) Engine fuel type.
(7) Recommended oil type.
(8) Exhaust pipe configuration pipe sizes, etc.

(9) Carb idle speed.
(10) Dynamic idle speed. (Automotive transmission engines only.)
(11) Engine parameter specifications such as spark timing, operating temperature, advance curves, etc.
(12) Engine performance data such as, maximum BHP, rated speed, fuel flow, governed speed, etc.
(13) Recommended start-up procedure.

(14) Maximum safe engine operating speed.
(15) Number of hours operation accumulated on engine.
(16) Manufacturer's recommended inlet depression limit and typical use inlet depression level.
(17) Exhaust system.
(18) Diesel engines. (A) Header pipe inside diameter.
(B) Tailpipe inside diameter.
(20) Inlet depression limit and typical in-use back pressure limit for the engine.
(21) Typical back pressure as determined by the maximum back pressure application of the engine.
(22) Minimum back pressure required to meet applicable noise regulations.
(23) Gasoline fueled engines. Typical in-use back pressure in vehicle exhaust system.
(24) Pre-test data. The following data shall be recorded, and reported to the Administrator for each test conducted for Compliance with the provisions of 40 CFR 86, Subpart A:

(1) Engine system combination.
(2) Engine identification.
(3) Instrument operator(s).
(4) Engine operator(s).
(5) Number of hours of operation accumulated on the engine prior to beginning the test sequence (Figure N80-12).
(6) Fuel identification with average of test fuel type.
(7) Date of most recent analytical assembly calibration.
(8) All pertinent instrument information such as tuning, gain, serial numbers, detector number, calibration curve number, etc. As long as this information is traceable, it may be summarized by system number or analyzer identification numbers.

(e) Test data. The physical parameters necessary to compute the test results and insure accuracy of the results shall be recorded for each test conducted for compliance with the provisions of 40 CFR 86, Subpart A. Additional test data may be recorded at the discretion of the manufacturer. Extreme details of the test measurements such as analyzer chart deflections will generally not be required on a routine basis to be reported to the Administrator for each test, unless a dispute about the accuracy of the data arises. The following type of data shall be required to be reported to the Administrator. The Application Format for Certification for the applicable Model Year will specify the exact requirements which may change slightly from year to year with the addition or deletion of certain items.

(1) Date and time of day.
(2) Test number.
(3) Engine intake air or test cell temperature.
(4) Barometric pressure.

Note—A central laboratory barometer may be used. Provided, that individual test cell barometric pressure is shown to be within ±0.1 percent of the barometric pressure at the central barometer location.

(5) Engine intake or test cell and CVS dilution air humidity.
(6) Maximum torque versus speed curve as determined in § 86.1332, with minimum and maximum engine speeds.
(7) Measured maximum horsepower, maximum torque, and rated speeds.
(8) Measured maximum horsepower and torque.
(9) High idle engine speed (diesel engines only).
(10) Fuel consumption at maximum power and torque (diesel engines only).
(11) Curb idle fuel flow rate.
(12) Cold soak time interval and cool down procedures.
(13) Temperature set point of the heated continuous analysis system components (if applicable).
(14) Test cycle validation criteria as specified in § 86.1341 for each test phase (cold/hot).
(15) Total CVS flow rate with dilution factor for each test phase (cold/hot).
(16) Sample concentrations (background corrected) for HC, CO, CO2, and NOx for each test phase (cold/hot).
(17) Brake specific emissions (g/BHP-hr) for HC, CO and NOx for each test phase (cold/hot).
(18) The weighted (cold/hot) brake specific emissions (g/BHP-hr) for the total test.
(19) The weighted (cold/hot) carbon balance brake specific fuel consumption for the total test.
(20) The number of hours of operation accumulated on the engine after completing the test sequences described in Figure N80-10.
(21) Additional required records for diesel engines. (i) Pressure and temperature of the dilute exhaust mixture and secondary-dilution air in the case of a double-dilution system at the inlet to the respective gas meter(s) or flow instrumentation used for particulate sampling.
(ii) The temperature of the dilute exhaust mixture immediately before the particulate filter.
(iii) Gas meter or flow instrument readings at the start of each sample period and at the end of each sample period.
(iv) The stabilized pre-test weight and post-test weight of each particulate sample filter.

(v) The temperature and humidity of the ambient air in which the particulate filters were stabilized.

(vi) The temperatures of the gas (1) flowing in the heated sample line before the heated filter and (2) before the HPID, and the temperature of the control system of the heated hydrocarbon detector.

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