Heavy Duty Transit Bus Emissions Test Protocol

Revised as of March 15, 2008

Revision History

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1. DEFINITIONS

2. ABBREVIATIONS

ABS – Antilock braking system
ASTM – ASTM International (formerly American Society for Testing and Materials)
CFR – Code of Federal Regulations
CFV – critical flow venturi
CH_4 – methane emissions
CNG – compressed natural gas
CLD – chemiluminescent detector
CO – carbon monoxide emissions
CO_2 – carbon dioxide emissions
COV – Coefficient of variation
CVS – constant volume sampling
CW – Curb Weight
EFC – electronic flow compensation
ESS – energy storage system
EPA – Environmental Protection Agency
FID – flame ionization detector
GC-FID – gas chromatograph-flame ionization detection
GAWR – Gross Axle Weight Rating
GVWR – Gross Vehicle Weight Rating
HFID – heated flame ionization detector
HVAC – heating ventilation and air conditioning
LNG – liquefied natural gas
MAN – Manhattan test cycle
MAP – Manifold air pressure
MAT – Manifold air temperature
OCTA – Orange County Transit Bus Cycle
NDIR – non-dispersive infrared
NEC – net energy change
NIST – National Institute of Standards and Technology

NMHC – non-methane hydrocarbon emissions

NO – nitric oxide

NOx – oxides of nitrogen emissions

NO$_2$ – nitrogen dioxide

OCTA – Orange County Transit Bus Cycle

PDP – positive displacement pump

PM – particulate matter emissions

PTFE – Polytetrafluoroethylene

SAE – Society of Automotive Engineers

SCR – Selective Catalytic Reduction

SOC – state of charge

SSV – subsonic venturi

T90 – response time from 0% to 90% of full-scale deflection

TCS – Traction control system

THC – total hydrocarbon emissions

3. TEST OBJECTIVE

The objective of this test is to provide accurate, uniform, reproducible and comparable exhaust emissions data for transit buses. It should be noted that most heavy-duty transit buses tested under this protocol will be powered by engines that are certified separately for emissions. The engine certification procedure appears in The Code of Regulations Title 40 Part 86 Subpart N (40 CFR 86) [1]. The results from this emissions test bear no relation to the heavy-duty engine emissions certification test procedure mandated by the Environmental Protection Agency (EPA) and are expressed in different units. This test protocol, as designated here, defines procedures for measuring exhaust emissions from a fully integrated transit bus while the vehicle is operated over specified driving cycles on a chassis dynamometer. This test protocol is applicable to all heavy-duty straight-frame and articulated transit buses including buses with conventional drive trains and buses with hybrid-drive systems. The test protocol was developed primarily to measure the emissions from new model transit buses as part of the United States Department of Transportation – Federal Transit Administration New Model Bus Testing Program but is applicable to emissions testing of transit buses in general.

The test protocol was developed with the guidance of 40 CFR Part 86 [1] and Part 1056 [3], EPA420-P-07-003 “SmartWay Fuel Efficiency Test Protocol for Medium and Heavy Duty Vehicles” [**Error! Reference source not found.**], SAE J2711 “Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy Duty Vehicles” [**Error! Reference source not found.**] and the CARB interim document, “California Interim Certification Procedures for 2004 and Subsequent Model Hybrid–Electric Vehicles in the Urban Bus and Heavy-Duty Vehicle Classes.” [**Error! Reference source not found.**]

4. TEST DESCRIPTION

This test protocol requires operation of the bus on a chassis dynamometer over specified driving cycles. Emissions will be measured as the bus is exercised over the Orange County Transit Bus Cycle (OCTA) and the Manhattan Cycle (MAN) (SAE J2711 §5.1 [2]). The testing shall occur at a simulated test weight representing the vehicle curb weight plus the driver weight plus one-half the seated passenger count using a weight of 150 lb/person (68 kg/person). Emissions of total hydrocarbons (THC), carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), and carbon dioxide (CO_2) will be measured. For buses fueled with compressed natural gas (CNG) and liquefied natural gas (LNG), methane (CH_4) non-methane hydrocarbons (NMHC) will also be determined. Emissions will be sampled using a full-exhaust dilution tunnel following procedures similar to those prescribed in 40 CFR 86 [1] with modifications as described in the detailed procedures below.

This test protocol builds upon SAE J2711 Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles [2], 40 CFR 86 – Emission Regulations for New Otto-Cycle and Diesel Heavy-Duty Engines; Gaseous and Particulate Exhaust Test Procedures [1] and 40 CFR Part 1065 (40 CFR 1065) – Engine Testing Procedures [3].

5. TEST FACILITY

This test will be performed at a chassis dynamometer emissions testing facility. The chassis dynamometer must be capable of simulating transient inertial load aerodynamic drag and rolling resistance associated with normal operation of heavy-duty straight-frame and articulated transit buses. Equipment referenced in 40 CFR Part 86 [1] and/or 40 CFR Part 1065 [3], where appropriate, is required for emissions sampling and analysis.

6. TEST EQUIPMENT REQUIREMENTS AND SPECIFICATIONS

6.1 Dynamometer Equipment Specifications

6.1.1 General Provisions

(A) The dynamometer must be capable of duplicating the inertial, road and aerodynamic loads associated with operating the vehicle in actual use. Additional guidance on dynamometer capabilities and specifications may be found in SAE J2711 §6.5 [2].

6.1.2 Inertial Loads

(B) Transient inertial load may be applied using appropriately sized flywheels or electronically controlled dynamometers or power absorbers. The value of equivalent inertia shall be within 250 pounds (113 kg) of the prescribed vehicle test weight. If electric dynamometers or power absorbers are used they must correctly simulate transient inertial loads during both acceleration and deceleration events in order to correctly characterize the effect of hybrid vehicle regenerative braking strategies on emissions and fuel economy. Transient inertial load should be simulated correctly from a complete stop throughout the full speed regime of the test cycle being used. In the event that the dynamometer cannot simulate inertial load at very low speeds, the minimum speed at which the inertia was properly simulated shall be stated.

6.1.3 Aerodynamic Drag and Rolling Resistance

(C) Road load power consists of non-recoverable aerodynamic drag and tire rolling resistance losses. Road load may be implemented as a function of vehicle speed by dynamometers or power absorbers with appropriate electronic control. Aerodynamic drag and rolling resistance should be established as a function of vehicle speed using appropriate coastdown procedures described later in this document. The dynamometer's inertia and power absorption shall be adjusted to reproduce the appropriate road load retarding force at all speeds as specified in 40 CFR 86.1229-85 [1]. The indicated road load power as set and measured by the dynamometer shall account for dynamometer friction power. Dynamometer frictional power may be determined as per the dynamometer coastdown procedure outlined in 40 CFR 86.1218-85 [1] or other appropriate procedure as specified by the dynamometer equipment manufacturer.

6.2 Exhaust Sampling and Analytical System Specifications

6.2.1 General Provisions

(A) In general the emissions sampling and analytical system should comply with the most recent edition of 40 CFR 86 Subpart N [1] or 40 CFR Part 1065 [3]. Exhaust sampling systems and equipment complying with 40 CFR 86 Subpart N [1] comply fully with this protocol.

(B) Buses powered by Otto-cycle and Diesel cycle internal combustion engines fueled on petroleum derived or synthetic diesel fuel, gasoline, natural gas or liquefied petroleum gas are tested identically except for the systems required to measure hydrocarbons and oxides of nitrogen. Vehicles with petroleum or synthetic diesel engines require a heated, continuous hydrocarbon detector and heated, continuous oxides of nitrogen detector. Natural gas-fueled, liquefied petroleum gas-fueled diesel engines and gasoline fueled vehicle may be tested with either a heated or non-heated hydrocarbon detector. For natural gas-fueled vehicles, methane and non-methane HC emissions must be determined by gas chromatography methods.

(C) A continuously integrated sampling system is recommended for measurement of THC, NOx, CO and CO_2. The use of a proportional bag sample is allowed for THC, NOx, CO and CO_2 but specific requirements for bag sampling must be met for THC and NOx measurement from diesel engines. Requirements for proportional bag sampling of THC and NOx emissions may be found in 40 CFR 86.1310-2007 [1]. CH_4 measurement for calculation of NMHC (if required) is accomplished using gas chromatograph-flame ionization detection (GC-FID) analysis of a proportional bag sample.

(D) General requirements of the exhaust sampling system described in this section follows from the specification and requirements 40 CFR 86.1310-90, 86.1310-2007 [1] and 40 CFR 1065.140 [3].

6.2.2 Exhaust System Connections

The vehicle exhaust system should be connected to the dilution tunnel as follows:

(A) The length of exhaust tubing between the vehicle tail pipe and dilution tunnel should be minimized and be no more than 33 ft (10 m) in length.

(B) No more than 6.5 ft (2 m) may be comprised of flexible exhaust tubing.

(C) Exhaust tubing in excess of the first 25 diameters downstream of the vehicle tailpipe must be insulated.

(D) Exhaust tubing materials should be smooth-walled, electrically conductive and not reactive with exhaust constituents. Stainless steel is an acceptable material.

(E) The entire exhaust transfer system should be electrically grounded.

(F) Exhaust tubing should be thin-walled (less than 2 mm) to minimize temperature differences between the wall and the exhaust gases.

6.2.3 Primary Dilution Tunnel

The primary dilution tunnel should:

(A) Induce turbulent flow (Reynolds Number > 4000) and be of sufficient length to cause complete mixing of the exhaust and dilution air. Turbulence generators such as mixing plates or mixing orifices may be used based to ensure a well-mixed sample. This protocol recommends flowing tracer gas (i.e. propane or CO_2) from the inlet of the dilution tunnel and measuring its concentration at several radial locations along the axial sample plane. Tracer gas concentrations should remain nearly constant (i.e. within 2%) between all these points.

(B) Be constructed of an electrically conductive material (300 series stainless steel is recommended) which does not react with the exhaust components.

(C) Be electrically grounded.

(D) Be thin-walled and insulated such that the temperature of the walls tracks with the temperature of the diluted exhaust.

6.2.4 Constant Volume Sampling System

(A) The recommended system utilizes the constant volume sampling (CVS) concept to measure true mass of both gaseous and particulate emissions. In the CVS concept, the total volume of the mixture of exhaust and dilution air must be measured and a continuously proportional volume of sample must be collected for analysis. The mass of gaseous emissions species is determined from the sample concentration and total flow over the test cycle. The mass of particulate matter emissions is determined from a proportional mass sample collected on a filter, the sample volume passed through the filter and the total flow through the CVS over the test cycle. A schematic representation of the CVS system is shown in Figure 6-1. Since various configurations can produce equivalent results, exact conformance to this diagram is not required. Additional guidance and detail on CVS sampling systems is available in 40 CFR 86.1309 and 86.1310-2007 [1].

(B) As long as a constant volumetric flow rate through the sampling system is maintained for the duration of the test as required in 40 CFR 86.1309 [1], the CVS system may use either:

  (1) A positive displacement pump (PDP) in combination with at heat exchanger,

  (2) A critical flow venturi (CFV) with a heat exchanger or electronic flow compensation, or

  (3) A subsonic venturi (SSV) with electronic flow compensation.

