Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 2
Society of Automotive Engineers - Surface Vehicle Recommended Practice SAE J1667 - Snap Acceleration Smoke Test Procedure for Heavy-Duty Diesel Powered Vehicles

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

March 1999

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1667

ISSUED FEB96

Issued 1996-02

Submitted for recognition as an American National Standard

SNAP-ACCELERATION SMOKE TEST PROCEDURE FOR HEAVY-DUTY DIESEL POWERED VEHICLES

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

TABLE OF CONTENTS

1. Scope—This SAE Recommended Practice applies to vehicle exhaust smoke measurements made using the Snap-Acceleration test procedure. Because this is a non-moving vehicle test, this test can be conducted along the roadside, in a truck depot, a vehicle repair facility, or other test facilities. The test is intended to be used on heavy-duty trucks and buses powered by diesel engines. It is designed to be used in conjunction with smokemeters using the light extinction principle of smoke measurement.

This procedure describes how the snap-acceleration test is to be performed. It also gives specifications for the smokemeter and other test instrumentation and describes the algorithm for the measurement and quantification of the exhaust smoke produced during the test. Included are discussions of factors which influence snap-acceleration test results and methods to correct for these conditions. Unless otherwise noted, these correction methodologies are to be considered an integral part of the snap-acceleration test procedure.

1.1 Purpose—This document provides a procedure for assessing smoke emissions from in-use vehicles powered by heavy-duty diesel engines. Testing conducted in accordance with this procedure, in combination with reference smoke values, is intended to provide an indication of the state of maintenance and/or tampering of the engine and fuel system relative to the parameters which affect exhaust smoke. The procedure is expected to be of use to regulatory and enforcement authorities responsible for controlling smoke emissions from heavy-duty diesel-powered vehicles, and to heavy-duty vehicle maintenance and repair facilities. However, the procedure as written does not replicate the federal engine certification smoke cycle, and is intended to identify gross emitters. Regulatory agencies using this procedure must establish pass/fail criteria since SAE by-laws prohibit assignment of such criteria.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

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

SAE J1349—Engine Power Test Code—Spark Ignition and Compression Ignition—Net Power Rating
SAE J1995—Engine Power Test Code—Spark Ignition and Compression Ignition—Gross Power Rating

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

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

SAE J255a—Diesel Engine Smoke Measurement
SAE J1243—Diesel Emission Production Audit Test Procedure

2.2.2 ISO PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO CD 11614—Apparatus for the Measurement of the Opacity of the Light Absorption Coefficient of Exhaust Gas from Internal Combustion Engines

2.2.3 Federal Publication—U. S. Government, DOD SSP, Subscription Service Division, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094

Code of Federal Regulations (CFR), Title 40, Part 86, Subpart I—Emission Regulation for New Diesel Heavy-Duty Engines: Smoke Exhaust Test Procedure

2.3 Other Publications

Procedures for Demonstrating Correlation Among Smokemeters

3. Definitions

3.1 Diesel Smoke—Particles, including aerosols, suspended in the exhaust stream of a diesel engine which absorb, reflect, or refract light.

3.2 Transmittance (T)—The fraction of light transmitted from a source which reaches a light detector.

3.3 Opacity (N)—The percentage of light transmitted from a source which is prevented from reaching a light detector. See Equation 1.

$$\text{Opacity \%} = 100*(1 - \text{Transmittance}) \quad \text{(Eq. 1)}$$

3.4 Effective Optical Path Length (L) or (EOPL)—The length of the smoke obscured optical path between the smokemeter light source and detector. Note that portions of the total light source to detector path length which are not smoke obscured do not contribute to the effective optical path length.

3.5 Smoke Density (K)—(also known as “Light Extinction Coefficient” and “Light Absorption Coefficient”) A fundamental means of quantifying the ability of a smoke plume or smoke containing gas sample to obscure light. By convention, smoke density is expressed on a per meter basis (m-1). The smoke density is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles, and the light absorption and scattering properties of the particles. In the absence of blue or white smoke, the size distribution and the light absorption/scattering properties are similar for all diesel exhaust gas samples and the smoke density is primarily a function of the smoke particle density.

3.6 Beer-Lambert Law—A mathematical equation describing the physical relationships between the smoke density (K) and the smoke parameters of transmittance (T), and effective optical path length (L). Because smoke density (K) cannot be measured directly, the Beer-Lambert equation is used to calculate (K), when opacity (N) and EOPL (L) are known.

3.7 Smoke Opacimeter—A type of smokemeter designed to measure the opacity of a plume or sample of smoke by means of a light extinction principle.

3.8 Full-Flow End-of-Line Smokemeter—A smokemeter which measures the opacity of the full exhaust plume as it exits the tailpipe. The light source and detector for this type of smokemeter are located on opposite sides of the smoke plume and in close proximity to the open end of the tailpipe. When applying this type of smokemeter, the effective optical path length is a function of the tailpipe design.

3.9 Sampling Type Smokemeter (Also called Partial Flow Smokemeter)—A smokemeter which continually samples a representative portion of the total exhaust flow and directs it to a measurement cell. With this type of smokemeter, the effective optical path length is a function of the smokemeter design.

3.10 Smokemeter Measurement Zone—The effective length between the smokemeter light source and light detector through which exhaust gases pass and interact with the smokemeter light beam.

3.11 Smokemeter Response Time—See 6.3 and Appendix A.

3.12 Smokemeter Linearity—A measure of the maximum absolute deviation of values measured by the smokemeter from the reference values.

4. Special Notes and Conventions

4.1 The term smokemeter is a broad term which applies to all smoke-measuring devices regardless of the smoke-sensing technique employed. Throughout this document, the term smokemeter will refer only to opacimeter type smokemeters.

4.2 To fully describe the light obscuration properties of a smoke sample (i.e., smoke density), opacity (N) must always be associated with an EOPL. Whenever specific smoke opacity values are referenced in this document, the associated effective optical path length is understood to be 0.127 m (5 in).

***5. Snap-Acceleration Test*—**The complete Snap-Acceleration process consists of five phases. These phases are:

a. Vehicle Preparation and Safety Check
b. Test Preparation and Equipment Set-up
c. Driver Familiarization and Vehicle Preconditioning
d. Execution of the Snap-Acceleration Test
e. Calculation and Reporting of Final Results

5.1 Vehicle Preparation and Safety Check—Prior to conducting the snap-acceleration test, the following items must be completed:

a. If the vehicle is equipped with a manual transmission, the transmission must be placed in neutral and the clutch must be released.
If the vehicle is equipped with an automatic transmission, the transmission must be placed in the park position, if available, or otherwise in the neutral position.
b. The vehicle wheels must be chocked or the vehicle must be otherwise restrained to prevent the vehicle from moving during the testing.
c. Vehicle air conditioning should be turned off.
d. If the engine is equipped with an engine brake, it must be deactivated during the snap-acceleration testing.
e. All devices installed on the engine or vehicle which alter the normal acceleration characteristics of the engine and have the effect of temporarily lowering snap-acceleration test results, or preventing the test from being successfully completed, shall be deactivated prior to testing.
f. Verify the speed-limiting capability of the engine governor using the following procedure:
With the engine at low idle, slowly depress the engine throttle and allow the engine speed to gradually increase toward its maximum governed high idle speed. As the engine speed increases, carefully note any visual or audible indications that the engine or vehicle may be of questionable soundness. If there are no indications of problems, allow the engine speed to increase to the point that it is possible to verify that the speed-limiting capability of the governor is functioning. Should there be any indication that the speed-limiting capability of the governor is not functioning, or that potential engine damage, or unsafe conditions for personnel or equipment may occur, the throttle should immediately be released and the snap-acceleration testing of the vehicle shall be aborted.
g. The vehicle should be inspected for exhaust leaks. Severe leaks in the system may cause the introduction of air into the exhaust stream which may cause erroneously low test results.
h. Users must be cautioned regarding the observance of blue or white smoke in the exhaust. Blue smoke can be an indicator of unburned hydrocarbons (possible oil burning or malfunctioning nozzle), and white smoke can be an indicator of water vapor (possible internal coolant leaking conditions).

5.2 Test Preparation and Equipment Set-up

5.2.1 AMBIENT AIR TEST CONDITIONS—Ambient air conditions can affect snap-acceleration smoke test results. To ensure reliable results, the correction factors in Appendix B should be applied to snap-acceleration testing results to account for normal changes in ambient conditions. However, these correction factors must be applied under the following conditions.

a. Altitude—Greater than 457 m (1500 ft) above sea level.
b. Air Temperature—Above or below the range of 2 to 30 x °C (36 to 86 x °F).
c. Wind—Excessively windy conditions should be avoided. Winds are excessive if they disturb the size, shape, or location of the vehicle exhaust plume in the region where exhaust samples are drawn or where the smoke plume is measured. The effect of wind may be eliminated or reduced by locating the vehicle in a wind-sheltered area or by using measuring equipment designs which preclude wind effects on the smoke in the measuring or sampling zones.
d. Dry Air Density—If the correction factors referenced in Appendix B are used, the useful range of dry air densities are: 0.908 to 1.235 kg/m^3 (0.0567 to 0.0771 lbm/ft^3). This range of dry air densities is based on air densities experienced during ambient conditions testing.
e. Humidity—No visible humidity (including fog, rain, and snow) in the region where exhaust samples are drawn or the smoke plume is measured. Some equipment designs preclude the effects of these conditions.

5.2.2 SMOKEMETER INSTALLATION—The smokemeter and other test equipment used for snap-acceleration tests shall meet the specifications of 6.1 through 6.5. The general installation procedures specified by the smokemeter manufacturer shall be followed when preparing to test a vehicle.

In addition, these special installation procedures shall be followed:

a. If the test results are to be reported in units of smoke opacity, the rated power of the engine should be determined. The rated power is needed to define the standard effective optical path length used to correct the as-measured smoke opacity to standard conditions as described in Appendix C. The rated power should be available from the tune-up label fixed to the engine or from literature supplied to the owner by the engine manufacturer. In some cases, particularly under roadside test conditions, it may not be possible to readily determine the rated engine power. In these cases, it is recommended that the OD of the vehicle tailpipe section be determined and used as the standard effective optical path length for the purposes of the Beer-Lambert corrections described in Appendix C. If the rated engine power becomes available after the test is run, the test result should be recorrected as necessary using Equation C3 and the appropriate standard effective optical path length from Table C1.
   Sampling in or immediately downstream of bends such as curved stack outlets in the exhaust pipe may cause some variability between individual Snap-Acceleration cycle readings.
b. For Full Flow End-of-Line Type Smokemeters—The axis of the smokemeter light beam shall be perpendicular to the axis of the exhaust flow. The centerline of the light beam axis should be located as close as possible, but in no case further than 7 cm (2.76 in) from the exhaust outlet. Appendix D provides additional guidance for smokemeter replacement.
   Determine the effective optical path length used to make the smoke measurements. For straight tailpipes of circular cross section, the effective optical path length is equal to the tailpipe ID, and for tubing construction can be reasonably approximated by the tailpipe OD. Appendix D provides guidance for determining the as-measured effective optical path length when irregular tailpipe configurations are encountered. The as-measured effective optical path length is required to convert measured smoke values to standard corrected smoke values using the procedures described in Appendix C.

c. For Sampling Type Smokemeters—The probe of the sampling type smokemeter shall be inserted into the exhaust tailpipe with the open end facing upstream and into the exhaust flow.
   The clearance between the inside edge of the open end of the sample probe and the tailpipe wall must be at least 5 mm (0.197 in).
   Only the probe and sampling pipe, or tubing, specified by the manufacturer of the smokemeter shall be used for the smoke sampling. Manufacturer's recommendations regarding the length of the sample line shall be adhered to.
d. Multiple Exhaust Outlets—When testing vehicles equipped with multiple exhaust outlets, such as dual exhaust systems originating from a single manifold or single pipe, it is normally not necessary to measure the smoke from each exhaust outlet. The following approach is suggested.
   If there is no discernible difference in the exhaust smoke exiting from each multiple exhaust outlet, the smoke should be measured from the exhaust outlet that provides the most convenient meter installation. A visual observation of one or more preliminary snap-acceleration test cycles should be sufficient to make this determination.
   Should there be a discernible difference in the smoke exiting from the multiple exhaust outlets, install the smokemeter and conduct the snap-acceleration test on the exhaust outlet that visually appears to have the highest smoke level.

5.2.3 A tachometer to measure the engine speed may be installed and calibrated per the manufacturer's recommendations. A tachometer provides useful data regarding idle RPM, maximum engine RPM, the time necessary for the operator to accelerate the engine from idle to maximum RPM, and the time the engine speed was held at maximum RPM. This information helps to ensure repeatability between test cycles.

5.3 Driver Familiarization and Vehicle Preconditioning

5.3.1 Prior to the preconditioning test, the vehicle should be operated under load for at least 15 min to ensure that the engine is warmed-up. Alternatively, vehicle water and oil temperature gages may be checked to verify that the engine is within its normal operating temperature range.

5.3.2 SNAP-ACCELERATION CYCLE—The vehicle operator shall be instructed on the proper execution of the snap-acceleration test sequence. It is of critical importance that the vehicle operator fully understand the proper movement of the vehicle throttle during the testing.

With the vehicle conditioned as in 5.1 and with the engine warmed-up and at low idle speed:

a. The operator shall move the throttle to the fully open position as rapidly as possible.
b. The operator shall hold the throttle in the fully open position until the time the engine reaches its maximum governed speed, plus an additional 1 to 4 s.
c. Upon completion of the 1 to 4 s with the engine at its maximum governed speed, the operator shall release the throttle and allow the engine to return to the low idle speed.
d. Once the engine reaches its low idle speed, the operator shall allow the engine to remain at idle for a minimum of 5 s, but no longer than 45 s, before initiating the next snap-acceleration test cycle.
   The time period at low idle allows the engine's turbocharger (if so equipped) to decelerate to its normal speed at engine idle. This helps to reduce the smoke variability between snap-acceleration cycles.
e. Steps (a) through (d) shall be repeated as necessary to complete the preliminary snap-acceleration cycles and the snap-acceleration test cycles described in 5.3.3 and 5.4.2.

5.3.3 PRELIMINARY SNAP-ACCELERATION TEST CYCLES—The vehicle shall receive at least three preliminary snap-acceleration test cycles using the sequence described in 5.3.2. The preliminary cycles allow the vehicle operator to become familiar with the proper throttle movement, and also remove any loose soot which may have accumulated in the vehicle exhaust system during prior operation.

If smoke measurements are made during the preliminary cycles, the preliminary cycles can also provide the opportunity to check for proper operation of the smoke measurement system, and to check if the test validation criteria of 5.4.4 can be met. In this case, the data-processing unit and the smokemeter zero and full scale should first be set according to 5.4.1 and 5.4.2.

5.4 Execution of the Snap-Acceleration Test

5.4.1 DATA PROCESSING UNIT SET-UP—Before snap-acceleration testing can proceed, the smokemeter data processing unit must be properly set up. The operating instructions supplied by the processing unit manufacturer should be consulted for specific set-up procedures; however, the following functional steps must be accomplished.

a. If a multi-mode test system is used, the appropriate mode for snap-acceleration testing must be selected.
b. The desired smoke output units (opacity or smoke density) must be selected.
c. If the Beer-Lambert corrections as described in Appendix C are to be performed within the data-processing unit, values must be supplied for the standard and as-measured effective optical path lengths if opacity output is desired and for the as-measured effective optical path lengths if smoke density output is desired. Appendices C and D provide guidance in determining these input values.
d. If a red LED smokemeter light source is used and light source wavelength corrections are to be performed within the data-processing unit, the appropriate selections must be made to trigger these calculations (see Appendix C).
e. If the ambient condition corrections described in Appendix B are to be performed automatically by the data-processing unit, the appropriate ambient parameters must be input.
f. Any additional test identification information consistent with the needs of the test program and capabilities of the data-processing unit should be supplied at this time. Normally this would include the test date, test operator, vehicle identification, and other such information.

5.4.2 SMOKEMETER ZERO AND FULL SCALE—Prior to conducting smoke measurements, the zero and full scale readings of the smokemeter shall be verified. (Some meter systems may automatically perform the zero and full scale checks. For other meters, this sequence will need to be done manually.) Should optional recording devices be part of the test set-up, this equipment should also be checked for proper operation and calibration.

a. Smokemeter Warm-up—Prior to any zero and/or full-scale checks or adjustments, the smokemeter shall be warmed up and stabilized according to the manufacturer's recommendations. If the smokemeter is equipped with a purge air system to prevent sooting of the meter optics, this system should also be activated and adjusted according to the manufacturer's recommendations.
b. Smokemeter Zero—With the smokemeter in the Opacity readout mode, and with no blockage of the smokemeter light beam, adjust the readout to display 0.0% ± 1.0% opacity.
c. Smokemeter Full Scale—With the smokemeter in the Opacity readout mode, and all light prevented from reaching the detector, adjust the readout of the smokemeter to display 100.0% ± 1.0% opacity.
   NOTE—For Smokemeter readouts in units of Smoke Density (K).
   Smoke density (K) is a calculation based upon opacity and EOPL. The opacity scale offers two truly definable calibration points, namely 0% opacity and 100% opacity. The upper end of the smoke density scale is infinite, which makes this point on the K scale undefined. Because of this, the preferred method to set the zero and full scale of the meter when measuring in either smoke density (K) or opacity (N) units is to set the meter to the opacity readout mode and make the zero and full-scale adjustments as described in 5.4.2 (a) to (c). The smoke density would then be correctly calculated based upon the measured opacity and, of course, the EOPL, when the meter is returned to the smoke density readout mode for testing.
   However, if this technique is not possible, it is acceptable to set the zero and span of the smokemeter in units of smoke density (K) with the use of a neutral density filter of known value. Should this be the case, the smokemeter zero and span shall be set as follows:

d. Smokemeter Zero—With the smokemeter in the Smoke Density (K) readout mode, and with no blockage of the smokemeter light beam, adjust the readout to display 0.00 m^{-1} ± 0.10 m^{-1}.
e. Smokemeter Span (If required by the smokemeter manufacturer)—With the smokemeter in the Smoke Density (K) readout mode, place a neutral density filter of known value between the light emitter and detector. The neutral density filter shall meet the accuracy requirements of 6.2.10 and have a known nominal value in the range of 1.5 to 5.5 m^{-1}. Adjust the smokemeter readout to display the filter nominal value, ±0.10 m^{-1}.

NOTE—Neutral density calibration filters are precision devices and can easily be damaged during use. Handling should be minimized and, when required, should be done with care to avoid scratching or dirtying of the filter.

5.4.3 SNAP-ACCELERATION TEST CYCLES—Within 2 min of the execution of the preliminary snap-acceleration cycles, conduct three snap-acceleration test cycles, actuating the vehicle throttle in the manner and sequence described in 5.3.2 (a to e).

Determine the corrected maximum 0.5 s average smoke values for each of the three snap-acceleration cycles using the smoke data processing algorithms described in Appendices A and C.

At the conclusion of the test sequence, and where needed as per manufacturer's recommendation, determine the degree of smokemeter zero shift by eliminating all exhaust from between the smokemeter light source and detector and noting the smokemeter display.

5.4.4 TEST VALIDATION CRITERIA—The test results from 5.4.3 shall be considered valid only after the following criteria have been met.

a. The post-test smokemeter zero shift values shall not exceed:

   1. ±2.0% opacity—For smoke measurements made in opacity.
   2. ±0.15 m^{-1}—For smoke measurements made in smoke density (K).

b. The arithmetical difference between the highest and lowest corrected maximum 0.5 s average smoke values from the three test cycles shall not exceed:

   1. 5.0% opacity—For smoke measurements made in opacity.
   2. 0.50 m^{-1}—For smoke measurements made in smoke density (K).

5.4.5 INVALID TESTS—Should the smoke test data from 5.4.3 not meet the test validation criteria of 5.4.4, the following items should be checked as possible causes for the invalid test results:

a. If the engine did not meet the operating temperature requirements, run the engine/vehicle under load for at least 15 min or until the vehicle oil and water temperature gages indicate that normal engine operating temperatures have been achieved. Return to 5.2.2 (Smokemeter Installation) and repeat the test sequence.
b. If improper or inconsistent application of the vehicle throttle is suspected, re-instruct the vehicle operator as to the proper execution of the snap-acceleration test, especially the movement of the vehicle throttle, as detailed in 5.3.2. Continue on with the procedure at this point and repeat the preliminary test cycles and the snap-acceleration test sequence while observing the vehicle operator.
c. Check the smokemeter, its installation on the tailpipe, and any support instrumentation for possible malfunctions. Correct as necessary and then return to 5.3.3 (Preliminary Snap-Acceleration Test Cycles), and repeat the test sequence.

d. If the post-test smokemeter zero check was exceeded due to positive zero drift, the probable cause is soot accumulation on the smokemeter optics. It is recommended that the snap-acceleration test sequence be repeated and while doing so, the smokemeter zero may be readjusted during the low idle period between each of the snap-acceleration test cycles. If the measured low idle smoke level of the vehicle is less than 2.0% opacity or 0.20 m^{-1} smoke density, it is permissible to re-zero the meter while it remains exposed to the vehicle exhaust. If the idle smoke level exceeds these limits, it is necessary to discontinue exposure to exhaust before rezeroing the meter.
   It is not necessary to complete an invalid test before employing the rezeroing technique discussed previously. If comparison of the low idle smoke readings shows an increasing trend from one test cycle to the next, sooting of meter optics can be suspected and the rezeroing technique can immediately be used.
   If it is not possible to rezero the meter, the meter optics should be cleaned per the smokemeter manufacturer's recommended procedures and the test sequence should be repeated beginning at 5.3.3 (preliminary snap-acceleration test cycles). If zero drift and rezeroing difficulties persist, it is recommended that the meter purge air system (if so equipped) be checked for proper operation.
e. If the procedure has been repeated in accordance with the requirements stated in 5.4.5 (a to d), and the test results still cannot be obtained that conform with the test validation criteria, then it is likely that the engine is in need of service.

5.5 Calculation and Reporting of Final Test Result—If the validation criteria of 5.4.4 are met, the data shall be deemed valid and the test complete. The average of the corrected maximum 0.5 s average smoke values from the three snap-acceleration test cycles shall be computed and reported as the final test result. (See Appendix A.)

6. Test Instrumentation Specifications—This section provides specifications for the required and optional test equipment used in the snap-acceleration test.

6.1 General Requirements for the Smoke Measurement Equipment—The snap-acceleration smoke test requires the use of a smoke measurement and data-processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

a. A full-flow end-of-line or a sampling type smokemeter meeting the specifications of 6.2 through 6.4.
b. A data-processing unit capable of performing the functions described in Appendices A and C.
c. A printer and/or electronic storage medium to record and output the individual corrected maximum 0.5 s average smoke values from each snap-acceleration test cycle, and the final average snap-acceleration test result.

6.2 Specific Requirements for the Smoke Measurement Equipment

6.2.1 LINEARITY—±2% opacity or ±0.30 m^{-1} density.

6.2.2 ZERO DRIFT RATE—Not to exceed ±1% opacity/hour.

6.3 Instrument Response Time Requirements

6.3.1 OVERALL INSTRUMENT RESPONSE TIME REQUIREMENT—The overall instrument response time (t) shall be: 0.500 s ± 0.015 s. It is defined as the difference between the times when the output of the smokemeter reaches 10% and 90% of full scale when the opacity of the gas being measured is changed in less than 0.01 s.
It shall include all the physical, electrical, and filter response times. Mathematically, it is represented by Equation 2. (See Appendix A for a more detailed methodology and an example calculation.)

$$t = SQRT(t_p^2 + t_e^2 + t_F^2) \qquad \text{(Eq. 2)}$$

where:

t_p = The physical response time
t_e = The electrical response time
t_F = The filter response time

6.3.2 PHYSICAL RESPONSE TIME (t_p)—This is the difference between the times when the output of a rapid response receiver (with a response time of not more than 0.01 s) reaches 10% and 90% of the full deviation when the opacity of the gas being measured is changed in less than 0.1 s.

The physical response time is defined for the smokemeter only and excludes the probe and sample line. However, on some in-use smokemeter systems, the probe and sample line may significantly affect the overall response time of the system. If necessary, this shall be taken into account for any particular smokemeter system.

For full-flow type smokemeters, the response time is a function of the velocity of flow in the vehicle exhaust pipe and the path length across the detector (detector diameter). It can be assumed equal to a negligible 0.01 s. For sampling type smokemeters where the measuring zone is a straight section of pipe of uniform diameter, the physical response can be estimated by Equation 3:

$$t = 0.8 * V / Q \quad \text{(Eq. 3)}$$

where:

Q = The rate of flow of gas through the measuring zone
V = The volume of the measuring zone

For such instruments, the speed of the gas through the measuring zone shall not differ by more than 50% from the average speed over 90% of the length of the measuring zone.

For all smokemeters, if the physical response calculates greater than 0.2 s, then the response time shall be measured.

6.3.3 ELECTRICAL RESPONSE TIME (t_e)—It is defined as the time needed for the recorder output to go from 10% of the maximum scale to 90% of the maximum scale value when a fully opaque screen is placed in front of the photo cell in less than 0.01 s, or the LED is turned off. This is to include all of the effects of recorder output response time.

6.3.4 FILTER RESPONSE TIME (t_f)—Filtering of the smoke signal will be necessary on most smokemeters to achieve an overall response time of 0.500 s ± 0.015 s. Most smokemeters have a very fast electrical response time, but physical response times will vary from one device to the next depending on design and gas flow.

Appendix A specifies the recommended second-order digital filtering algorithm to be used.

6.3.5 DETERMINATION OF THE PEAK SMOKE VALUE—An algorithm in Appendix A shall be used to determine the reported peak exhaust smoke levels.

6.4 Smokemeter Light Source and Detector

6.4.1 LIGHT SOURCE—The light source shall be an incandescent lamp with a color temperature in the range of 2800 to 3250 °K, or a green light emitting diode (LED) with a spectral peak between 550 and 570 nm.

Alternatively, a red LED may be used provided that the appropriate light wavelength correction is made as described in Appendix C.

6.4.2 LIGHT DETECTOR—The light detector shall be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the detector shall have a peak spectral response in the range of 550 to 570 nm, and shall have a gradual reduction in response to values of less than 4% of the peak response value below 430 nm and above 680 nm.

6.4.3 The rays of the light beam shall be parallel within a tolerance of 3 degrees of the optical axis. The detector shall be designed such that it is not affected by direct or indirect light rays with an angle of incidence greater than 3 degrees to the optical axis.

6.4.4 Any method such as purge air which is used to protect the light source and detector from direct contact with exhaust soot shall be designed to minimize any unknown effect on the effective optical path length of the measured smoke (see C.5.1). For full-flow end-of-line smokemeters, the protection feature must not cause the smoke plume to be distorted by more than 0.5 cm. For sampling type smokemeters, the meter manufacturer must account for any effect of the protection feature in specifying the effective optical path length of the meter.

6.4.5 The sampling and digitization rate of the data processing units shall be at least 20 Hz (i.e., at least 10 data samples per 0.5 s interval). Additionally, the product of the data sampling time increment (seconds) and one half the data sample rate (Hz) rounded to the next higher integer value must be within the range of 0.500 to 0.510 s.

6.5 Specifications for Auxiliary Test Equipment

6.5.1 NEUTRAL DENSITY FILTERS—Any neutral density filter used in conjunction with smokemeter calibration, linearity measurements, or setting span shall have its value known to within 0.5% opacity or 0.04 m^{-1}. The filter's named value must be checked for accuracy at least yearly using a reference traceable to a national standard.

6.5.2 If altitude correction (i.e., the altitude is greater than 457 m (1500 ft)) then:

a. Equipment used to measure barometric pressure must be accurate within ±0.30 kPa (±0.089 in-Hg)
b. Ambient dry bulb temperature must be accurate within ±2 °C (±3.6 °F)

6.5.3 Measurement of the following parameters is optional; however, if measured, the specified accuracy requirements should be met:

a. Ambient Dry Bulb Temperature—±2 °C (±3.6 °F)
b. Dew Point Temperature—±2 °C (±3.6 °F)
c. Engine Speed—±100 rpm

6.5.4 OPTIONAL RECORDING DEVICES—A supplemental chart recorder or other collection media may be used provided that the device(s) does not affect the smoke measurement.

7. Smokemeter Maintenance and Calibration—The smokemeter should be maintained and serviced per the manufacturer's recommendations. In addition to the zero and span adjustments to be made prior to each snap-acceleration test (5.4.2), the linearity of the meter response should be periodically checked as per manufacturer's recommendations in the range of measurement interest using neutral density filters meeting the requirements of 6.5.1. Non-linearities in excess of 2% opacity or 0.30 m^{-1} smoke density should be corrected prior to resuming testing with the meter.

PREPARED BY THE SAE HEAVY-DUTY IN-USE EMISSION STANDARDS COMMITTEE

APPENDIX A

SECOND-ORDER FILTER ALGORITHM USED TO CALCULATE A MAXIMUM 0.500 S AVERAGE SMOKE VALUE

A.1 ***Introduction—***This appendix explains how to create and use the recommended Bessel low-pass digital filter algorithm in a smokemeter to filter out the high-frequency smoke readings which are produced during a snap-acceleration test. This appendix in particular describes the methodology used to design a low-pass second-order Bessel filter with a response time as needed for a particular smokemeter application. This appendix also describes the procedure for determining the final snap-acceleration test. Two example calculations detailing the selection of Bessel filter coefficients and their use are also provided in this appendix to illustrate the concepts more clearly.

The digital Bessel filter described in this appendix is a second-order (2-pole) low-pass digital filter algorithm. It is the recommended filter to be used for designing smokemeters with 0.500 s overall response times as required in 6.3. The Bessel filter type was chosen because it allows passage of all signals which do not change very much with time, but effectively blocks all signals with higher-frequency components. Its linear-phase characteristics also enable it to approximate a constant time delay over a limited frequency range. Transient waveforms can also be passed with minimal distortion when it is used as a running average type filter. A digital approach was chosen due to the relative ease of implementing a software algorithm in most smokemeters. However, analog Bessel filters using the appropriate electronic circuits may also be used.

A.2 ***Definitions***

B = Bessel parameter constant. It equals [Sqrt(5)-1]/2
f_c = Bessel cutoff frequency used to control the filtered response
t_e = Electrical response time of the smokemeter (seconds)
t_F = Filter response time (seconds)
t_{Fd} = Desired filter response time (seconds)
t_p = Physical response time of the smokemeter (seconds)
t_{10} = The test time when the output response to an input step response is equal to 10% of the step input
t_{90} = The test time when the output response to an input step response is equal to 90% of the step input
Δ_t = Time between two stored opacity values (i.e., sampling period (seconds))
X_i = Bessel filter input at sample number (i)
X_{i-1} = Bessel filter input at sample number (i-1)
X_{1-2}= Bessel filter input at sample number (i-2)
Y_i = Bessel filter output at sample number (i)
Y_{i-1} = Bessel filter output at sample number (i-1)
Y_{i-2}= Bessel filter output at sample number (i-2)

A.3 ***Designing a Bessel Low-Pass Filter—***Designing the 0.500 s Bessel low-pass digital filter is a multistep process which may involve several iterative calculations to determine coefficients. This section provides a method for determining the desired amount of filtering for smokemeters with different electrical and physical response times, or different sample rates. Bessel filters can be designed to accommodate filter designs having response times ranging from 0.010 to 0.500 s, and digitization rates of 50 Hz and higher.

It is recommended that all Bessel filter calculations be performed in opacity units for the sake of consistency between smokemeters. If smokemeter output in units of density need to be reported, the Beer-Lambert law may be used to convert the final opacity results to density results, and perform any necessary stack size correction. This conversion should be done only after all Bessel filter equations have been performed due to the non-linearity of the Beer-Lambert law.

A.3.1 Calculating the Desired Filter Response Time (t_{Fd})—Prior to designing a digital Bessel filter, it is necessary to determine the physical response time (t_p) and the electrical response time (t_e) for the relevant smokemeter. These parameters are necessary in order to determine how much electronic filtering is necessary to achieve an overall 0.500 s response time. For some partial flow smokemeters this may require experimental data. For other smokemeters the procedures and equations in 6.3 may be used.

Once the values of t_p and t_e are known, the desired filter response time (t_{Fd}) can be determined by using Equation A1.

$$t_{Fd} = SQRT[0.500^2 - (t_p^2 + t_e^2)] \quad \text{(Eq. A1)}$$

A.3.2 Estimating Bessel Filter Cutoff Frequency (f_c)—The Bessel filter response time (t_F) is defined as the time in which the output signal (Y_i) reaches 10% (Y_{10}) and 90% (Y_{90}) of a full-scale input step (X_i) which occurs in less than 0.01 s. The difference in time between the 90% response (t_{90}) and the 10% response time (t_{10}) defines the response time (t_F). Thus,

$$(t_F) = (t_{90}) - (t_{10}) \quad \text{(Eq. A2)}$$

For the filter to operate properly, the filter response time (t_F) should be within 1% of the desired response time (t_{Fd}), that is, $[(t_F) - (t_{Fd})] < [0.01 * (t_{Fd})]$.

To create a filter where t_F approximates t_{Fd}, the appropriate cutoff frequency (f_c) must be determined. This is an iterative process of choosing successively better values of (f_c) until $[(t_F) - (t_{Fd})] < [0.01 * (t_{Fd})]$.