(C) The CVS system must maintain a nominal mass flow of diluted exhaust.

  (1) For PDP systems, the gas mixture temperature, measured at a point immediately ahead of the positive displacement pump and after the heat exchanger shall be maintained within ±10°F (±5.6°C) if the average operating temperature observed during the test (40CFR 86.1309 [1]).

    (a) Alternatively, acceptable flow compensation may be validated by demonstrating that the density at the pump inlet was constant within ±2.5% of the mean density over the test interval (1 Hz or higher data rate). For a CVS pump this may be demonstrated by showing that the absolute temperature at the pump inlet was constant within ±2% of the mean absolute temperature over the test interval (40 CFR 1065.545 [3]).

  (2) For CFV systems, either a heat exchanger (i.e. CFV-CVS) or electronic flow compensation (i.e. EFC-CFV-CVS) is required.

    (a) When a heat exchanger is used the gas mixture temperature, measured at a point immediately ahead of the critical flow venturi, shall be within ± 20°F (±11°C) of the average temperature observed during the test interval (40 CFR 86.1310-2007 [1]).

    (b) The pressure measuring equipment shall have an accuracy and precision of ±3 mm hg (0.4 kPa) (40 CFR 86.1909-90 [1]).

    (c) For systems using flow compensation, maintaining a constant temperature is not necessary.

    (d) Alternatively, acceptable flow compensation may be validated by demonstrating that the flow density at the venturi inlet was constant within ±2.5% of the mean density over the test interval (1 Hz or higher data rate). For a CVS critical-flow venturi this may be demonstrated by showing that the absolute temperature at the venturi inlet was constant within ±4% of the mean absolute temperature over the test interval (40 CFR 1065.545 [3]).

  (3) For SSV systems, electronic flow compensation may be achieved by directly controlling the flow of diluted exhaust based on temperature and pressure measurements (40 CFR 1065.140 [3]).

  (4) The temperature measuring system shall have an accuracy and precision of ±3.4°F (±1.9°C) (40 CFR 86.1310-90 [1]).

(D) The CVS system must not artificially lower the exhaust system backpressure. Maintain the static pressure at the location where the raw exhaust is introduced into the dilution tunnel within ±5 inches of water (1.2 kPa) of the atmospheric pressure [3].

6.2.5 Exhaust Dilution System

(A) For PM measurement, the intent of this measurement procedure is to perform sample cooling primarily by dilution and mixing with air rather than by heat transfer to the surfaces of the sampling system.

(B) The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream in the primary dilution tunnel at a temperature of 375°F (191°C) or less at the sampling zone and at, or above, the temperature required to prevent aqueous condensation at any point in the dilution tunnel. Dehumidifying the dilution air before it enters the dilution tunnel is allowed as well as heating of the dilution air provided that:

   (1) The diluted exhaust gas temperature does not exceed 125°F (52°C) for particulate emission measurement.

   (2) Determination of the CVS flow rate to prevent moisture condensation is based on the lowest temperature encountered prior to the sampling zone.

   (3) The dilution ratio is sufficiently high to prevent condensation in bag samples as they cool to room temperature.

(C) Gaseous emissions sample may be taken directly from the sampling zone.

(D) An exhaust sample must be taken at the sampling zone for dilution a second time for use in determining particulate emissions. The secondary dilution system must provide sufficient dilution air to maintain the double-diluted exhaust sample stream at a temperature of 117°F ± 9°F (47 °C ± 5°C) at a point located no further than 6.3 inches (16 cm) upstream of the filter face (40 CFR 86.1310-2007 [1]).

(E) The primary dilution air and secondary dilution air (if applicable):

   (1) Shall have a primary and secondary dilution air temperature equal to or greater than 59° (15°C) (40 CFR 86.1310-2007 [1]).

   (2) Primary dilution air shall be filtered at the dilution air inlet. The filter must achieve a minimum particle removal efficiency of 98% (less than 0.02 penetration) as determined by ASTM test method F 1471-93 [4]. It is recommended that the primary dilution air be filtered using a HEPA filter (40 CFR 86.1310-2007 [1].

   (3) It is acceptable to use a booster blower upstream or downstream of the HEPA filter in the primary dilution tunnel (and upstream of introduction of engine exhaust into the CVS) to compensate for additional pressure loss associated with the filter. The design of any booster blower located downstream of the HEPA filter should minimize introduction of additional particulate matter into the sample stream.

(4) Secondary dilution air shall be filtered at the dilution air inlet using a high-efficiency particulate air filter (HEPA). The HEPA filter must achieve a minimum particle removal efficiency of 99.97% (less than 0.0003 penetration) as determined by ASTM test method F 1471-93 [4].

(5) Primary dilution air may be sampled to determine background particulate levels, which can be subtracted from the values measured in the diluted exhaust stream. The background filter sample shall be taken immediately downstream of the dilution air filter and upstream of the point where the engine exhaust enters the dilution tunnel.

6.2.6 Gaseous Sample Probes, Transfer Lines and Sample Pumps

(A) A probe is the first fitting in a sampling system. It protrudes into the diluted exhaust stream to extract a sample. The following provisions apply to sample probes.

(1) Inside surfaces should be of 300 series stainless steel.

(2) Sample probe should be located sufficiently distant from the dilution tunnel entrance or turbulence generator to ensure exhaust constituents and dilution air are well mixed (i.e. 10 tunnel diameters).

(3) Probe should be located to minimize interference with the flow to other probes and remain free from influence of boundary layers, wakes and eddies.

(4) Single-port or multi-port probes may be used to sample gaseous emissions. Probes may be oriented in any direction relative to the diluted exhaust flow.

(B) Transfer lines transport the sample from the probe to the gaseous emissions analyzer or sample storage medium. The following provisions apply to transfer lines.

(1) Inside surfaces of 300 series stainless steel, Teflon® (PTFE) or Viton™ or other non-reactive material capable of withstanding exhaust gas temperatures.

(2) Length of transfer lines should be minimized by locating analyzer and storage media as close to the probes as possible.

(3) The number of bends in transfer lines should be minimized. Avoid using 90° elbows, tees, and cross-fittings.

(4) Where fittings are necessary, precautions should be taken to meet temperature tolerances and avoid cold spots in the transfer lines.

(C) Sample pumps may be used upstream of an analyzer or storage medium for any gas. Sample pumps should have inside surfaces of series 300 stainless steel, PTFE or other non-reactive material.

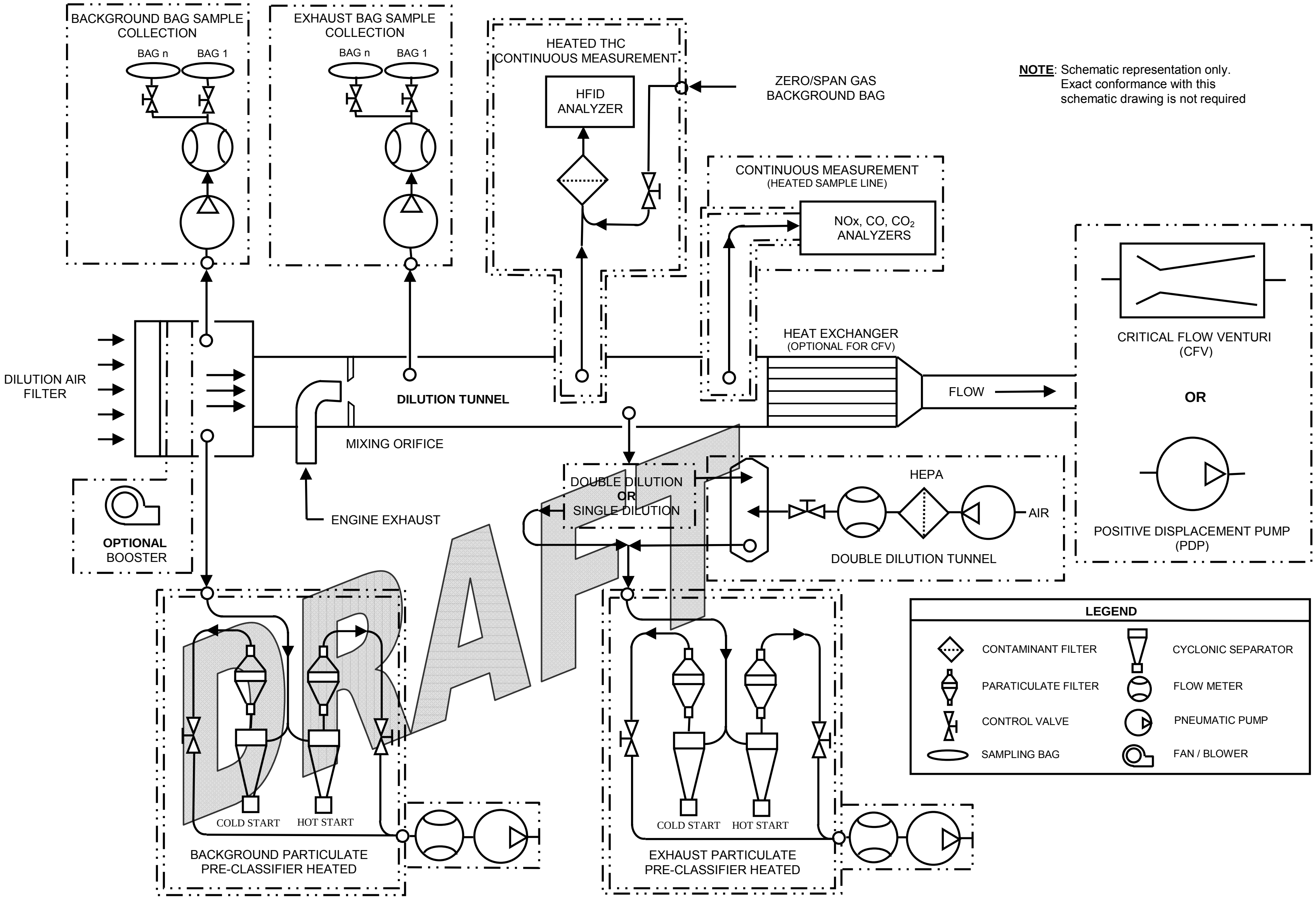


Figure 6-1: Gaseous and Particulate Emissions Sampling System PDP – CFV Constant Volume Sampler (40 CFR 86.1310-2007 Figure N07-1[1]).

6.2.7 Continuously Integrated THC Measurement System

(A) The continuous THC measurement system consists of a probe, exhaust sample transfer system and THC analyzer. The THC sampling system is subject to the following requirements.

(B) The THC sample probe is defined as the first component in the continuous hydrocarbon sampling system and is subject to the following.

(1) Comply with the requirements of Section 6.2.6.

(2) Have a minimum inside diameter of 0.19 in (0.483 cm)

(3) Must increase the gas stream temperature to 375°F (191°C) by the exit of the probe. The ability of the probe to accomplish and maintain this temperature shall be demonstrated at typical sample flow rates using the insertion thermocouple technique at initial installation and after any major maintenance. A detailed description of the insertion thermocouple technique may be found in 40 CFR 86.1310-2007 [1]. Compliance with this temperature specification shall be demonstrated by monitoring the temperature of the either gas stream or the wall of the sample probe at its terminus during each test.