The first step in the process is to calculate a first guess value for f_c using Equation A3.

$$f_c = \pi/(10*t_{Fd}) \quad \text{(Eq. A3)}$$

The values of B, Ω, C, and K are then calculated using Equation A4 through A7.

$$B = 0.618034 \quad \text{(Eq. A4)}$$

$$\Omega = 1/[\tan(\pi*\Delta t*f_c)] \quad \text{(Eq. A5)}$$

$$C = 1/[1 + \Omega*sqrt(3*B) + B*\Omega^2] \quad \text{(Eq. A6)}$$

$$K = 2 * C * [B*\Omega^2 - 1] - 1 \quad \text{(Eq. A7)}$$

Δt = Time between two stored opacity values (i.e., sampling period (seconds)).

The values of K and C are then used in Equation A8 to calculate the Bessel filter response to the given step input. Because of the recursive nature of Equation A8, the values of X and Y listed as follows are used to begin the process.

$$Y_i = Y_{i-1} + C*[X_i + 2*X_{i-1} + X_{i-2} - 4*Y_{i-2}] + K*(Y_{i-1} - Y_{i-2}) \quad \text{(Eq. A8)}$$

where:

X_i = 100
X_{i-1} = 0
X_{i-2} = 0
Y_{i-1} = 0
Y_{i-2} = 0

As shown in the example (A.7.1), calculate Y_i for successive values of X_i = 100 until the value of Y_i has exceeded 90% of the step input (X_i). The difference in time between the 90% response (t_{90}) and the 10% response (t_{10}) defines the response time (t_F) for that value of (f_c). Since the data are digital, linear interpolation may be needed to precisely calculate t_{10} and t_{90}.

If the response time is not close enough to the desired response time {that is, if [(t_F)-(t_{Fd})] > [0.01*(t_{Fd})]}, then the iterative process must be repeated with a new value of (f_c). The variables (t_F) and (f_c) are approximately proportional to each other, so the new (f_c) should be selected based on the difference between (t_F) and (t_{Fd}) as shown in the example calculations (A.5.1).

A.4 Using the Bessel Filter Algorithm—The proper cutoff frequency (f_c) is the one that produces the desired filter response time (t_{Fd}). Once this frequency has been determined through the iterative process, the proper Bessel filter algorithm coefficients for Equation A4 through A7 are specified. Equation A8 and the coefficients can then be programmed into the smokemeter to produce the desired filter.

The Bessel filter equation (Equation A8) is recursive in nature. Thus, it needs some initial input values of X_{i-1} and X_{i-2} and initial output values Y_{i-1} and Y_{i-2} to get the algorithm started. These may be assumed to be 0% opacity. A detailed example calculation is shown in A.7.3.

A.5 Determining the Maximum 0.500 s Averaged Smoke Value—The maximum smoke value for a snap-acceleration test cycle (Y_{max}) is then selected from among the individual Y_i values computed using Equation A8 (after suitable Beer-Lambert and light source wavelength corrections are applied). This is the final test result for the test cycle and is used in combination with the results from the other snap-acceleration cycles in the test to determine a final snap-acceleration test result.

In equation form:

$$Y_{max} = \text{Maximum}(Y_i) \quad \text{(Eq. A9)}$$

A.6 Determination of the Final Test Result—If the test validation criteria of 5.4.4 have been met, the final snap-acceleration test result shall be computed by taking the simple average of the three corrected maximum 0.500 s averaged smoke values obtained from the three snap-acceleration test cycles.

$$A = (Y_{max,1} + Y_{max,2} + Y_{max,3})/3 \quad \text{(Eq. A10)}$$

A.7 A.7 Example of Incorporating a Bessel Filter Into a Smokemeter Design—This example illustrates how a full flow meter with a fast physical and electrical response time can implement the Bessel filter algorithm. The sample smokemeter has the following characteristics:

a. Physical Response Time = 0.020 s
b. Electrical Response Time = 0.010 s
c. Sampling Rate = 100 Hz
d. Sampling Period = 0.01 s

A.7.1 First Iteration to Estimate Bessel Function Cutoff Frequency (f_c)—This section displays the initial calculations which are performed to estimate the correct value of the cutoff frequency (f_c).

The results from Equation A1 indicate that the desired filter response (t_{Fd}) is 0.4995 (for simplicity, a value of 0.50 will be used in the sample calculations). This may be typical of a full flow meter with a very fast electrical and physical response time. It suggests that most of the desired 0.500 s filtering will be performed by the digital filter rather than the instrument.

$$t_{Fd} = 0.4995 = \text{SQRT}[0.500^2 - (0.020^2 + 0.010^2)\ ] \quad \text{(Eq. A11)}$$

By inserting the correct values of Δt and t_F into Equations A2 through A7, the Bessel function coefficients are determined. These are shown in Table A1.

TABLE A1—INITIAL BESSEL COEFFICIENTS

Equation A1	t_F	0.500
Equation A2	f_c	0.6283
Equation A4	B	0.618
Equation A5	Ω	50.6555063
Equation A6	C	0.00060396
Equation A7	K	0.91427037
	Δt	0.01

The Bessel coefficients can now be inserted into Equation A8 along with the step input function (i.e., an input of 0% opacity to 100% opacity in 0.01 s) to illustrate the effect of the Bessel filter on the step response as a function of time. The input step function is shown as X_i in Table A2. To simulate the step response, input X_I = 100. This will create the sudden jump from 0 to 100%.

The Bessel filtered output is shown as Y_i in Table A2. The two output points which are of interest are the 10% response point and the 90% response point. These are the values where Y_i first exceeds 10% and 90%. Since the output Y_i is digital, the exact 10% and 90% points must be interpolated from Table A2. The four points which bound the 10% and 90% points are indicated by an “X” in the Index column of Table A2. These are index numbers 9, 10, and 64, 65.

For this specific case, the following interpolation formulas are used to calculate the values of $t_{10\%}$ and $t_{90\%}$.

$$t_{10\%} = 0.01*[9 + (10 - 8.647)/(10.260 - 8.647) \text{ ǂ } 0.0984s \quad \text{(Eq. A12)}$$

$$t_{90\%} = 0.01*[64 + (90 - 89.834)/(90.427 - 89.834) \text{ ǂ } 0.6428s \quad \text{(Eq. A13)}$$

Now calculate the difference between $t_{90\%}$ and $t_{10\%}$ and see if it is close enough to t_F (close enough means within 1% or in this case 0.005).

$$0.6428 - 0.0984 = 0.5444s \quad \text{(Eq. A14)}$$

The calculation shows that the response time of the filter is 0.5444 s using a value of f_c of 0.6283. The difference between this value and the desired value of 0.50 is 0.0444 which is about 10% greater than desired. Thus, another attempt to reach the desired response time will have to be made. Since 0.5444 is about 10% too high, use a cutoff frequency (f_c) which is 10% larger for the second iteration.

A.7.2 Second Iteration to Estimate Bessel Function Cutoff Frequency (f_c)—For the second iteration, a value of 0.690 is chosen for the value of f_c. This is approximately 10% higher than the value previously used. When this value is used, the Bessel function coefficients in Table A3 are obtained.

The filter responses Y_i were also recalculated for the step input X_i. The entire table of inputs (X_i) and responses (Y_i) (analogous to Table A2) is not shown. However, the values of t_{10} and t_{90} and the difference between were calculated and are shown in Table A4. In this case, the difference between the filter response time and the desired filter response time of 0.50 s is 0.0049. This is less than the 1% difference criteria (0.005 s). Thus, the value of 0.692 for the frequency cutoff (f_c) is the correct one for this smokemeter application.

A.7.3 Sample Calculation of the Bessel Filter Opacity Response—Once the appropriate value for the cutoff frequency (f_c) has been determined, then Equations A4 through A8 are used to calculate the Bessel filtered opacity values (Y_i) for any given input opacity values (X_i). The maximum filtered response is then selected and reported as the smoke reading for that particular snap-acceleration cycle.

TABLE A2—INITIAL SIMULATION OF THE BESSEL FILTER EFFECT (USED TO DETERMINE f_c)

	Index	Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
	0	0.00	100	0	0	0.060	0.000	0.000
	1	0.01	100	100	0	0.297	0.060	0.000
	2	0.02	100	100	100	0.754	0.297	0.060
	3	0.03	100	100	100	1.414	0.754	0.297
	4	0.04	100	100	100	2.256	1.414	0.754
	5	0.05	100	100	100	3.264	2.256	1.414
	6	0.06	100	100	100	4.423	3.264	2.256
	7	0.07	100	100	100	5.715	4.423	3.264
	8	0.08	100	100	100	7.128	5.715	4.423
X	9	0.09	100	100	100	8.647	7.128	5.715
X	10	0.10	100	100	100	10.260	8.647	7.128
	11	0.11	100	100	100	11.956	10.260	8.647
	12	0.12	100	100	100	13.723	11.956	10.260
	13	0.13	100	100	100	15.552	13.723	11.956
	14	0.14	100	100	100	17.432	15.552	13.723
	15	0.15	100	100	100	19.355	17.432	15.552
	16	0.16	100	100	100	21.312	19.355	17.432
	17	0.17	100	100	100	23.297	21.312	19.355
	18	0.18	100	100	100	25.301	23.297	21.312
	19	0.19	100	100	100	27.319	25.301	23.297
	20	0.20	100	100	100	29.344	27.319	25.301
	21	0.21	100	100	100	31.372	29.344	27.319
	22	0.22	100	100	100	33.396	31.372	29.344
	23	0.23	100	100	100	35.413	33.396	31.372
	24	0.24	100	100	100	37.417	35.413	33.396
	25	0.25	100	100	100	39.406	37.417	35.413
	26	0.26	100	100	100	41.375	39.406	37.417
	27	0.27	100	100	100	43.322	41.375	39.406
	28	0.28	100	100	100	45.244	43.322	41.375
	29	0.29	100	100	100	47.138	45.244	43.322
	30	0.30	100	100	100	49.001	47.138	45.244
	31	0.31	100	100	100	50.833	49.001	47.138
	32	0.32	100	100	100	52.631	50.833	49.001
	33	0.33	100	100	100	54.394	52.631	50.833
	34	0.34	100	100	100	56.119	54.394	52.631
	35	0.35	100	100	100	57.807	56.119	54.394
	36	0.36	100	100	100	59.457	57.807	56.119
	37	0.37	100	100	100	61.067	59.457	57.807
	38	0.38	100	100	100	62.637	61.067	59.457
	39	0.39	100	100	100	64.166	62.637	61.067
	40	0.40	100	100	100	65.654	64.166	62.637
	41	0.41	100	100	100	67.102	65.654	64.166
	42	0.42	100	100	100	68.508	67.102	65.654

TABLE A2—INITIAL SIMULATION OF THE BESSEL FILTER EFFECT (USED TO DETERMINE f_c) (CONTINUED)

	Index	Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
	43	0.43	100	100	100	69.873	68.508	67.102
	44	0.44	100	100	100	71.198	69.873	68.508
	45	0.45	100	100	100	72.481	71.198	69.873
	46	0.46	100	100	100	73.724	72.481	71.198
	47	0.47	100	100	100	74.927	73.724	72.481
	48	0.48	100	100	100	76.090	74.927	73.724
	49	0.49	100	100	100	77.215	76.090	74.927
	50	0.50	100	100	100	78.300	77.215	76.090
	51	0.51	100	100	100	79.348	78.300	77.215
	52	0.52	100	100	100	80.358	79.348	78.300
	53	0.53	100	100	100	81.331	80.358	79.348
	54	0.54	100	100	100	82.269	81.331	80.358
	55	0.55	100	100	100	83.171	82.269	81.331
	56	0.56	100	100	100	84.039	83.171	82.269
	57	0.57	100	100	100	84.872	84.039	83.171
	58	0.58	100	100	100	85.673	84.872	84.039
	59	0.59	100	100	100	86.442	85.673	84.872
	60	0.60	100	100	100	87.180	86.442	85.673
	61	0.61	100	100	100	87.887	87.180	86.442
	62	0.62	100	100	100	88.564	87.887	87.180
	63	0.63	100	100	100	89.213	88.564	87.887
X	64	0.64	100	100	100	89.834	89.213	88.564
X	65	0.65	100	100	100	90.427	89.834	89.213
	66	0.66	100	100	100	90.994	90.427	89.834
	67	0.67	100	100	100	91.536	90.994	90.427
	68	0.68	100	100	100	92.053	91.536	90.994
	69	0.69	100	100	100	92.546	92.053	91.536
	70	0.70	100	100	100	93.016	92.546	92.053

TABLE A3—FINAL BESSEL COEFFICIENTS

Equation A1	t_F	0.500
Equation A2	f_c	0.6292
Equation A4	B	0.618000
Equation A5	Ω	45.991292
Equation A6	C	0.000729
Equation A7	K	0.905717
	Δt	0.01

TABLE A4—BOUNDARY RESPONSE TIMES (SECOND ITERATION)

$t_{10\%}$	0.09145
$t_{90\%}$	0.5856
$\Delta\ t_{90\%} - t_{10\%}$	0.4951

Table A5 shows a sample calculation for an actual snap-acceleration smoke event collected at 100 Hz. Only 100 (1 s) readings and calculated values are shown so as to reduce the length of the table. The Bessel coefficients shown in Table A3 are used with Equation A8 to calculate the Bessel filter responses (Y_i) to the raw smoke inputs (X_i).

TABLE A5—BESSEL FILTER EXAMPLE

Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
0.00	0.00	0.00	0.00	0.000	0.000	0.000
0.01	0.00	0.00	0.00	0.000	0.000	0.000
0.02	0.30	0.00	0.00	0.000	0.000	0.000
0.03	0.60	0.30	0.00	0.001	0.000	0.000
0.04	0.50	0.60	0.30	0.004	0.001	0.000
0.05	0.40	0.50	0.60	0.007	0.004	0.001
0.06	0.30	0.40	0.50	0.012	0.007	0.004
0.07	0.10	0.30	0.40	0.017	0.012	0.007
0.08	0.00	0.10	0.30	0.021	0.017	0.012
0.09	0.00	0.00	0.10	0.026	0.021	0.017
0.10	0.00	0.00	0.00	0.029	0.026	0.021
0.11	0.00	0.00	0.00	0.033	0.029	0.026
0.12	0.00	0.00	0.00	0.036	0.033	0.029
0.13	0.20	0.00	0.00	0.039	0.036	0.033
0.14	0.40	0.20	0.00	0.042	0.039	0.036
0.15	0.40	0.40	0.20	0.045	0.042	0.039
0.16	0.30	0.40	0.40	0.049	0.045	0.042
0.17	0.30	0.30	0.40	0.054	0.049	0.045
0.18	0.70	0.30	0.30	0.059	0.054	0.049
0.19	0.80	0.70	0.30	0.066	0.059	0.054
0.20	0.70	0.80	0.70	0.073	0.066	0.059
0.21	0.40	0.70	0.80	0.082	0.073	0.066
0.22	0.20	0.40	0.70	0.091	0.082	0.073
0.23	0.20	0.20	0.40	0.100	0.091	0.082
0.24	0.30	0.20	0.20	0.108	0.100	0.091
0.25	0.50	0.30	0.20	0.116	0.108	0.100
0.26	0.40	0.50	0.30	0.124	0.116	0.108
0.27	0.20	0.40	0.50	0.133	0.124	0.116
0.28	0.00	0.20	0.40	0.140	0.133	0.124
0.29	0.40	0.00	0.20	0.147	0.140	0.133
0.30	0.30	0.40	0.00	0.154	0.147	0.140
0.31	0.20	0.30	0.40	0.161	0.154	0.147
0.32	0.20	0.20	0.30	0.167	0.161	0.154
0.33	0.10	0.20	0.20	0.172	0.167	0.161
0.34	0.10	0.10	0.20	0.177	0.172	0.167
0.35	0.30	0.10	0.10	0.182	0.177	0.172
0.36	0.70	0.30	0.10	0.186	0.182	0.177
0.37	1.10	0.70	0.30	0.192	0.186	0.182
0.38	2.60	1.10	0.70	0.200	0.192	0.186
0.39	3.50	2.60	1.10	0.215	0.200	0.192
0.40	7.10	3.50	2.60	0.239	0.215	0.200
0.41	10.20	7.10	3.50	0.281	0.239	0.215
0.42	15.90	10.20	7.10	0.350	0.281	0.239
0.43	21.80	15.90	10.20	0.458	0.350	0.281

TABLE A5—BESSEL FILTER EXAMPLE (CONTINUED)

Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
0.44	28.10	21.80	15.90	0.619	0.458	0.350
0.45	34.40	28.10	21.80	0.846	0.619	0.458
0.46	39.90	34.40	28.10	1.149	0.846	0.619
0.47	44.80	39.90	34.40	1.537	1.149	0.846
0.48	50.30	44.80	39.90	2.016	1.537	1.149
0.49	52.70	50.30	44.80	2.590	2.016	1.537
0.50	56.40	52.70	50.30	3.259	2.590	2.016
0.51	58.80	56.40	52.70	4.020	3.259	2.590
0.52	61.50	58.80	56.40	4.873	4.020	3.259
0.53	63.40	61.50	58.80	5.812	4.873	4.020
0.54	64.70	63.40	61.50	6.832	5.812	4.873
0.55	65.00	64.70	63.40	7.928	6.832	5.812
0.56	66.20	65.00	64.70	9.091	7.928	6.832
0.57	66.40	66.20	65.00	10.313	9.091	7.928
0.58	68.30	66.40	66.20	11.589	10.313	9.091
0.59	67.00	68.30	66.40	12.911	11.589	10.313
0.60	66.30	67.00	68.30	14.271	12.911	11.589
0.61	66.40	66.30	67.00	15.659	14.271	12.911
0.62	65.90	66.40	66.30	17.068	15.659	14.271
0.63	66.10	65.90	66.40	18.491	17.068	15.659
0.64	63.50	66.10	65.90	19.921	18.491	17.068
0.65	63.40	63.50	66.10	21.349	19.921	18.491
0.66	61.20	63.40	63.50	22.768	21.349	19.921
0.67	59.90	61.20	63.40	24.170	22.768	21.349
0.68	59.40	59.90	61.20	25.549	24.170	22.768
0.69	58.20	59.40	59.90	26.900	25.549	24.170
0.70	56.60	58.20	59.40	28.218	26.900	25.549
0.71	54.70	56.60	58.20	29.499	28.218	26.900
0.72	53.80	54.70	56.60	30.737	29.499	28.218
0.73	53.40	53.80	54.70	31.930	30.737	29.499
0.74	51.70	53.40	53.80	33.075	31.930	30.737
0.75	50.80	51.70	53.40	34.171	33.075	31.930
0.76	48.80	50.80	51.70	35.214	34.171	33.075
0.77	48.30	48.80	50.80	36.203	35.214	34.171
0.78	45.80	48.30	48.80	37.135	36.203	35.214
0.79	45.30	45.80	48.30	38.009	37.135	36.203
0.80	44.30	45.30	45.80	38.823	38.009	37.135
0.81	42.00	44.30	45.30	39.579	38.823	38.009
0.82	42.20	42.00	44.30	40.274	39.579	38.823
0.83	39.90	42.20	42.00	40.910	40.274	39.579
0.84	39.20	39.90	42.20	41.485	40.910	40.274
0.85	39.10	39.20	39.90	42.002	41.485	40.910
0.86	36.90	39.10	39.20	42.462	42.002	41.485
0.87	36.50	36.90	39.10	42.865	42.462	42.002
0.88	35.20	36.50	36.90	43.211	42.865	42.462
0.89	34.50	35.20	36.50	43.503	43.211	42.865
0.90	34.90	34.50	35.20	43.743	43.503	43.211
0.91	32.70	34.90	34.50	43.934	43.743	43.503
0.92	32.10	32.70	34.90	44.075	43.934	43.743
0.93	31.50	32.10	32.70	44.169	44.075	43.934
0.94	30.50	31.50	32.10	44.216	44.169	44.075

TABLE A5—BESSEL FILTER EXAMPLE (CONTINUED)

Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
0.95	30.70	30.50	31.50	44.220	44.216	44.169
0.96	30.20	30.70	30.50	44.184	44.220	44.216
0.97	29.30	30.20	30.70	44.110	44.184	44.220
0.98	26.90	29.30	30.20	43.999	44.110	44.184
0.99	25.80	26.90	29.30	43.848	43.999	44.110
1.00	25.30	25.80	26.90	43.660	43.848	43.999

APPENDIX B

CORRECTIONS FOR AMBIENT TEST CONDITIONS

***B.1 Introduction*—**Adjustment of snap-acceleration smoke values for the influence of ambient measurement conditions is an important and integral part of the SAE J1667 smoke measurement procedure. Testing has shown at-site ambient environmental conditions to be among the most influential testing factors that affect as-measured snap-acceleration smoke results. The ambient environmental factors incurred at the point of measurement in the form of altitude, barometric pressure, air temperature, and humidity have been combined into the single parameter of dry air density in order to provide a means of accounting for the influence of these factors on snap-acceleration test results. This appendix details procedures and offers guidelines for performing this important adjustment to snap-acceleration smoke values.

As will be summarized in Section B.7, the adjustment equations provided in this appendix were derived from an extensive snap-acceleration smoke test program involving a wide variety of heavy-duty diesel powered vehicles. One of the main conclusions of this test program was that each of the engines powering the test vehicles displayed different degrees of sensitivity to changes in air density. These differences were likely due to the different combustion and smoke control technologies employed by these engines at the time of their manufacture.

The air density adjustment equations provided in this appendix reflect the best fit nominal sensitivity of the sample of engines/vehicles evaluated. Some engines were more sensitive, and some were less sensitive, to the air density changes than predicted by the adjustment equations. In light of this, applying the correction equations to specific engines/vehicles of unknown air density sensitivity, the adjustment equations can only be considered approximate. It is recommended that regulatory agencies adopting this procedure in enforcement programs make some allowance for the fact that the air density sensitivity of individual vehicles tested in the program will, in general, not be known precisely and may be different than indicated by the nominal adjustment.

B.1.1 Reference Conditions—To perform an air density adjustment to an observed smoke value, it is necessary to define a reference air density which is used as the basis for the adjustment. The reference dry air density which was selected is:

$$1.1567 \text{ kg/m}^3 \text{ } (0.0722 \text{ lbm/ft}^3)$$

This dry air density is the reference density specified in SAE J1349 and J1995, which specify the net and gross power rating conditions for diesel engines.

B.1.2 Precautions

a. The air density extremes encountered during the smoke test program (see Section B.7) used to derive the adjustment equations ranged from a low of 0.908 kg/m^3 (0.0567 lbm/ft^3) to a high of 1.235 kg/m^3 (0.0771 lbm/ft^3). The adjustment equations provided in this appendix should not be used outside of this range of air density.
b. The results from the study used to develop these correction factors suggested that at high temperatures above 32 °C (90 °F) and at low altitude sites around 412 m (1350 ft) in elevation there appeared to be a systematic temperature effect present that may not be accounted for by these correction factors. Residuals (the difference between measured values and calculated values) at these sites tend to decrease in value with increasing temperature. This may suggest the need for further adjustments to the equations to account for these temperature trends.
c. The air density adjustment equations presented here were developed specifically for use with snap-acceleration smoke values obtained using the procedures, equipment, and analysis techniques described in this document. The adjustment equations are not recommended for use with snap-acceleration smoke values obtained using peak-reading type smokemeters, or other smoke measurement procedures.

B.2 Symbols

A = Final avg. snap-acceleration test result, in units of opacity (%) or smoke density K(m^{-1}), from Equation A4. "A" is equivalent to N_t or K_t, depending on the smoke units being used.
BARO = Barometric pressure, absolute, kPa (in-Hg).
c = Regression coefficient for ambient condition adjustment equation.
DBT = Dry bulb temperature, ambient temperature measured in conjunction with WBT, °C (°F).
DPT = Dew point temperature, °C (°F).
F = Ferrel's equation, saturation pressure adjustment factor.
K = Smoke density (extinction coefficient), per meter (m^{-1}).
N = Smoke opacity, in percent (%).
r = Air density (dry), kg/m^3 (lbm/ft^3).
Dr = Dry air density differential between actual test conditions or reference conditions, and base conditions.
RH = Relative humidity, percent (%).
SPT = Water saturation pressure at the ambient temperature, kPa (in-Hg).
SPWBT= Water saturation pressure at the wet bulb temperature, kPa (in-Hg).
T = Ambient temperature, if different from the DBT, °C (°F).
WBT = Wet bulb temperature, °C (°F).
WVP = Water vapor pressure, kPa (in-Hg).

NOTE—Pressure units given in in-Hg are referenced to 0 °C.

subscripts
abs = absolute temperature. T + 273.15 Kelvin (T + 459.67 °R)
base = base dry air density. The air density upon which the ambient conditions correction regression efficients are based.
ref = at reference dry air density conditions, 1.1567 kg/m^3 (0.0722 lbm/ft^3).
t = at non-reference dry air density, usually actual test dry air density.

B.3 Snap-Acceleration Smoke Adjustment Methods—This appendix contains snap-acceleration adjustment equations that account for the air density effects on snap-acceleration smoke. The measured vehicle smoke value (A) is adjusted to the reference air density (ρ_{ref}). The measured smoke value (A), along with the actual dry air density (ρ_t) at the time of the test, are used in Section B.4 for opacity units or Section B.5 for smoke density units to compute the smoke level (N_{ref} or K_{ref}) at the reference air density (ρ_{ref}).

B.4 Adjustment of Snap-Acceleration Smoke Opacity (N) Values for the Effects of Changes in the Dry Air Density—The approach for adjusting smoke opacity values for the effects of changes in the dry air density is to convert the smoke opacity value, N_t, to smoke density units (K), adjust the smoke density value according to the procedures described in Section B.5, and then re-convert the adjusted smoke density value back into smoke opacity units as N_{ref}.

To adjust a snap-acceleration smoke opacity value for the effects of changes in the dry air density:

a. Convert the smoke opacity value to the equivalent smoke density units using the following equation:

$$K = (-1/L) * 1n(1 - (N/100)) \quad \text{(Eq. B1)}$$

where:

K = Smoke density (m-1).
L = Optical path length of the smoke measurement, in meters (m). If L is not known, assume a value of 0.127 m.
N = Smoke opacity value to be converted, usually Nt.

b. Adjust the resulting smoke density value, calculated in step 1, according to the procedures described in Section B.5 to produce K_{ref}.

c. Convert the resulting adjusted smoke density value calculated in Section B.5 to equivalent smoke opacity units according to the following equation:

$$N = (1 - e^{-KL})^{*}100 \quad \text{(Eq. B2)}$$

where:

N = Ambient conditions adjusted smoke opacity value, N_{ref}.
K = Ambient conditions adjusted smoke density value, K_{ref}, determined in Section B.5.
L = Optical path length value used in Equation B1.

NOTE—It is important to use the same value of L (optical path length) for the conversion to smoke density units and for the re-conversion back to smoke opacity units. The actual value of L is not critical; however, it must be a positive non-zero value.

B.5 ***Adjustment of Snap-Acceleration Smoke Density (K) Values for the Effects of Changes in the Dry Air Density—***The base air density (ρ_{base}) parameter used in this section should not be confused with the reference air density (ρ_{ref}). The base air density is the ambient condition used to develop the adjustment regression coefficient used in this section. The adjustment equations in this section provide for the reference air density to be different from the base air density used in the regression analysis of the ambient conditions test data.

To adjust a measured snap-acceleration smoke density value to reference air density conditions:

a. Calculate the air density differences using ρ_{ref} and ρ_{base}:

$$\Delta\rho_1 = \rho_{ref} - \rho_{base} \quad \text{(Eq. B3)}$$

$$\Delta\rho_2 = \rho_t - \rho_{base} \quad \text{(Eq. B4)}$$

b. Calculate the adjusted snap-acceleration smoke density value, K_{ref}, at the reference dry air density, using Equation B5, and the appropriate values for coefficient c and r from Table B1.

$$K_{ref} = K_t^{*}\frac{(c^{*}\Delta\rho_1^{\,2} + 1)}{(c^{*}\Delta\rho_2^{\,2} + 1)} \quad \text{(Eq. B5)}$$

TABLE B1—SMOKE DENSITY ADJUSTMENT CONSTANTS

Air Density Units	c	ρ_{base}	
kg/m^3	21.1234	1.2094	(metric)
lbm/ft^3	5420.0671	0.0755	(English)

c. Substituting the values in Table B1 for c and ρ into Equation B3 through B5 produces Equation B6 and B7 for K_{ref}.

Metric Units ρ (kg/m^3)

$$K_{ref} = \frac{K_t}{19.952\ \rho_t^{2} - 48.259\ \rho_t + 30.126} \quad \text{(Eq. B6)}$$

English Units ρ (lbm/ft^3)

$$K_{ref} = \frac{K_t}{5119.55\ \rho_t^2 - 773.05\ \rho_t + 30.126} \qquad \text{(Eq. B7)}$$

B.6 Calculation of Dry Air Density—In order to correct the smoke values using the equations in Sections B.4 or B.5, it is first necessary to determine the dry air density at the test conditions. This can be done by measuring the barometric pressure (BARO), the ambient air temperature (T or DBT), and either the dew point temperature (DPT), or the wet and dry bulb temperatures (WBT and DBT), or the relative humidity (RH). From these measurements the dry air density may be determined from the following equation.

$$\rho = (u*(BARO - WVP))/(T_{abs}) \qquad \text{(Eq. B8)}$$

where:

TABLE B2—

	Metric	English
ρ, Air Density (dry)	kg/m^3	lbm/ft^3
Units conversion (u)	3.4836	1.3255
Barometric Pressure (BARO)	kPa	in-Hg
Water Vapor Pressure (WVP)	kPa	in-Hg
Ambient Temperature (T_{abs})	Kelvin	°R

The barometric pressure and the ambient temperature must be measured at the test conditions of interest. The water vapor pressure may be calculated as described in B.6.1, or obtained from a psychrometric chart.

NOTE—Exclusion of the water vapor pressure term in Equation B8 (calculation of dry air density) is permissible, thus eliminating the need to measure DPT, WBT, or RH and calculate the WVP. However, the user should be aware that this results in a bias error, usually towards a smaller adjustment factor applied to the smoke values. In addition, it should be noted that as the ambient temperature increases, the amount of water the air can hold increases rapidly, and thus, the potential impact of this error also increases. The examples in Section B.6 illustrate the impact of ignoring the water vapor pressure in the adjustment equations.

B.6.1 Calculation of Water Vapor Pressure (WVP)—The method of calculating the water vapor pressure is dependent upon the instrumentation used to determine the moisture in the ambient air. The most common methods utilized are by the measurement of the dew point temperature (DPT), the measurement of the wet bulb/dry bulb temperatures, and by the measurement of the relative humidity (RH). From these measurements, the vapor pressure of the air may be determined.

B.6.1.1 CALCULATION OF WVP FROM DEW POINT TEMPERATURE—This procedure uses a dimensionless (normalized) polynomial for the vapor pressure calculation. This allows calculations to be performed in any units, utilizing the same polynomial coefficients. In using this technique, the input and output parameters to the polynomial are normalized and un-normalized, respectively, with the supplied support equations.

a. Calculate the normalized dew point temperature (NT) from the measured dew point temperature (DPT).

$$NT = (DPT - TL)/(TH - TL) \qquad \text{(Eq. B9)}$$

TABLE B3—

Temperature Units	TL	TH
°C	-30.0	+40.0
°F	-22.0	+104.0

NOTE—DPT, TL, and TH must be in the same temperature units. Equation B9 applies over a dew point temperature range of -30 to +40 °C (-22 to +104 °F).

b. Calculate the normalized water vapor pressure (NP) at the normalized dew point temperature (NT).

$$NP = -4.959658E\text{-}5 + (4.956773E\text{-}2 * NT) + (9.455172E\text{-}2 * NT^2) + (4.199096E\text{-}1 * NT^3) + (-7.549164E\text{-}2 * NT^4) + (5.114628E\text{-}1 * NT^5) \quad \text{(Eq. B10)}$$

c. Un-normalize the saturation pressure (NP) to produce the WVP at the dew point temperature, DPT, in the units of choice.

$$WVP = PL + (NP * (PH - PL)) \quad \text{(Eq. B11)}$$

TABLE B4—

Pressure Units	PL	PH
kPa	5.0951E-2	7.375
in-Hg	1.5046E-2	2.178

NOTE—WVP, PL, and PH must be in the same pressure units.

B.6.1.2 CALCULATION OF WVP FROM WET BULB/DRY BULB TEMPERATURES—This procedure uses a dimensionless (normalized) polynomial for the vapor pressure calculation. This allows calculations to be performed in any units, utilizing the same polynomial coefficients. In using this technique, the input and output parameters to the polynomial are normalized and un-normalized, respectively, with the supplied support equations.

a. Calculate the normalized wet bulb temperature (NT) from the measured wet bulb temperature (WBT).

$$NT = (WBT - TL) / (TH - TL) \quad \text{(Eq. B12)}$$

TABLE B5—

Temperature Units	TL	TH
°C	-30.0	+40.0
°F	-22.0	+104.0

NOTE—WBT, TL, and TH must be in the same temperature units. Equation B12 applies over a wet bulb temperature range of -30 to +40 °C (-22 to +104 °F).

b. Calculate the normalized saturation pressure (NP) at the normalized wet bulb temperature (NT).

$$NP = -4.959658E\text{-}5 + (4.956673E\text{-}2 * NT) + (9.455172E\text{-}2 * NT^2) + (4.199096E\text{-}1 * NT^3) + (-7.549164E\text{-}2 * NT^4) + (5.114628E\text{-}1 * NT^5) \quad \text{(Eq. B13)}$$

c. Un-normalize the saturation pressure (NP) to produce the saturation pressure at the wet bulb temperature, SPWBT, in the units of choice.

$$SPWBT = PL + (NP*(PH - PL)) \quad \text{(Eq. B14)}$$

TABLE B6—

Pressure Units	PL	PH
kPa	5.0951E-2	7.375
in-Hg	1.5046E-2	2.178

NOTE—SPWBT, PL, and PH must be in the same pressure units.

d. Using Ferrel's equation, calculate the adjustment factor (F).
Metric Units—WBT in °C

$$F = 3.67E\text{-}4*(1 + (1.152E\text{-}3*WBT)) \quad \text{(Eq. B15)}$$

English Units—WBT in °F

$$F = 3.67E\text{-}4*(1 + (6.4E\text{–}4*(WBT - 32))) \quad \text{(Eq. B16)}$$

e. Calculate the Water Vapor Pressure (WVP).

Metric Units—SPWBT, BARO in kPa; DBT, WBT in °C.

$$WVP = SPWBT - (1.8*F*BARO*(DBT - WBT)) \quad \text{(Eq. B17)}$$

English Units—SPWB, BARO in in-Hg; DBT, WBT in °F.

$$WVP = SPWBT - (F*BARO*(DBT - WBT)) \quad \text{(Eq. B18)}$$

B.6.1.3 CALCULATION OF WVP FROM RELATIVE HUMIDITY AND AMBIENT TEMPERATURE—This procedure uses a dimensionless (normalized) polynomial for the vapor pressure calculation. This allows calculations to be performed in any units, utilizing the same polynomial coefficients. In using this technique, the input and output parameters to the polynomial are normalized and un-normalized, respectively, with the supplied support equations.

a. Calculate the normalized ambient temperature (NT) from the measured ambient temperature (T).

$$NT = (T - TL)/(TH - TL) \quad \text{(Eq. B19)}$$

TABLE B7—

Temperature Units	TL	TH
°C	-30.0	+40.0
°F	-22.0	+104.0

NOTE—T, TL, and TH must be in the same temperature units. Equation B19 applies over an ambient temperature range of -30 to +40 °C (-22 to +104 °F).

b. Calculate the normalized saturation pressure (NP) at the normalized ambient temperature (NT).

$$NP = -4.959658E\text{-}5 + (4.956673E\text{-}2*NT) + (9.455172E\text{-}2*NT^2) + (4.199096E\text{-}1*NT^3) + (-7.549164E\text{-}2*NT^4) + (5.114628E\text{-}1*NT^5) \quad \text{(Eq. B20)}$$

c. Un-normalize the saturation pressure (NP) to produce the saturation pressure at the ambient temperature, SPT, in the units of choice.

$$SPT = PL + (NP*(PH - PL)) \quad \text{(Eq. B21)}$$

TABLE B8—

Pressure Units	PL	PH
kPa	5.0951E-2	7.375
in-Hg	1.5046E-2	2.178

NOTE—SPT, PL, and PH must be in the same pressure units.

d. Calculate the WVP at the measured relative humidity, RH. WVP will be in the same units as SPT.

$$WVP = SPT*(RH/100) \quad \text{(Eq. B22)}$$

B.7 Examples of Adjustments to Ambient Smoke Values—The following hypothetical examples may assist in applying the ambient correction equations. Both metric and English unit based examples are provided. Also included for reference are the applicable equation numbers used in this appendix.

Example 1

Situation—A vehicle tested for smoke at a moderate elevation produces an average snap-acceleration smoke value of 60% opacity (the (A) value reported from Equation B3).

Task—From the ambient conditions measurements, determine the adjusted smoke opacity (N_{ref}) at the reference air density (ρ_{ref}).

Ambient measurements	Equation Constants
Smoke (A)= 60% opacity	c = 54.200671
(BARO)= 27.00 in-Hg	TL = -22 x °F
(T)= 77 x °F	TH = 104 x °F
(RH)= 50%	PL = 1.5046E-2 in-Hg
	PH = 2.178 in-Hg
	EOPL = 0.127 m
	(ρ_{ref}) = 0.0722 lbm/ft^3
	(ρ_{base}) = 0.0755 lbm/ft^3

Calculations:

(Eq.B19)	NT	=	(77 - (-22))/(104 - (-22)) = 0.785714
(Eq.B20)	NP	=	0.425334 (polynomial)
(Eq.B21)	SPT	=	1.5046E-2 + 0.425334 * (2.178 - 1.5046E-2)
		=	0.935024
(Eq.B22)	WVP	=	0.935024 * (50.0/100)
		=	0.4675
(Eq.B8)	ρ_{dry}	=	(1.3255 * (27.0 - 0.4675))/(77 + 459.67)
		=	0.06553
(Eq.B1)	K_t	=	7.215
(Eq.B3)	$\Delta \rho 1$	=	0.0722 - 0.0755 = -0.0033
(Eq.B4)	$\Delta \rho 2$	=	0.06553 - 0.0755 = -0.00996
(Eq.B5)	K_{ref}	=	4.966
(Eq.B2)	N_{ref}	=	46.8%

Result—A vehicle with a snap-acceleration smoke level of 60% opacity at a dry air density of 0.0655 lbm/ft^3 would be projected to produce a smoke value of 46.8% opacity at the reference dry air density of 0.0722 lbm/ft^3.

It should be noted that if the RH measurement had not been performed and the effect of WVP ignored, the resulting impact would have changed N_{ref} from 46.8% to 49.5% opacity.

Example 2

Situation—A vehicle tested for smoke at a moderate elevation produces an average snap-acceleration smoke density of 7.2 m^{-1} (the (A) value reported from Equation B3).

Task—From the ambient conditions measurements, determine the adjusted smoke density (K^{ref}) at the reference air density (ρ_{ref}).

Ambient measurements		Equation Constants		
Smoke (A)	= 7.2 m^{-1}	c	=	0.211234
(BARO)	= 88.50 kPa	TL	=	-30 °C
(T)	= 20 °C	TH	=	40 °C
(DPT)	= 10 °C	PL	=	5.0951E-2 kPa
		PH	=	7.375 kPa
		(ρ_{ref})	=	1.1567 kg/m^3
		(ρ_{base})	=	1.2094 kg/m^3

Calculations:

(Eq.B9)	NT	= (10 – (–30))/(40 – (–30)) = 0.571428
(Eq.B10)	NP	= 0.160612 (polynomial)
(Eq.B11)	WVP	= 5.0951E-2– (0.160612 * (7.375 – 5.0951E-2))
		= 1.2272
(Eq.B8)	ρ_{dry}	= (3.4836 * (88.5 – 1.227))/(20 + 273.15)
		= 1.0370
(Eq.B3)	$\Delta\rho_1$	= 1.1567– 1.2094 = –0.0527
(Eq.B4)	$\Delta\rho_2$	= 1.0370 – 1.2094 = –0.17230
(Eq.B5)	K_{ref}	= 4.684 m-^{1}

Result—A vehicle with a snap-acceleration smoke density of 7.2 m^{-1} at a dry air density of 1.0370 kg/m^3 would be projected to produce a smoke density of 4.684 (m^{-1}) at the reference dry air density of 1.1567 kg/m^3.

B.8 Snap-Acceleration/Air Density Field Test Program—The snap-acceleration smoke adjustment equations of this appendix were derived using data from a smoke test program designed to study the effects of ambient conditions on snap-acceleration smoke levels. The test program was conducted during the summer of 1993 and involved measuring the snap-acceleration levels of several heavy-duty diesel-powered vehicles, as the vehicles traveled an out and back route over a wide range of elevations on Interstate 80, in California. The vehicles were tested for snap-acceleration smoke with several types of smokemeters using the SAE J1667 test procedures and data analysis algorithm. Eight tests were performed at six different elevations along the route. At two of the elevations, tests were performed on both the outbound and return legs of the test route. The range of the ambient test conditions encountered during the test program are shown in Table B9.

TABLE B9—TEST PROGRAM AMBIENT EXTREMES

Units	min	max
Metric		
Elevation	12 m	2207 m
Air Density (dry)	0.906 kg/m^3	1.235 kg/m^3
Air Density (wet)	0.915 kg/m^3	1.240 kg/m^3
Barometer	78.3 kPa	101.7 kPa
Ambient Temp.	11.7 °C	37.2 °C
Specific Humidity	0.6 gm/kg	12.7 gm/kg
English		
Elevation	40 ft	7240 ft
Air Density (dry)	0.0567 lbm/ft^3	0.0771 lbm/ft^3
Air Density (wet)	0.0571 lbm/ft^3	0.0774 lbm/ft^3
Barometer	23.11 in-Hg	30.03 in-Hg
Ambient Temp.	53 °F	99 °F
Specific Humidity	4 grains	89 grains

A total of 24 diesel-powered vehicles were tested in the program, with the number, type, and manufacturer of the diesel engines powering these vehicles providing a fairly representative sample of the engines in the general U.S. heavy-duty vehicle population. Engines manufactured by Caterpillar, Cummins, Detroit Diesel (both 2 and 4 cycle), and Mack were included in the test sample, as were engines with both mechanical and electronic injection control systems. There was one naturally aspirated engine in the test sample with the rest being turbocharged. The manufacturing dates of the engines covered a range from 1971 to 1993 with about 46% of the engines manufactured in the 1985-1989 period and about 33% manufactured between 1990 and 1993.

Four different manufacturers of smokemeters (Bosch, Caltest, Sun, and Wager) participated in the test program. The smokemeters included full flow end-of-line (EOL) and sampling type smokemeters. Both peak-reading meters and prototype meters which were programmed to perform the SAE J1667 half-second averaging algorithm were included in the testing.

The data from the testing program were assembled into a single data base so that standard mathematical and statistical procedures could be utilized to query for relationships among the various test parameters. Data from the peak-reading meters and data which did not meet the SAE J1667 test validation criteria, as given in 5.4.4, were excluded from the analyses. Dry air density, barometric pressure, and altitude all produced significant correlations with the snap-acceleration smoke values, with dry air density providing the better correlation.

The data from this test program were also used to quantify the repeatability of the test procedure. This was done in two ways. In the first method, the average of the ambient condition corrected smoke values was computed for each vehicle, test day and smokemeter combination. The deviations of the individual corrected smoke values from this average were then computed and used to provide a measure of the repeatability of the test procedure over the full range of ambient conditions encountered in the test program and allowed by the procedure. When this was done for all the data in the test program data base, 91% of the deviations from average were less than 6% opacity.

In the second method, only the data taken at the two elevations where repeat tests were run were utilized. For each vehicle/meter combination the two test results obtained at these test locations created a data pair which differed only slightly in ambient dry air density. (Since the elevation was the same for both points in the data pair, the only source of air density differences was the change in ambient conditions which occurred in the few hours between the two tests.) All these smoke values were corrected to the standard reference air density using the methods described in this appendix and the deviation of the corrected smoke values was noted for each data pair. For 90% of the pairs, the deviations were less than 3% opacity.

The difference in the repeatabilities quantified by the two methods reflects the imprecision of applying the ambient condition corrections to specific vehicles over wide ranges of air density.

APPENDIX C

APPLICATION OF CORRECTIONS TO MEASURED SMOKE VALUES

C.1 Introduction—Fundamentally, all smoke opacimeters measure the transmittance of light through a smoke plume or a sample of gas which contains smoke particles. Typically, however, it is desired to quantify and report the exhaust smoke emissions in units of either smoke opacity (N) or smoke density (k). Furthermore, if the smoke level is reported as smoke opacity, then is it also necessary to report the associated effective optical path length to fully specify the smoke level of the vehicle. This is because measured smoke opacity is a function of the effective optical path length (EOPL) used to make the measurement. For example, an engine that yielded a 20% opacity when tested with a tailpipe which caused the EOPL to be 76 mm would have measured opacities of 26%, 31%, and 36%, respectively, when tested with larger tailpipes which caused the EOPL to be 102, 127, and 152 mm. Therefore, to facilitate comparisons of smoke opacity data from different sources and with smoke standards which may be developed, opacity values must be reported at standard effective optical path lengths.

When smoke is measured using an effective optical path length which is different than the standard path length, the measured smoke values must be converted to opacity at the standard path length using the appropriate Beer-Lambert relationship. Similarly, if it is desired to report the test results in units of smoke density, it is necessary to use the Beer-Lambert relationship to convert the measured opacity results to smoke density.

Finally, if smoke measurements are made using a smokemeter having a red LED light source, a wavelength correction is necessary to account for the fact that the ability of diesel smoke to absorb light depends on the wavelength of the light.

This appendix describes how measured smoke values are to be corrected to the desired reporting units using the Beer-Lambert relationships and how the light source wavelength corrections are to be made.

C.2 Definitions and Symbols

C.2.1 Diesel Smoke—Particles, including aerosols, suspended in the exhaust stream of a diesel engine which absorb, reflect, or refract light.

C.2.2 Transmittance (T)—The fraction of light transmitted from a source which reaches a light detector.

C.2.3 Opacity (N)—The percentage of light transmitted from a source which is prevented from reaching a light detector.

C.2.4 Effective Optical Path Length (L)—The length of the smoke obscured optical path between the smokemeter light source and light detector. Note that portions of the total light source to detector path length which are not smoke obscured do not contribute to the effective optical path length.

C.2.5 Smoke Density (k)—A fundamental means of quantifying the ability of a smoke plume or a smoke-containing gas sample to prevent the passage of light. By convention, smoke density is expressed on a per meter basis (m^{-1}).

C.2.6 W—The wavelength of the smokemeter light source.

C.2.7 Subscripts

C.2.7.1 m—Refers to the as-measured condition

C.2.7.2 s—Refers to values corrected to a standard condition

C.3 Beer-Lambert Relationships—The Beer-Lambert Law defines the relationship between transmittance, smoke density, and effective optical path length as shown in Equation C1.

$$T = e^{-kL} \qquad \text{(Eq. C1)}$$

From the definitions of transmittance and opacity, the relationship between these parameters may be defined as shown in Equation C2.

$$N(\%) = 100*(1 - T) \qquad \text{(Eq. C2)}$$

From Equations C1 and C2 the following important relationships can be derived:

$$N_s = 100*(1 - ((1 - (N_m / 100))(L_s / L_m))) \qquad \text{(Eq. C3)}$$

$$k = -(1 / L_m)*(1n(1 - (N_m / 100))) \qquad \text{(Eq. C4)}$$

To achieve proper results in applying Equations C1 and C4, the effective optical path lengths (L and L_m) must be expressed in units of meters (m). It is recommended that the effective optical path lengths used in Equation C3 also be expressed in meters (m); however, any length unit may be used as long as L_s and L_m are expressed in the same measurement unit.

C.4 Use of Beer-Lambert Relationships—Conversion from as-measured smoke values to appropriate reporting units is a two-step process. Since, as noted in Section C.1, the basic measurement unit of all smokemeters is transmittance, the first step in all cases is to convert from transmittance (T) to opacity at the as-measured effective optical path length (N_m) using Equation C2. Since all opacimeters do this internally, this step is transparent to the user.

The second step of the process is to convert from N_m to the desired reporting units as follows:

a. If the test results are to be reported in opacity units, Equation C3 must be used to convert from opacity at the as-measured effective optical path length to opacity at the standard effective optical path length. (In the event that the measured and standard effective optical path lengths are identical, N_s is equal to N_m and this secondary conversion step is not required.)
b. If the test results are to be reported in units of smoke density, then Equation C4 must be applied.

C.5 Effective Optical Path Length Input Values—In order to apply conversion Equation C4, it is necessary to input the as-measured effective optical path length (L_m). To use Equation C3, values must be input both for L_m and for L_s, the standard effective optical path length. This section provides guidance on the determination of these input values.

C.5.1 Determination of L_m—For full-flow end-of-line type smokemeters, L_m is a function of the vehicle tailpipe design. For straight tailpipes with a circular cross section, L_m is equal to the tailpipe ID. For tailpipes constructed of common tubing, the tubing OD may be used to approximate the tubing ID. Appendix D provides guidance in determining L_m for other tailpipe configurations.

For sampling type smokemeters, L_m is a fixed function of the meter measurement cell and purge air system design. Specification data supplied by the meter manufacturer should be consulted to determine the appropriate value for L_m when this type of smokemeter is used.

Typically, it is necessary to determine L_m within ±5 mm to achieve corrected smoke results that are accurate within ±2% opacity or ±0.2 m^{-1} smoke density.

C.5.2 Determination of L_s—To ensure meaningful smoke data comparisons, smoke opacity results should be reported at the standard effective optical path lengths, L_s shown in Table C1. Table C1 is constructed such that the standard effective optical path length increases with the engine power rating and approximates exhaust tailpipe sizes commonly used in vehicle applications. In cases where the engine rated power cannot be determined, the actual tailpipe OD usually provides a good approximation of L_s and may be used in lieu of Table C1.

TABLE C1—STANDARD EFFECTIVE OPTICAL PATH LENGTHS

Related Engine Power kW	Rated Engine Power BHP	Standard Effective Optical Path length mm	Standard Effective Optical Path Length in
Less than 75	Less than 101	51	2
75 to 149	101 to 200	76	3
150 to 224	201 to 300	102	4
225 or More	301 or more	127	5

When testing vehicles with multiple exhaust outlets, the total rated engine power must be used with Table C1 to determine the standard effective optical path length. The rated engine power must not be divided by the number of exhaust outlets when using Table C1. If this error is made, it will result in reported smoke opacity values which are erroneously low.

C.6 Sequencing of Beer-Lambert Corrections

C.6.1 Preferred Method—To achieve the highest degree of accuracy, the Beer-Lambert conversion calculations described in Section C.4 should be performed on each instantaneous measured smoke value before any further data-processing takes place. To perform the calculations in this manner during snap-acceleration testing requires significant data-processing capacity since the minimum smoke data-processing rate is 20 Hz. In addition, the ability to input values for L_m and L_s to the data-processing unit is required.

C.6.2 Alternate Methods—In some cases, users may wish to use data-processing systems which are not capable of performing the Beer-Lambert corrections using the preferred method in C.6.1. In these cases, either of the following alternate techniques may be employed; however, users are cautioned that there will be some loss of accuracy.

a. The appropriate Beer-Lambert conversion equations as defined in Section C.4 may be applied after instantaneous smoke values have been averaged using the procedures described in Appendix A. The snap-acceleration test error that results from the use of this method will, in most cases, be less than 1% opacity or 0.15 m^{-1} smoke density, but could be somewhat higher when the snap-acceleration test generates a very high and sharp smoke spike.
b. Appropriate Beer-Lambert conversions may be performed manually on as-measured average smoke values by using the alignment chart shown in Figure C1. In this method, an as-measured smoke opacity (N_m) is located on the vertical column which most closely represents the as-measured effective optical path length (L_m). The user then reads horizontally across the chart to the column which represents the standard effective optical path length (L_s) if a smoke opacity output is desired, or to the smoke density column if a density output is desired. The user then reads the desired output by interpolating the scale of the target column. For example, if an opacity value of 40% were measured using an effective optical path length of 102 mm (4 in), the chart could be used to determine that the equivalent opacity at a path length of 127 mm (5 in) is approximately 47% and that the associated smoke density is about 5.0 m^{-1}.

Since the alignment chart was developed using Equations C3 and C4, the fundamental accuracy of this method is the same as alternate method (a). However, when the as-measured effective optical path length is not equal to one of the values which appear as one of the vertical chart scales the utility and/or accuracy of this method is reduced. This method also introduces the potential for small errors due to resolution and readability of the non-linear chart scales.

C.7 Smokemeter Light Source Wavelength Corrections—The ability of diesel smoke to absorb light is wavelength dependent (i.e., diesel smoke does not have neutral spectral density). For this reason, smokemeters using different light sources will respond differently to the same smoke sample, and corrections are required to achieve comparable results.

Since most smokemeters today use either a green LED or an incandescent light source, with an equivalent peak spectral emissivity, this will be the standard for reporting snap-acceleration test results. Smoke measurements made with meters using red LED light sources must be corrected using the following equations.

$$N_s = 100*(1-((1-(N_m/100))(w_m/w_s))) \quad \text{(Eq. C5)}$$

$$K_s = (-1/L)*1n((1-(N_m/100))(w_m/w_s)) \quad \text{(Eq. C6)}$$

where:

Ws = the wavelength of a standard green LED light source = 570 nm
Wm= the wavelength of a red LED light source = 660 nm

It is preferred that the wavelength corrections, like the Beer-Lambert corrections, be applied to each instantaneous measured smoke value. However, if this is not possible, and if small errors are acceptable, the wavelength corrections may be applied after average smoke values are obtained as described in Appendix A.

Light source wavelength corrections using Equations C5 and C6 should be applied when the meter is used to measure diesel smoke, but should not be used when the meter is being calibrated using a neutral density filter.

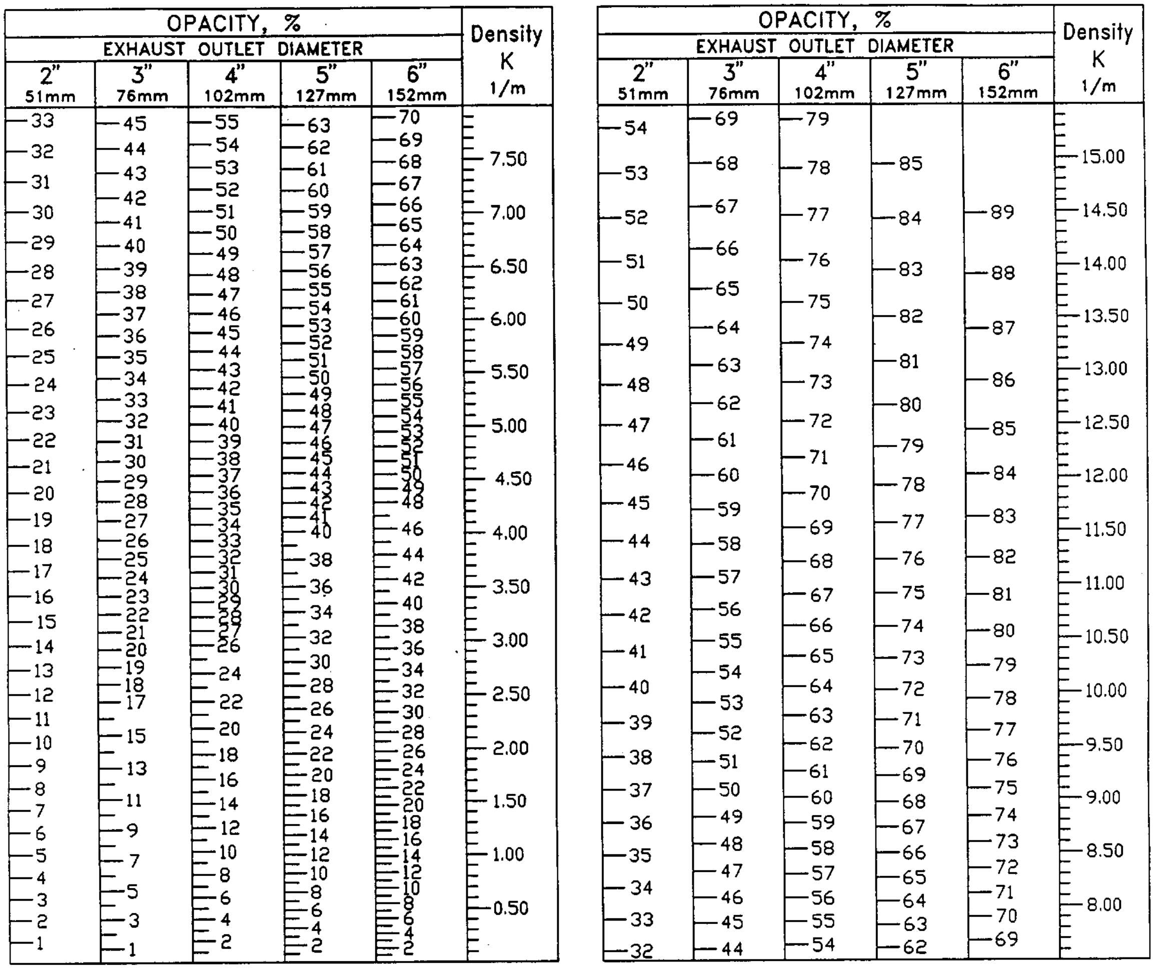


FIGURE C1—ALIGNMENT CHART

APPENDIX D

EXHAUST SYSTEMS AND SPECIAL APPLICATIONS

***D.1 Introduction*—**In order to report snap-acceleration test results at standard conditions, the Beer-Lambert effective optical path length corrections described in Appendix C must be applied to the as-measured smoke values. A required input for the Beer-Lambert corrections is the as-measured effective optical path length (L_m). When a sampling type smokemeter is used, L_m is a function of the meter design and is expected to be supplied by the meter manufacturer. When a full-flow end-of-line smokemeter is used, L_m is a function of the vehicle exhaust system and the way the meter is mounted on the tailpipe. Users of full-flow smokemeters must, therefore, determine L_m for each test conducted on a case by case basis.

Recognizing the wide variety of exhaust systems that may be encountered when conducting vehicle tests, this appendix provides guidelines which will assist full-flow smokemeter users in determining L_m. This appendix also includes suggestions for mounting full-flow meters on specific types of vehicular exhaust systems. Following these suggestions will facilitate the determination of L_m and will insure that proper smoke measurement principles are adhered to.

D.2 Determination of the As-Measured Effective Optical Path Length (L_m)

D.2.1 General Comments—The effective optical path length has been defined as "the length of the smoke obscured path between the smokemeter light source and detector." Portions of the light source to detector path length which are not smoke obscured do not contribute to the effective optical path length. If the smokemeter light beam is located sufficiently close to the exhaust outlet (within 7 cm or 2.76 in) the cross section of the smoke plume as it passes by the smokemeter is essentially the same as the tailpipe outlet and the effective optical path length is equal to the internal distance across the tailpipe outlet along the line of orientation of the smokemeter light beam. In general, this distance should be determined by direct measurement of the tailpipe outlet, and to achieve corrected smoke results which are within ±2% opacity or ±0.2 m^{-1} smoke density, this measurement should be made within ±5 mm (±0.197 in).

It is often difficult, particularly in roadside testing applications, to gain access to and obtain direct measurements of the tailpipe outlets on many vehicles. Fortunately, for many common tailpipe designs L_m can be determined with sufficient accuracy from external exhaust system dimensions which are more easily measured. The remainder of this section describes these cases and the principles and procedures that should be adhered to in determining L_m.

D.2.2 External Versus Internal Tailpipe Dimensions—Most tailpipes encountered on vehicles are constructed from metal tubing of various standard nominal sizes. Nominal tubing sizes are based on the tubing OD whereas it is the internal dimension of the tailpipe that dictates L_m. The difference between the external and internal tailpipe dimension is twice the tubing wall thickness which is typically about 1.5 mm (0.060 in).

Use of the external tailpipe dimension as the as-measured effective optical path length results in corrected smoke values which are slightly less than the true corrected smoke values (~1% opacity or 0.01 m^{-1} smoke density). In most cases, this small error is acceptable. However, in cases where extreme accuracy is required or where the tailpipe wall thickness is unusually large, the material thickness should be accounted for in determining L_m.

D.2.3 Straight Circular Non-Beveled Tailpipes—This is the simplest tailpipe design that may be encountered and is illustrated in Figure D1. In this case, the smokemeter light beam should be oriented such that it is perpendicular to and passes through the central axis of the smoke plume and is within 70 mm (2.76 in) of the tailpipe exit. If these guidelines are followed, L_m is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see D.2.2).

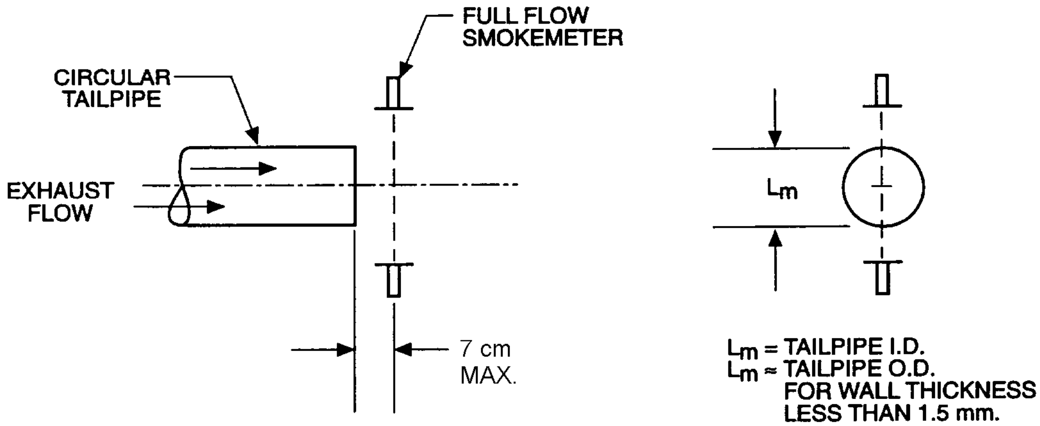


FIGURE D1—STRAIGHT CIRCULAR NON-BEVELED TAILPIPE

D.2.4 Straight Circular Beveled Tailpipes—A beveled tailpipe is formed when the outlet of the tailpipe is not cut off square (perpendicular) to the axis of the exhaust flow. When this type of tailpipe is encountered, there is only one recommended smokemeter mounting orientation. The axis of the smokemeter light beam should be perpendicular to and passing through the central axis of the smoke plume and should be parallel to the minor axis of the elliptical shape of the tailpipe exit. The smokemeter light beam must also be within 70 mm (2.76 in) of the tailpipe outlet (Figure D2). If these guidelines are followed, L_m is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see D.2.2).

D.2.5 Curved Circular Tailpipes—When the central axis of the tailpipe is curved at the approach to the exit, the tailpipe is said to be curved and the cross section of the tailpipe outlet is non-circular. To avoid erroneously low readings when this type of tailpipe is encountered, the smokemeter should be mounted such that the axis of the smokemeter light beam is perpendicular to and passing through the central axis of the smoke plume (not necessarily the centerline of the pipe) and is parallel to the minor axis of the tailpipe exit. The smokemeter light beam must also be within 70 mm (2.76 in) of the tailpipe exit (Figure D3). If these guidelines are followed, L_m is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see D.2.2).

Smokemeter orientations in which the smokemeter light beam is not parallel to the minor axis of the tailpipe exit may be used, but in these cases it will be necessary to determine L_m by direct measurement.

D.2.6 Non-Circular Tailpipe—If the tailpipe cross section is non-circular, the smokemeter should be mounted such that the smokemeter light beam is perpendicular to and passes through the central axis of the smoke plume and is within 70 mm (2.76 in) of the tailpipe exit. For these cases, L_m will need to be determined by direct measurement. If the tailpipe cross section is an oval or ellipse, it is recommended that the smokemeter light beam be aligned with either the major or minor axis of the tailpipe cross section in order to facilitate the measurement of L_m (Figure D4).