(4) No other analyzers may draw sample from the continuous THC sample probe line of system, unless a common sample pump is used for all analyzers and the common sample system design reflects good engineering practice.

(C) The THC sample transfer system consisting of the transfer line, sample pump, filter and any other sample conditioning devices and shall be subject to the following requirements.

(1) Maintain a wall temperature of 375 ± 20°F (191 ± 11°C) over its entire length including the sample pump and filter assembly if applicable. The ability of the sample system to maintain this temperature shall be demonstrated by profiling the thermal characteristics of the transfer system at initial installation and after any major maintenance using the insertion thermocouple technique described in 40 CFR 86.1310-2007 [1]. Compliance with this temperature specification shall be demonstrated by monitoring the gas stream temperature through each component of the sampling system during each test.

(2) The continuous THC sample system shown in Figure 6-1 uses an “overflow” or “flooded probe” zero, and span system. The flooded probe system is also recommended for calibration of the THC analyzer; however, this is not required. The zero/span/calibration overflow gas flow rate into the sample line shall be at least 105% of the sample system flow rate. The overflow gas shall enter the heated sample probe as close as practical to the outside surface of the dilution tunnel.

(D) The THC analytical system for petroleum-fueled diesel engines requires a heated flame ionization detector (HFID) maintained a temperature of 375 ± 20°F (191 ± 11°C). For natural gas-fueled, petroleum gas-fueled and gasoline-fueled engines either a heated or non-heated flame ionization detector may be used. This protocol recommends the use of a HFID for all fuel types.

(E) The 0-90% response time (T90) of the continuous THC measurement system shall be no greater than:

  (1) 1.5 seconds from and instantaneous step change in concentration introduced at the port entrance of the THC analyzer.
  (2) 10 seconds from an instantaneous step change in concentration introduced at the entrance to the THC sample probe or overflow gas port.
  (3) For the purposes of response time verification the step change shall be at least 60% of full-scale instrument deflection.

6.2.8 Continuously Integrated CO and CO_2 Measurement Systems

(A) The continuous CO and CO_2 measurement systems consist of a probe(s), exhaust sample transfer system, water removal device, CO analyzer(s) and a CO_2 analyzer. The CO and CO_2 probe and sample transfer system may share common components. The CO and CO_2 sampling system may also be combined with the NOx sample system. The continuous CO and CO_2 sampling system(s) shall conform to the following specifications.

(B) The CO/CO_2 sample probe(s) shall:

  (1) Comply with the requirements of Section 6.2.6.
  (2) Be heated to a minimum temperature of 131 °F (55°C) and insulated to prevent water condensation. Higher temperatures may be required to prevent condensation during testing of natural gas and petroleum gas vehicles. A temperature of 235°F (112°C) is recommended for all fuel types.

(C) The sample transfer system shall be subject to the following requirements.

  (1) The sample transfer system shall be heated to a minimum temperature of 131 °F (55°C) and insulated to prevent water condensation upstream of the water trap or sample dryer. Higher temperatures may be required to prevent condensation during testing of natural gas and petroleum gas vehicles. A temperature of 235°F (112°C) is recommended for all fuel types. Heating of system components downstream of the water trap or dryer unit is not required.
  (2) Water vapor in the sample stream can cause interference with and damage to CO and CO_2 analyzers and therefore must be removed from the sample stream prior to the analyzers. Water vapor may be removed by condensation using water traps, or refrigerated dryers. Chemical dryers are not and acceptable method of removing water vapor and may not be used. If water is removed by condensation, the sample gas temperature or sample dew point must be monitored either within the dryer unit or downstream and may not exceed 45°F (7°C) [1].
  (3) Carbon monoxide and carbon dioxide measurements are to be made using non-dispersive infrared (NDIR) analyzers. The use of linearizing circuits is permitted. Water interference and CO_2 interference requirements and check procedures are discussed later in this document.

(4) The T90 system response shall be no greater than 10 seconds (40 CFR 86.1310-2007 [1]).

6.2.9 Continuously Integrated NOx Measurement System

(A) The continuous NOx measurement systems consist of probe, exhaust sample transfer system, filter, optional external NO_2-to-NO converter and NOx analyzer(s). The NOx sample system may share a common probe and some common sample transfer system components with the CO and CO_2 sample systems.

(B) The NOx sample probe(s) shall:

(1) Comply with the requirements of Section 6.2.6.

(2) Be heated to a minimum temperature of 131 °F (55°C) and insulated to prevent water condensation. Higher temperatures may be required to prevent condensation during testing of natural gas and petroleum gas vehicles. A temperature of 235°F (112°C) is recommended for all fuel types.

(C) The sample transfer system shall be subject to the following requirements.

(1) The sample transfer system shall be heated to a minimum temperature of 131 °F (55°C) and insulated to prevent water condensation. Higher temperatures may be required to prevent condensation during testing of natural gas and petroleum gas vehicles. A temperature of 235°F (112°C) is recommended for all fuel types.

(2) Chemiluminescent analysis of NOx requires that NO_2 in the sample be converted to NO before analysis.

(3) Nitrogen dioxide (NO_2), a component of NOx emissions, is soluble in water. Therefore it is critical that the NO_2 present in the sample stream be converted to nitric oxide (NO) before water is removed from the sample stream. If the conversion of NO_2 to NO occurs internally within the NOx analyzer then the sample must be heated up to the analyzer inlet port. If an external NO_2-to-NO converter is employed then heating is required up to the inlet port of the converter.

(4) The T90 system response shall be no greater than 10 seconds (40 CFR 86.1310-2007 [1]).

6.2.10 Particulate Sampling System

(A) The method collects a proportional sample from the primary dilution tunnel, and transfers the sample to a secondary dilution tunnel where the sample is further diluted. The double-diluted sample is passed through the particulate matter collection filter. The filters are conditioned and weighed before and after sample collection to determine particulate mass (40 CFR 86.1310-90 [1]).

(B) The particulate sample transfer tube shall be configured such that:

(1) The inlet faces upstream in the primary dilution tunnel at a point where the primary dilution air and exhaust are well mixed.

(2) The particulate sample exits on the centerline of the secondary tunnel.

(3) The probe is sufficiently distant (spacially) from other sampling probes in the primary dilution tunnel so as to be free from the influence of any wakes or eddies.

(4) 0.335 in (0.85 cm) minimum inside diameter.

(5) No longer than 36 inches (91 cm) from inlet plan to exit plane.

(6) Designed to minimize the diffusion and thermophoretic deposition of particulate matter during transfer (i.e. sample residence time should be minimized, temperature gradients between the flow stream and the transfer tube should be minimized). Double-walled, air-gap insulated or a controlled heated construction for the transfer tube is recommended.

(7) Constructed such that surfaces exposed to the sample shall be electrically conductive material, which does not react with exhaust components and the surface shall be electrically grounded so as to minimize electrostatic particulate matter deposition.

(C) The secondary dilution tunnel shall be constructed such that surfaces exposed to the sample shall be electrically conductive material, which does not react with exhaust components and the surface shall be electrically grounded so as to minimize electrostatic particulate matter deposition.

(D) The filter holder assembly shall be located with in 12 in (30.5 cm) of the exit of the secondary dilution tunnel.

(E) Additional dilution air must be provided so as to maintain a sample temperature of 117°F ± 9°F (47 °C ± 5°C) upstream of the sample filter.

(1) The secondary dilution air shall be at a temperature equal to or greater than 59° (15°C).

(2) The temperature shall be measured with a thermocouple with a 3/16 in (4.76 mm) shank having thermocouple wires with a gage diameter 24 AWG or smaller, a bare wire butt welded junction; or other suitable temperature measurement with an equivalent or faster response time constant and an accuracy and precision of 3.4 °F (1.9°C).

(F) Proportionality (i.e., mass flow ratio) between the primary tunnel flow rate and the sample flow rate must be maintained within 5%, excluding the first 10 seconds of the test at start-up.

(G) The face velocity through the sample filter shall not exceed 3.28 ft/second (100 cm/second). Face velocity is defined as the standard volumetric sample flow rate divided by the sample filter stain area.

6.2.11 Particle Preclassifier

(A) A particle preclassifier shall be installed immediately upstream of the filter holder assembly. The purpose of the preclassifier is to remove coarse, mechanically generated particles (such as rust from the engine exhaust or carbon sheared from the walls of the sampling system) while allowing combustion generated particles to pass through to the filter (40 CFR 86.1310-2007 [1]).

(B) The preclassifier may be either and inertial impactor or a cyclonic separator.

(C) The 50% cutpoint particle diameter shall be between 2.5 μm and 10 μm at the volumetric flow rate selected for sampling particulate matter emissions.

(D) The preclassifier shall allow at least 99% of the mass concentration of 1 μm particles to pass through the exit of the preclassifier to the filter at the selected volumetric flow rate.

(E) The particle preclassifier may be made integral to the top of the filter holder assembly or integral with a mixing tee for introduction of secondary dilution air, thus replacing the secondary dilution tunnel provided that the preclassifier provides sufficient mixing.

6.2.12 Filter Holder Assembly

(A) The filter holder assembly shall comply with the specifications of 40 CFR 50 Appendix L 7.3.5 [7] as shown in Figure 6-2 and Figure 6-3 with the following exceptions:

(1) The filter holder material shall be 302, 303 or 304 stainless steel.

(2) The diameter of the entrance to the filter holder may be adapted to an inside diameter no smaller than 0.85 cm, maintaining the 12.5° angle from the inlet of the top of the filter holder to the area near the sealing surface at the top of the filter cartridge assembly. Modifications to the filter holder geometry must conform to the requirements of 40 CFR 86.1310-2007 [1].

(3) If multiple filters are stored in an automated sequential sampler carousel, all filter cartridges unless installed in the sample flow shall be covered or sealed to prevent communication of semi-volatile matter from filter to filter; contamination of filters before and after sampling; or loss of volatile or semi-volatile particulate matter after sampling.

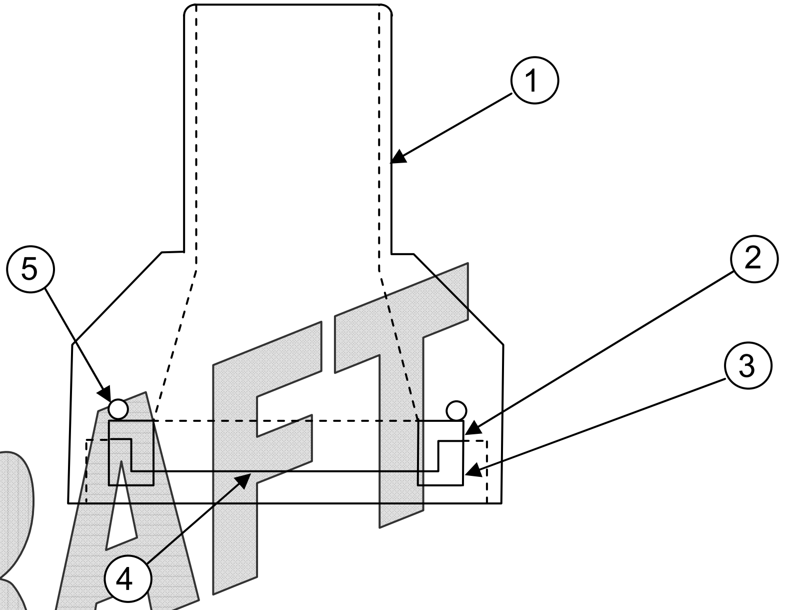
6.2.13 Filter Cartridge Assembly

(A) The filter cartridge assembly shall comply with the specifications of 40 CFR 50 Appendix L 7.3.5 [7] as shown in Figure 6-4 with the following exceptions (40 CFR 86.1310-2007 [1]:

(1) The cartridge assembly may be fabricated from Delrin $^{\text{TM}}$, 302, 303, 304 stainless steel, polycarbonate or acrylonitrile/butadiene/styrene (ABS) resin of a combination of these materials.