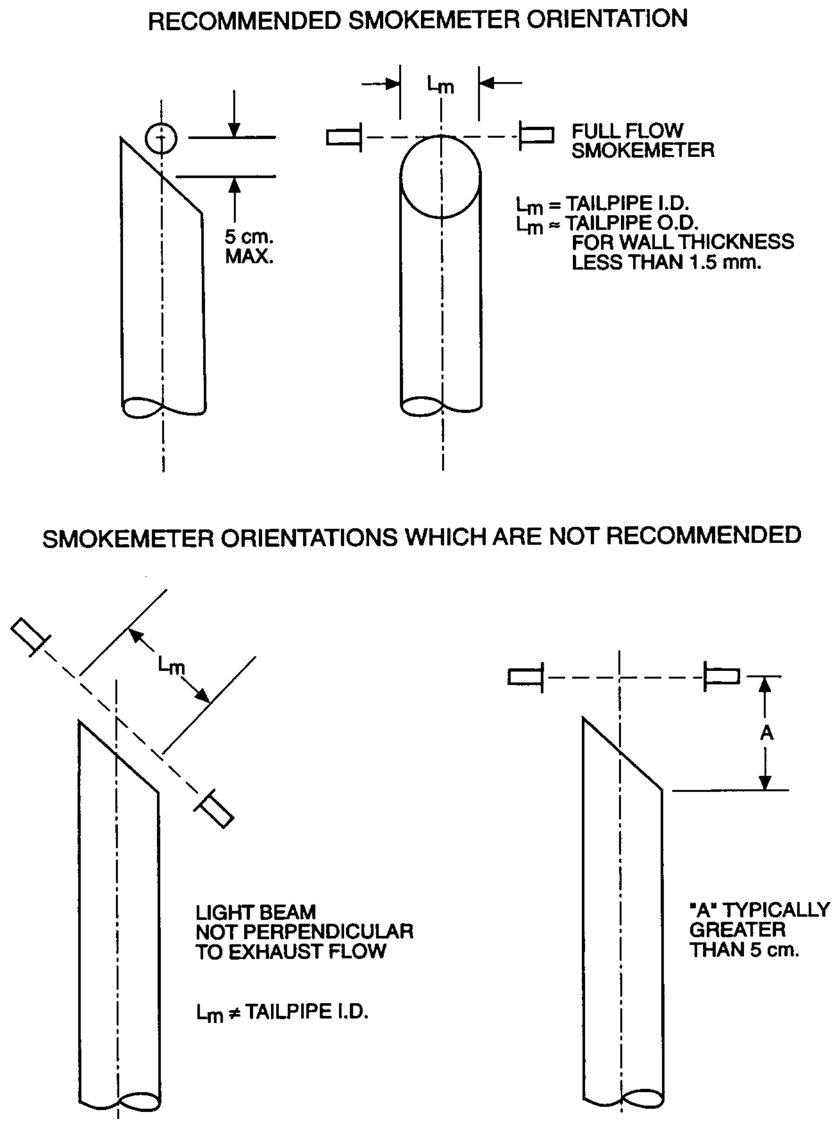
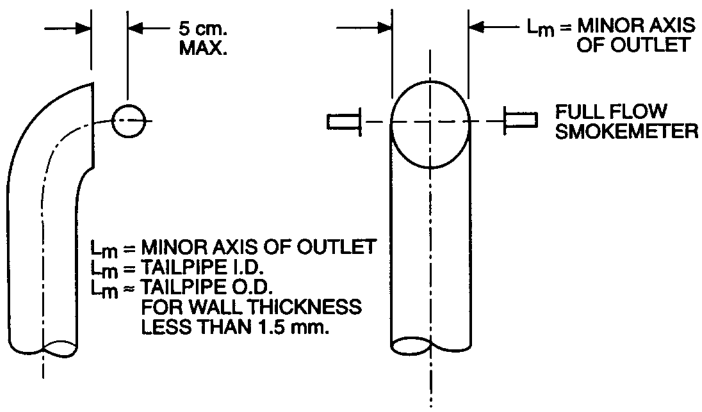


FIGURE D2—STRAIGHT CIRCULAR BEVELED TAILPIPE

RECOMMENDED SMOKEMETER ORIENTATION



ACCEPTABLE SMOKEMETER ORIENTATION

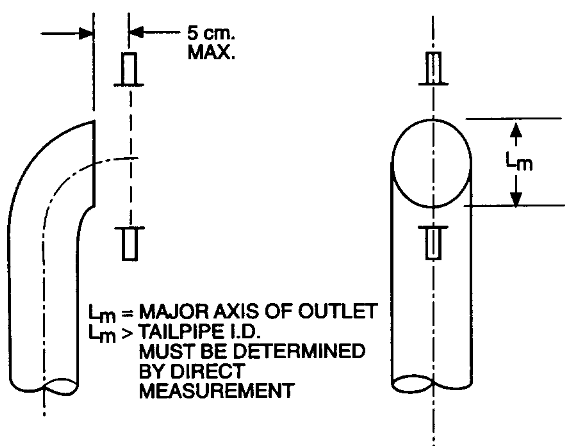


FIGURE D3—CURVED CIRCULAR TAILPIPE

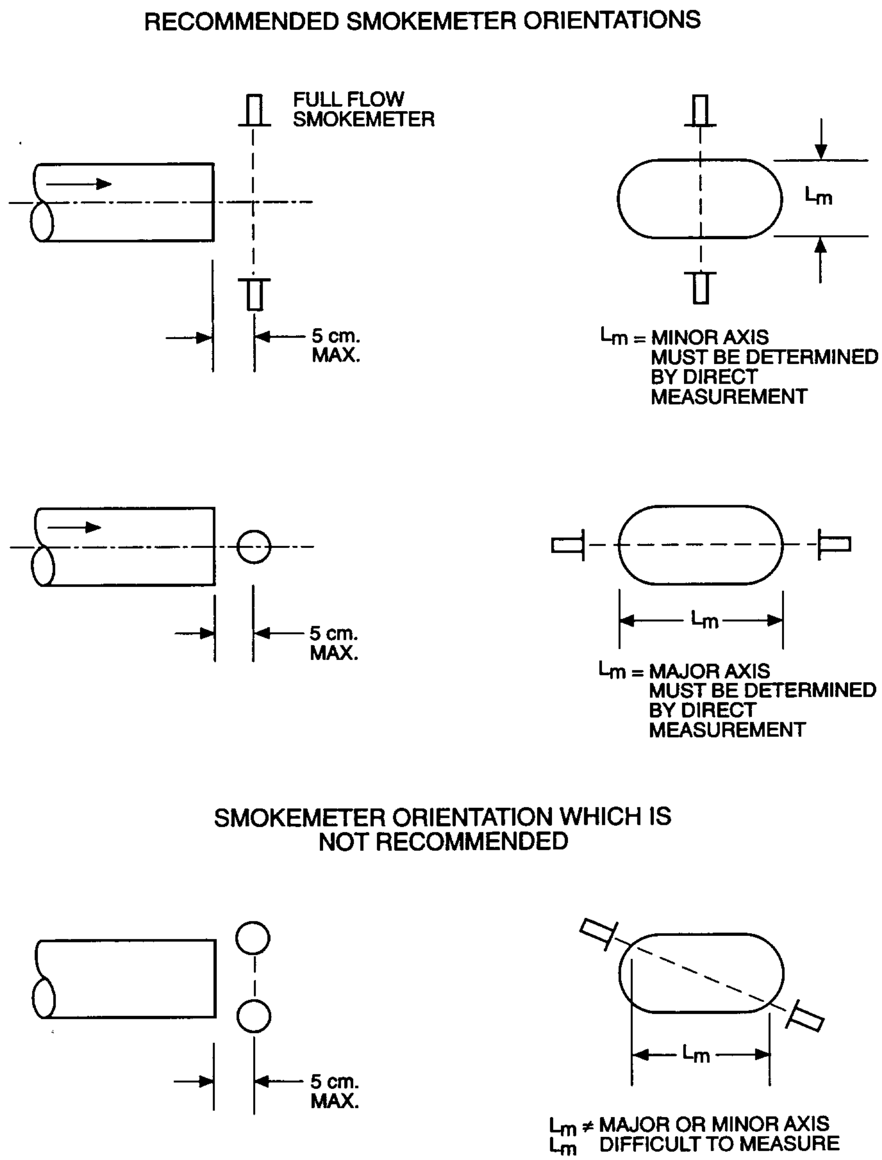


FIGURE D4—NON-CIRCULAR TAILPIPE

D.3 Other Conditions

D.3.1 Rain Caps—Smoke measurements cannot be performed using a full-flow end-of-line smokemeter when a tailpipe rain cap is operational. If present, rain caps must be removed or secured in the fully open position prior to smoke testing. If the smokemeter is installed without removing the rain cap, the meter must be oriented so that the cap does not interfere with the smoke plume or block any portion of the smokemeter light beam (Figure D5).

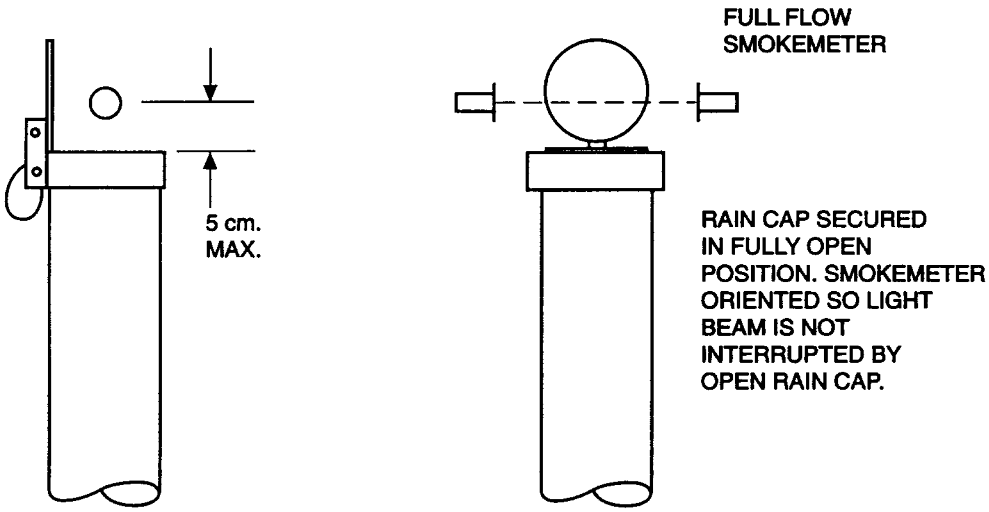


FIGURE D5—RAIN CAP

D.3.2 Downward Directed Exhaust—Many vehicles have horizontal exhaust systems affixed to the underside of the vehicle chassis. Typically these exhaust systems have a curved tailpipe which directs the exhaust flow down against the surface of the roadway.

Care should be exercised when using a full-flow end-of-line smokemeter with vehicles having this type of exhaust system. In some cases, exhaust gases can “rebound” off the roadway surface and recirculate through the smokemeter light beam causing erroneously high smoke measurements. This condition can be aggravated if road dust becomes entrained in the recirculating exhaust flow.

In most cases, little can be done to prevent this condition; however, it is recommended that testing personnel attempt to observe whether recirculation is occurring when testing vehicles with downward directed exhaust systems. If recirculation appears to be influencing the smoke measurement, the test results should be considered unreliable (too high) and should be used with caution.

Rationale—Not applicable.

Relationship of SAE Standard to ISO Standard—Not applicable.

Application—This SAE Recommended Practice applies to vehicle exhaust smoke measurements made using the Snap-Acceleration test procedure. Because this is a non-moving vehicle test, this test can be conducted along the roadside, in a truck depot, a vehicle repair facility, or other test facilities. The test is intended to be used on heavy-duty trucks and buses powered by diesel engines. It is designed to be used in conjunction with smokemeters using the light extinction principle of smoke measurement.

This procedure describes how the snap-acceleration test is to be performed. It also gives specifications for the smokemeter and other test instrumentation and describes the algorithm for the measurement and quantification of the exhaust smoke produced during the test. Included are discussions of factors which influence snap-acceleration test results and methods to correct for these conditions. Unless otherwise noted, these correction methodologies are to be considered an integral part of the snap-acceleration test procedure.

Reference Section

SAE J255a—Diesel Engine Smoke Measurement

SAE J1243—Diesel Emission Production Audit Test Procedure

SAE J1349—Engine Power Test Code—Spark Ignition and Compression Ignition—Net Power Rating

SAE J1995—Engine Power Test Code—Spark Ignition and Compression Ignition—Gross Power Rating

ISO CD 11614—Apparatus for the Measurement of the Opacity of the Light Absorption Coefficient of Exhaust Gas from Internal Combustion Engines

Code of Federal Regulations (CFR), Title 40, Part 86, Subpart I—Emission Regulation for New Diesel Heavy-Duty Engines: Smoke Exhaust Test Procedure

Procedures for Demonstrating Correlation Among Smokemeters

Developed by the SAE Heavy-Duty In-Use Emission Standards Committee

Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 3

P Anyon - Diesel Inspection and Maintenance
The D550 Short Test Drive Cycle

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

March 1999

Appendix 1

DIESEL INSPECTION & MAINTENANCE

THE D550 SHORT TEST DRIVE CYCLE

Abstract

This paper introduces a low cost, loaded test procedure for light and medium duty diesel powered vehicles utilising existing ASM dynamometers and gas analysis equipment.

The test provides regulators with a simple procedure for identifying excess emissions of the most important diesel pollutants: oxides of nitrogen, visible smoke and fine particulate matter

Introduction

The ASM (Acceleration Simulation Mode) short test has proved to be very successful in gasoline vehicle I/M programs because it:

- gives a good indication of real-world emissions
- is relatively simple and quick
- uses relatively low-cost equipment
- can be used in both centralised and de-centralised programs.

Unfortunately, the ASM test is not suitable for many diesel vehicles because they generally have lower power-to-weight ratios than passenger automobiles and hence may have difficulty in achieving the ASM test speed/load combinations.

For the sake of simplicity, some authorities have started to use snap-idle tests, where the engine is rapidly accelerated (with the transmission in neutral) from idle to the maximum governed speed. The maximum smoke level in the exhaust plume is measured using a standard opacimeter. While this is a relatively quick and easy test to perform, it is of limited value in estimating the vehicle's actual emissions under load in typical driving situations.

A number of loaded (lug-down) diesel test protocols have been developed but none has been widely implemented. The lug-down tests usually involve running the vehicle on a chassis dynamometer up to its maximum speed/power before further increasing the dynamometer torque to pull down engine speed. This naturally results in very high loads and speeds for many vehicles, necessitating the use of expensive and specialised equipment. These procedures also introduce potential safety problems.

Another perverse outcome of lug-down tests is that vehicles which are under-powered for the duty imposed upon them (and are hence most susceptible to tampering) will be tested more favourably than those that have a larger engine, better matched to the duty cycle.

The D550 Test

To overcome the shortcomings of existing tests, and to use as much as possible of the dynamometer and gas analysis hardware developed for gasoline vehicle ASM programs, a new diesel test has been devised. It simulates a vehicle being driven fully laden in a typical urban situation, *ie* up a 5% gradient at a steady 50km/h. Hence its designation D550.

Analysis of the power, mass and driveline characteristics of a wide range of diesel vehicles indicates that 50km/h up a 5% grade (fully laden) is within the upper end of the capabilities of most current vehicles. Vehicles that are under powered will not be able to achieve this set point , and so will be tested at the real world limitations of their engine and drivetrain (see Test Procedure below).

One fundamental advantage of the D550 test is that only the vehicle's GVW needs to be known by the test operator. Engine size, power, aspiration method and other technical characteristics are not required. As well as eliminating sources of error, this reduces preparation time as the dynamometer power settings are linked solely to the GVW and can be read off a table by the operator (or alternatively calculated and automatically set by the dynamometer control computer).

Although the only input variable is the GVW, the formula used to calculate the dynamometer power setting takes into account empirical values for aerodynamic drag and rolling resistance to ensure that the test loads are comparable to actual on-road power requirements.

Those vehicles that can maintain a speed of 50km/h under this load setting will be tested at that speed. Other vehicles will be tested at the maximum speed that they can maintain on a 5% grade. For these vehicles the dynamometer load is adjusted to match 5km/h incremental reductions in road speed (see test procedure below).

PARAMETERS MEASURED

The most significant emissions from diesel engines are: fine particulate matter, oxides of nitrogen, hydrocarbons, and visible smoke. Carbon monoxide is not generally emitted at sufficient levels to be a major concern.

The measurement of some of these pollutants is, however, problematical. Because of the heavy hydrocarbon fractions present in diesel exhaust , reliable measurements can only be made using heated sample lines. In addition, current technology does not provide simple or quick techniques for the determination of fine (<10 micron) particulate emissions.

Visible smoke is, however, very readily measured using simple, low cost equipment. As well as being a socially unacceptable pollutant in its own right, some studies have shown a very close linear relationship between fine particulate content and exhaust opacity (at low to medium opacity levels). Whilst this relationship has not always been so clearly defined in experimental work, it is generally agreed that a reduction in visible smoke will generally result in a reduction in fine particulate emissions. It is thus possible to introduce strategies for reducing visible smoke that will have a positive (though only loosely quantifiable) impact on particulates.

Using simple, low-cost filtration and water extraction techniques to avoid analyser contamination, it is also possible to measure diesel NOx emissions to acceptable levels of accuracy using commercial grade (BAR 94) analysers. Since it is difficult to accurately measure hydrocarbons without the added expense and complexity of heated sample lines, and given that HC emissions are not a significant problem with diesel engines, the test does not measure hydrocarbon emissions.

It is therefore entirely feasible to introduce a light/medium duty diesel I/M program based on the two most important diesel emissions - NOx and particulates (using visible smoke as a surrogate for particulates) that is not only viable, but can be done using the same basic equipment developed for the ASM test (within the mass/power limitations of this equipment).

DETERMINING THE DYNAMOMETER POWER SETTING

Calculations

(a) Aerodynamic Drag

$$Fdrag = \frac{1}{2} CA\rho v^2 \qquad \text{eqn(1)}$$

Where C is the drag coefficient, a dimensionless number that describes the aerodynamic properties of the vehicle. For this purpose, an empirical value for C of 1.00 is used.

A is the frontal area of the vehicle in m^2. For vehicles with mass of 1000kg, A is set to $1.8m^2$ (1.5m x 1.2m), increasing linearly to $A=8m^2$ for a vehicle of 16 tonnes GVW.

ρ is the density of air, in this case $1.2kg/m^3$

v is the velocity of the vehicle in m/s.

(b) Rolling Resistance

Rolling resistance is nearly independent of vehicle speed and for a pneumatic tyre on a road is around 0.015. The force due to this is determined by

$$Frol = \mu r \times m \times g \qquad \text{eqn (2)}$$

Hence the power required to maintain a constant speed on a flat road is:

$$Pvel = (Fdrag + Frol) \times v \qquad \text{eqn(3)}$$

The second part of the load calculation is the power required to climb the gradient.

$$\frac{dh}{dt} = \frac{grade}{100} \times v \qquad \text{eqn(4)}$$

Where $\frac{dh}{dt}$ is the rate of climb in m/s, and the *grade* is in %

$$Pc\lim b = \frac{grade}{100} \times v \times m \times g \qquad \text{eqn(5)}$$

where m is the vehicle mass in kg and g is acceleration due to gravity.

Dynamometer Power Setting in Kilowatts is thus:

$$Ptot = Pvel + Pc\lim b$$

$$= .001v \times \left[\frac{1}{2} CA\rho v^2 + \left(\mu r \times m \times g \right) + \left(\frac{grade}{100} \times m \times g \right) \right] \qquad \text{eqn(6)}$$

(The results of this equation are tabulated in the accompanying EXCEL spreadsheet "550DYNO.XLS")

TEST PROCEDURE

Record the vehicle's GVW or GCW from the vehicle plate or registration label.

Install the vehicle onto the dynamometer, warm up the engine and tyres by running at idle in first gear for three minutes.

Using the provided table, adjust the dynamometer power setting to the value appropriate for the vehicle's plated GVW (GCW) at 50 km/h. (The dynamometer control computer may be programmed to do this automatically).

Run the vehicle at these dynamometer settings in the highest gear that can be used to maintain the test speed/load. (In the event that the vehicle cannot maintain 50km/h in any gear, lower the test speed by 5 km/hr and re-set the dynamometer load according to the table (or formula). If necessary, repeat this step in 5km/hr decrements until the vehicle is capable of maintaining the test speed and load).

Run the vehicle up to the test speed/load. Allow the engine to stabilise for two minutes, then record NOx and Opacity using the same test stability and recording criteria as the ASM test.

Slow and stop the vehicle, remove the vehicle from the dynamometer.

Sheet1

D550 Dynamometer Load Settings (KW)

VEHICLE MASS (Kg)	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750
Dyno Speed km/h												
5	0.9	1.1	1.3	1.6	1.8	2.0	2.2	2.4	2.7	2.9	3.1	3.3
10	1.8	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.3	5.8	6.2	6.7
15	2.7	3.4	4.1	4.7	5.4	6.1	6.7	7.4	8.1	8.7	9.4	10.1
20	3.7	4.6	5.5	6.4	7.3	8.2	9.1	10.0	10.9	11.8	12.7	13.6
25	4.8	5.9	7.0	8.2	9.3	10.4	11.5	12.7	13.8	14.9	16.0	17.1
30	5.9	7.3	8.7	10.0	11.4	12.7	14.1	15.4	16.8	18.2	19.5	20.9
35	7.2	8.8	10.4	12.0	13.6	15.2	16.8	18.4	20.0	21.6	23.2	24.8
40	8.6	10.4	12.2	14.1	15.9	17.8	19.6	21.5	23.3	25.2	27.0	28.8
45	10.1	12.2	14.3	16.4	18.5	20.6	22.6	24.7	26.8	28.9	31.0	33.1
50	11.7.	14.1	16.5	18.8	21.2	23.5	25.9	28.2	30.6	32.9	35.3	37.7
55	13.6	16.2	18.8	21.5	24.1	26.7	29.3	32.0	34.6	37.2	39.8	42.5
60	15.6	18.5	21.4	24.3	27.2	30.1	33.0	35.9	38.9	41.8	44.7	47.6
Drag Coefficient	1											
Air Density (Kg/m^3)	1.2											
Grade (%)	5											
Gravity (m/s^2)	9.8											
Rolling Resistance	0.015											

VEHICLE MA	4000	4250	4500	4750	5000	5250	5500	5750	6000	6250	6500	6750	7000
Dyno													
Speed km/h													
5	3.5	3.8	4.0	4.2	4.4	4.7	4.9	5.1	5.3	5.5	5.8	6.0	6.2
10	7.1	7.6	8.0	8.4	8.9	9.3	9.8	10.2	10.7	11.1	11.6	12.0	12.4
15	10.7	11.4	12.1	12.7	13.4	14.1	14.7	15.4	16.1	16.7	17.4	18.1	18.8
20	14.5	15.3	16.2	17.1	18.0	18.9	19.8	20.7	21.6	22.5	23.4	24.3	25.2
25	18.3	19.4	20.5	21.6	22.8	23.9	25.0	26.1	27.3	28.4	29.5	30.6	31.8
30	22.2	23.6	25.0	26.3	27.7	29.0	30.4	31.7	33.1	34.5	35.8	37.2	38.5
35	26.4	28.0	29.6	31.2	32.8	34.3	35.9	37.5	39.1	40.7	42.3	43.9	45.5
40	30.7	32.5	34.4	36.2	38.1	39.9	41.7	43.6	45.4	47.3	49.1	51.0	52.8
45	35.2	37.3	39.4	41.5	43.6	45.7	47.8	49.9	52.0	54.1	56.2	58.3	60.4
50	40.0	42.4	44.7	47.1	49.4	51.8	54.2	56.5	58.9	61.2	63.6	65.9	68.3
55	45.1	47.7	50.3	53.0	55.6	58.2	60.8	63.5	66.1	68.7	71.3	74.0	76.6
60	50.5	53.4	56.3	59.2	62.1	65.0	67.9	70.8	73.7	76.6	79.5	82.4	85.3
Drag Coeffic													
Air Density (													
Grade (%)													
Gravity (m/s													
Rolling Resi													

Sheet1

VEHICLE MA	7250	7500	7750	8000	8250	8500	8750	9000	9250	9500	9750	10000	10250
Dyno													
Speed km/h													
5	6.4	6.6	6.9	7.1	7.3	7.5	7.7	8.0	8.2	8.4	8.6	8.9	9.1
10	12.9	13.3	13.8	14.2	14.7	15.1	15.5	16.0	16.4	16.9	17.3	17.8	18.2
15	19.4	20.1	20.8	21.4	22.1	22.8	23.4	24.1	24.8	25.4	26.1	26.8	27.4
20	26.1	27.0	27.9	28.8	29.6	30.5	31.4	32.3	33.2	34.1	35.0	35.9	36.8
25	32.9	34.0	35.1	36.3	37.4	38.5	39.6	40.8	41.9	43.0	44.1	45.2	46.4
30	39.9	41.3	42.6	44.0	45.3	46.7	48.0	49.4	50.8	52.1	53.5	54.8	56.2
35	47.1	48.7	50.3	51.9	53.5	55.1	56.7	58.3	59.9	61.5	63.1	64.7	66.3
40	54.6	56.5	58.3	60.2	62.0	63.9	65.7	67.6	69.4	71.2	73.1	74.9	76.8
45	62.5	64.6	66.7	68.8	70.9	73.0	75.1	77.1	79.2	81.3	83.4	85.5	87.6
50	70.7	73.0	75.4	77.7	80.1	82.4	84.8	87.1	89.5	91.9	94.2	96.6	98.9
55	79.2	81.8	84.5	87.1	89.7	92.4	95.0	97.6	100.2	102.9	105.5	108.1	110.7
60	88.2	91.1	94.0	96.9	99.8	102.7	105.6	108.6	111.5	114.4	117.3	120.2	123.1
Drag Coeffic													
Air Density (													
Grade (%)													
Gravity (m/s'													
Rolling Resi:													

Sheet1

VEHICLE MA	10500	10750	11000	11250	11500	11750	12000	12250	12500	12750	13000	13250	13500
Dyno													
Speed km/h													
5	9.3	9.5	9.7	10.0	10.2	10.4	10.6	10.8	11.1	11.3	11.5	11.7	12.0
10	18.6	19.1	19.5	20.0	20.4	20.9	21.3	21.8	22.2	22.6	23.1	23.5	24.0
15	28.1	28.8	29.4	30.1	30.8	31.4	32.1	32.8	33.4	34.1	34.8	35.4	36.1
20	37.7	38.6	39.5	40.4	41.3	42.2	43.1	44.0	44.8	45.7	46.6	47.5	48.4
25	47.5	48.6	49.7	50.9	52.0	53.1	54.2	55.4	56.5	57.6	58.7	59.9	61.0
30	57.6	58.9	60.3	61.6	63.0	64.3	65.7	67.1	68.4	69.8	71.1	72.5	73.9
35	67.9	69.5	71.1	72.7	74.3	75.9	77.5	79.1	80.7	82.3	83.9	85.5	87.1
40	78.6	80.5	82.3	84.1	86.0	87.8	89.7	91.5	93.4	95.2	97.0	98.9	100.7
45	89.7	91.8	93.9	96.0	98.1	100.2	102.3	104.4	106.5	108.6	110.7	112.8	114.9
50	101.3	103.6	106.0	108.4	110.7	113.1	115.4	117.8	120.1	122.5	124.9	127.2	129.6
55	113.4	116.0	118.6	121.2	123.9	126.5	129.1	131.7	134.4	137.0	139.6	142.2	144.9
60	126.0	128.9	131.8	134.7	137.6	140.5	143.4	146.3	149.2	152.1	155.0	157.9	160.8
Drag Coeffic													
Air Density (													
Grade (%)													
Gravity (m/s													
Rolling Resi													

Sheet1

VEHICLE MA	13750	14000	14250	14500	14750	15000	15250	15500	15750	16000
Dyno										
Speed km/h										
5	12.2	12.4	12.6	12.8	13.1	13.3	13.5	13.7	13.9	14.2
10	24.4	24.9	25.3	25.7	26.2	26.6	27.1	27.5	28.0	28.4
15	36.8	37.4	38.1	38.8	39.4	40.1	40.8	41.4	42.1	42.8
20	49.3	50.2	51.1	52.0	52.9	53.8	54.7	55.6	56.5	57.4
25	62.1	63.2	64.4	65.5	66.6	67.7	68.9	70.0	71.1	72.2
30	75.2	76.6	77.9	79.3	80.6	82.0	83.4	84.7	86.1	87.4
35	88.7	90.3	91.9	93.5	95.1	96.7	98.3	99.9	101.5	103.1
40	102.6	104.4	106.3	108.1	110.0	111.8	113.6	115.5	117.3	119.2
45	117.0	119.1	121.2	123.3	125.4	127.5	129.6	131.6	133.7	135.8
50	131.9	134.3	136.6	139.0	141.3	143.7	146.1	148.4	150.8	153.1
55	147.5	150.1	152.7	155.4	158.0	160.6	163.2	165.9	168.5	171.1
60	163.7	166.6	169.5	172.4	175.3	178.3	181.2	184.1	187.0	189.9
Drag Coeffic										
Air Density (										
Grade (%)										
Gravity (m/s'										
Rolling Resi:										

Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 4
Federal Office of Road Safety -
Australian Design Rule 30
Diesel Engine Exhaust Smoke
Emissions

March 1999

AUSTRALIAN DESIGN RULE 30/00
DIESEL ENGINE EXHAUST SMOKE EMISSIONS

PURPOSE AND SCOPE

This Australian Design Rule (ADR) is part of the Australian motor vehicle standards system and is a national standard for the purposes of the Motor Vehicle Standards Act 1989.

The function of this Australian Design Rule is to limit the opacity of *'Diesel Engine'* exhaust smoke emissions.

APPLICABILITY

This ADR applies to the design and construction of **all diesel fuelled** vehicles as set out in the table hereunder.

The Package 17 issue of /00 limits the applicability of the Rule to diesel engined vehicles only.

VEHICLE CATEGORY (As defined in Part 1 of "ADR Definitions")	**Vehicle Category Code**	**MANUFACTURED ON OR AFTER**	**ACCEPTABLE PRIOR RULES**
Moped 2 wheels	(LA)	1 Jul 1988	
Moped 3 wheels	(LB)	1 Mar 1991	
Motor Cycle	(LC)	1 Jul 1988	
Motor Cycle and Side-car	(LD)	1 Jul 1988	
Motor Tricycle	(LE)	1 Mar 1991	
Passenger Car	(MA)	1 Jul 1988	
Forward-control Passenger Vehicle	(MB)	1 Jul 1988	
Off-road Passenger Vehicle	(MC)	1 Jul 1988	
Light Omnibus	(MD)		
(MD1) up to 3.5 tonnes '*GVM*', up to 12 seats		1 Jul 1988	
(MD2) up to 3.5 tonnes '*GVM*', over 12 seats		1 Jul 1988	
(MD3) over 3.5 tonnes, up to 4.5 tonnes '*GVM*'		1 Jul 1988	
(MD4) over 4.5 tonnes, up to 5 tonnes '*GVM*'		1 Jul 1988	
Heavy Omnibus	(ME)	1 Jul 1988	
Light Goods Vehicle	(NA)	1 Jul 1988	
Medium Goods Vehicle	(NB)	1 Jul 1988	
Heavy Goods Vehicle	(NC)	1 Jul 1988	
Very Light Trailer	(TA)	Not Applicable	
Light Trailer	(TB)	Not Applicable	
Medium Trailer	(TC)	Not Applicable	
Heavy Trailer	(TD)	Not Applicable	

This Rule was first issued in December 1986.

Amendments to the Rule were approved by the Minister for Land Transport in May 1992 and were notified in Road Vehicle (National Standards) Determination No. 2 of 1992, published in Commonwealth Government Gazette No. GN 20, of Wed 20th May 1992. Amendments made by this Determination are side-lined on the pages marked "ADR Package 17".

Issued by the ADR Subscriptions Service of the Federal Department of Transport and Communications on behalf of the Administrator of Vehicle Standards.

30.1 DEFINITIONS

30.1.0 All '*Defined Terms*' are identified in the text (other than the title of the Rule) by being in italics, and by having the first letter of each main word capitalised. For convenience, definitions for certain '*Defined Terms*' used in this Rule are set out below. Definitions for other '*Defined Terms*' are given in Part 2 of "ADR Definitions".

Reference should also be made to Part 3 of "ADR Definitions" with respect to units and abbreviations used in the ADR system.

30.1.1 '*Engine System*' - A system consisting of the engine together with all devices essential for its operation plus its appropriate intake and exhaust assemblies. Equipment other than '*Superchargers'* which use engine power for its operation is not part of the engine system.

30.1.2 '*Diesel Engine*' - An engine which operates on the compression-ignition principle, in this Rule referred to as "the engine".

30.1.3 '*Cold-starting Device*' - A device which when activated increases the amount of fuel (excluding special starting fuels) supplied to the engine and is intended to facilitate starting of the engine.

30.1.4 '*Opacimeter*' - An instrument designed for continuous measurement of the '*Light Absorption Coefficients*' of the exhaust gases emitted by '*Engine Systems*'.

30.1.5 '*Smoke Meter*' - An instrument which determines the smoke density in exhaust gases emitted by '*Engine Systems*'.

30.1.6 '*Light Absorption Coefficient*' - The coefficient (k) as calculated by the formula

$$ø = ø_O.e^{-kL},$$

where L is the effective length of the light path through the gas to be measured for a given '*Opacimeter*', $ø_O$ is the incident flux and ø is the emergent flux.

30.1.7 '*Full Load*' - The condition at which the engine, as specified for certification, in accordance with clause 30.3.1.3 produces the maximum power possible at a given speed.

30.1.8 '*Supercharger*' - A device which increases the pressure of the engine intake air it passes into the engine and includes turbochargers.

30.2 REQUIREMENTS

30.2.1 '*Cold-starting Devices'*

30.2.1.1 Any '*Cold-starting Device*' shall be designed so that it cannot be brought into or retained in operation when the engine is running normally.

30.2.1.2 The provisions of clause 30.2.1.1 above shall not apply if at least one of the following conditions is met:

30.2.1.2.1 the '*Light Absorption Coefficient*' of the exhaust gases emitted by the engine at steady speeds when measured by the procedure prescribed in Sections 30.3 and 30.4 and with the '*Cold-starting Device*' operating, is within the limits prescribed in Table 1;

30.2.1.2.2 continued use of the '*Cold-starting Device*' causes the engine to stop.

30.2.2 Exhaust Gas Opacity Limits

30.2.2.1 Each motor vehicle shall be propelled by an engine which, when tested according to the method described in Sections 30.3 and 30.4, emits exhaust gases with a '*Light Absorption Coefficient*' not exceeding the limits prescribed in Table 1.

30.2.2.2 Not used.

30.2.3 Labelling Requirements

30.2.3.0 Every engine shall have affixed to it a durable legible label of the type described in clause 30.2.3.1. The label shall indicate that the engine was manufactured to comply with this Rule and show the month and year of its manufacture.

30.2.3.1 The label shall be plastic or metal and shall be bonded, welded, or riveted or otherwise securely attached to a part of the engine necessary for normal engine operation and not normally requiring replacement during life and in a position in which it can be read after installation in the vehicle.

30.2.3.2 A label approved by the Environmental Protection Agency (USA) and attached in accordance with "Emission Regulations for New Diesel Fuelled Heavy Duty Engines" shall be deemed to satisfy the labelling requirements of this Rule, provided it contains the information required in clause 30.2.3.

30.2.4 The engine, as installed in the vehicle, shall be adjusted to the '*Manufacturer's*' specifications and these specifications shall be consistent with the settings used during compliance testing.

30.3 PRE-TEST CONDITIONS

30.3.1 Engine System

30.3.1.1 The test may be carried out either on a complete vehicle or on a vehicle '*Engine System*'. In the latter case the ***'Engine System'*** may be fitted with an alternative exhaust system for test purposes provided that it produces a back pressure not less than that of the standard vehicle exhaust system.

30.3.1.2 The vehicle shall have been run in for not less than 240 kilometres or the '*Engine System*' for not less than 5 hours.

30.3.1.3 The engine shall be adjusted to the '*Manufacturer's*' specifications.

30.3.1.4 Any orifice which would permit air to be drawn into the exhaust system shall be blocked.

30.3.1.5 The '*Engine System*' shall be within the normal operating temperature ranges of water, oil and fuel prescribed by the vehicle '*Manufacturer*'.

30.3.1.6 The absolute temperature T of the inlet air, measured within 150 mm $\pm$10 mm of the point of entry to the '*Engine System*', expressed in kelvin and the atmospheric pressure H, expressed in kPa, shall be measured, and the factor F shall be determined by the formula:

$$F = \frac{(100)^{0.65}}{(H)} \times \frac{(T)^{0.5}}{(298)}$$

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

30.3.2 Fuel and Lubricants

30.3.2.1 Unless otherwise '*Approved*', the test fuel shall be as specified in Appendix 1, Appendix 2 or

Appendix 3.

30.3.2.2 The lubricants shall be of the type recommended by the vehicle '*Manufacturer*' for normal service and no additional additives shall be used.

30.3.3 Smoke Sampling and/or Measuring Apparatus

30.3.3.1 The '*Opacimeter*', any ancillary instrument and their installation, shall be in accordance with the requirements of ECE Regulation 24/00 "Diesel and Pollutants" August 1971.#

30.3.3.2 Notwithstanding the requirements of clause 30.3.3.1 the following instruments may be used provided that the procedure is in accordance with the instrument manufacturer's recommendations:

30.3.3.2.1 Hartridge Mark II or Mark III Smokemeters,

30.3.3.2.2 Robert Bosch Smokemeter (with sampling pump EFAW65A and evaluating instrument EFAW68A or ETD.02.050),

30.3.3.2.3 United States Public Health Service Smokemeter; or

30.3.3.2.4 other '*Approved*' instrument.

30.3.3.3 For the purpose of this Rule, conversion of results from other scales to '*Light Absorption Coefficients*' (m^{-1}) shall be made in accordance with Appendix 4. Interpolation is permitted.

30.4 MEASUREMENT OF 'LIGHT ABSORPTION COEFFICIENTS'

30.4.1 Test at '*Full Load*' and Steady Speeds

30.4.1.1 The smoke density of the exhaust gases produced by vehicle or '*Engine System*' shall be measured with the engine running at '*Full Load*' and at steady speed. Measurements shall be taken at 4 speeds as follows:

30.4.1.1.1 At the engine speed corresponding with maximum power; and

30.4.1.1.2 At engine speeds representing increments of 2/5, 3/5 and 4/5 of the range from the engine speed which is 45% of that for maximum power or 1,000 r/min, whichever is the higher, to the engine speed corresponding with maximum power.

30.4.1.2 For engines fitted with a '*Supercharger*' which may be engaged by the driver, measurements shall be made both with and without the '*Supercharger*' in operation.

30.4.1.3 For each of the 4 engine speeds at which the '*Light Absorption Coefficient*' is measured in accordance with clause 30.4.1.1 above, the nominal gas flow G shall be calculated from the appropriate following formula:

30.4.1.3.1

For 2-cycle engines $G = \frac{Vn}{60}$

30.4.1.3.2

For 4-cycle engines $G = \frac{Vn}{120}$

where:

G is the nominal gas flow (litres per second)

V is the total engine swept volume (litres)

n is the engine speed (r/min).

30.5 ALTERNATIVE STANDARDS

30.5.1 A vehicle shall be deemed to satisfy the requirements of clause 30.2.2.1 if it is:

30.5.1.1 propelled by an engine which is approved by the Environmental Protection Agency (USA) with regard to "Federal Regulations for Control of Air Pollution", for 1974 or later model year engines provided that the engine was tested with fuel recognised in the Federal Regulations as "Type 2-D";

30.5.1.1.1 An engine '*Approved*' under the provisions of clause 30.5.1.1 shall have an approved US EPA label attached to it as specified in the US Federal Regulations (refer to clause 30.2.3.2);

30.5.1.2 propelled by an engine in a vehicle which is covered by a type test certificate in accordance with the British Standard Specifications for the "Performance of Diesel Engines for Road Vehicles", BS AU 141a:1971#; or

30.5.1.3 propelled by an engine in a vehicle which is covered by a type test certificate in accordance with ECE R 24/00, 24/01, 24/02 or 24/03 "Diesel and Pollutants"# (or in the case of an engine alone is covered by a type test certificate in accordance with ECE R 24/03 #).

Note: Or as subsequently amended, endorsed by ATAC and included in the Schedule in Part 5 of "ADR Definitions".

TABLE 1
EXHAUST GAS '*LIGHT ABSORPTION COEFFICIENT*' LIMIT VALUES

Nominal Gas Flow G	'*Light Absorption Coefficient*' m^{-1}
≤42	2.26
45	2.19
50	2.08
55	1.985
60	1.90
65	1.84
70	1.775
75	1.72
80	1.665
85	1.62
90	1.575
95	1.535
100	1.495
105	1.465
110	1.425
115	1.395
120	1.37
125	1.345
130	1.32
135	1.30
140	1.27
145	1.25
150	1.225
155	1.205
160	1.19
165	1.17
170	1.155
175	1.14
180	1.125
185	1.11
190	1.095
195	1.08
≥200	1.065

NOTE: Where the nominal gas flow is not one of those tabulated, the appropriate '*Light Absorption Coefficient*' shall be determined by applying the principle of interpolation by proportional parts.

APPENDIX 1
SPECIFICATIONS OF TEST FUEL

PROPERTY	LIMITS AND UNITS	ASTM TEST METHOD#
Density at 15°C	0.830 ± 0.005	D1298-67
Distillation		D86-67
50%	minimum 245°C	
90%	330 ± 10°C	
Final boiling point	maximum 370°C	
Cetane index	54 ± 3	D976-66
Viscosity (Kinematic) at 37.8°C (100°F)	3 ± 0.5 mm^2/s (cst)	D445-65
Sulphur content	0.4 ± 0.1% by mass	D129-64
Flash-point k	minimum 55°C	D99-66
Aniline Point	69 ±5°C	D611-64
Carbon Residue on 10% Bottoms	maximum 0.2% by mass	D524-64
Ash	maximum 0.01% by mass	D482-63
Water content	maximum 0.05% by mass	D95-62
Copper-corrosion test at 100°C	maximum 1	D130-68
Strong Acid Number	nil mg KOH/g	D974-64

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

Note: Or as subsequently amended, endorsed by ATAC and included in the Schedule in Part 5 of "ADR Definitions"

APPENDIX 2
SPECIFICATIONS OF ALTERNATIVE TEST FUEL

PROPERTY	LIMITS AND UNITS	ASTM TEST METHOD#
Cetane Number	42-50	D613-82
Distillation Range		D86-67
IBP	170-205^{o}C	
10%	205-240^{o}C	
50%	240-285^{o}C	
90%	285-320^{o}C	
EP	305-350^{o}C	
Gravity	33-37^{o}API	D287-82
Total Sulphur	0.2-0.5% by mass	D129-64 or
		D2622-82
Hydrocarbon Composition (per cent by volume)		D1319-84
Aromatics	minimum 27	
Paraffins, Naphthenes and Olefins	Remainder	
Flash Point	minimum 55^{o}C	D 93-80
Viscosity	2.0-3.2 mm^{2}/s (cst)	D445-65

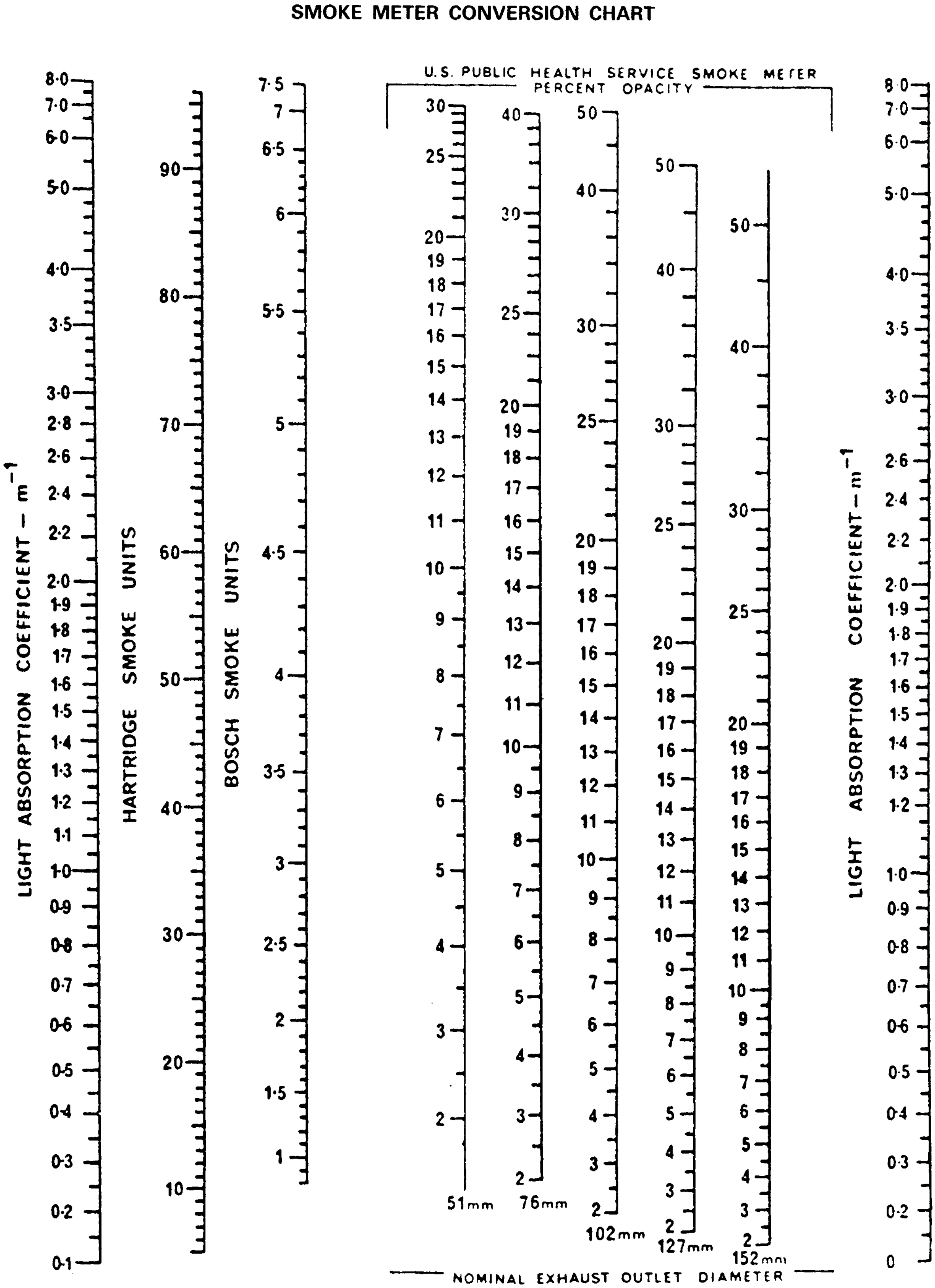
Note: The fuel employed shall be clean and bright, with pour and cloud points adequate for operability. The fuel may contain non-metallic additives as follows: cetane improver, metal deactivator, antioxidant, dehazer, anti-rust, pour depressant, dye and dispersant.

Note: Or as subsequently amended, endorsed by ATAC and included in the Schedule in Part 5 of “ADR Definitions”

APPENDIX 3
(Identical to Specifications set out in Annex 6
of ECE R24/03 "Diesel and Pollutants")
"SPECIFICATIONS OF THE REFERENCE FUEL PRESCRIBED FOR APPROVAL TESTS AND TO VERIFY CONFORMITY OF PRODUCTION

PROPERTY	LIMITS AND UNITS	ASTM METHOD
Density at 15°C	min. 0.835 kg/l max. 0.845 kg/l	D1298
Cetane index	min. 51 max. 57	D976
Distillation (2)		D86
50% Vol. point	min. 245°C	
90% Vol. point	min. 320°C max. 340°C	
Final boiling point	max. 370°C	
Viscosity at 40°C	min. 2.5 mm^2/s max. 3.5 mm^2/s	D445
Sulphur content	min. 0.20% mass max. 0.50% mass	D1266, D2622, or D2785
Flash point	min. 55°C	D93
Cold filter plugging point	max. -5°C	CEN Draft Pr EN116 or IP309
Conradson carbon residue on 10% dist. residue	max. 0.20% mass	D189
Ash content	max. 0.01% mass	D482
Water content	max. 0.05% mass	D95 or D1744
Copper corrosion 100°C	max. 1	D130
Neutralisation (Strong acid) number	max. 0.20 mg KOH/g	D974"

APPENDIX 4


SMOKE METER CONVERSION CHART
LIGHT ABSORPTION COEFFICIENT – m⁻¹
HARTRIDGE SMOKE UNITS
BOSCH SMOKE UNITS
U.S. PUBLIC HEALTH SERVICE SMOKE METER
PERCENT OPACITY
51mm
76mm
102mm
127mm
152mm
NOMINAL EXHAUST OUTLET DIAMETER
LIGHT ABSORPTION COEFFICIENT – m⁻¹

Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 5

State of Colorado
Regulation 12
'The Reduction of Diesel
Vehicle Emissions'

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

March 1999

Regulation No. 12

Reduction of Diesel Vehicle Emissions

Colorado Air Quality
Control Commission

Colorado Department
of Public Health
and Environment

TABLE OF CONTENTS

REGULATION 12

PART A - DIESEL FLEET SELF-CERTIFICATION PROGRAM

REGULATION 12

"The Reduction of Diesel Vehicle Emissions"

PART A - DIESEL FLEET SELF-CERTIFICATION PROGRAM

I. GENERAL PROVISIONS

A. Statement of Purpose

The purpose of PART A of this regulation is to reduce air pollution resulting from emissions from diesel-powered motor vehicles in the AIR Program area through opacity inspections, by all diesel fleets registered or required to be registered in the AIR Program area with nine (9) or more vehicles over 7,500 lbs. empty weight.

B. Definitions

The following terms shall have the following meanings when used in this regulation:

1. "Commission" means The Colorado Air Quality Control Commission

2. "Compliance Plans" means a written plan of action completed by applicable diesel vehicle fleets conforming with the requirements of this regulation.

3. "Certification of Emissions Control" (CEC), means the official certificate issued by a private (non-government) fleet opacity inspector to a fleet vehicle which has been inspected and tested according to the procedures in Part A, Section IV, and is in compliance with the opacity standards.

4. "Diesel Fleet Self-Certification Program" (DFSCP) means the Opacity Inspection Program for Diesel Powered Fleet Vehicles Established by Section 42-4-320 C.R.S., as amended, and the Air Quality Control Commission, as AQCC Regulation No. 12., Part A.

5. "Diesel Powered Motor Vehicle" or "Diesel Vehicle" as applicable to opacity insepctions, includes only a motor vehicle with four wheels or more on the ground, powered by an internal combustion, compression ignition, diesel fueled engine, and also includes any motor vehicle having a personal property classification of A,B, or C, pursuant to Section 42-3-105, C.R.S., as specified on its vehicle registration, and for which registration in this state is required for operation on the public roads and highways. "Diesel Vehicle" does not include the following: vehicles registered pursuant to Section 42-3-123 (11), or 42-3-128, C.R.S.: off-the-road powered vehicles or heavy construction equipment.

6. “Division” means the Air Pollution Control Division of the Colorado Department of Health.

7. “Empty Weight” (E.W.) (Curb Weight, Unloaded Weight) means the weight of the vehicle with maximum capacity of all fluids necessary for operation of the vehicle but minus the driver, passengers, and payload.

8. “Excessive Violation” means non-compliance with the provisions of II.A.2.b, c or d of this Part A.

9. “Fleet” means diesel vehicle fleet consisting of nine (9) or more diesel vehicles having empty weight of greater than 7,500 lbs., registered or required to be registered, or operated from a facility within the AIR Program area.

10. Highest opacity reading is that greatest stable opacity value for other than the snap/free acceleration procedures.

11. “Opacity Compliance Coordinator” means designated person from each vehicle fleet to be the contact person between the fleet and the Division for carrying out this regulation

12. “Opacity Determination Certification” means a valid, non-expired, certification to be maintained by an opacity compliance coordinator and/or other fleet personnel charged with determining opacity levels. Opacity training and certification are to be conducted by the Division.

13. “Opacity “ means the degree to which an air pollutant obscures the view of an observer expressed in percentage of obscuration, or the degree, expressed in percent, to which transmittance of light is reduced by the air pollutant.

14. “Opacity Inspection Form”(OIF) means the official form issued by the Division to diesel self-certification fleets for recording opacity test results.

15. “Opacity meter” means an optical instrument which is designed to measure the opacity of diesel exhaust gases by measuring the full flow of exhaust gases which pass through the optical unit.

16. “Rated RPM” means a specific rpm which the manufacturer states that the engine’ s maximum/rated brake horsepower is attained. Rated horsepower and rpm information is usually found on a label affixed to the engine itself or other underhood location.

17. “Verification of Emissions Test” (VET) means a sticker which is issued and affixed to the windshield of a diesel powered fleet vehicle which has

complied with the diesel fleet self-certification program opacity inspection requirements.

18. "WOT" means wide open throttle.

C. Applicability

1. Geographic Area of Applicability

This regulation shall apply to the AIR program areas as defined in Section 42-4-304(20)(a)(b), C.R.S. Those portions of the program area within the counties of El Paso, Larimer and Weld shall not be an element of the State Implementation Plan.

2. Vehicles eligible for diesel fleet self-certification program.

Heavy-duty diesel vehicles, weighing in excess of 7,500 lbs. empty weight, identified as a fleet (nine (9) or more vehicles) and registered or required to be registered within the AIR program area, are required to participate in the diesel fleet self-certification program.

D. Legislative Authority

Authority and responsibility for the enactment of this regulation is provided for in Section 42-4-320, CRS.

II. Requirements to File Compliance Plans.

A. Compliance Plan Requirements and Contents

1. Every Fleet in the Area of Applicability with nine (9) or more diesel vehicles of empty weights greater than 7,500 lbs. shall prepare, adopt, and submit to the Division within the time period hereinafter provided a complete Compliance Plan form signed by an authorized agent and containing a commitment to implement and maintain a program which meets the requirements of this regulation.

Each participating fleet shall provide the Division with an updated/revised compliance plan and fleet vehicle inventory on an annual basis. Should fleet size or compliance coordinator change, the Division shall be notified within thirty (30) days of a change.

2. Each Compliance Plan shall set forth with reasonable detail a plan which shall include provisions for at least the following:

a. Dissemination of written information to all employees who maintain and/or operate diesel vehicles subject to these regulations, regarding Colorado opacity laws, penalties for non-compliance, and health and environmental impacts of diesel emissions, as provided by the Division.

b. Establishment of test procedures to be used for determining and certifying compliance with State opacity standards as given in Section VII of this Part A of this regulation.

c. Establishment of maintenance practices and schedules to be followed for maintaining low-smoke levels. Maintenance schedules at a minimum will follow manufacturer' s recommended procedures and intervals.

d. Performance of annual opacity compliance tests as described in Section IV of this Part A of this regulation prior to the vehicles' s annual registration on each vehicle subject to these regulations, repair of any vehicle found to be exceeding the State opacity standard (found in Section VII of Part A of this regulation) and bring it into compliance with State opacity standards before being returned to service, maintaining records of such testing, including the opacity inspection form, the verification of emissions test (window stickers), the window sticker log sheet and any other forms provided by the Division and submit the white copies of the opacity inspection form and copies of the window sticker log sheet to the Division annually by December 31, of each year. Subsequent year forms and documents may not be dispensed to fleets which fail to submit the prior year opacity inspection forms to the Division as required.

e. Establishment of an Opacity Compliance Coordinator from each fleet to oversee the carrying out of this regulation.

f. Determination of vehicle smoke opacity by a fleet compliance coordinator and/or other trained observer employed by the fleet having possession of a valid, non-expired, opacity determination certificate issued by the Division. Such persons shall determine vehicle smoke opacity levels by either the visual method or by use of a continuous-reading, full-flow, light extinction opacity meter with peak hold feature or interfaced chart recorder.

g. Participating fleets shall submit fleet vehicle inventory information to include but not necessarily limited to make, VIN, unit ID, and license plate type, number and state.

h. Notwithstanding the provisions of Part A, Section II.A.2.D., new diesel vehicles shall be issued a certification of emissions compliance without inspection or testing. Such certificate shall expire on the anniversary of the day of the issuance of such certification when such vehicle has reached its second model year or on the date of the transfer of ownership at any time prior to the second model year. Prior to the expiration of such certification, such vehicle shall be inspected pursuant to Section IV of this Part A.

B. Additional Requirement

Each Opacity Compliance Coordinator shall provide to all new employees or newly reassigned employees who work in the maintenance or operation of diesel vehicles, the most current information regarding this regulation and the Fleet' s Compliance Plan within thirty (30) days of the employees commencing work. Each Opacity Compliance Coordinator shall provide updated information to all employees regarding this regulation within thirty (30) days of any substantial change to this regulation and/or the Fleet' s Compliance Plan.

III. Compliance Plan Filing - Time, Approval

A. Filing of Plans

Fleets which meet the applicability criteria of this regulation 12, are required to participate in the DFACP of this regulation 12, and such fleets bear the responsibility of contacting and notifying the Division of their fleet status and intent to participate in the DFACP Affected fleets shall complete and submit a compliance plan and a vehicle inventory to the Division for approval within 30 days of initial contact with the Division.

B. Approval and Disapproval

The Division shall review and evaluate each Compliance Plan filed with it within thirty (30) days of its receipt by the Division. Upon approval of a Compliance Plan, the Division shall return a copy of the plan marked "approved" to the Fleet who shall post the plan in a conspicuous place in the Business Location. If a Compliance Plan as filed is disapproved by the Division, the Division shall issue a letter of disapproval, and the Fleet shall have thirty (30) days within which to revise the plan and resubmit it to the Division. The Division shall have thirty (30) days to approve or disapprove the resubmitted plan.

IV. HDDV Self-Certification Opacity Test Procedures

A. Opacity Evaluation Methods

Fleets shall utilize one of the following two methods of evaluating smoke opacity.

1. A visual evaluation by means of a smoke observer trained and certified by the Colorado Department of Health. The observer is to be positioned in a location perpendicular to the exhaust plume and at a distance which will provide a clear view of the exhaust plume.

2. Opacity meter evaluation of the exhaust stream by means of a portable full-flow light extinction opacity meter as specified in Part B, Section II.C.1., (a) through (b) (v) of this regulation. The meter is to be attached to the exhaust piping and calibrated as specified by the manufacturer.

B. Test Site and Vehicle Parameters

1. On-Road test procedures will require a testing site approximately 300 yards in length that is suitable for vehicle full-power runs to be conducted in complete safety.

2. An ambient temperature of 35° F (1.7 °C) or above is required during any given vehicle test.

3. Vehicles scheduled for opacity testing shall be in safe operating condition..

4. Vehicles shall be at normal operating temperatures.

5. If the vehicle to be tested is equipped with multiple exhaust outlets, and if it is determined that they emit different exhaust smoke levels, the outlet emitting the heavier smoke level shall be opacity evaluated.

6. Vehicles undergoing opacity testing are to use fuel obtained from the fleet’ s normal fuel supply. No special fuels, fuel additives, or devices are to be utilized for the sole purpose of obtaining opacity readings during testing that are lower than those typically observed when the vehicle is operating on the fleet’ s usual fuel supply.

C. Self-Certification Program Opacity Test Procedures

Fleets shall inspect their vehicles for compliance with opacity standards as defined in Part A, Section VII by utilizing one of the following compulsory test procedures, 1 thru 4. In addition to one of the compulsory tests, fleets may also elect to perform either one or both of the optional tests, (C.5.a and/or b).

1. On-Road Acceleration Test Procedure

   a. Select a gear which will permit the vehicle to accelerate under wide open throttle (WOT) from a moving position (approximately 900 to

1000 engine rpm) up to maximum engine rpm in no less than seven (7) seconds. This step is vital in order to ensure that the engine will be operated in an rpm range and timeframe which will allow sufficient time and engine loading in order to accurately monitor the vehicle’ s smoke opacity levels. Bring vehicle to a stop.

b. If an opacity meter is being utilized, shutdown the engine and verify the zero setting of the opacity meter. Clean the monitoring unit as necessary.

c. Restart engine and with the transmission in the selected gear as described in step a, accelerate the vehicle under WOT from a road speed equivalent of 900 to 1000 engine rpm up to maximum engine rpm.

If a visual opacity observation is being used, alert the certified observer by means of a horn or other communication that the test is completed and to record on the opacity inspection worksheet the highest opacity which was observed in a engine rpm range which encompasses 70% of rated rpm up to maximum governed rpm. If an opacity meter was utilized, note and record the highest opacity reading displayed during the afore mentioned rpm range.

d. Bring the vehicle to a safe controlled stop and shutdown the engine. Examine opacity meter reading, if applicable, and if there is more than a five percent (5%) shift (deviation) in the zero position and the highest opacity reading observed during the test exceeds the standard as defined in Part A, VIII, clean the meter lenses, zero the meter and repeat the procedure beginning at step c.

e. If the highest opacity observed during Step c exceeds the opacity standard and the opacity meter zero shift, if applicable, is less than five percent (5%), the vehicle fails the inspection.

f. If neither the highest opacity observed during step c nor the opacity meter zero shift, if applicable, exceeds the opacity standard, the vehicle passes the inspection.

g. The opacity inspector shall then record on the self-certification fleet opacity inspection form (OIF), the highest opacity reading the opacity meter zero shift (if applicable), the pass/fail determination and sign the (OIF). Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a complete CEC and receive a completed vet which shall be affixed to the lower left corner of the vehicle’ s windshield. The inspector shall record the required information on the windshield sticker log.

2. On-Road Brake Lug-Down Test Procedure

a. Select a gear which will permit the vehicle to attain a road speed of 15 to 25 mph with the engine at maximum rpm, wide open throttle (WOT). Due to the many variables, this gear selection is basically a trial and error effort. Upon completing the gear selection, bring vehicle to a stop.

b. If an opacity meter is being utilized, shutdown the engine and verify the zero setting of the opacity meter. Clean the monitoring unit as necessary.

c. Restart engine and with the vehicle operating at WOT in the selected gear as described in Step a, maintain WOT and slowly begin loading the engine by means of the vehicle' s service brakes. The loading is to be applied linearly throughout an engine rpm range which extends from maximum engine rpm down to seventy percent (70%) of the engine' s rated rpm in a time span which encompasses no less than seven (7) seconds.

d. Momentarily maintain the seventy percent (70%) rated rpm/WOT relationship and if a visual opacity observation is being used, alert the certified observer by means of a horn or other communication that the test is completed and to record on the opacity inspection worksheet the highest opacity which was observed during the brake lugdown procedure.

If an opacity meter was utilized, note and record the highest opacity reading displayed during the brake lugdown procedure.

e. Bring the vehicle to a safe controlled stop and shutdown the engine. Examine opacity meter reading, if applicable, and if there is more than a five percent (5%) shift (deviation) in the zero position, and the highest opacity reading observed during the test exceeds the standard as defined in Part A, VIII, clean the meter lenses, zero the meter, and repeat the procedure beginning at Step c.

f. If the highest opacity observed during Step c exceeds the opacity standard and the opacity meter zero shift, if applicable, is less then then five percent (5%), the vehicle fails the inspection.

g. If neither the highest opacity observed during Step c nor the opacity meter zero shift, if applicable, exceeds the opacity standard, the vehicle passes the inspection.

h. The opacity inspector shall then record on the self-certification fleet opacity inspection form (OIF), the highest opacity reading, the opacity meter zero shift (if applicable), the pass/fail determination and sign the (OIF). Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a completed CEC and receive a competed vet which shall be affixed to the lower left corner of the vehicle' s windshield. The inspector shall record the required information on the windshield sticker log.

3. Stall Test Procedure (Vehicles with Automatic Transmissions)

This is a full-load stationary test designed for vehicles equipped with automatic transmissions.

a. Transmission/torque converter oil is to be at normal operating temperature (160 to 200° F).

b. If an opacity meter is being utilized, verify the zero setting of the opacity meter. Clean the monitoring unit if necessary.

c. Start engine and operate at idle rpm. Apply vehicle' s parking brake and securely block the vehicle. Apply the service brakes and shift the transmission gear selector to a forward range.

d. Accelerate the engine by means of wide open throttle (WOT) until the transmissions' s stall speed rpm is attained. Maintain stall speed rpm for approximately five seconds in order to allow for stabilization.

e. Momentarily maintain stall speed rpm and if a visual opacity observation is being used, alert the certified observer by means of a horn or other communication that the test is completed and to record on the opacity inspection worksheet the opacity attained at this time (stall speed rpm).

   If an opacity meter is utilized, note and record the opacity meter reading at this time (stall speed rpm).

f. Return the engine to idle rpm and shut down the engine.

   Examine opacity meter reading, if applicable, and if there is more than a five percent (5%) shift (deviation) in the zero position, and the highest opacity reading observed during the test exceeds the standard as stated in Part A, VII, clean the meter lenses, zero the meter and repeat the procedure beginning at Step c.

   Allow approximately two minutes of neutral operation between stall tests in order to prevent overheating of the transmission. During the two-minute period, maintain 1000 to 1400 engine rpm.

g. If the highest opacity observed during Step e exceeds the opacity standard and the opacity meter zero shift, if applicable, is less than five percent (5%), the vehicle fails the inspection.

h. If neither the highest opacity observed during Step e nor the opacity meter zero shift, if applicable, exceeds the opacity standard, the vehicle passes the inspection.

i. The opacity inspector shall then record on the self-certification fleet opacity inspection form (OIF), the highest opacity reading, the opacity meter zero shift (if applicable), the pass/fail determination and sign the OIF. Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a completed CEC and receive a completed vet which shall be affixed to the lower left corner of the vehicle’ s windshield. The inspector shall record the required information on the windshield sticker log.

4. Dynamometer Test Procedure

a. If a smoke opacity meter is being used, verify the meter is set at zero. Start engine and with the dynamometer in an unloaded mode/condition, select a gear which will allow the vehicle to attain and maintain a no-load vehicle speed of 60 to 70 miles per hour (mph) at wide open throttle (WOT). It is preferred and recommended that vehicles be operated at the lower end of this mph range whenever possible. If vehicle has a maximum road speed that is less than 60 mph, operate vehicle at the highest mph possible. Upon stabilization, maintain speed for ten (plus or minus four) seconds and record engine rpm and mph on opacity worksheet.

b. While maintaining full throttle (WOT), slowly increase the dynamometer loading until engine rated rpm (plus or minus 15 mph) is obtained. Maintain this speed/load for ten (plus or minus four) seconds and record data on opacity worksheet; engine rpm, smoke opacity, and horsepower (hp).

c. Maintain full throttle (WOT) and slowly increase dynamometer loading until engine is at 90 percent of rated rpm (plus or minus 15 rpm). Maintain this speed/load for ten (plus or minus four) seconds and record data on opacity worksheet; engine rpm, smoke opacity, and hp.

d. Maintain full throttle (WOT) and slowly increase dynamometer loading until engine is at 80 percent of rated rpm (plus or minus 15 rpm). Maintain this speed/load for at least ten (plus or minus four) seconds and record data on opacity worksheet; engine rpm, smoke opacity, and hp.

e. Maintain full throttle (WOT) and slowly increase dynamometer loading until engine is at 70 percent of rated rpm (plus or minus 15 rpm). Maintain this speed/load for ten (plus or minus four) seconds and record data on opacity worksheet; engine rpm, smoke opacity, and hp. This step concludes the engine loading procedure; do not apply additional loading under any circumstances.

f. Vehicles with automatic transmissions are allowed one downshift to the next lower gear at any point during the dynamometer lugdown test. If a downshift occurs, continue with the test.

g. Remove dynamometer loading and shutdown engine after observing engine cool down procedure.

h. Examine opacity meter reading, if applicable, and if there is more than a five percent (5%) shift (deviation) in the zero position and the highest opacity reading observed during the test exceeds the standard as defined in Part A, VIII, clean the meter lenses, zero the meter and repeat the procedure beginning at Step a.

i. If the highest opacity observed during Steps b through e exceeds the opacity standard and the opacity meter zero shift, if applicable, is less than five percent (5%) the vehicle fails the inspection.

j. If neither the highest opacity observed during Step b through e nor the opacity meter zero shift, if applicable, exceeds the opacity standard, the vehicle passes the inspection.

k. The opacity inspector shall then record on the self-certification fleet opacity inspection form (OIF), the highest opacity reading, the opacity meter zero shift (if applicable), the pass/fail determination and sign the report OIF. Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a complete CEC and receive a completed which shall vet affixed to the lower left corner of the vehicle’ s windshield sticker log.

5. Optional No-Load Opacity Tests (the opacity results of these tests (5, a and b) are for data collection and engine diagnosis information only and

will not be used in determining a vehicle' s compliance with Regulation 12, Part A, VIII, opacity standards).

a. High Idle Opacity Test Procedure

(i) If an opacity meter is being utilized, verify the zero setting of the meter. Start engine and operate at idle rpm.