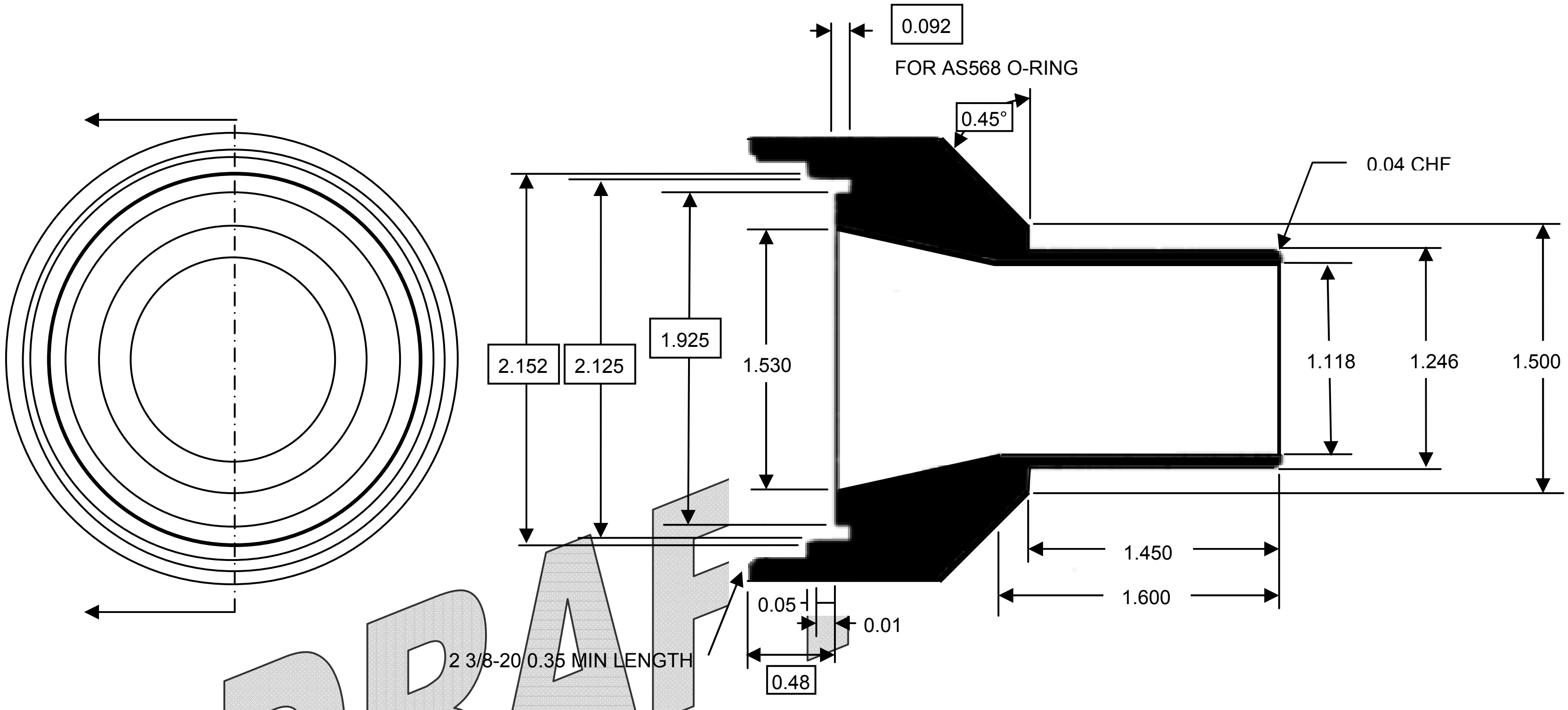
(2) A bevel introduced on the inside diameter of the entrance to the filter cartridge as used on some commercially available automated sequential filter cartridge changers is acceptable.

ITEM	DESCRIPTION	QTY
1	FILTER HOLDER TOP	1
2	FILTER CASSETTE, UPPER	1
3	FILTER CASSETTE, LOWER	1
4	FILTER SCREEN AND FILTER	1
5	O-RING	1



TOLERANCES				ALL DIMENSIONS IN INCHES
2 PLCS	3 PLCS	FRAC.	ANGLE.	
+/- 0.010	+/- 0.005	+/- 1/64	+/- 15’	

Figure 6-2: Filter Holder Assembly (40 CFR 50 Appendix L Figure L-24 [7])

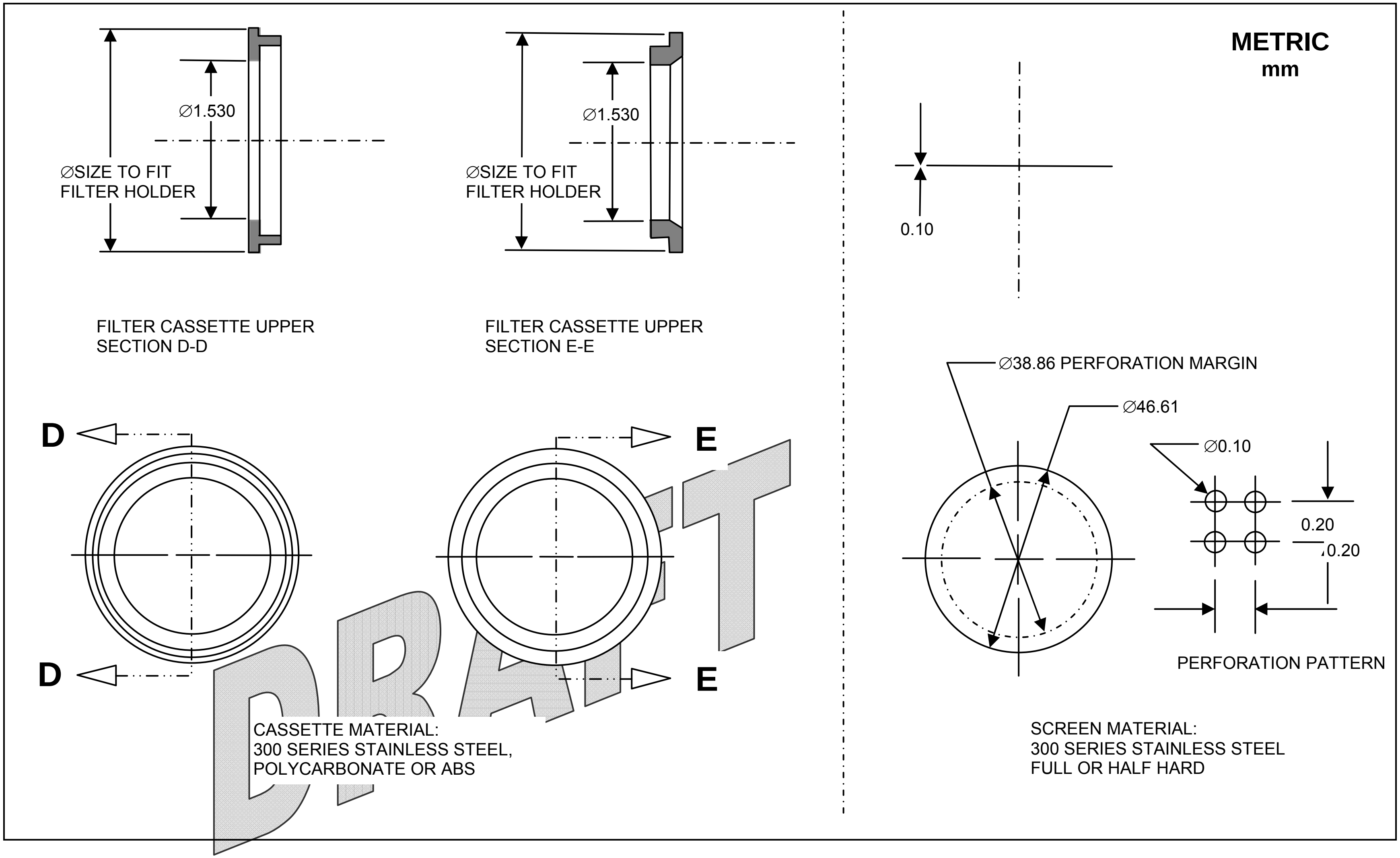


NOTES:

1. MATERIAL IS 302, 303, 304 STAINLESS STEEL
2. 32 RMS FINISH ALL OVER
3. BOXED DIMEMSIONS ARE OPTIONAL

TOLERANCES				ALL DIMENSIONS IN INCHES
2 PLCS	3 PLCS	FRAC.	ANGLE	
+/- 0.010	+/- 0.005	+/- 1/64	+/- 15’	

Figure 6-3: Filter Holder Top (40 CFR 50 Appendix L Figure L-26 [7])



CASSETTE MATERIAL:
300 SERIES STAINLESS STEEL,
POLYCARBONATE OR ABS

SCREEN MATERIAL:
300 SERIES STAINLESS STEEL
FULL OR HALF HARD

Figure 6-4: Filter Cassette and Screen (40 CFR 86.1310-2007 Figure N07-3[1])

6.3 Exhaust Gas CVS Bag Sample Analytical System

6.3.1 General Provisions

(A) This protocol recommends the use of continuously integrated measurement systems for THC, NOx, CO and CO_2 emissions. However, CVS bag sampling may be used provided certain conditions are met. Additionally, bag sampling of dilute exhaust and of the dilution air may be useful for quality control/quality assurance and background correction of emissions results.

6.3.2 Bag Sample Analytical System Schematic

(A) Figure 6-5 shows a schematic drawing of the exhaust gas analytical system used for analyzing CVS bag samples from either Otto-cycle or diesel engines. Exact conformance to this schematic is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the system.

(B) This system can be used to analyze bag samples of diluted exhaust and/or background samples of the dilution air. Analyzer components of this system do not need to be separate from those shown in Figure 6-5 but rather plumbing may be such that either the continuous sample from the dilution tunnel or from the bag(s) can be routed to the analyzers.

(C) The THC analytical system for petroleum-fueled diesel engines requires a heated flame ionization detector (HFID) maintained a temperature of 375 ± 20°F (191 ± 11°C). For natural gas-fueled, petroleum gas-fueled and gasoline-fueled engines either a heated or non-heated flame ionization detector may be used. This protocol recommends the use of a HFID for all fuel types.