(ii) With the transmission in neutral, slowly increase the engine speed to high idle (maximum governed no-load rpm) and allow engine rpm to stabilize.

(iii) Momentarily maintain high idle rpm and if a visual observation is being used, alert the certified observer by means of a horn or other communication that the test procedure has reached completion and the observer is to record on the opacity inspection worksheet the opacity observed a this time (high idle rpm).

If an opacity meter is utilized, note and record the meter reading/value at this time (high idle rpm).

(iv) Return the engine to idle rpm and shutdown the engine.

Enter the highest opacity reading observed and record in step (iii) on the self-certification opacity inspection form.

b. Snap/Free Acceleration Test Procedure. This procedure requires a rapid wide open throttle (WOT) no-load acceleration of the engine from low idle rpm to maximum governed no-load engine rpm with the transmission in neutral.

(i) If an opacity meter is being utilized, verify the zero setting of the meter. Start engine and operate at idle rpm.

(ii) With the transmission in neutral and the engine at idle rpm, slowly accelerate the engine, allowing the engine to reach its maximum stabilized, no-load governed speed/rpm. Allow the engine to return to idle.

(iii) If an opacity meter is being utilized, place the meter in "Peak Hold" position. If a visual observation is being used, te certified observer shall note and record the highest opacity observed during the following (Step iv) rapid acceleration procedure.

(iv) Perform the acceleration procedure as described in step (ii) but accelerate the engine as rapidly as possible. Allow engine to return to idle and shut down engine.

(v) Enter on the opacity inspection form the highest opacity observed and recorded by the certified observer or captured by the opacity meter’ s peak hold feature, whichever is applicable.

V. Determination of Compliance

A.. On-Site Fleet Inspection

The Division shall have the authority to determine a Fleet’ s compliance with this regualtion or the Fleet’ s Compliance Plan by personal inspection of a Fleet’ s Business Location. The Division shall notify each inspected fleet of any violations of this regualtion or the Fleet’ s Compliance Plan immediately upon completion of the inspections and shall be supplied with a written report of the results of the inspection within thirty (30) days of the inspection date. Such inspections by the Division may not be made more frequently than twice in any twelve (12) month period unless complaints of violation of this regulation have been received by the Division or the Division otherwise has cause to believe that the Fleet is not in compliance with the requirements of this regulation or the Fleets Compliance Plan. Such inspections may be made by the Division only during the normal working hours of a Fleet. The time of inspection will be determined by the Division, but must be at times reasonably convenient to the fleet. Individual vehicles of the fleet requested by the Division should be available at the time of inspection, as reasonably convenient to the fleet operators, with advance notice by the Division of such inspection.

B. Record Keeping Requirements

Opacity test results from the annual inspections shall be kept by the Fleets and shall be available to the Division at inspections as described in Section V.A. Copies of test data shall be submitted to the Division annually by December 31 of each year. fleets which fail to submit the test data to the Division as required my not be dispensed forms and documents for the following year. Standardized test forms shall be developed and provided by the Division.

VI. Penalties for Non-Compliance

A. Failure of a Fleet to comply with the requirements of this regulation will subject the Fleet to fines ranging from twenty-five (25) dollars to three hundred (300) dollars, per vehicle, per event as provided for in Section 42-4-320 (3)(a)(b), CRS.

B. Excessive violations, two or more within a 12 month period, as defined in Part A, Section I.B. 8 of this regulation shall result in the fleet being removed from the self-certification program (Regulation 12, Part A) and being placed under the diesel opacity inspection program (Regulation 12, Part B) for a minimum of one year (twelve months).

VII. Replacement Vets

In order to issue a replacement verification of emission test windshield sticker due to windshield replacement, the following procedures are to be followed:

1. A valid vehicle inspection report form or the legible remains of the previous valid windshield sticker matching the vehicle must be presented and verified by the certified opacity inspector.

2. The original test date is to be determined from the inspection report form or windshield sticker. The replacement sticker is to be punched for the time period which remains from the original inspection date based on the model year of the vehicle.

3. Complete the required information on the back of the windshield sticker as well as the windshield sticker log. The issuance of the sticker is to be noted as a "Replacement" on the log.

4. The verification of emissions test windshield sticker is to be affixed to the lower left hand corner of the vehicle windshield and placed so as not to block the vehicle identification number.

   A replacement windshield sticker may only be issued by a certified DFSCP opacity inspector.

VIII. Opacity Standards for Diesel-Powered Motor Vehicles Subject to Part A of This Regulation.

Subject to the provisions of Section 18-13-110 CRS, as amended, and Section 42-4-320 CRS, as amended vehicles inspected following the procedures established in the Part A of this regulation shall meet the following opacity standards.

The smoke opacity standard for all diesel vehicles subject to opacity tests, under Part A of this regulation shall be thirty-five percent (35%) and twenty percent (20%) for naturally aspirated and turbocharged diesel vehicles respectively for five (5) seconds.

REGULATION 12

PART B - DIESEL OPACITY INSPECTION PROGRAM

PART B - DIESEL OPACITY INSPECTION PROGRAM

PART B - DIESEL OPACITY INSPECTION PROGRAM

I. General Provisions

A. Statement of Purpose

The purpose of PART B of this regulation is to reduce air pollution resulting from emissions from diesel-powered motor vehicles, as defined in Part B of this regulation, registered or required to be registered, or operated from a facility in the AIR Program area, and not subject to Part A of this regulation.

B. Definitions

1. "AIR Account" is a special fund set aside in the Highway Users Tax Fund for the operation of the "AIR Program" and the "Diesel Opacity Inspection Program".

2. "AIR Program" is the Automobile Inspection and Readjustment (AIR) Program established pursuant to Section 43-4-306.5 to 42-4-320, C.R.S. as amended.

3. "AQCC" means Air Quality Control Commission.

4. "Basic Engine Systems" are those parts or assemblies which provide for the efficient conversion of diesel fuel into useful power to include, but not limited to valve train mechanisms, cylinder heads, block, piston-ring-cylinder sealing integrity and post-combustion emissions control devices.

5. "Certificate of Qualification" means official certificate issued by the Division to candidates who have successfully passed the qualification test, required in order to become licensed as a diesel opacity inspector in the Diesel Opacity Inspection program.

6. "Certification" of Diesel Smoke Opacity Compliance" is the document which indicates that the smoke emissions from the vehicle comply with applicable smoke opacity limits at the time of inspection or after needed adjustments or repairs and re-inspection.

7. "Certification" or "Certification of Emissions Control" means either a "Certification of Diesel Smoke Opacity Compliance" or owner of a diesel vehicle which is subject to the diesel emissions inspection program in order to indicate the status of inspection requirement compliance of such a vehicle. A verification of emissions test (VET) sticker shall be issued with each certification of emissions control (CEC).

8. “Certified Neutral Density Filter” means an optical quality filter which reduces the amount of transmitted light, an amount which is dependent upon the filter’s optical density rating, uniformly across the visible light spectrum for the purpose of verifying the accuracy of the opacity meters.

9. “Certification of Emissions Exemption” means the official document issued by the Department of Revenue, in lieu of the Certification of Emissions Control.

10. “Certified Thermometer” means a laboratory grade ambient temperature measuring device with a range of at least 20°F through 120°F and an attested accuracy of at least plus or minus 1°F with increments of 1°, with protective shielding, and approved by the Department.

11. “Certification of Diesel Smoke Opacity Waiver” is the document which indicates that the smoke emissions from the vehicle do not comply with the applicable smoke opacity limits after inspection, adjustment and smoke-related repairs.

12. “Chassis Dynamometer” means a vehicle power absorption device which has the ability to approximate or simulate actual on-road operation of motor vehicles through the application of variable loading.

13. “Commission” means Colorado Air Quality Control Commission.

14. “Department” means Department of Revenue.

15. “Diesel Opacity Inspection” means an inspection of a diesel powered vehicle performed by a licensed inspector, employed by a licensed station, pursuant to 25-7-604 C.R.S. using the procedures and provisions set forth in Part B of AQCC Regulation No. 12 and Department rules.

16. “Diesel Opacity Inspection Program” means the opacity inspection program for diesel powered vehicles established by 25-7-601 to 25-7-609 C.R.S., as amended and Regulation 12, Part B.

17. “Diesel Opacity Inspection Program Station” is a station that qualifies and is licensed to operate as an emissions inspection station for light or heavy-duty diesel vehicles, or both in accordance with requirements set forth in 25-7-605 C.R.S. as amended, AQCC Regulation No. 12, Part B, and Department Rules required under 25-7-603 C.R.S.

18. “Diesel Opacity Inspector” means an individual licensed to perform opacity inspections on vehicles required under 25-7-604 C.R.S. who is employed at a licensed diesel opacity inspection station and is qualified in accordance with AQCC Regulation No. 12, Part B and the Department of Revenue.

19. "Diesel Powered Motor Vehicle" or "Diesel Vehicle" as applicable to opacity inspections, includes only a motor vehicle with four wheels or more on the ground, powered by an internal combustion, compression ignition, diesel fueled engine, and also includes any motor vehicle having a personal property classification of A,B, or C pursuant to Section 42-3-105, C.R.S., as specified on its vehicle registration, and for which registration in this state is required for operation on the public roads and highways. "Diesel Vehicle" does not include the following: vehicles registered pursuant to Section 42-3-123 (11), or 42-3-128, C.R.S.: off-the-road diesel powered vehicles or heavy construction equipment.

20. "Diesel Vehicle Inspection Report (DVIR)" means official form issued by the Colorado Department of Revenue to licensed diesel opacity inspection stations, which contains a Certification of Emissions Control.

21. "Division" is the Air Pollution Control Division of the Colorado Department of Health.

22. "Emissions Control Systems" are those parts, assemblies or systems originally installed by the manufacturer in or on a vehicle for the specific purpose of reducing emissions.

23. "Empty Weight" (E.W.) (curb weight, unloaded weight) means the weight of the vehicle with maximum capacity of all fluids necessary for operation of the vehicle, but minus the driver, passengers, and payload.

24. "Engine Rated RPM" means a specific rpm at which the manufacturer states that the engine's maximum/rated brake horsepower is attained. Above this rpm, the engine's governor will typically begin limiting full load fuel quantity and thus prevent the engine from developing full power beyond this rpm. Rated engine power and speed information is usually found on a label affixed to the engine itself or other underhood location.

25. "GCWR" (Gross Combined Weight Rating) means the weight specified by the vehicle manufacturer as the maximum allowable loaded weight (vehicle empty weight, plus the driver, passengers and payload) of the truck tractor and trailer(s).

26. "GVWR" (gross vehicle weight rating) means the weight specified by the vehicle manufacturer as the maximum allowable loaded weight (vehicle empty weight plus the driver, passengers and payload) of a single vehicle.

27. "Heavy Duty Diesel Vehicle" as applicable to the Diesel Opacity Inspection Program refers to diesel vehicles weighing more than 7,500 lbs., empty weight. This classification correlates closely but not precisely, to the

MVMA vehicle classes 5 thru 8 (vehicles with a GVWR or GCWR of more than 16,000 lbs.)

28. “Heavy Duty Diesel Opacity Inspection Station” means a facility licensed to inspect heavy-duty diesel vehicles only (greater than 7500 lbs. E.W.).

29. “Heavy Duty Dynamometer “ means a chassis dynamometer meeting the requirements for accurately and safely testing heavy-duty vehicles.

30. “Highest Opacity Reading” is that greatest stable opacity value for other than the snap/free acceleration proceedure.

31. “ISO” means International Standards Organization.

32. “Light Duty Diesel Opacity Inspection Station” means a facility licensed to inspect light-duty diesel vehicles only (7500 lbs. E.W. and less).

33. “Light Duty Diesel Vehicle” as applicable to the Diesel Opacity Inspection Program refers to diesel vehicles weighting 7,500 lbs. and less, empty weight. This classification correlates closely, but not exactly, to the MVMA vehicle classes 1 thru 4 (vehicles with a GVWR of 16, 000 lbs. and less).

34. ‘ Light Duty Dynamometer” means a chassis dynamometer meeting the requirements for testing light duty vehicles. These dynamometers may have a limited heavy duty capability.

35. “Maximum No-Load RPM or High Idle RPM” means the maximum rpm that the engine’s governor will allow the engine to attain under no-load, wide open throttle (WOT) conditions. For many vehicular diesel engines, this rpm is typically 8 to 11% higher than the engine’s rated rpm.

36. “MPH” means miles per hour.

37. “Motor Vehicle Emissions Compliance Officers (MVECO)” are those persons employed by the Department of Revenue for licensing and enforcement of the AIR Program and the Diesel Opacity Inspection Program.

38. “On-Road Test Procedures” means the heavy-duty diesel test procedures described in Part B, Section III. D. of this regulation.

39. “Opacity means the degree to which an air pollutant obscures the view of an observer expressed in percentage of obscuration, or the degree, expressed in percent, to which transmittance of light is reduced by the air pollutant.

40. “Opacity Meter” means an optical instrument which is designed to measure the opacity of diesel exhaust gases by measuring the full flow of exhaust gases which pass through the optical unit.

41. “Opacity Meter Calibration Form” means official form provided by the Division for recording weekly opacity meter calibration procedures, to be kept on file at the inspection station.

42. “Opacity Testing” means the testing of motor vehicles using procedures prescribed in this regulation in order to determine the magnitude (expressed as a percentage) of obscured light (opacity) due to exhaust constituents, mainly fine particles.

43. ‘ Opacity Worksheet” means official worksheet provided by the Division for recording measured opacity levels during dynamometer testing for determining opacity compliance, to be maintained with station’ s DVIR for auditing purposes.

44. “Phototachometer” means a non-contact rotational speed measuring instrument which processes data received from a reflected light beam and remotely displays the results as revolutions per minute (rpm).

45. “RPM” means revolutions per minute as pertaining to engine crankshaft speed.

46. “SAE” means Society of Automotive Engineers.

47. “State Emissions Technical Centers” are those facilities, operated by the Department of Health for technical or administrative support of the AIR Program and the Diesel Opacity Inspection Program.

48. “Stripchart Recorder” means an instrument which receives and records data from one or more electrical inputs and displays that information in the form of real-time, continuous (non-impact) tracings on paper.

49. “Training Program “ means instruction developed by the Division for training diesel opacity inspectors.

50. “Verification of Emission Test” (VET) is a sticker which is issued and affixed to the windshield of a motor vehicle which has complied with the diesel opacity inspection.

51. “WOT” means wide open throttle.

C. Applicability

1. Geographic Area of Applicability

This regulation shall apply to the AIR Program area as defined in Section 42-4-304(20)(a)(b), C.R.S. Those portions of the program area within the counties of El Paso, Larimer and Weld shall not be an element of the State Implementation Plan.

2. Vehicles Eligible for Diesel Opacity Inspection Program

Part B of this regulation shall apply to all diesel-fueled motor vehicles as defined in Section 42-4-401(5), C.R.S. except those diesel-powered vehicles subject to the provisions of Part A of this regulation (Diesel Fleet Self-Certification Program), pursuant to Section 42-4-414, C.R.S.

a. The burden of proof in establishing an exemption from all or any part of the diesel opacity inspection requirements is on the vehicle owner. Any applications for exemptions must be submitted to the Colorado Department of Revenue for approval.

D. Conditions for Issuance of Certification of Emissions Control

1. Effective January 1, 1990, no diesel vehicle which is registered or required to be registered, or is principally operated from a terminal, maintenance facility, branch or Division located within the program area shall be sold, registered for the first time in the program area or reregistered, unless such vehicle has a Certification of Emissions Control. The Certification of Emissions Control will be valid for one year from date of issuance.

2. Effective January 1, 1990, all diesel-fueled motor vehicles owned by the United States government, State of Colorado, and local governments within the AIR Program area, except those diesel-powered vehicles subject to the provisions of Part A of this regulation (Diesel Fleet Self-Certification Program), and except as otherwise provided in Section I.D.3 of this Part B, shall be inspected once each year, and shall comply with the inspection provisions and obtain a Certification of Emissions Control. Inspection results will be reported to the Department of Revenue by transfer of the Certification of Emissions Control.

3. For new diesel motor vehicles being registered for the first time, a Certification of Emissions Control shall be issued without testing for diesel opacity compliance. Such certificate shall expire on the anniversary of the day of the issuance of such certification when such vehicle has reached its second model year or on the date of the transfer of ownership at any time prior to the second model year. Prior to the expiration of such certification, such vehicle shall be inspected and a Certification of Emissions Control shall be obtained for diesel smoke opacity compliance..

4. For used diesel vehicle retail sales transactions by a licensed dealer conducted within the AIR Program area, a Certification of Diesel Smoke Opacity Compliance will be required at the time of sale. The responsibility of complying with the inspection provisions is that of the selling dealer.

5. A "Certification of Diesel Smoke Opacity Compliance" shall be issued by a licensed diesel inspection station to any diesel vehicle which has been inspected and tested according to the procedures in Part B, Section III of this regulation and found to be within applicable smoke opacity limits and equipment requirements as stated in Sections IV and VI, Part B of this regulation.

6. No Certification of Diesel Emissions Control may be issued to a diesel vehicle of model year 1991 and newer if there is evidence of diesel emissions control system tampering, as determined by the procedures described in Section III. A (4) of Part B of this regulation.

7. A temporary Certification of Emissions Control may be issued by a Department of Revenue AIR Program Motor Vehicle Emissions Compliance Officer to those vehicles which fail the initial opacity inspection and continue to exceed applicable opacity standards, and for which needed parts are not presently available in order to make corrective repairs to that specific vehicle.

8. A "Certification of Diesel Smoke Opacity Waiver" shall be issued by a Department of Revenue AIR Program Motor Vehicle Emissions Compliance Officer to any diesel vehicle which has been reinspected after failing the initial opacity inspection procedure as prescribed in Part B, Section III of this regulation, and exceed the applicable smoke opacity limits as stated in Section VI of this Part B of this regulation, and for which proper presentation of documented evidence, of expenditures for smoke emissions related adjustments and repairs have been made which equal or exceed minimum dollar expenditures as follows:

    a. For light-duty diesel vehicles (those weighing 7500 lbs. and less empty weight) a minimum expenditure of seven hundred and fifty dollars ($750) must be made in an attempt to comply with smoke opacity standards.

    b. For heavy-duty diesel vehicles (greater than 7500 lbs. E.W.), a minimum expenditure of fifteen hundred dollars ($1500) must be made in an attempt to comply with smoke opacity standards.

    c. Confirmation of documented evidence that minimum expenditures for smoke emissions related repairs have been made and issuance of a "Certification of Diesel Smoke Opacity Waiver" shall be made only by a Department of Revenue AIR Program Motor Vehicle Emissions Compliance Officer.

d. Documented proof of smoke emissions repair costs for the specific failing vehicle shall be in the form of an itemized bill, invoice, work order, manifest, or statement, for the following types of work and/or parts.

(i) Replacements, adjustments and repairs to the diesel vehicle which are directly related to the reduction of exhaust smoke, necessary to comply with the applicable opacity standards.

(ii) Replacements, repairs and adjustments to the following systems shall qualify as emissions related repairs for the purpose of reducing exhaust smoke opacity:

(A). Air intake systems

(B). Fuel system components, including fuel injection pumps, injectors and related components.

(C). Exhaust systems

(D). Turbochargers and superchargers

(E). Air scavenging pumps (blower) for two-stroke cycle engines

(F). Fuel control systems, such as governors, aneroids, puff limiters and fuel modulators, utilized to control the air/fuel ratio, including microprocessor/electronic control systems, mechanical systems, hydraulic systems or pneumatic systems.

(G) Basic Engine Systems

(iii) The expenditure for smoke reduction activities does not include the opacity inspection or reinspection fee(s) as specified in C.R.S. Section 25-7-606(3), nor does the expenditure include the costs of replacement, adjustment, or repair of air pollution control equipment due to instances of neglect, maladjustment, abuse, tampering or disconnection.

(iv). Air pollution control equipment is any part, assembly or system originally installed by the manufacturer for the sole or primary purpose of reducing emissions. Such equipment shall include, but is not limited to, catalytic converters, exhaust gas treatment devices, particulate filters or traps, and exhaust gas recirculating (EGR) systems.

E. Fees for Diesel Opacity Inspections

1. Initial Opacity Inspection Fees

A licensed Diesel Opacity Inspection station shall charge a fee not to exceed forty-five dollars ($45) and not to exceed the maximum fee established by and posted by the station pursuant to Section IV.A.4 of this regulation, for the inspection of any diesel-fueled motor vehicle required to be inspected pursuant to this regulation.

2. Reinspection Fees for Vehicles Failing Initial Opacity Inspection

If the vehicle fails the initial opacity inspection, the vehicle owner has 30 days in which to have repairs or adjustments made and return the vehicle to the licensed diesel inspection station which performed the initial inspection for one reinspection at a reduced cost of a maximum of thirty-five dollars ($35).

3. Certificate of Emissions Control Fee

In order to encompass cost incurred by the Department of Revenue and the Department of Health in the administration, operation and evaluation of the diesel Opacity Inspection Program, the Certificate of Emissions Control (CEC) shall be sold to licensed diesel vehicle inspection stations for a cost of five dollars ($5) each. Certificates of emissions control must be purchased from the agency designated by the Commission (AQCC).

F. Home Rule Inclusion in the Diesel Opacity Inspection Program.

Any home rule city, town, or county shall, upon request by the governing body of such local government to the Department of Health and the Department of Revenue, be included in the Diesel Opacity Inspection Program. When such a request is made, said departments and governing body shall agree to a start-up date for the Diesel Opacity Inspection Program in such areas. On or after such dates, all diesel-fueled motor vehicles which are registered in the area shall be inspected and required to comply with the provisions of this regulation, as if such area was in the AIR Program area.

II. Standards and Procedures for the Operation, Adjustment, Calibration and Certification of the Division Approved Smoke Opacity Meters, Chassis Dynamometers, and Other Required Equipment in the Performance of Diesel Opacity Inspections for the Diesel Opacity Inspection Program.

A. Approval of Required Test Equipment

From January 1, 1990 and thereafter, no diesel opacity inspection required by the Diesel Opacity Inspection Program shall be performed unless the equipment used meets the specifications of the Colorado Diesel Opacity Inspection Program as defined in this regulation and as approved by the Division. Opacity meters, chassis dynamometers, photo tachometers and strip chart recorders must be approved by the Division. A manufacturer requesting the approval of an instrument for use in Colorado’ s Diesel Opacity Inspection Program shall make application thereof on forms provided thereby, and sources of vendors for the qualifying instruments may be obtained from the Program Administrator, Mobile Sources Section, Air Pollution Control Division, Colorado Department of Health, 4210 East 11th Avenue, Denver, CO 80220.

B. Running Changes and Equipment Updates

Any changes to design or performance characteristics of components specifications which may affect equipment or instrument performance must be approved by the Commission. It will be the instrument manufacturer’ s responsibility to confirm that such changes have no detrimental effect on opacity meter or other equipment or instrument performance. All equipment and instruments used in Colorado’ s Diesel Opacity Inspection Program will be updated as needed and specified in revisions to Commission Regulation No. 12.

C. Opacity Meter

Every licensed station shall have on the premises an approved portable opacity meter meeting specifications to conduct opacity tests for the Diesel Opacity Inspection Program. Only opacity meters approved by the Division shall be used for opacity inspections in the Diesel Opacity Inspection programs.

The opacity meter is to be portable in design and function with an emphasis on compactness and light weight. The instrument will consist of two major, separate components connected by an interconnecting cable. The major components are the stack monitor/sensor and the control/indicator unit.

Opacity meters are to meet EPA spectral specifications, and all applicable ISO and SAE specifications.

1. Opacity Meter Specifications

a. Stack Monitor/Sensor

(i). Must be adaptable by means of a quick connect device, to exhaust piping and outlets having outside diameters from two to six inches.

(ii). Light Source: Light emitting diode (LED), pulsed green light.

(iii). Light Detector: Silicon photo detector.

(iv). Provide for full flow, in line, continuous measurement of exhaust opacity.

b. Control/Indicator Unit

(i). Meter Display

A. Range: 0-100 percent opacity

B. Digital read-out

C. Accuracy; Plus or minus two percent of full scale

D. Drift: Less than 2.5% per hour

E. Response time: Less than two seconds from 0-90% of scale

F. Peak Hold Feature

(ii). Warm-up time: Not to exceed ten minutes

(iii). Operating temperature range: 32°-120°F.

(iv). Integrated with a chart recorder and/or provide for a linear 0-1 VDC OR 0-10 VDC output signal.

(v). Power Requirements

A. 115 Volts AC input

B. Internal replaceable or rechargeable batteries allowing for operation independent of AC input.

(vi). Connecting Cable

A. Heat and abrasion resistant

B. Not less than 25' in length required for light-duty inspection stations. Not less than 50' in length required for heavy-duty inspection stations.

(vii). Calibration: Opacity meters must be calibration checked weekly. Calibration results must be recorded on a calibration form provided by the Department or Division and kept on file at the inspection station.

D. Dynamometer Specifications and Criteria

1. Light Duty Dynamometers

a. Capacity: A minimum requirement is the capacity to absorb up to 180 horsepower at speeds between 50 and 80 miles per hour (mph), capable of accommodating vehicles with individual axle loads up to 5,000 lbs.

b. Rolls: Minimum roll diameter: 8.5 in.

c. Load and Speed Control

(i). Infinitely variable throughout the load and speed range from no-load to full-load. Reference the dynamometer's "performance envelope" or power absorption capacity curve.

(ii). Ability to set a load or speed and until deactivated, maintain that preset setting without additional input from the load controller.

d. Instrumentation: Interfaced, calibrated horsepower and road speed indicators located in such a manner to be readily visible and discernable by the operator of the vehicle under test.

e. Calibration:

(i). Provision for field checking the accuracy of the dynamometer's calibration including the electrical output signal, interface and attendant instrumentation.

(ii). Availability of manufacturer's recommended/specified equipment, tools and procedures for the field calibration and adjustment of the dynamometer.

2. Heavy Duty Dynamometers

a. Capacity: A minimum requirement is the capacity to absorb a minimum of 400 horsepower at speeds between 50 and 80 mph. Capable of accommodating vehicles with individual axle loads up to 22,000 lbs.

b. Rolls:

(i) Minimum roll diameter: 8.5 in.

(ii). Minimum usable overall length of roll(s): 107 in.

(iii). Tandem axle capability to accommodate, at a minimum, vehicle interaxle spacing of 48 to 58 inches.

c. Load and Speed Control:

(i) Infinitely variable throughout the load and speed range from no-load to full-load. Reference the dynamometer’ s “ performance envelope” or power absorption capacity curve.

(ii). Ability to set a load or speed and until deactivated, maintain that preset setting without additional input from the load controller.

d. Instrumentation: Interfaced, calibrated horsepower and road speed indicators located in such a manner to be readily readable and discernable by the operator of the vehicle under test.

e. Calibration:

(i) Provision for field checking the accuracy of the dynamometer’ s calibration including the electrical output signal, interface and attendant instrumentation.

(ii). Availability of manufacturers’ s recomended/specified equipment, tools, and procedures for the field calibration and adjustment of dynamometer.

E. Other Required Equipment for Diesel Opacity Inspection Stations.

1. Photo Tachometer (Heavy-duty Vehicle Inspection Stations Only)

Every heavy-duty diesel vehicle inspection station shall have a photo tachometer capable of sensing a vehicle' s engine rpm and digitally displaying that rpm in the vehicle operator' s compartment. This tachometer must be capable of measuring rpm from 0-6000 rpm with an accuracy of plus or minus five rpm or better. For heavy-duty on-road testing stations this unit must be of portable design with the readout capable of being read from the vehicle' s cab, and must be easily interfaced with the strip chart recorder.

2. Strip Chart Recorders (Heavy Duty On-Road Inspection Stations Only)

In those instances where on-road opacity testing will be utilized, strip chart recorders shall be used in order to accurately monitor and analyze the test sequence.

Description of an approved strip chart recorder is as follows:

a. Recorder capable of accurately recording data in a moving heavy-duty vehicle.

b. Unit is to be powered by internal batteries (rechargeable or non-rechargeable) or 12 VDC external source. A 115 VAC, 60 hz, unit powered by means of a DC/AC inverter is also acceptable.

c. A minimum of two channels for recording 1) exhaust opacity and, 2) engine speed (rpm).

d. A recorder chart speed of approximately four to eight inches/min. (10 to 20 cm/min.).

e. A minimum chart paper width of three inches.

3. Certified Neutral Density Filter.

A neutral density filter, certified and calibrated by the Division, must be kept by each diesel testing station for weekly calibration checks of the opacity meter. The results of the calibration checks of each approved opacity meter must be recorded on a calibration log provided by the Division and made available to Department of Revenue, Motor Vehicle Emissions compliance officers upon request during station inspections.

4. Certified Thermometer

For use in the Diesel Opacity Inspection Program, the thermometer must be a laboratory grade ambient temperature measuring device with a range of at least 20°F (twenty degrees) through 120°F (one-hundred-twenty degrees) and an attested accuracy of at least plus or minus 1° (one degree) fahrenheit with increments of one degree, with protective shielding, and approved by the Department of Revenue.

5. Safety Restraint Equipment

Adequate safety restraint equipment for all dynamometer test stations is required. Restraint equipment must be capable of restraining type of vehicles tested at that station. Equipment may be chains, fabric tie-down straps, wheel chocks, as appropriate and as approved upon licensing.

6. Hearing ear protectors, as needed.

7. Auxiliary engine cooling fan.

Light-duty inspection stations are required to have available on premises and for use during opacity inspections, an auxiliary engine cooling fan which meets the following minimum specifications.

- Guarded fan complying with OSHA regulations.
- CFM free air delivery of 3200 CFM
- Fan diameter of 24 inches.
- 1/4 H.P. motor.

8. Exhaust gas removal equipment.

If a closed exhaust system is utilized, the pressure within the system shall be maintained between 4 inches H_2O positive pressure and 2 inches H_2O negative pressure at all times when any given vehicle is undergoing opacity testing.

9. Required reference materials.

10. Basic hand tools necessary to perform inspection.

III. Procedures and Practices to Ensure the Proper Performance of Opacity Inspections

A. General Inspection Requirements

1. All aspects of the inspection must be performed by a licensed diesel emissions inspector. It is the responsibility of the inspector to notify the Department of Revenue of his/her current place of employment.

2. The inspection shall take place at the address of the station license.

3. The temperature of the inspection area (or ambient temperature for on-road tests) shall be between 35°F and 110°F (2° C and 43° C) during the inspection. Temperatures during the inspection must be accurately recorded and monitored in a well-ventilated location, away from vehicle engine and exhaust heat sources and out of direct sunlight.

   For 1991 and later model year diesel vehicles, the diesel emissions inspector shall perform an inspection for the integrity of the emissions control systems and/or devices as listed on the vehicle' s emissions control label or in an emissions control systems application guide. The following system/devices if original must be installed, intact and apparently operational:

   (1). Any fuel injection pump seals and covers

   (2). Any seals and/or covers protecting the aneroid, throttle delay, boost compresation device, or other air/fuel ratio adjustments.

   (3). The particulate matter trap system or catalytic converter system, including pipes and valves.

   (4). Engine computer controls, related sensors, actualors, malfunction indicator, or service maintenance reminder lights.

   (5). Positive crankcase ventilation, crankcase depression and air box drain equipment, including their hoses, pipes, valves and connectors.

   (6). The exhaust gas recirculation value.

   (7). Related hoses, connectors, brackets, and hardware for these components.

   (8). Any other emissions-related components for a particular vehicle/engine as listed on a vehicle evaluation form (DR2365) issued by Emissions Technical Center staff.

   The vehicle shall fail the inspection if the emission control components are found to be tampered, defective, or otherwise rendered partially or completely inoperative. When determining original equipment emissions control systems/devices, the vehicle' s underhood emissions control label takes precedence over any other sources of information.

B. Inspection Procedure for Light-Duty Diesel vehicles (7500 lbs. E.W. or Less)

1. Preliminary Check of Vehicle

   a) Safety check vehicle (tires, drive-line, etc.)

   b) Ensure engine lube oil and coolant levels are at proper levels.

   c) For vehicles with multiple exhaust outlet, operate engine, observe and determine which emits the heavier exhaust smoke. During testing, monitor the exhaust outlet which emits the heavier smoke; if there is a difference in smoke levels.

2. Diesel Vehicle Inspection Report Forms (DVIR)

   a). The opacity inspector shall accurately identify and enter vehicle and owner information from vehicle to be tested as required on the DVIR.

3. Prepare Vehicle for Opacity Testing

   a). Locate vehicle on dynamometer.

   b). Secure vehicle with adequate safety restraints such as chains, nylon straps, wheel chocks or tie downs.

   c). Locate auxiliary engine cooling fan in front of vehicle radiator or engine cooling inlet, whichever is applicable.

   d). Vehicle is to be at a stabilized normal operating temperature. This shall be determined by feeling the top radiator hose, by checking the temperature gauge, and/or operating the vehicle prior to performing the inspection.

   e). Zero/span opacity meter following manufacturer' s specifications. Clean and recalibrate as necessary before conducting test.

   f). Attach pre-calibrated opacity meter to vehicle' s exhaust outlet and calibrate meter according to the manufacturer' s instructions.

4. Opacity Testing

   Opacity testing of light-duty diesel vehicles involves a dynamometer loaded-mode lug-down test procedure.

Engine temperature and oil pressure are to be closely monitored during all testing. Testing is to be discontinued if engine and vehicle operating parameters are not within acceptable limits.

a. Dynamometer Test Procedure

(i). Verify smoke opacity meter is set at zero. Start and operate engine at idle rpm. With the dynamometer in an unloaded mode/condition and the vehicle in direct or drive gear (do not use overdrive), slowly increase vehicle speed to 60 mph (plus or minus two mph). Continue to maintain (by manual or automatic control) 60 mph while slowly increasing dynamometer loading until maximum horsepower (hp) is developed at 60 mph. Maintain this full throttle speed/load condition for a minimum of 10 seconds (plus or minus four seconds) and record mph, opacity, and hp on Opacity Worksheet. Proceed directly to Step iii.

(ii). NOTE: Vehicles with automatic transmissions are allowed one downshift to the next lower gear at any point during the dynamometer lugdown test. If a downshift occurs, continue with the test.

(iii). While maintaining full throttle, slowly increase the dynamometer loading until a vehicle speed of 50 mph (plus or minus two mph) is achieved. Maintain this full throttle speed/load condition for a minimum of 10 seconds (plus or minus four seconds) and record mph, opacity, and hp on Opacity Worksheet. Proceed directly to Step (iv).

(iv). While maintaining full throttle, slowly increase the dynamometer loading until a vehicle speed of 40 mph (plus or minus two mph) is achieved. Maintain this full throttle speed/load condition for a minimum of ten seconds (plus or minus four seconds) and record mph, opacity, and hp on Opacity Worksheet.

(v). Slowly remove dynamometer loading while returning engine to idle. Shut down engine after observing cool down procedure. Note, and record residual opacity meter reading on Opacity Worksheet.

(vi). The inspector shall refer to the opacity standards in Section VI of Part B of this regulation.

If the highest opacity reading taken from steps (I) through (iv) exceeds the opacity standard and the opacity meter shift exceeds five percent (5%), clean the lenses, zero meter and repeat the dynamometer test procedure starting at step (I). At least one additional test will be conducted at no cost to the motorist.

If the highest opacity reading taken from steps (I) through (iv) exceeds the opacity standard and the opacity meter zero shift is less than five percent (5%), the vehicle fails the inspection.

If neither the highest opacity meter reading taken in steps (I) through (iv) nor the opacity meter zero shift exceeds the opacity standard, the vehicle passes the inspection..

(vii). The inspector shall then enter the highest opacity reading, the opacity meter zero shift, the pass/fail determination, inspector signature and other required information on the DVIR form. Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a completed CEC and receive a completed VET which shall be affixed to the lower left corner of the vehicle' s windshield. The inspector shall record the required information on the windshield sticker log.

5. <u>Vehicle Removal From Dynamometer</u>

a. Detach all test equipment, restraints and remove them from the vehicle.

b. Remove vehicle from dynamometer

C. Dynamometer Inspection Procedures for Heavy-Duty Diesel Vehicles (Greater than 7500 lbs. E.W.)

1. <u>Preliminary Check of Vehicle</u>

a. Safety check vehicle (tires, drive-line, etc.)

b. Ensure engine lube oil and coolant levels are at proper levels.

c. Verify proper operation of vehicle tachometer, or mount and connect approved photo tachometer.

d. For vehicles with multiple exhaust outlets, operate engine, observe and determine which outlet emits the heavier exhaust smoke, if there is a difference. During testing, monitor the exhaust outlet which emits the heavier smoke.

2. <u>Diesel Vehicle Inspection Report Forms</u>

a. The opacity inspector shall accurately identify and enter vehicle and owner information from vehicle being tested as required on the DVIR.

b. Determine the engine' s rated horsepower and attendant rpm and enter on DVIR form and also on the opacity worksheet.

3. <u>Prepare Vehicle for Opacity Testing</u>

a. Locate vehicle on dynamometer.

b. Secure vehicle with adequate safety restraints such as chains, nylon straps, wheel chocks or tie downs.

c. Vehicle is to be at a stabilized operating temperature. This shall be determined by feeling the top radiator hose, by checking the temperature gauge, and/or by operating the vehicle prior to performing the inspection.

d. Zero/span opacity meter, following manufacturer' s specifications. Clean and recalibrate, as necessary, before conducting test.

e. Attach pre-calibrated opacity meter to vehicle' s exhaust outlet and calibrate meter according to the manufacturer' s instructions.

4. <u>Opacity Testing</u>

Dynamometer opacity testing of heavy-duty diesel vehicles involves two separate and distinct test procedures. The two tests are 1) a snap/free no-load acceleration test and 2) a dynamometer loaded-mode lug-down test procedure.

Engine temperature and oil pressure are to be closely monitored during all testing. Testing is to be discontinued if engine and vehicle operating parameters are not within acceptable limits.

NOTE: If the vehicle is equipped with a temperature regulated radiator shutter or modulating fan and its operation is erratic, unstable or questionable, secure the shutter in the open position for the duration of the opacity test.

a. SNAP/FREE ACCELERATION TEST PROCEDURE

This procedure requires a rapid Wide Open Throttle (WOT) no-load acceleration of the engine from low idle to maximum governed no-load rpm with the transmission in neutral.

(i). Verify the zero setting of the opacity meter. Start and operate the engine at idle rpm.

(ii). With the transmission in neutral and the engine at idle rpm, slowly accelerate the engine allowing the engine to reach its maximum stabilized governed speed. Allow the engine to return to idle.

(iii). Place the opacity meter in the peak hold position.

(iv). Perform the acceleration procedure as in Step (ii), but rapidly accelerate the engine. Record on the opacity worksheet the highest or peak smoke opacity reading attained during the procedure.

(v). Return the engine to idle rpm and shut down engine.

(vi). Return opacity meter to normal mode (peak hold off) and note zero shift (deviation) reading. Record the peak opacity value obtain in step (iv) and the meter zero shift on the DVIR form, and proceed to the dynamometer test procedure.

b. DYNAMOMETER TEST PROCECURE

(i). Verify smoke opacity meter is set at zero. Start and operate engine at idle rpm. With the dynamometer in an unloaded mode/condition, select a gear which will allow the vehicle to attain and maintain a no-load vehicle speed of 60 to 70 miles per hour (mph) at wide open throttle (WOT). It is preferred and recommended that vehicle be operated at the lower end of this mph range whenever possible. If vehicle has a maximum road speed that is less than 60 mph, operate vehicle at the highest mph possible. Upon stabilization, maintain speed for at least ten seconds (plus or minus four seconds) and record engine rpm and mph on opacity worksheet..

(ii). While maintaining full throttle (WOT), slowly increase the dynamometer loading until engine rated rpm (plus or minus 15 rpm) is obtained. Maintain this speed/load for at least ten seconds (plus or minus four seconds) and record data on opacity worksheet; engine rpm, smoke opacity, and horsepower (hp).

(iii). Maintain full throttle (WOT) and slowly increase dynamometer loading until engine is at 90% of rated rpm (plus or minus 15 rpm). Maintain this speed/load for at least ten seconds (plus or minus four seconds) and record data on opacity worksheet; engine rpm, smoke opacity, and hp.

(iv). Maintain full throttle (WOT) and slowly increase dynamometer loading until engine is at 80% of rated rpm (plus or minus 15 rpm). Maintain this speed/load for at least ten seconds (plus or minus four seconds) and record data on opacity worksheet; engine rpm, smoke opacity, and hp.

(v). Maintain full throttle (WOT) and slowly increase dynamometer loading until engine is at 70% of rated rpm (plus or minus 15 rpm). Maintain this speed/load for at least ten seconds (plus or minus four seconds) and record data on opacity worksheet; engine rpm, smoke opacity, and hp. This step concludes the engine loading procedure; do not apply additional loading under any circumstances.

(vi). Note: Vehicles with automatic transmissions are allowed one downshift to the next lower gear at any point during the dynamometer lugdown test. If a downshift occurs, continue with the test.

(vii). Slowly remove dynamometer loading while returning engine to idle. Shutdown engine after observing cool down procedure. Note and record residual opacity meter reading on Opacity Worksheet.

(viii). The inspector shall refer to the opacity standards in Section VI of Part B of this regulation.

If the highest opacity reading taken from steps (ii) through (v) exceeds the opacity standard and the opacity meter zero shift exceeds five percent (5%), clean the lenses, zero meter and repeat the dynamometer test procedure starting at step

(I). At least one additional test will be conducted at no cost to the motorist.

If the highest opacity reading taken from steps (ii) through (v) exceeds the opacity standard and the opacity meter zero shift is less than five percent (5%), the vehicle fails the inspection.

If neither the highest opacity meter reading taken in steps (ii) through (v) nor the opacity meter zero shift exceeds the opacity standard, the vehicle passes the inspection.

(ix). The inspector shall then enter the highest opacity reading, the opacity meter zero shift, the pass/fail determination, inspector signature, and other required information on the DVIR form. Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a completed CEC and receive a completed VET which shall be affixed to the lower left corner of the vehicle' s windshield. The inspector shall record the required information on the windshield sticker log.

a. Vehicle Removal From Dynamometer

(i). Detach all test equipment, restraints and remove them from the vehicle.

(ii). If the vehicle is equipped with a radiator shutter or modulating fan which has been secured in the open position prior to testing, restore unit to normal operation.

(iii). Remove vehicle from dynamometer.

D. On-Road Inspection Procedures for Heavy-Duty Diesel Vehicles (Greater than 7500 lbs. E.W.)

1. Test Site Requirements and Conditions

In addition to the prescribed test equipment and other requirements, as set forth by this regulation, a test site will only be considered adequate for on-road opacity testing when there is:

a. Approximately three-hundred (300) yards of sound, smooth, paved test lane in a safe, uncongested area on private property (non-public roads).

b. An ambient temperature between 35°F and 110°F (2°C and 43°C) during any given vehicle test procedure.

c. An opacity inspector licensed by the Department of Revenue and in possession of a valid opacity inspector license.

d. A driver, knowledgeable in the operation of the vehicle to be tested and in possession of a valid operator' s license relative to that vehicle. (Refer to IV.B.3)

2. Vehicle Preparation

Prior to proceeding with the actual opacity testing of the vehicle, the following guidelines must be followed:

a. Verify that the vehicle to be tested meets the program definition of a heavy-duty vehicle (Greater than 7500 lbs. empty weight).

b. Vehicle is to be equipped with a speedometer in good working order.

c. Perform a safety inspection of the vehicle' s brakes, tires and driveline for defects or unsafe conditions.

d. Enter the requested vehicle/owner information on the Diesel Vehicle Inspection Report (DVIR) form.

e. Determine the engine' s rated horsepower and attendant rpm and enter on DVIR form and also on the opacity worksheet.

f. Securely mount the test/reference tachometer and interface it with the approved strip chart recorder which is to be located in the vehicle' s cab. Ensure that all wires and cables do not pose any potential safety hazards.

g. Securely attach the approved/registered opacity meter to the vehicle' s exhaust piping in such a manner that the opacity meter' s emitter and detector light path is perpendicular to the vehicle' s direction of travel and is centered approximately 5" plus or minus 1" from the exhaust outlet. Interface the meter with the strip chart recorder. Follow the calibration procedures prescribed by the equipment manufacturers.

3. Test Procedures

The on-road opacity testing of heavy-duty diesel vehicles involves two separate and distinct test procedures. The two tests are 1) a snap/free no-load-mode acceleration test and, 2) either an on-road loaded-mode acceleration test or an on-road loaded-mode brake lug-down test.

a. SNAP/FREE ACCELERATION TEST PROCEDURE

This procedure requires a rapid Wide Open Throttle (WOT) no-load acceleration of the engine from low idle to maximum governed no-load rpm with the transmission in neutral.

(i). Verify the zero settings of the opacity meter and chart recorder. Start and operate the engine at idle rpm.

(ii). With the transmission in neutral and the engine at idle rpm, slowly accelerate the engine allowing the engine to reach its maximum stabilized no-load governed speed. Allow the engine to return to idle.

(iii). Place the opacity meter in the peak hold position.

(iv.) Perform the acceleration procedure as in Step (ii), but rapidly accelerate the engine. Record on the opacity worksheet the highest or peak smoke opacity reading attained during the procedure.

(v). Return the engine to idle rpm and shutdown engine.

(vi). Return opacity meter to normal mode (peak hold off) and note zero shift (deviation) reading. Record the peak opacity value obtained in step (iv) and the meter zero shift on the DVIR form, and proceed to the on-road test; either acceleration or lugdown procedure, as applicable.

b. ON-ROAD ACCELERATION OPACITY TEST PROCEDURE

(i). Verify smoke opacity meter and chart recorder are set at zero. Start and operate engine at idle rpm.

Select a gear which will permit the vehicle to accelerate under WOT from a moving position (approximately 900 to 1000 engine rpm) up to maximum engine rpm in no less than seven seconds. This step is vital in order to ensure that the engine will be operated in an rpm range and time frame which will allow sufficient time and engine loading in order to accurately monitor the vehicle’ s smoke opacity levels.

(ii). Bring the vehicle to a stop and shutdown the engine. Verify the zero settings of the opacity meter and the strip chart recorder. Clean the monitoring unit as necessary.

(iii). With the transmission in the selected gear (as described in Step (I) and the strip chart recorder in record mode, accelerate the vehicle under WOT from a road speed equivalent of 900 to 1000 engine rpm up to maximum engine rpm. Maintain maximum rpm for a few seconds in order to allow for stabilized conditions.

(iv). Bring the vehicle to a safe controlled stop, shut down engine and discontinue the recording. Note and record on the opacity worksheet, 1) the highest opacity reading observed between maximum engine rpm and 70 percent (70%) rated rpm and, 2) the opacity meter/chart recorder zero shift (deviation) reading.

(v). The inspector shall refer to the opacity standards in Section VI of Part B of this regulation.

(vi). If the highest recorded opacity taken from step (iii) through (iv) exceeds the opacity standard and the opacity meter/chart recorder zero shift (deviation) exceeds five percent (5%), clean the lenses, zero meter and repeat the acceleration test procedure starting at step (iii). At least one additional test will be conducted at no cost to the motorist.

If the highest opacity reading taken from steps (iii) through (iv) exceeds the opacity standard over the required time period, with five percent (5%) or less zero shift, the vehicle fails the inspection.

If neither the highest opacity meter reading taken in steps (iii) through (iv) nor the zero shift exceeds the opacity standard, the vehicle passes the inspection and the inspector shall proceed directly to step (xi).

If the highest opacity meter reading exceeds the opacity standard with five percent (5%) or less zero shift, but for less than the required time period, the vehicle will require additional testing as follows.

(vii). Verify the zero settings of the opacity meter and strip chart recorder. Clean the monitoring unit as necessary.

(viii). Accelerate the vehicle as in step (iii), however, the vehicle' s acceleration must be temporarily restrained (10 $\pm$ 4 seconds) at that rpm point in the procedure where the highest opacity reading was observed. Decreased throttle is not to be used to slow the vehicle' s rate of acceleration. The vehicle' s' s service brakes should be utilized for that purpose. Opacity and rpm must be accurately recorded at this time.

(ix). Bring the vehicle to a safe controlled stop, shut down engine, and discontinue the recording. Note the highest opacity meter reading and the opacity meter/chart recorder zero shift.

(x). If the highest opacity meter reading taken from steps (viii) and (ix) exceeds the opacity standard and the opacity meter/chart recorder zero shift (deviation) exceeds five percent (5%), clean the lenses, zero meter and repeat the acceleration test procedure starting at step (viii).

If the highest opacity reading taken from steps (viii) through (ix) exceeds the opacity standard over the required time period, with five percent (5%) or less zero shift, the vehicle fails the inspection.

If neither the highest opacity meter reading taken in steps (viii) through (ix) nor the opacity meter zero shift exceeds the opacity standard, the vehicle passes the inspection.

(xi). The inspector shall then enter the highest opacity reading, the opacity meter/chart recorder zero shift, the pass/fail determination, inspector signature, and other required information on the DVIR form. vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a completed CEC and receive a completed VET which shall be affixed to the lower left corner of the vehicle' s windshield. The inspector shall record the required information on the windshield sticker log.

C. ON-ROAD BRAKE LUG-DOWN TEST PROCEDURE

(i). Verify smoke opacity meter and chart recorder are set at zero. Start and operate engine at idle rpm.

(ii). Select a gear which will permit the vehicle to attain a road speed of 15 to 25 mph with the engine at maximum rpm, wide open throttle (WOT). Due to the many variables, this gear selection process is basically a trial and error effort. Bring the vehicle to a stop and shut-down the engine.

(iii). Verify the zero settings of the opacity meter and strip chart recorder. Clean the monitoring unit as necessary.

(iv). With the vehicle operating at WOT in the selected gear as described in Step (ii) and the chart recorder in record mode, maintain WOT and slowly begin loading the engine by means of the vehicle' s service brakes. The loading is to be applied linearly throughout an engine rpm range which extends from maximum engine rpm down to 70 percent of the engine' s rated rpm in a time span which encompasses no less than ten seconds.

(v). Note: Vehicles with automatic transmissions are allowed one downshift to the next lower gear at any point during the brake lug-down test. If a downshift occurs, continue with the test.

(vi). Bring the vehicle to a safe controlled stop, shut down engine and discontinue the recording. Note and record on the Opacity Worksheet, 1) the highest opacity reading observed between maximum engine rpm and 70% rated rpm and, 2) the opacity meter/chart recording zero shift (deviation) reading.

(vii). The inspector shall refer to the Opacity Standards in Section VI of Part B of this regulation.

(viii). If the highest opacity meter reading taken from steps (iv) through (vi) exceeds the opacity standard and the opacity meter/chart recorder zero shift exceeds five percent (5%), clean the lenses, zero meter and repeat the brake lugdown test procedure starting at step (iv). At least one additional test will be conducted at no cost to the motorist.

If the highest opacity meter reading taken from steps (iv) through (vi) exceeds the opacity standard over the required time period with five percent (5%) or less zero shift, the vehicle fails the inspection.

If neither the highest opacity meter reading taken in steps (iv) through (vi) nor the opacity meter zero shift exceeds the opacity standard, the vehicle passes the inspection and the inspector shall proceed directly to step (xiii).

If the highest opacity meter reading exceeds the opacity standard with five percent (5%) or less zero shift but for less than the required time period, the vehicle will require additional testing as follows.

(ix). Verify the zero settings of the opacity meter and chart recorder, clean the monitoring unit as necessary.

(x). Again, operate the vehicle as in Step (iv), however restrain the vehicle for ten, plus or minus four, seconds (10 ± 4 seconds) by means of the vehicle's service brakes at that rpm point in the procedure where the highest opacity reading was observed.

(xi). Bring the vehicle to a safe controlled stop, shut down engine and discontinue the recording. Note the highest opacity meter reading and the opacity meter/chart recorder zero shift.

(xii). If the highest opacity meter reading taken from steps (x) and (xi) exceeds the opacity standard and the opacity meter/chart recorder zero shift exceeds five percent (5%), clean the lenses, zero meter and repeat the brake lugdown test procedure starting at step (x).

If the highest opacity meter reading taken from steps (x) and (xi) exceeds the opacity standard over the required time period with five percent **(5)** or less zero shift, the vehicle fails the inspection.

If neither the highest opacity meter reading taken in steps (x) through (xi) nor the zero shift exceeds the opacity standard, the vehicle passes the inspection.

(xiii). The inspector shall then enter the highest opacity reading, the opacity meter/chart recorder zero shift, the pass/fail determination, inspector signature, and other required information on the DVIR form. Vehicles which comply with the inspection procedures and applicable opacity standards shall be issued a completed CEC and receive a completed VET which shall be affixed to the lower left corner of the vehicle's windshield. The inspector shall record the required information on the windshield sticker log.

IV. Qualification of Inspection Stations and Testing and Licensing of Diesel Opacity Inspectors

A. Requirements for Licensing of a Diesel Opacity Inspection Station

1. The following equipment and tools shall be available at Diesel Opacity Inspection Stations for performance of diesel opacity inspections:

a. Smoke opacity meter (see Section II.C) in proper calibration according to the manufacturer’ s guidelines.

b. Chassis dynamometer (see Section II.D). Not required for Heavy-Duty On-Road Test Stations.

c. Photo tachometer (See Section II.E.1).

d. Strip Chart Recorder (See Section II.E.2). Heavy duty on-road test stations only.

e. Neutral density filter for calibration check of opacity meter. (See Section II.E.3).

f. Manufacturer’ s operation , maintenance and calibration manuals for opacity meters and dynamometers must be retained in the inspection area.

g. Certified thermometer, as described in Section II.E.4.

h. Safety restraint equipment, as described in Section II.E.5.

i. Hearing ear protectors.

j. Engine cooling fan.
Required for light-duty inspection stations only.

k. Exhaust removal equipment.

l. Reference materials as required by licensing.

m. Basic hand tools necessary to perform inspection.

2. The station must be a permanent location which meets all applicable zoning requirements to provide for the inspection of diesel vehicles, as licensed, and as defined in this regulation.

3. A licensed diesel emissions inspector is employed and is available to make a proper inspection during all hours the station is open for business.

4. All Diesel Opacity Inspection stations are required to post in a conspicuous location in a clearly legible fashion a sign indicating the fees charged for the initial inspection and first reinspection.

5. Additional requirements for Heavy Duty On-Road Testing Stations

    a. Approximately three-hundred (300) yard of sound, smooth paved test lane in a safe, uncongested area, on private property (non-public roads).

    b. A driver knowledgeable in the operation of the vehicle to be tested and in possession of a valid operator' s license relative to that vehicle.

B. Testing and Licensing of Applicants for Diesel Opacity Inspectors

1. Certificates of Qualification for Diesel Opacity Inspectors

    a. Applications for Certificates of Qualification for diesel opacity inspectors shall be filed with the Air Pollution Control Division, 4210 East 11th Avenue, Denver, Colorado 80220, and the issuance of Certificates of Qualification shall be administered by the Division. Applications for such Certificates of Qualification shall be completed on forms provided by the Division. Before an applicant may be given a Certificate of Qualification, he must comply with the requirements of this section. The Division will notify applicants of the evaluation requirements prior to testing.

2. An applicant must demonstrate knowledge, skill, and competence concerning the conduct of diesel opacity inspections. Such knowledge, skill and competence will be shown by passing a qualification test including, but not limited to, knowledge of the following:

    a. Knowledge of rules and regulations of Diesel Opacity Inspection Program procedures.

    b. Visual inspection procedures of the required emission control equipment for 1991 and newer vehicles.

c. Operation of and proper use, care, maintenance and calibration of the Commission - approved opacity meters, chassis dynamometers, photo tachometers and strip chart recorders.

d. Proper use of and distribution of DVIR forms, Certificates of Emissions Control, opacity worksheets and supplemental documents.

e. Waiver requirements for all diesel vehicles failing the initial emissions inspection.

3. For on-road heavy-duty diesel inspector licenses only, the applicant must possess a valid Colorado Class A operator’ s license.

4. The Division shall issue a Certificate of Qualification to an applicant upon successful completion of the requirements of this section.

5. Requalification Requirements for all Diesel Opacity Inspectors

a. Upon the determination by the Commission of the necessity of technically updating the qualifications for diesel opacity inspectors and, upon development or approval of retraining courses and retesting requirements for diesel opacity inspectors to demonstrate said qualifications, diesel opacity inspectors, or holders of certificates of qualification, shall be required to requalify.

b. Diesel Opacity Inspectors shall be required to requalify within ninety (90) days from the date of written notification by the Division. Said notice shall be mailed to the address of record in the office of the Department of Revenue (Department) charged with licensing of diesel opacity inspectors which notice shall inform the person of the necessity of requalification and the nature of such skills, systems, and procedures requiring the retraining for the continued performance of the opacity inspection. The notice shall give the name and location of training sources approved or accredited for purposes of retraining, the necessity of requalification by a certain date, and the nature and evidence of documentation to be filed with the Division evidencing such requalification, and state that failure to requalify within said period of time shall result in suspension or revocation of the diesel opacity inspector’ s license or certification as described in the Department’ s rules and regulations.

c. The Division shall issue a Certificate of Requalification to any person who has requalified to the satisfaction of the Division and according to the requalification regulation of the Department.

6. Transmittal of Certificates and Issuance of Diesel Opacity Inspector’ s Licenses

The Division shall provide a duplicate copy of any Certificate of Qualification to the opacity inspector authority of the Department of Revenue, and, upon application by any person so certified or recertified, the Department shall issue a diesel opacity inspectors license in accord with the regulations of that department.

7. Lapse of Certificate of Qualification for Diesel Opacity Inspector

A person to whom the Division has issued a Certificate of Qualification, or Certificate of Requalification, who has not been issued a Diesel Opacity Inspector’ s license within six (6) months from the date of issuance of the most recently issued certificate shall be deemed to have forfeited the said certificate and shall be required to reapply if a new Certificate of Qualification is requested.

V. Replacements VETS

In order to issue a replacement verification of emissions test windshield sticker due to windshield replacement, the following procedures are to be followed:

1. A valid vehicle inspection report form or the legible remains of the previous valid windshield sticker matching the vehicle must be presented and verified by the diesel opacity inspector.

2. The original test date is to be determined from the inspection report form or windshield sticker. The replacement sticker is to be punched for the time period which remains from the original inspection date based on the model year of the vehicle.

3. Complete the required information on the back of the windshield sticker as well as the station log. The issuance of the sticker is to be noted as a “Replacement” in the log.

4. The verification of emissions test windshield sticker is to be affixed to the lower left-hand corner of the vehicle windshield and placed so as not to block the vehicle identification number.

A replacement windshield sticker may only be issued by a licensed diesel opacity inspector. A fee of no greater than $2.50 may be charged.

VI. Opacity Standards for Diesel-Powered Motor Vehicles Subject to Part B of This Regulation

A. In order for a vehicle (owner) to obtain a valid Certification of Emissions Compliance, the exhaust opacity from the diesel-powered motor vehicle subject to the annual Diesel Opacity Inspection Program may not exceed the following maximum opacity level.

B. The smoke opacity standard for all naturally aspirated light duty diesel vehicles subject to opacity tests under Part B of this regulation shall be forty percent (40%) opacity for (5) five seconds. The smoke opacity standard for turbocharged light duty vehicles shall be thirty-five percent (35%) for five (5) seconds.

For all heavy duty vehicles subject to opacity tests under Part B of this regulation, the opacity standards shall be thirty-five percent (35%) and twenty percent (20%) for naturally aspirated and turbocharged diesel vehicles respectively for five (5) seconds.

C. Peak opacity (snap/free acceleration) tests shall be a component of the heavy duty diesel vehicle tests and conducted following the procedures specified in Section III, Part B of this regulation, and recorded on the Opacity Inspection form, but no peak opacity standard shall apply.

D. Opacity Standards for Diesel Vehicles with Non-Original Engines (Engine Changes)

For those vehicles in which the original engine has been replaced, the opacity standards and applicable emissions control equipment for the year and model of the vehicle body/chassis, shall apply.

Those diesel-powered vehicles titled/registered as model year 1991 and newer, that were assembled by other than a licensed manufacturer such as a kit-car, and registered/titled according to Section(s) 42-6-107.5 and/or 42-6-117, the applicable emissions control equipment will be based upon a determination by technical center personnel of the vintage of the vehicle engine. An affidavit may be issued by the technical center personnel and the year of the engine shall be presumed to be that stated by the vehicle owner unless it is determined by center personnel, after physical inspection of the vehicle engine, that the year of the engine is other than stated by the owner. The emissions standards for a vehicle of this classification will be determined by the model year of the vehicle as registered/titled.

Part C - Standards for Visible Pollutants from Diesel Engine Powered Vehicles (Operating on Roads, Streets and Highways)

A. No person shall emit or cause to be emitted into the atmosphere from any diesel-powered motor vehicle weighing 7,500 pounds and less, empty weight, any air contaminant, for a period greater than five (5) consecutive seconds, which is of such a shade or density as to obscure an observer' s vision to a degree in excess of 40% opacity.

B. No person shall emit or cause to be emitted into the atmosphere from any diesel-powered motor vehicle weighing more than 7.500 pounds, empty weight, any air contaminant, for a period greater than five (5) consecutive seconds, which is of such a shade or density as to obscure an observer' s vision to a degree in excess of 35% opacity, with the exception of subpart "C".

C. No person shall emit or cause to be emitted into the atmosphere from any naturally aspirated (non-turbocharged) diesel-powered motor vehicle weighting more than 7,500 pounds, empty weight, operated above 7,000 feet (mean sea level) any air contaminant for a period greater than five (5) consecutive seconds, which is of such a shade or density as to obscure an observer' s vision to a degree in excess of 40% opacity.

D. Any diesel-powered motor vehicle exceeding these requirements shall be exempt for a period of 10 minutes, if the emissions are a direct result of a cold engine start-up and provided the vehicle is in a stationary position.

E. These standards shall apply to motor vehicles intended, designed, and manufactured primarily for travel or use in transporting persons, property, auxiliary equipment, and/or cargo over roads, streets, and highways.

F. Enforcement of these emission standards shall be by peace officers and environmental officers pursuant to the authority of Section 18-13-110 C.R.S., or Section 42-4-319 C.R.S. within AIR program boundaries.

PART D

Statement of Basis, Specific Statutory Authority and Purpose

I. Amendment to Parts A and B, and creation of this Part D adopted January 15, 1998.

BASIS AND PURPOSE

Regulation No.12 establishes programs for Diesel Opacity Inspections and for Diesel Fleet Self-Certification. Both programs require annual emissions inspections for diesel vehicles covered by such programs. In 1997, the General Assembly revised § 42-4-406 (1) (b) (II), C.R.S. to provide that new diesel vehicles do not need to be inspected until such vehicles are two years old, or upon a transfer of ownership. The revisions adopted on January 15, 1998 create such an exemption from inspection requirements for new diesel vehicles.

FEDERAL REQUIREMENTS

The Diesel Inspection Programs established in Regulation No.12 are federally required because the State took emission reduction credit for such programs in the Denver element of the State Implementation Plan for particulate matter (Denver PM_{10} SIP). However, federal law does not expressly require the State to have opacity or emissions inspection programs for diesel vehicles and such programs are not required for areas outside of the Denver PM_{10} non- attainment area.

Federal law is entirely silent on the question of whether the creation of a two-year exemption from inspection requirements for new diesel vehicles will change the emissions reduction credit associated with such programs. Since federal law is silent on this issue, the Commission cannot determine whether federal law permits the State to create an exemption for such vehicles for more than the two years established by § 42-4-406 (1) (b) (II), C.R.S., or whether such exemption is not required by provisions of the Federal Act or is otherwise more stringent than requirements of the Federal Act. Nevertheless, the January 15, 1998 revisions should be submitted to EPA as a revisions to the Denver PM_{10} SIP. The submission of this revision to EPA is required in order to give effect to § 42-4-406 (1)(b)(II) in federal law. Failure to include the January 15, 1998 revisions in the SIP would result in more stringent SIP provisions.

The Division intends to propose a revision to Regulation No.12 to remove the Diesel Inspection Programs for Colorado Springs, Greeley, and Fort Collins from the SIP.

STATUTORY AUTHORITY

Specific statutory authority for the amendments is provided in §§ 42-4-403(1) and 42-4-406 (1)(b)(II).

FINDINGS PURSUANT TO § 25-7-110.8

The January 15, 1998 rule revisions relax existing inspection requirements for diesel vehicles and are not intended to increase the effectiveness of the relevant programs in reducing air pollution. Furthermore, the Commission has no discretion under state law not to create such an exemption for new diesel vehicles. For these reasons the determinations enumerated in §25-7-110.8 (1), C.R.S. do not apply.

II. Amendments to Parts A, B and D adopted March 16, 2000.

Basis and Purpose

Regulation No.12 establishes as a control strategy, the Diesel Opacity Inspection and the Diesel Fleet Self-Certification programs. Both programs require periodic inspection of both light-duty and heavy-duty diesel powered vehicles. Emissions related repairs are required of those vehicles that do not comply with inspection requirements. The intended purpose of Regulation No. 12 is to reduce diesel vehicle emissions. The Diesel Inspection and Maintenance (Diesel I/M) Program is one of the control measures relied on to demonstrate attainment of federal requirements in the Denver PM_{10} State Implementation Plan (SIP).

The rule revision removes the program areas of Larimer, El Paso and Weld counties out of the Denver element of the PM_{10} State Implementation Plan. Pursuant to Section 42-4-304 (20), C.R.S., the Diesel I//M Programs remain as state-only programs for these same areas. The rule revisions have no effect of parties regulated under Regulation No. 12. The revisions also correct the statutory reference defining the areas of applicability for inclusion in Diesel I/M Programs as well as the statutory references that specify eligible vehicles under the Diesel Opacity Inspection and Diesel Fleet Self-Certification Programs.

Federal Requirements

The diesel inspection programs established in Regulation No. 12 are federally required because the State took emissions reduction credit for such programs in the attainment demonstration for the year 1995 contained in the Denver element of the State Implementation Plan for particulate matter (Denver PM_{10} SIP). However, federal law does not expressly require the State to have opacity or emission inspection programs for diesel vehicles.

The Diesel I/M Program in its entirety was included in the SIP. The area of applicability in Regulation No. 12 also includes areas outside of the Denver non-attainment area, El Paso, Larimer and Weld counties. The Diesel I/M Program is not necessary to meet minimum federal requirements in areas outside the Denver non-attainment area and therefore should not be included in the SIP.