(D) If a heated (191 ± 11°) proportional bag sampling system is used to report THC results, sample bag must demonstrate minimal outgassing and permeability by passing the following performance test:

  (1) Bring the bag system to its operating temperature. Fill the heated sample bag with a nominal mixture of 1% CO_2 in N_2. Perform an initial measurement of CO_2 and THC from the sample bag, and repeat the measurement after 1 hour. Acceptable performance criteria are <2% decrease of the initial CO_2 reading and <1 ppmC THC (40 CFR 86.1310-2007 [1]).

(E) Determination of CH_4 emissions may be accomplished using a methane analyzer consisting of a gas chromatograph combined with an FID, done in accordance with SAE Recommended Practice J1151, Methane Measurement Using Gas Chromatography [9]. For natural gas vehicles, gas chromatography may be used to measure NMHC through direct quantization of individual hydrocarbon species.

(F) Carbon monoxide and carbon dioxide measurements are to be made using non-dispersive infrared (NDIR) analyzers.

  (1) The carbon monoxide (NDIR) may require a sample conditioning column containing $CaSO_4$ or desiccating silica get to remove water vapor, and containing ascarite to remove CO_2 from the sample stream.

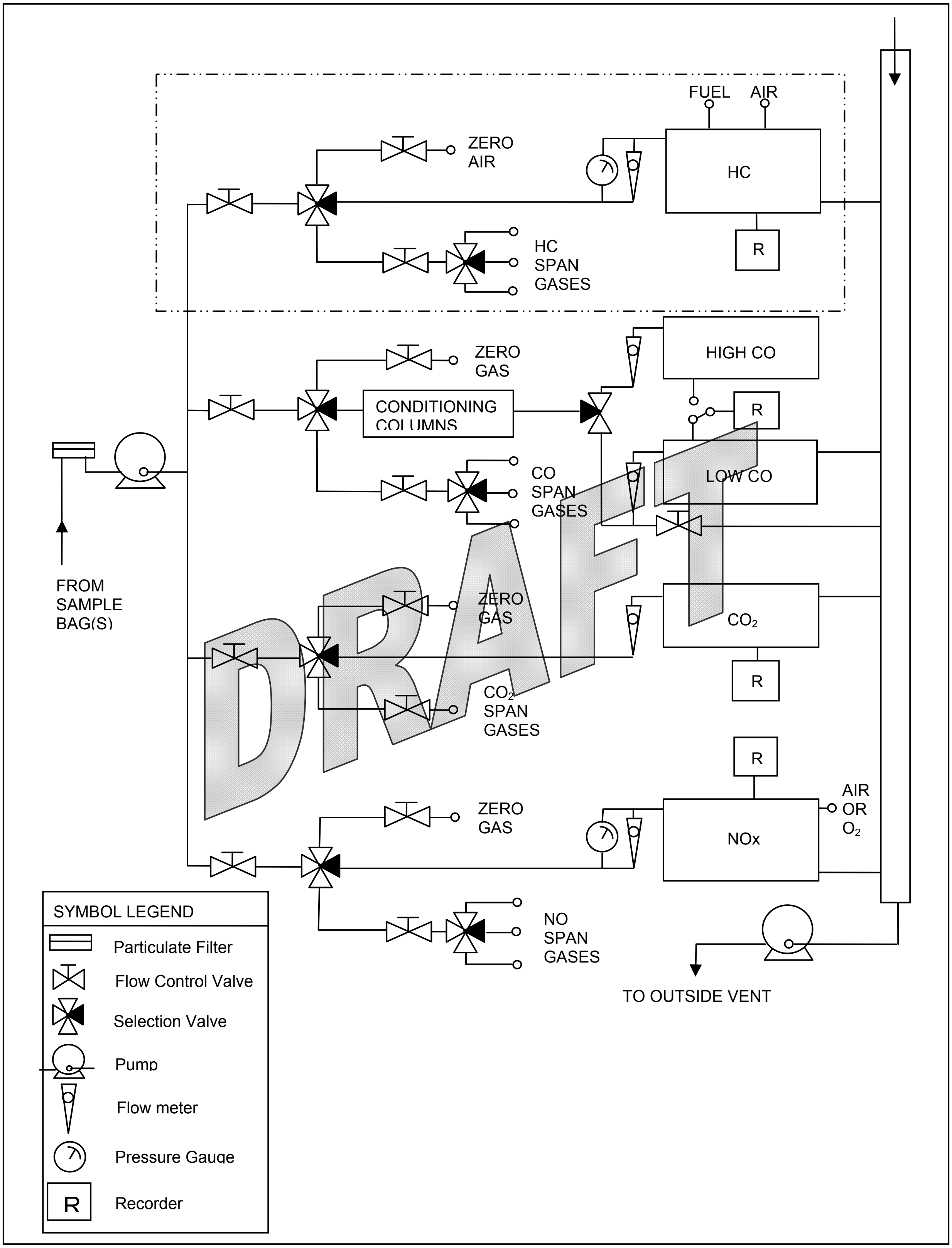


Figure 6-5: CVS Bag Sample Analytical System (40 CFR 86.1311-90 Figure N90-9 [1].

(2) If CO instruments are used which are essentially free of CO_2 and water vapor interference, the uses of conditioning column may be deleted.

(3) A CO instrument is considered essentially free of CO_2 and water vapor interference if its response to a mixture of 3% CO_2 in N_2 which has been bubbled through water at room temperature, produces and equivalent CO response, as measured on the most sensitive CO range, which is less than 1% full scale or less than 3 ppm on ranges below 300 ppm full scale.

(G) Oxides of Nitrogen measurements are made using chemiluminescent analyzers.

(1) Chemiluminescent analysis of NOx requires that NO_2 in the sample be converted to NO before analysis.

(2) Bag sampling of NOx will be allowed provided that sample gas temperature is maintained above the sample's aqueous dew point at all times during collection and analysis.

6.4 Filter Stabilization and Microbalance Workstation Environment

6.4.1 Ambient Conditions for Filter Stabilization and Weighing

(A) The filter stabilization environment must be maintained at 71.6 ± 5.4°F (22 ± 3°C) and a dew point of 49.1 ± 1.8 °F (9.5 ± 1 °C). Dew point shall measured with an instrument accurate to at least ±0.45°F (±0.25°C) NIST traceable as stated by the instrument manufacturer. Temperature shall be measured with an accuracy of at least ±0.36 °F (±0.2°C) or better (40 CFR 86.1312-2007 [1]).

(B) The microbalance workstation environment must be maintained at 71.6 ± 1.8°F(22 ± 1°C) and a dew point of 49.1 ± 1.8 °F (9.5 ± 1 °C). If the microbalance workstation environment freely circulates with the filter stabilization environment maintained at 71.6 ± 1.8°F(22 ± 1°C) and a dew point of 49.1 ± 1.8 °F (9.5 ± 1 °C), then there is no requirement to measure temperature and dew point at the microbalance workstation. Otherwise, temperature at the microbalance workstation shall be measured with an accuracy of at least ±0.36 °F (±0.2°C) or better and dew point shall measured with an instrument accurate to at least ±0.45°F (±0.25°C) NIST traceable as stated by the instrument manufacturer (40 CFR 86.1312-2007 [1]).

6.4.2 Quality Control of Ambient Conditions

(A) If the temperature or dew point of the filter stabilization environment is not within specification prior to the start of a weighing sessions, then filters must remain in the environment for a minimum of 30 minutes after conditions are corrected.

(B) If the stabilization environment changes during a weighing session such that the specifications are no longer satisfied, then the weighing session must be suspended until the proper ambient conditions are restored and maintained for a minimum of 30 minutes. Once the environment has been restored, the reference filters must be reweighed and the criteria of paragraph (D) of this section must be satisfied.

(C) The temperature and dew point shall be sampled once per second and an unweighted 5-minute moving average of this data calculated once per second. This moving average shall be used to determine whether or not the environment is within specification (40 CFR 86.1312-2007 [1]).

(D) If the average change in the weight of the reference filters is more than 10 micrograms (after correcting for buoyancy as described in Section 8.11.4 then all filters in the process of stabilization shall be discarded and all data collected with respect to the discarded filters shall be void. More than two reference filters may be used if desired to achieve a more robust average of the change in weight (40 CFR 86.1312-2007 [1]).

6.4.3 Cleanliness

(A) The microbalance workstation and filter stabilization environments shall be free of ambient contaminants that could settle on the particulate filters. It is recommended that these environments be built to conform to Class 1000 specifications as determined by Federal Standard 209D or 209E for clean room classification [8].

(B) Reference filters shall be used to monitor for gross particle contamination. At least two unused reference filters must remain in the filter stabilization environment at all times in partially covered glass Petri dishes. These reference filters shall be weighed with in two hours of, but preferably at the same time as, the sample filters. The reference filters shall be changed at least once a month but never while an sample filters are between their tare weight (pre-sampling) and gross weight (post sampling) measurements. The reference filters shall be of the same size and material as the sample filters.

6.5 Microbalance Specifications

(A) The microbalance used to determine the weights of all filters shall have a precision (standard deviation) of at least ±0.25 micrograms or better for repeated weighing of a calibration weight, a precision of at least ±2.5 micrograms or better for repeated weighing of a clean filter, and readability equal to or less than 0.1 micrograms (40 CFR 86.1312-2007 [1]).

(B) It is recommended that the microbalance be installed on a vibration isolation platform to isolate it from external vibration. It is also recommended that the microbalance be shielded from convective airflow by means of an electrically grounded static dissipative draft shield.

(C) Microbalance manufacturer specifications for all preventative maintenance, periodic certification, calibration and re-zeroing shall be followed. All certification and calibration procedures shall be NIST traceable or traceable to an equivalent national standard.

6.6 Calibration Gases and Analytical Supplies

6.6.1 Analytical Calibration Gas Specifications

(A) Analytical calibration and span gases should conform to 40 CFR 86.1314-94 [1]. The following calibration gas blends shall be used:

  (1) For CO and CO_2 analyzer calibration – single blends of CO and CO_2 respectively, using nitrogen as the diluent.

  (2) For hydrocarbon analyzer calibration – single blends of propane using air as the diluent.

  (3) Methane analyzer calibration (if used) – single blends of methane using air as the diluent.

  (4) For NOx analyzer calibration – single blends of NO named as NOx with a maximum NO_2 concentration of five percent of the nominal value using nitrogen as the diluent.

  (5) Fuel for HFIDs and methane analyzers – blend of 40 ±2 percent hydrogen with balance being helium. The mixture shall contain less than 1 ppm equivalent carbon response, 1 ppm carbon monoxide, 0.04 percent (400 ppm) carbon dioxide and -.1 ppm nitric oxide.

(B) The following shall apply to zero gases:

  (1) For hydrocarbon and methane analyzers, zero-grade air shall be used.

  (2) For CO, CO_2 and NOx analyzers, zero-grade air or nitrogen may be used. This protocol recommends nitrogen.

  (3) The allowable impurity concentrations shall not exceed 1 ppm equivalent carbon response, 1 ppm carbon monoxide, 0.04 percent (400 ppm) carbon dioxide and 0.1 ppm nitric oxide.

  (4) “Zero-grade air” includes artificial “air” consisting of a blend of nitrogen and oxygen with oxygen concentrations between 18 and 12 mole percent.

(C) Calibration and span gases shall be accurate to with in two percent of NIST gas standards.

(D) The use of precision blending devices (gas dividers) to obtain the required calibration gas concentration is acceptable, provided that the blended gases are accurate to within ±1.5 percent of NIST gas standards. This accuracy implies that the primary gases used for blending must be “named” to and accuracy of ±1 percent traceable to NIST standards.

6.6.2 Particulate Sampling Filter Specifications

(A) Particulate filters must have a minimum diameter of 46.5 ± 0.6 mm (38 mm minimum stain diameter).

(B) Polytetrafluoroethylene (PTFE or Teflon ^{TM}) coated borosilicate glass fiber high-efficiency or PTFE high efficiency membrane filters with and integral support ring of polymethylpentene or equivalent inert material are required by 40 CFR 86.1310-2007 [1]. The Coordinating Research Council E-66 program recommends Whatmann Teflo filter media [10].

6.7 Fuel Specifications

6.7.1 Gasoline Fuels

(A) Gasoline having the specifications listed in Table 6–1 will be used as the test fuel for vehicles powered by petroleum-fueled Otto-cycle engines.

(B) The octane number of the test fuel is not specified but shall not be higher than one Research Octane Number above the minimum recommended by the engine manufacturer and have a minimum sensitivity of 7.5 octane numbers where sensitivity is defined as the Research Octane Number minus the Motor Octane Number (40 CFR 86.1313-2004 [1]).

Table 6–1: Gasoline Test Fuel Specifications (40 CFR 86.1313-2004 [1])

Item	Units	ASTM Test Method	Value
Octane, Research, min.		D2699	-
Sensitivity, min.			7.5
Lead (organic), max.	g/US gal (g/liter)	D3237	0.050 (0.013)
Distillation Range	°F (°C)	D86	
IBP			75-95 (23.9-35)
10% point			120-135 (48.9-57.2)
50% point			200-230 (93.3-110)
90% point			300-325 (148.9-162.8)
EP			415 (212.8)
Sulfur	wt. %	D1266	0.0015-0.008
Phosphorous, max	g/US gal (g/liter)	D3231	0.005 (0.0013)
Reid Vapor Pressure,	psi (kPa)	D323	8.7-9.2 (60.0-63.4)
Hydrocarbon Composition		D1319	
Olefins, max.	%		10
Aromatics, max.	%		35
Saturates			Remainder

6.7.2 Ethanol Fuels

[RESERVED]

6.7.3 Petroleum Diesel Fuels

(A) Petroleum fuels for testing diesel engine shall be clean and bright, with pour and cloud points adequate for operability. The petroleum diesel fuel may contain non-metallic additives as follows: Cetane improver, metal deactivator, anti-oxidant, dehazer, antirust, pour depressant, dye, dispersant and biocide. Fuel specified for emissions testing are intended to be representative of commercially available in-use fuels.

(B) Petroleum fuel meeting the specifications in Table 6–2 shall be used for exhaust emissions testing of vehicles powered by diesel engines. Type 2-D grade diesel fuel shall be used except in cases where the manufacturer has submitted evidence that Type 1-D grade diesel fuel will be the predominant in-use fuel.

Table 6–2: Petroleum Diesel Test Fuel Specifications (40 CFR 86.1313-2007 [1])

Item	Units	ASTM Test Method	Type 1-D	Type 2-D
Cetane Number		D613	40-54	40-50
Cetane Index		D976	40-54	40-50
Distillation Range	°F (°C)	D86		
IBP			330-390 (165.6-198.9)	340-400 (171.1-204.4)
10% Point			370-430 (187.8-221.1)	400-460 (204.4-237.8)
50% Point			410-480 (210.0-248.9)	470-540 (243.3-282.2)
90% Point			460-520 (237.8-271.1)	560-630 (293.3-332.2)
EP			500-560 (260.0-293.3)	610-690 (321.1-365.6)
Gravity	°API	D287	40-44	32-37
Total Sulfur	ppm	D2622	7-15	7-15
Hydrocarbon Composition				
Aromatics, min.[1]	%	D5186	8	27
Flashpoint, min.	°F (°C)	D93	120 (48.9)	130 (54.4)
Viscosity	centistokes	D445	1.6-2.0	2.0-3.2

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[1] Remainder shall be pariffins, Naphthenes and olefins

6.7.4 Synthetic Diesel Fuels

Synthetic diesel fuel having specifications meeting ASTM Standard D975 shall be used for emissions testing of vehicles powered by engines burning synthetic diesel.

[RESERVED]

6.7.5 Biodiesel Fuels

Biodiesel fuel having specifications meeting ASTM Standard D6751 shall be used for emissions testing of vehicles powered by engines burning biodiesel.

[RESERVED]

6.7.6 Natural Gas Fuels

(A) Natural gas fuel having the specification in Table 6–3 shall be used for emissions testing of vehicles powered by natural gas engines.

Table 6–3: Natural Gas Test Fuel Specifications (40 CFR 86.1313-98 [1])

Item	Units	ASTM Test Method	Value
Methane, min.	mole %	D1945	89.0
Ethane, max.	mole %	D1945	4.5
C_3 and higher, max.	mole %	D1945	2.3
C_6 and higher, max.	mole %	D1945	0.2
Oxygen, max	mole %	D1945	0.6
Inert gases: Sum of CO_2 and N_2, max	mole %	D1945	4.0
Odorant[2]			

6.7.7 Liquefied Petroleum Gas Fuels

(A) Liquefied petroleum bas fuel used for emissions testing shall be commercially available liquefied petroleum gas fuel. The vehicle/engine manufacturer shall recommend the liquefied petroleum gas fuel to be used.

(B) The specification range of the fuels to be used shall be measured and reported in accordance with ASTM D2163-91.

6.7.8 Hydrogen Fuels

Hydrogen fuels will meet new standards defined by D7265-06 “Standard Specification for Hydrogen Thermophysical Property Tables.” written by NIST staff and approved by ASTM Committee D03 on Gaseous Fuels.

[RESERVED]

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[2] The natural gas at ambient conditions must have a distinctive odor potent enough for it presence to be detected down to a concentration in air of not over 1/5 (one fifth) of the lower limit of flammability.

7. EQUIPMENT CALIBRATION

7.1 Dynamometer Calibration

7.1.1 Calibration Overview and Frequency

(A) The dynamometer shall be calibrated at least monthly or performance verified at least weekly and calibrated as required.

(B) The calibration shall consist of the manufacturer's recommended calibration procedure for torque and speed transducers plus determination of the dynamometer frictional power throughout the speed range over which typical vehicles are tested.

(C) Dynamometer inertial and road load settings for each vehicle's emission test sequence shall be verified by comparing the force imposed during the dynamometer operation with actual road load force by the vehicle during operation on a smooth level road, during calm winds, with no precipitation. The indicated road load power setting shall take into account the dynamometer friction

(D) Procedures for determination of dynamometer friction and verification of road load forces applied by the dynamometer are discussed in Section 8.5 of this document.

7.2 CVS Calibration

7.2.1 Calibration Overview and Frequency

(A) The CVS flow meter shall receive the following initial and periodic calibration procedures:

(1) *Initial and Periodic Calibration* - Calibrate the CVS flow meter using a reference flow meter that reports quantities that are NIST-traceable within ±1% uncertainty. Calibration should be conducted:

(a) prior to introduction into service

(b) after changing of servicing any part of the flow configuration upstream or downstream of the flow meter that may affect the flow meter calibration.

(c) Whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (i.e. propane injection check).

(2) *CVS System Verification* – A propane injection check serves as a verification to determine if there is a discrepancy in measured values of diluted exhaust flow. The cause of any discrepancy greater than ±2 percent must be corrected.

7.2.2 CVS Flow Meter Calibration Procedure

(A) Calibration of the CVS shall be performed according to 40 CFR 86.1319-90 [1] or 40 CFR 1065.340 [3].

(B) Calibrate a CVS flow meter using a reference flow meter such as a subsonic venturi flow meter, a long-radius ASME/NIST flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. Use a reference flow meter that reports quantities that are NIST-traceable within ±1% uncertainty.

(C) In no case should an upstream screen or other restriction which can affect the flow ahead of the reference flow meter be used unless the reference flow meter has been calibrated with such a restriction in place.

7.2.3 PDP Calibration

(A) The PDP calibration determines a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure.

(B) Unique equation coefficient must be determined for each speed at which the PDP will be operated.

(C) Calibrate the PDP as follows:

(1) Connect the system as shown in Figure 7-1.

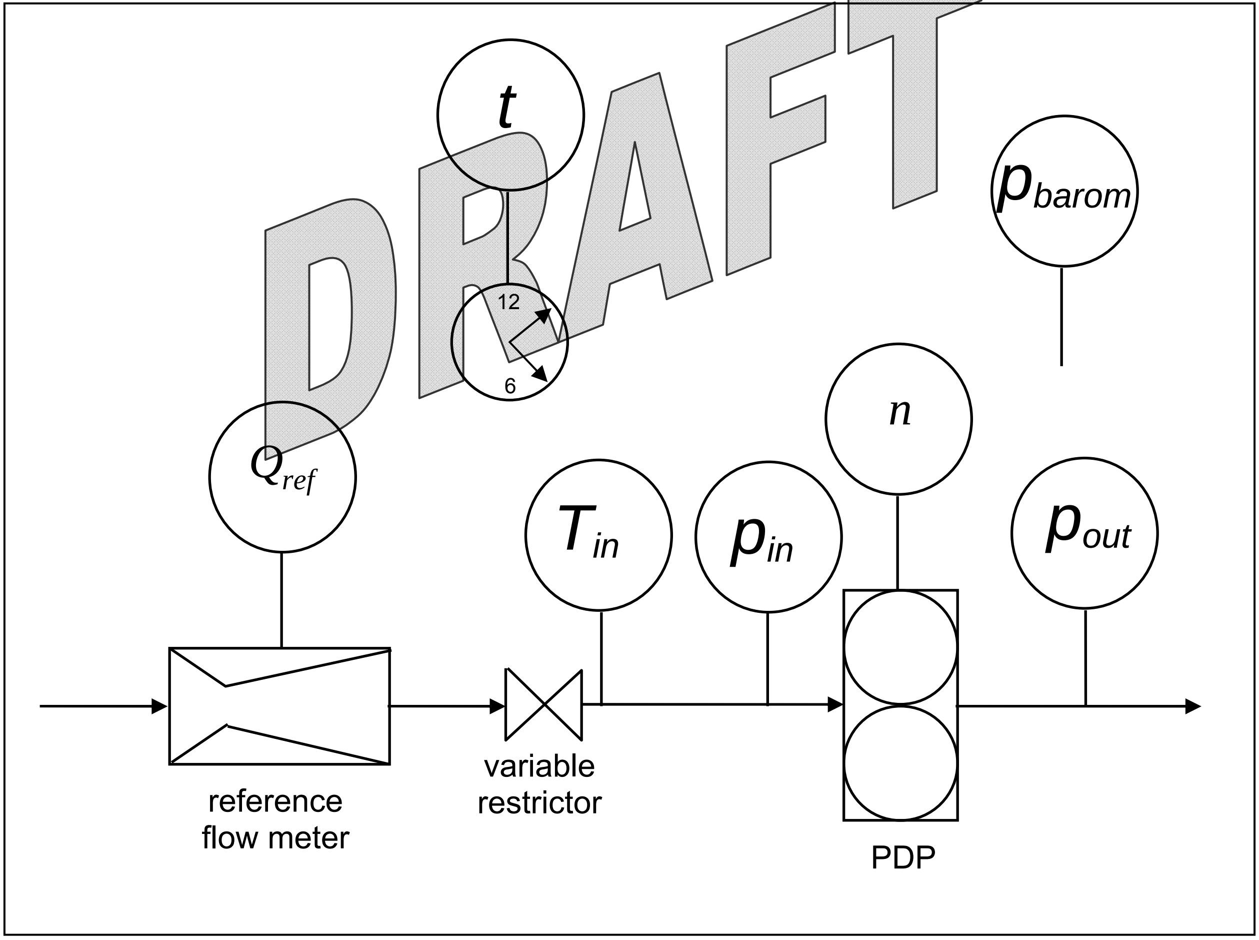

Figure 7-1: Schematic diagram of PDP calibration apparatus

(2) Leaks between the calibration flow meter and the PDP must be less than 0.3 percent of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point.