Statutory Authority

Specific statutory authority for the amendments are Sections 25-7-105.1, 25-7-105 (a)(1), and 42-4-403, C.R.S.

Finding Pursuant to Section 25-7-110.8, C.R.S.

The March 16, 2000 rule revisions have no effect on the existing inspection requirements for diesel vehicles and does not alter the effectiveness of the programs in reducing air pollution. The Commission is obligated under Section 25-7-105.1, C.R.S. to remove those elements under the SIP that are not federally required. The Diesel I/M program shall be retained as a state-only program for those areas outside of the Denver non-attainment area. For these reasons, the determinations enumerated in Section 25-7-110.8(1), C.R.S. do not apply.

Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 6

Suggested Protocol for ‘DT80’ Full Acceleration 80km/hr Cruise Test

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

March 1999

Suggested Protocol for
'DT80' Full Acceleration, 80 km/hr Cruise Test

The DT80 test cycle has two basic phases; a smoke transient cycle (acceleration modes) and a NOx steady state phase (cruise mode). Within the two cycles there are three operating modes; idle acceleration and cruise. These are outlined below.

Idle modes: (AB,DE,GH in figure 6.1(II))
The idle modes are used only to simulate real world urban driving conditions, not to measure smoke opacity or NOx emissions. They provide diagnostic information and assist in pre-conditioning the combustion chamber prior to acceleration.

Data collected during the Drive Cycle phase of the project identified that a diesel vehicle spends a considerable amount of time in the idle condition. During this state, diesel engines if worn or poorly maintained will build up excessive fluids (oil and fuel) in the combustion chamber that during later acceleration will be emitted primarily as particulate matter and smoke. Faults such as worn or sticking fuel injectors, leaking seals and worn oil rings may be a cause of such emissions.

Acceleration modes: (BC, EF, HI) – Smoke opacity test modes
The vehicle is to be accelerated as quickly as possible at wide open throttle, through to top gear and a speed of 80km/hr. This is typical of acceleration from a set of traffic lights following a position of rest. The speed of 80km/hr typifies speed limits of urban highways and is high enough to allow the vehicle to be evaluated throughout the gears.

Three acceleration modes are performed. The first, following a long 60s idle provides information on potential leaking injectors, worn seals etc while the second follows a short 10s idle placing more emphasis on the condition of the turbo charger (leaks, lagging etc) and air intake system. The third acceleration allows for averaging of the acceleration modes as described in SAE J1667 and pre-conditions the combustion chamber (raising temperatures and clearing any build up of soot) prior to measuring NOx during the cruise mode.

An opacity trace during each acceleration mode is to be recorded for diagnostic purposes only. An opacity test result is calculated i.a.w SAE J1667 i.e. the average of the corrected maximum 0.5s average smoke values from the three acceleration modes. NOx is not measured during acceleration modes.

Cruise mode: (IJ) NOx test mode
Following the third acceleration the vehicle is to be maintained at a cruise speed of 80km/hr for 60 seconds. This speed ensures combustion chamber conditions (temperature and pressure) are conducive to the formation of NOx. The first 50 seconds of the mode are for stabilisation of combustion chamber conditions and to provide a means of reducing the potential of soot entering the NOx analyser. During the last 10s, NOx is measured and the test result calculated by averaging the readings.

An opacity trace is recorded during the complete (60second) cruise mode for diagnostic purposes.

Test cycle

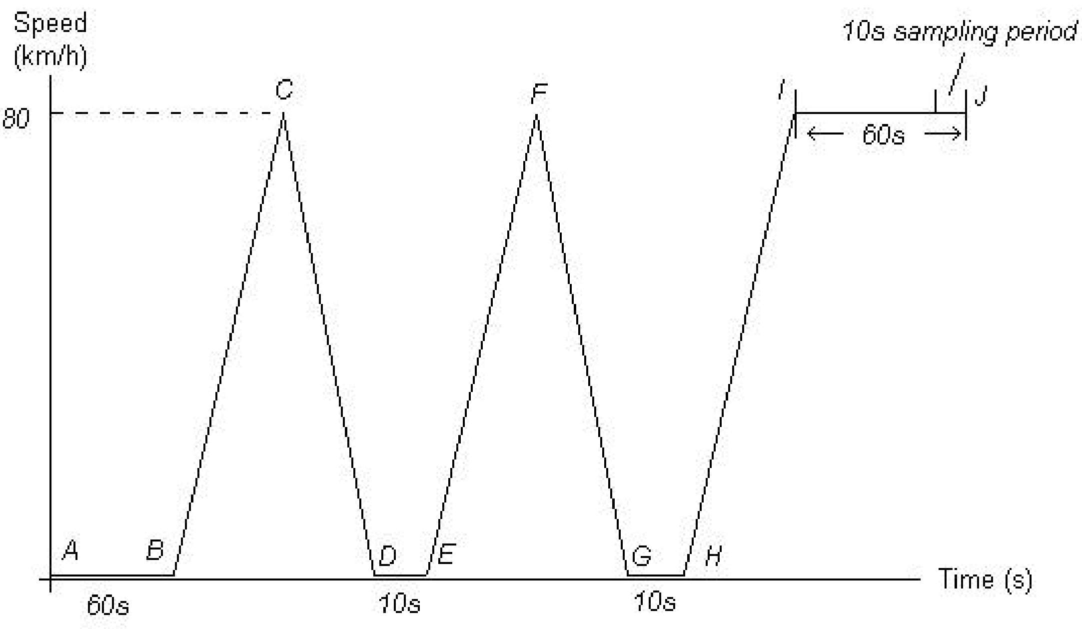


Figure 6.1(II): Diesel Transient 80 (DT80) test cycle

A Following pre-conditioning, idle the vehicle with brake on and in neutral gear for 60 seconds, then release brake and engage first gear (forward gear) in readiness for acceleration at point B. No measurements are to be recorded during idle.

B With dynamometer load and simulated vehicle inertia set, accelerate the vehicle at ‘wide open throttle’ (WOT) to a vehicle speed of 80km/hr. Change gears as required during the mode until top gear is achieved. Measure smoke opacity during the acceleration (point B to C)

C Having attained 80km/hr, apply brakes and decelerate back to standstill, declutching as normal.

D With brakes on, and in neutral gear, maintain idle for 10 seconds.

E Repeat steps B, C and D as shown on figure 6.1(II) as points E, F and G.

H Accelerate the vehicle again to 80 km/hr as previously performed at points B and E.

I Maintain 80km/hr, in top gear, for 60 seconds. Record smoke opacity (for diagnostic purposes) during the cruise mode (I to J) and measure NOx emissions during the last 10 seconds of the mode. The average reading during the last 10 seconds is recorded as the NOx result.

J At point J the test is complete. Decelerate the vehicle by applying brakes to standstill, declutching as normal. Apply the parking brake and engage neutral gear.

Load

Vehicles are to be tested at an inertia load equal to their TARE weight plus the difference between the TARE weight and GVM ie the TARE plus half the permissible payload.

Pre-conditioning

Establish normal engine operating temperatures and pressures.

Test Equipment

Smoke shall be measured using an opacity meter of the type specified within SAEJ1667. NOx shall be measured using a laboratory or workshop grade analyser.

Test Results

Smoke Opacity result: calculated in accordance with the method specified in SAE J1667-
The average of the corrected (ambient conditions, optical path length, wavelength and bessel filter algorithm) maximum 0.5second average smoke opacity values from the three acceleration modes.

NOx result: the average reading (ppm) obtained during the last 10 seconds of the cruise mode.

Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 7
NSW EPA Report - Analysis of Diesel Vehicle Smoke Enforcement Program

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

March 1999

NSW EPA's Diesel Vehicle Smoke Enforcement Program

Description:

In order to obtain real world data on which particular faults were directly responsible for causing high emissions, the records were analysed of vehicles reported for breaches of the "10 second smoke rule" under the Clean Air Act. These records are held by the EPA's Motor Vehicle Enforcement Unit. A number of these records were for vehicles reported by "non-authorised" Officers. In this case, the vehicles were waived from prosecution on condition that they provided evidence that corrective action had been taken to prevent further smoke emissions. This evidence was a form completed by a certified mechanic stating the cause of the problem and detailing the remedial work performed. It should be noted that mechanic's statements were not disputed and the vehicles were therefore not retested.

A random selection of 304 of these forms, issued between 1993 and 1997, were analysed to ascertain the most common causes of smoke emissions.

The information on the forms was reviewed and the causes of the high emissions divided into nine categories, each describing the fault or defective component as stated by the mechanic. The categories were:

- Fuel contamination
- Air intake and/or turbocharging problems
- Major engine and cylinder head problems
- Vacuum and/or exhaust brake problems
- Dirty or blocked air filters
- Dirty or blocked fuel filters
- Incorrect fuel pump timing or fuel screw setting
- Dirty or worn fuel injectors
- Other causes, eg driving technique

In order to see if there was any relationship between the occurrence of these problem and vehicle type, the information was further divided into four vehicle type categories. These four vehicle type categories were amalgamated from the ADR vehicle categories and categories used previously in this project to define vehicle types. The categories are as follows:

- Passenger vehicles and light trucks/vans <3.5t GVM
- Medium trucks/vans 3.5-12t GVM
- Heavy trucks and prime movers >12t GVM
- Buses > 12t GVM

Analysis:

The information collected has been collated in table 7.1(II) and plotted in figure 7.1(II)

Table 7.1(II): Numbers of Emission Related Faults for Each Vehicle Category

	Fuel Injectors	Fuel Pump	Air Filter	Fuel Filter	Vacuum Exhaust Brake	Engine/ Cylinder Head	Air Intake /Turbo	Contam Fuel	Other
vehicles <3.5t GVM									
Number of faults	32	27	35	19	2	6	0	0	2
% of total faults	26	22	28	15	2	5	0	0	2
vehicles 3.5-12t GVM									
Number of faults	56	46	44	25	5	13	1	3	1
% of total faults	29	24	23	13	3	7	1	2	1
vehicles >12t GVM									
Number of faults	19	16	22	8	0	6	2	3	2
% of total faults	24	21	28	10	0	8	3	4	3
Buses >3.5t GVM									
Number of faults	11	8	11	5	0	4	0	0	0
% of total faults	28	21	28	13	0	10	0	0	0

Using the table and chart, the following information on emission related faults was obtained:

- the breakdown of vehicle faults was very similar across all vehicle categories.
- the most common faults stated as a cause of high emissions were associated with the fuel pump, fuel injectors and air filter. These three areas, in approximately equal proportions, together accounted for 73 – 77% of total emission related faults.
- based on the sample of 304 vehicles, the most common vehicle categories reported for excessive smoke emission were medium trucks, followed by light vehicles, heavy trucks and then buses.

This data however, does not account for the relative numbers of vehicles in existence in each category and consequently the categories that are likely to have the highest proportion of vehicles with emission related faults. For instance it would be expected that a greater number of medium trucks than buses would be reported due solely to the greater number of medium trucks on the road. Therefore, the data in table 7.1(II) was "normalised" according to actual numbers of vehicles registered in the Sydney Metropolitan Area. This was done by dividing the product of the number of faults and the total number of vehicles registered in Sydney, by the number of vehicles in each of the four categories. The normalised data is presented as a chart in figure 7.2(II).

- According to the normalised data, the vehicle categories likely to have the highest proportion of vehicles with emission related faults were buses and medium trucks, followed by heavy trucks. The light vehicle category was likely to have the smallest proportion of vehicles with emission related faults.

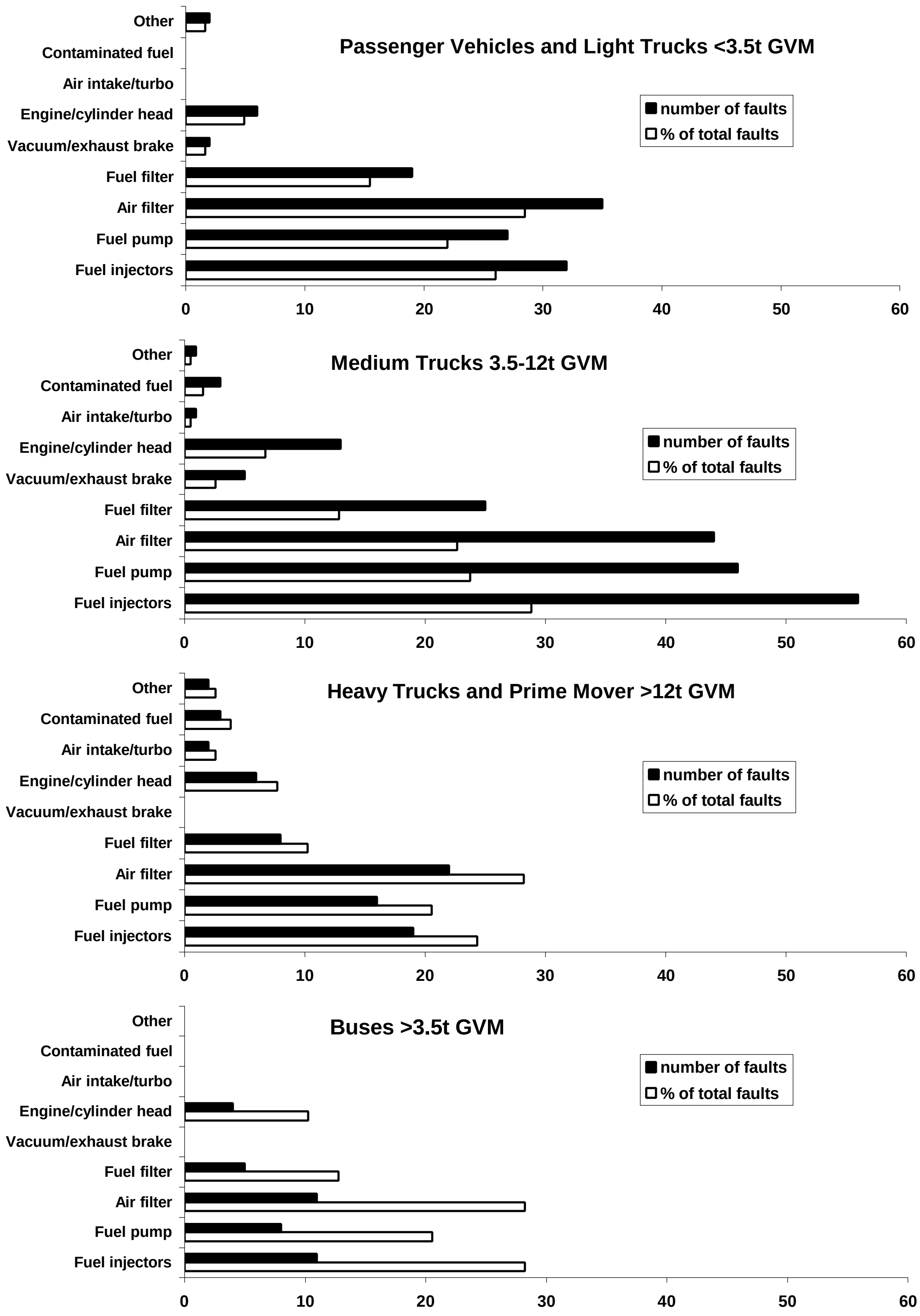


Figure 7.1(II): Numbers of Emission Related Faults for Each Vehicle Category

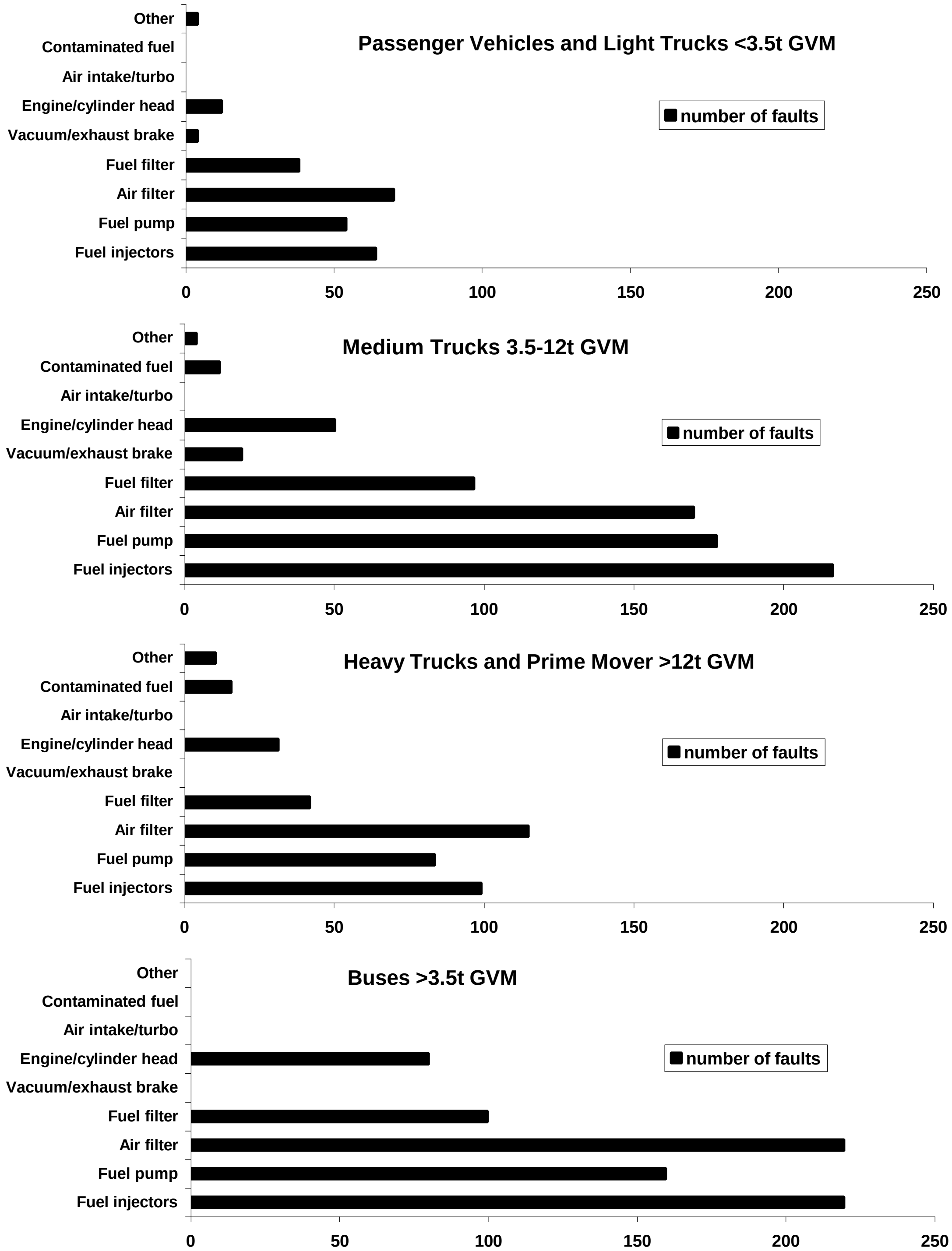


Figure 7.2(II): Numbers of Emission Related Faults 'Normalised' to the Number of Sydney Registered Vehicles in Each Vehicle Category

Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance
Phase 1: Urban Drive Cycle Development

Volume 2

Attachment 8
NSW EPA Report -
Industry Focus Groups

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

March 1999

Industry Focus Groups:

In order to obtain an industry perspective on the causes of high emissions, it was decided to organise focus group discussion meetings with representatives of the transport and repair industry. Two separate Focus Group discussions were held, on 12 and 13 November 1998.

The first group was organised with assistance from the Institute of Automotive Mechanical Engineers (IAME), and comprised a number of their members who were involved principally in maintenance and repair of diesel vehicles.

The second group was organised with assistance from the Road Transport Forum, and comprised technical managers of haulage and bus companies together with representatives of their industry associations.

The information obtained and viewpoints of the two focus discussion groups are outlined in the following sections:

IAME Focus Group:

Factors contributing to excess smoke emissions:

The discussion group identified a number of factors contributing to excess smoke emissions from diesel vehicles.

Fueling system calibration and tampering

As the industry is highly competitive, operators are driven by a desire to reduce delivery times by increasing vehicle speeds, thereby maximising profitability. The focus group suggested that a few operators tamper with the fueling system or exert pressure on diesel mechanics to achieve greater engine power by increasing the engine fuel supply in excess of specification, thus over-fueling the engine. Although over-fueling will often improve the performance of the vehicle in terms of speed and acceleration this is frequently at the expense of increased smoke emissions. Deliberate over-fueling was considered to be more common with older vehicles which have a lower power to weight ratio.

Most diesel mechanics will always ensure a pump is within specification as the workshop could be legally liable for not so doing. Many workshops are also bound by the codes of conduct of the Australian Association of Diesel Specialists to which they are affiliated. However, the specifications set by the manufacturers often have a certain amount of leeway allowing the fuel rate to be set to the higher end of the manufacturer’s tolerances. Setting fuel rates to the maximum allowed by the specification is common practice in the repair industry as customers place prime importance on achieving maximum power and speed rather than low emissions.

After the workshop has calibrated the fuel pump to the correct specifications, the settings are usually sealed using lock wire to avoid tampering. However there is evidence that a few operators will break the wire in order to tamper with the fuel settings and have even managed to adjust the settings without actually breaking the seal.

Maintenance

Lack of proper vehicle maintenance was also identified as a cause of smoke emissions. This problem is greater amongst the smaller owner-driver operators compared to the large fleet operators. For economic reasons the smaller operators will often ignore emission problems and would rather pay an occasional penalty for a vehicle smoke infringement than pay to have their vehicle repaired. Larger operators on the other hand are often subject to industry standards, such as those required to maintain a bus operator's license and must heed the commercial considerations of portraying a "clean" image.

Driver behavior

Drivers often do not look for smoke and even if they do, may not report the problem. The group held the view that even new vehicles will emit smoke when driven hard. Drivers need to be educated into maintaining engine speed within the maximum torque range and avoid over-revving the engine.

Driving patterns

Certain types of vehicle by virtue of their use patterns are more likely to emit smoke than others. Buses for instance typically have a use pattern of frequent accelerations, short periods of cruising, frequent decelerations and long periods of idle. This pattern is more likely to cause excess smoke than the typical patterns of trucks, which include longer periods of constant speed driving.

Fuel quality

Poor quality fuel can contribute to excess smoke by causing fuel injectors to become blocked. The group felt that certain additives added to the fuel by suppliers in the past had been beneficial in maintaining clean engines. Their removal coincided with an increase in the occurrence of fuel injector problems although there is some suggestion that, as a result of complaints, they may be reintroduced. Improper storage of fuel can also cause problems with fuel quality. Waxing and formation of fungus in storage tanks can occur, though this can be reduced by the use of certain additives.

Testing to identify causes of excess smoke

Engine components causing excess smoke emissions:

The group identified a number of engine components and commented on faults that could produce excess smoke emissions:

- **Fuel injectors:** Faulty fuel injectors are often the first component to be suspected for causing smoke emissions. Injectors can become worn or dirty resulting in a distorted spray pattern. Variation between the performance of a set of injectors will decrease engine power and increase smoke emissions.

- **Fuel pump:** Incorrectly calibrated fuel pump timing or wrongly adjusted governor stops can cause excess smoke emissions
- **Air cleaners:** Blocked air cleaners or restrictions in the inlet air path are likely to increase smoke emissions.
- **Turbo-charging:** Faults in the turbocharging system can cause high emissions of smoke.
- **Fuel filter:** Restricted fuel filters can increase smoke emissions. The fuel filter and injectors should be serviced at the same time.
- **Major engine faults:** Worn piston rings, valves and valve seals will produce excess smoke emissions. These faults are usually detected using a compression test, and are expensive to repair (ie engine overhaul usually required).

Engine components causing high oxides of nitrogen (NO_X) emissions

The group suggested a number of components where faults could contribute to high NO_X emissions:

- Incorrect Pump Timing
- Defective Cooling System
- Defective Intercooler

It was apparent however that NO_X emissions are not usually taken into account when testing to determine if an engine has been satisfactorily repaired.

Current testing procedures:

After vehicles have been serviced or repaired, the normal way in which performance of the engine performance is usually checked is by on-road driving. After the vehicle has been warmed up, it is driven on the road with as much load as possible and the driver watches for signs of smoke. It is rare for vehicles to be checked using a chassis dynamometer as few workshops have access to this facility.

Potential non-intrusive inspection methods:

A number of plausible inspection methods were proposed by the focus group:

- **Smell of exhaust gas:** Diesel mechanics currently assess the efficiency of combustion in a diesel engine by the odour of the exhaust emission. (This is however not recommended due to health concerns)
- **Inspect fuel pump seals:** Inspecting the anti-tampering seals on the fuel pump for signs of unauthorised adjustment.
- **Checking smoke colour/quantity:** A visual assessment of the level of smoke emissions made by a vehicle.
- **Checking service records:** Checking the service records of a vehicle to see if adequate maintenance has been performed.

- **Crankcase blow-by:** Crankcase blow-by could be assessed to check for major engine wear.
- **Air intake system:** A visual inspection could be carried out to see if any restrictions or blockages are present or the if air filter is dirty.

Potential emission tests:

The driving conditions under which diesel vehicles are most likely to emit smoke, is uphill and under load. It was generally agreed therefore that stationary free-acceleration tests will not detect vehicles that emit smoke under these conditions and a dynamometer test would be more suitable. However steady state dynamometer tests will not provide sufficient information.

It was generally agreed that if a dynamometer test was to be used, a suitable driving cycle could follow that illustrated in figure 8.1(II). Smoke conditions would be monitored over the cycle.

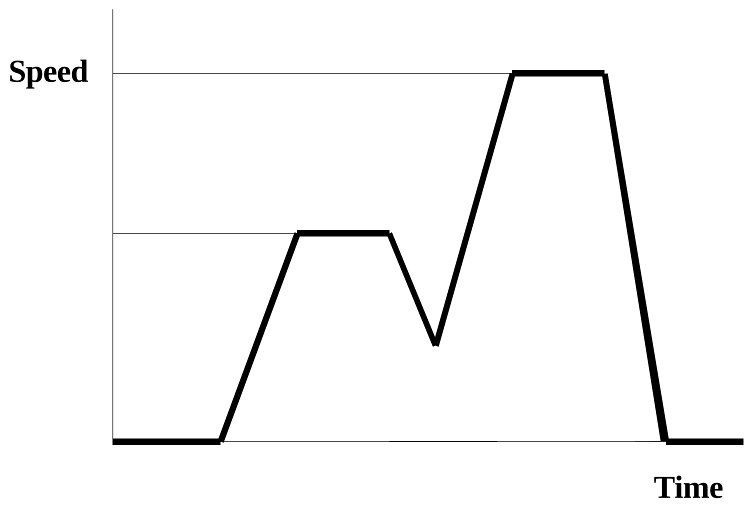


Figure 8.1(II): Suggested drive cycle for dynamometer emissions testing

This driving cycle includes periods of acceleration which are likely to detect fuel supply problems (injector and pump) together with periods of steady state driving which should identify air inlet path restrictions (air cleaner).

The acceleration periods would also identify high levels of NO_X.

Technical Managers' Focus Group

Factors contributing to excess smoke emissions:

Type of vehicles and operators:

Several Focus group members suggested that excess smoke emissions were mainly confined to smaller trucks operated by small companies and "tradesman". This type of truck is frequently over-loaded and poorly maintained. The larger vehicles (over 20t GVM) which are typically used by fleet operators, tended to be of a much more modern design with electronically managed engines. This type of vehicle is inherently designed to emit less smoke and less likely to deteriorate in service. Large fleet operators are also required to use clean vehicles by their customers who are keen to promote a "clean" image and will not permit their trailers to be transported by smoky vehicles.

Buses:

Suburban buses have a stop start duty cycle which can create high emissions. Furthermore, the economics of operating many "local" routes does not allow for the purchase of newer vehicles with electronically controlled engines and these fleets are therefore typically made up of old second hand buses. Though these vehicles provide reliable service, they are often under-powered and so it is difficult for the driver to avoid lugging the engine on occasions where the vehicle is under heavy load.

Tampering:

The group felt that tampering with electronically managed engines was rare. However, it was theoretically possible to change and reprogram engine management control modules in order to increase power, torque and fuel economy without regard for emissions.

Fuel quality:

Some members of the group felt that poor quality fuel was a significant factor in creating high smoke emissions and that commercial fuel available in Australia needed to be of a better standard. Others however indicated that they buy fuel from one supplier and have experienced no problems. It was also pointed out that some operators chose to buy cheap fuel aware of its poor quality or buy a bulk summer or winter blend for use all year round. Blending of used engine sump oil into diesel fuel was not thought to be a cause of high emissions and was widely practiced.

Testing to identify causes of excess smoke

Engine components causing excess smoke emissions:

One member of the focus group provided a list of engine components and faults that could produce excess smoke emissions:

- **Fuel injectors:** eg use of the wrong type of injector, incorrect calibration, injector "leak-by" and broken springs.
- **Fuel pump:** eg puncture of the air ratio solenoid diaphragm, aeronoid malfunction, worn pump check valves, calibration altered from specifications (tampering) and incorrect fuel pressure.
- **Engine:** eg worn cylinder rings causing oil by-pass and leaking cylinder head gasket.
- **Air intake:** eg blocked air intake, worn turbo causing oil by-pass, installation of wrong turbo, boost pressure sensor malfunction and leaks in the intercooler/ aftercooler/ hose from air inlet to compressor.
- **Engine management system:** Incorrect software introduced to increase power.

Non-intrusive tests:

It was widely agreed that it is not possible to detect all problems by simply a visual check. Problems with fuel injectors and the fuel pump normally require removal before faults can be diagnosed. Despite this a number of visual checks were suggested which could be performed with a minimum of disturbance to engine components:

- Check condition of air filter and air inlet system to see if dirty or blocked
- Check seals on fuel pump and suspect tampering if seal is broken
- Check for missing parts
- Check for blue smoke indicating oil by-pass
- Check body of turbocharger for oil leaks
- Check integrity of intercooler and compressed air inlet pump hoses

Fuel consumption records:

A number of fleet managers keep records of fuel consumption for their vehicles. Where a truck shows an increase in fuel consumption relative to other similar trucks in the fleet, the cause can be investigated and corrective action taken. It is likely that this will contribute to the minimisation of smoke emissions. However small operators are unlikely to keep such precise information on fuel usage.

'10-second Smoke Rule':

The group criticised the present '10-second smoke rule' for a number of reasons:

- Smoke emissions may not be related to the vehicle but to driving technique, driving conditions or fuel quality. All vehicles will emit constant smoke when lugged up a hill.

- The actual test was very subjective, with no conclusive definition of what constitutes dark smoke and no evidence which can be challenged when a subsequent check of the vehicle does not identify the problem.
- Too much time has elapsed between the offence and receiving the infringement notice for the cause to be investigated if the problem was related to fuel quality, driving conditions or driver behavior.

It was suggested that the observation of a smoky vehicle should be used to identify vehicles that could then be subjected to further testing to ascertain whether a smoke problem existed. It was also felt that a different standard should be applied to older mechanically controlled vehicles than applied to newer electronically controlled vehicles.

Stationary smoke tests:

Although less subjective than the ‘10-second rule’ when readings are obtained using an opacity meter, stationary free-acceleration testing does not provide a true indication of whether a vehicle will emit excess smoke under load. This is especially true for vehicles with an electronic engine management system that will control a vehicle differently when in neutral compared to when in motion.

Control of NOx emissions:

High NOx emissions were perceived to be a problem with modern electronically controlled engines and not with older engines. A check of the engine components, cooling system, turbocharger operation, boost pressure and intercooler was considered to be the best way to minimise NOx production.

It was also generally believed that NOx emissions were mainly the result of engine design and apart from the checks, little can be done to reduce them.

Transient test:

To test a vehicle for both smoke and NOx, it is necessary to check the emissions from the vehicle through a full range of power and torque settings. A possible dynamometer test cycle was discussed which is presented in figure 8.2(II)

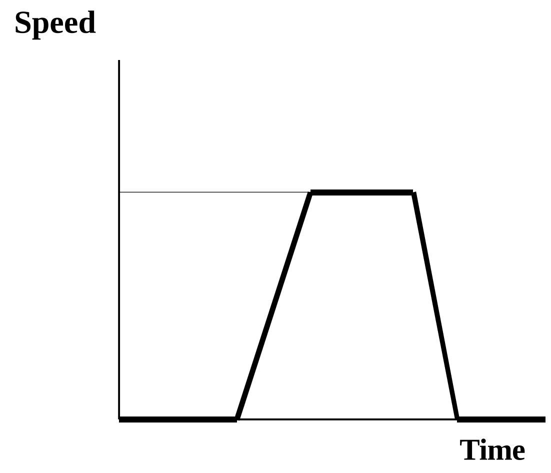


Figure 8.2(II): Suggested Transient Dynamometer Based Emission Drive Cycle

Implementation of in-service testing of diesel vehicles:

Fleet operators did want any new procedure requiring centralised annual compliance testing introduced, having recently succeeded in introducing their “alternative compliance procedure” as an alternative to the annual RTA re-registration inspection.

If testing was to be carried out, the operator should be told the result of the test and be given the responsibility of detecting the problem and taking appropriate corrective action. There was considerable opposition to suggestions of test inspectors performing fault diagnosis. It was felt that inspectors could easily misdiagnose a fault resulting in the operator wasting time and money trying to fix a wrongly identified problem.

It was suggested that a centralised testing facility may however have a place in testing vehicles reported for excess smoke emissions under the 10 second smoke rule or vehicles where engine control seals were found to have been tampered with.