(3) While performing the calibration the PDP inlet temperature must be maintained within ±2 percent of the mean absolute inlet temperature (T_{in}).

(4) Set the PDP speed to the first speed for which calibration is to be performed.

(5) Set the variable restrictor to it wide-open position.

(6) Operate the PDP for at least 3 minutes to stabilize the system. Continue operating the PDP and record at least 30 seconds of sampled data of each of the following quantities:

  (a) The mean temperature at the PDP inlet (T_{in}).

  (b) The mean static absolute pressure at the PDP inlet (P_{in}).

  (c) The mean static absolute pressure at the PDP outlet (P_{out}).

  (d) The mean PDP speed (n).

  (e) All parameters necessary to calculate the mean flow rate through the reference flow meter (Q_{ref}) using the manufacturer's prescribed method. This may include several measurements of different quantities such as reference meter pressures and temperatures.

(7) Incrementally close the variable restrictor valve to decrease the absolute pressure at the inlet to the PDP.

(8) Repeat the steps in paragraphs (6) and (7) of this section. Record data at a minimum of six restrictor valve positions reflecting the full range of possible in-use pressures at the PDP inlet.

(9) Repeat the steps in paragraphs(5) through (8) for each speed at which the PDP will be operated.

(10) Data analysis:

  (a) Calculate the air flow rate, Q_{ref}, at each test point in standard cubic feet per minute (68° F, 29.92 in Hg) from the reference flow meter using the manufacturer's prescribed method.

  (b) Convert the air flow rate to pump flow, V_O, in cubic feet per revolution at absolute pump inlet temperature and pressure.

$$V_O = (Q_{ref} / n) x (T_{in} / 528) x (29.92 / P_{PDP})$$

Where:

V_O = Pump flow, ft^3/rev, at T_{in} and P_{in}

Q_{ref} = Air flow rate measured by the reference flow meter, ft^3/min at standard conditions

n = pump speed, revolutions per minute

T_{in} = pump inlet temperature, °R

P_{PDP} = absolute pressure at pump inlet, in Hg

= $P_B - P_{in}$

P_B = barometric pressure, in Hg

(c) The correlation function at each test point is then calculated from the calibration data:

$$X_O = \frac{1}{n}\sqrt{\frac{\Delta P}{P_e}}$$

Where:

X_O = correlation function

ΔP = Pressure differential from pump inlet to pump outlet, in Hg

= $P_{out} - P_{in}$

P_e = absolute pump outlet pressure, in Hg

= $P_B + P_{out}$

(d) A linear least squares fit is performed to generate the calibration equation of the form:

$$V_O = D_O - M(X_O)$$

Where

D_O and M are the intercept and slope describing the regression line.

(11) If the calibration has been performed carefully, calculated value from the equation will be within ±percent of the measured value of V_O.

7.2.4 CFV Calibration

(A) Calibration of the CFV determines the discharge coefficient K_v, at the lowest expected static differential pressure between the CFV inlet and outlet. Gas flow is a function of inlet pressure and temperature:

$$Q_s = \frac{K_V P}{\sqrt{T}}$$

Where:

Q_S = flow

K_V = discharge coefficient

P = absolute pressure

T = absolute temperature

(B) Calibrate the CFV as follows:

(1) Connect the system as shown in Figure 7-2.

(2) Start the blower downstream of the CFV.

(3) Leaks between the calibration flow meter and the CFV must be less than 0.3 percent of the total flow at the highest restriction.

(4) While performing the calibration the CFV inlet temperature must be maintained within ±2 percent of the mean absolute inlet temperature (T_{in}).

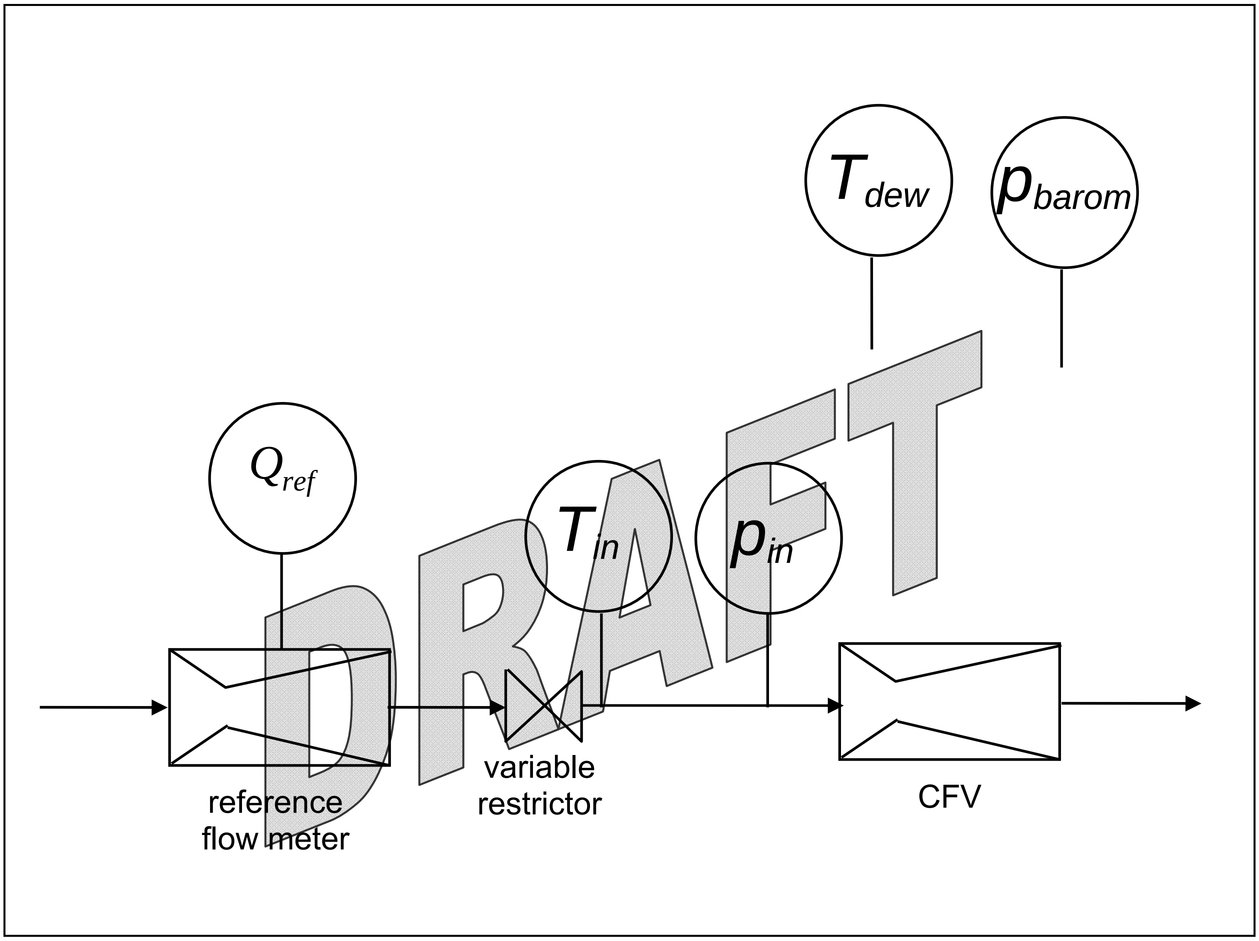

Figure 7-2: Schematic diagram of CFV calibration apparatus

(5) Set the variable restrictor to its wide-open position.

(6) Operate the CFV for at least 3 minutes to stabilize the system. Continue operating the CFV and record the mean values of at least 30 seconds of sampled data of each of the following quantities:

(a) Optionally record the mean dew point of the calibration air $T_{dew.}$

(b) The mean temperature at the venturi inlet, T_{in}.

(c) The mean static absolute pressure at the venturi inlet, P_{in}.

(d) The mean static differential pressure between the CFV inlet and CFV outlet, ΔP_{CFV}.

(e) All parameters necessary to calculate the mean flow rate through the reference flow meter (Q_{ref}) using the manufacturer's prescribed method. This may include several measurements of different quantities such as reference meter pressures and temperatures.

(7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the CFV.

(8) Repeat the steps in paragraphs (6) and (7) of this section to record mean data at a minimum of ten restrictor positions covering the fullest practical range of ΔP_{CFV} expected during testing.

(9) Data analysis:

(a) Calculate values of the discharge coefficient for each test point:

$$K_V = \frac{Q_{ref}\sqrt{T_{in}}}{P_V}$$

Where:

Q_{ref} = air flow rate measured by the reference flow meter, ft^3/min at standard conditions

T_{in} = temperature at venturi inlet, °R

P_V = absolute pressure at venturi inlet, in Hg

$=P_B - P_{in}$

(10)

7.2.5 SSV Calibration

(A) Calibration of the SSV is conducted in a similar fashion as the CFV and PDP. The flowrate within the SSV is a function of inlet pressure (P_i) and temperature (T_i), and the pressure drop between the inlet and the throat (ΔP_{ssv}), as well as the geometric features (inlet pipe and throat diameters):

$$Q_s = \frac{Q_m}{\rho_s} = \frac{K_q}{\rho_s}\left(\frac{C_d \cdot Y \cdot d^2}{\sqrt{1-\beta^4}}\right)\sqrt{\rho_i \cdot \Delta P_{ssv}}$$

Where:

K_q = 0.0021074 (SI units)

Q_s = air volumetric flow rate measured by the flow meter, in SCFM (ft^3/min at standard conditions)

Q_m= air mass flow rate, ft^3/min

ρ_s = air density at standard conditions, lbm/ft^3

ρ_s = air density at standard conditions, lbm/ft^3

C_d = discharge coefficient (actual air flow rate/theoretical air flow rate)

d = throat diameter, inches

β = ratio of venturi throat diameter to approach pipe diameter

ΔP_{ssv} = pressure drop between inlet and throat, in. H_2O

Y = expansion factor, defined below.

(B) Calibrate the SSV using a known reference flowmeter as was done for the CFV (Section **Error! Reference source not found.** (B)), except the variable flow restrictor valve can be set to full open or removed from the system and a device to read pressure drop between the venturi inlet and throat must be added. The SSV must be calibrated in its permanent position, as any changes in upstream or downstream configuration could cause a shift in calibration. .

(1) Follow the procedures and measurement standards for the CFV.

(2) Adjust the blower to maximum in-use flow rate, avoiding a choked throat condition. Allow the system to stabilize as for the CFV and record data from all instruments for 30 seconds.

(a) The mean temperature at the venturi inlet, T_i.

(b) The mean static absolute pressure at the venturi inlet, P_i.

(c) The mean static differential pressure between the SSV inlet and throat, ΔP_{ssv}.

(d) All parameters necessary to calculate the mean flow rate through the reference flow meter (Q_{ref}) using the manufacturer's prescribed method. This may include several measurements of different quantities such as reference meter pressures and temperatures.

(3) Vary the flow rate through the SSV a minimum of 8 steps covering the intended operating range of the SSV.

(4) Data analysis:

(a) Calculate the expansion factor (Y) for each test point. If the SSV is used at the tunnel inlet, assume a value of β=0, if the SSV is installed in the CVS tunnel, use the tunnel inside diameter and throat diameter to compute β:

$$Y = \left[r^{\frac{2}{k}} \left(\frac{k}{k-1} \right) \left(\frac{1 - r^{\left(\frac{k-1}{k}\right)}}{1-r} \right) \left(\frac{1-\beta^4}{1-\beta^4 \cdot r^{\frac{2}{k}}} \right) \right]^{\frac{1}{2}}$$

Where:

$r = 1 - \Delta P / P_{abs}$

$\beta = d/D$

d = throat diameter, inches

D = inlet pipe diameter, inches

k = specific heat ratio (c_p/c_v) (1.4 for air)

(b) The inlet density ρ_i (lbm/ft^3) is determined as follows:

$$\rho_i = \frac{P_{abs}}{R_{mix} \cdot T_{abs}}$$

Where:

$P_{abs} = P_i + P_{atm}$, absolute pressure at SSV inlet, psia

P_{atm} = atmospheric pressure, psia

T_{abs} = absolute temperature at SSV inlet, °R

$R_{mix} = R_u/MW_{mix}$, for air 0.3704 psi-ft^3/lbm-°R

MW_{mix} = molecular weight of the mixture

(c) The molecular weight of the mixture is determined as follows:

$$MW_{mix} = \frac{MW_{air} \cdot (P_{abs} - P_v) + MW_{H_2O} \cdot P_v}{P_{abs}}$$

Where:

P_v = vapor pressure, in. Hg

MW_{air} = 28.964 lbm/lbmol

MW_{H2O} = 18.015 lbm/lbmol

(d) The density at standard conditions of 1 atm pressure and 68°F is 0.0752 lbm/ft^3.

(e) To determine the discharge coefficient, assume an initial value C_d=0.98 to calculate Q_m for the calculation of the Reynolds number, Re:

$$\mathrm{Re} = \frac{6.667E4 \cdot Q_m}{\pi \cdot d \cdot \mu}$$

Where the viscosity (μ) of air, in centipoises, is computed by:

$$\mu = K_\mu \frac{T_k^{\ 1.5}}{(T_k + 110.4)}$$

Where:

K_μ = 1.458E-3

$T_k = T_i$ in units of degrees Kelvin

(f) From initial calibration of the SSV, establish an equation of discharge coefficient (C_d) as a function of Reynolds number (Re). Fit the resulting data with a power series least-squares fit. Use this new C_d to determine a final value of Q_m at each test point.

(g) Compute the percent difference in air flow between the calibration flow meter and SSV. If the difference is higher than 1%, compute a new C_d and Re for the SSV as follows:

$$C_{d,\,new} = \text{actual air flow/theoretical air flow} = Q_{m,\,act}/Q_{m,\,theor}$$

Where $Q_{m,\,act}$ is the flow measured by the calibration flow meter and $Q_{m,\,theor}$ is the theoretical calculated flow based on SSV conditions with C_d set to 1.

(h) Recalculate a curve fit of C_d as a function of Reynolds number and determine the SSV flow rate. The agreement between the SSV and calibration flow meter should be within 1%.

7.3 Hydrocarbon Analyzer Calibration

7.3.1 Calibration Overview and Frequency

(A) The HFID used for measuring hydrocarbon emissions from petroleum-fueled, natural gas fueled and liquefied petroleum gas fueled vehicles shall be operated to a set point of 375 ± 10 °F (190.5 ± 5.5 °C).

(B) The HFID hydrocarbon analyzer shall receive the following initial and periodic calibration procedures:

(1) *Detector Response Optimization* – The HFID hydrocarbon analyzer shall be adjusted for optimum hydrocarbon response:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in the FID fuel source

(e) at least annually thereafter

(2) *Oxygen Interference Optimization* – The response of the HFID hydrocarbon analyzer to oxygen interference check gases must not exceed 3%. Verification of the HFID response to oxygen interference shall be conducted:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in the FID fuel source

(e) at least annually thereafter

(3) *Initial and Periodic Calibration* – The HFID hydrocarbon analyzer shall be calibrated on the most appropriate instrument range(s) for the vehicle under test. Calibration should be conducted:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in FID fuel source

(e) following any change in the calibration gas source

(f) following any change in analyzer range

(g) at least monthly thereafter

(4) HFID Response Factor to Methane – When the HFID analyzer is used for the analysis of natural gas-fueled vehicles, the methane response factor of the analyzer shall be established. The methane response factor shall be determined or verified:

(a) prior to testing any natural gas fueled vehicle

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in the FID fuel source

(e) following any change in calibration gas source

(f) following any change in analyzer range

(g) monthly thereafter

7.3.2 Detector Response Optimization Procedure

(A) The HFID response optimization is performed to ensure that the fuel/air mixture supplied to the analyzer results in the maximum response.

(B) Optimize the HFID's response on the most common operating range using the either the procedure specified by the manufacturer or the procedure prescribed below (Reference 40 CFR 86.331-79(c) [1]):

(1) Follow good engineering practices foe initial instrument start-up and basic operating adjustment using the appropriate fuel as specified in Section 6.6.1(A)(5).

(2) Set the fuel and air flow rates at the manufacturer's recommendations

(3) Introduce a span gas representative of the most common instrument range to the detector.

(4) Determine the response at a given fuel flow rate from the difference between the span-gas response and the zero-gas response.

(5) Incrementally adjust the fuel flow rate above and below the manufacturer's specifications and record the span and zero response at these fuel flows.

(6) Plot the difference between the span and zero response versus fuel flow as shown in Figure 7-3.

(7) Adjust the fuel flow rate slightly to the rich side of the curve as shown.

(8) Record the optimum fuel and air pressures or flow rates for future reference.

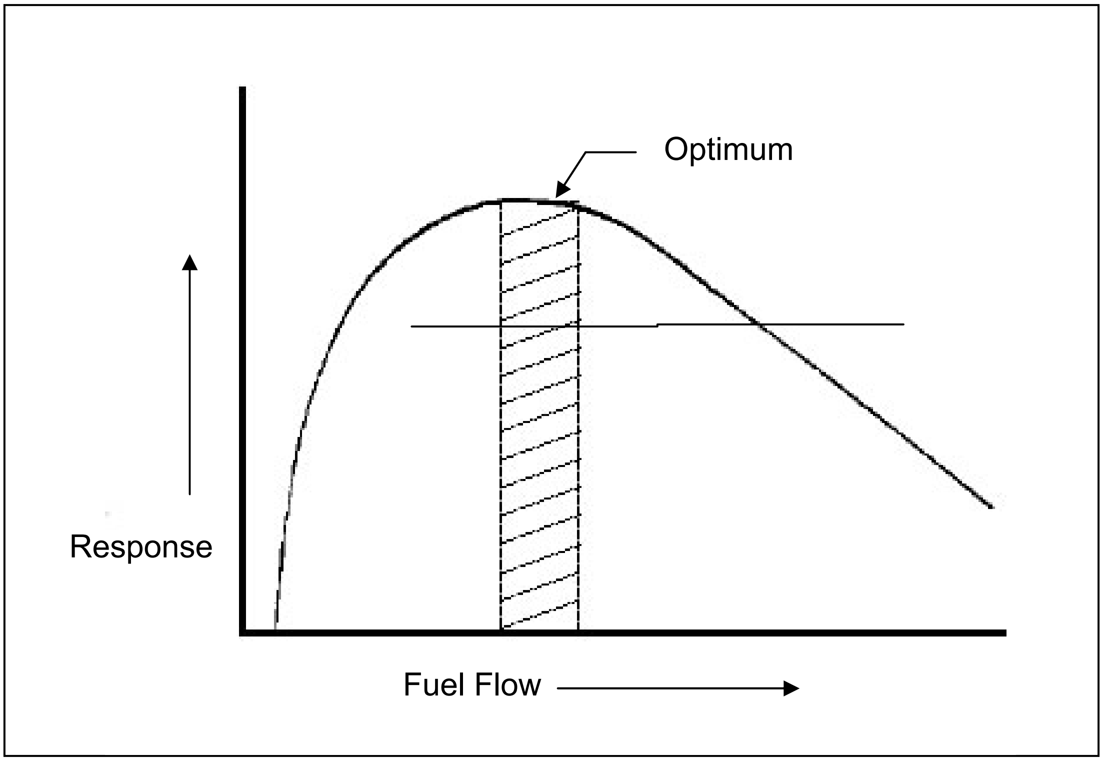

Figure 7-3: HFID Response as a Function of Fuel Flow Rate [1]

7.3.3 Oxygen Interference Optimization Procedure

(A) The oxygen interference optimization is performed to verify that oxygen present in the exhaust sample does not interfere with the accurate measurement of hydrocarbons.

(B) Oxygen interference shall be determined by the following procedure (Reference 40 CFR 86.331-79(d) [1]):

(1) Choose an analyzer range where the oxygen interference check gases will fall in the upper 50%.

(2) Zero the analyzer using zero-grade air.

(3) Span the analyzer using a propane-in-air span gas mixture representative of the most commonly used range.

(4) Recheck the zero response. If it has changed more than 0.5% of full scale repeat steps (2) and (3) of this section.

(5) Introduce an interference check gas consisting of 10% pure oxygen and 90% span gas. A gas divider may be used to blend the interference check gas.

(6) Recheck the zero response. If it has changed more than ±1%, then repeat the test.

(7) Calculate the percent of oxygen interference ($\%O_2I$)

$$\%O_2I = \frac{B - AR\ (ppmC)}{B}(100)$$

$$AR = A\frac{(\text{Percent of full-scale analyzer response due to } B)}{(\text{Percent of full-scale analyzer response due to } A)}$$

A = hydrocarbon concentration (*ppmC*) of the span gas used in step (3)

B = hydrocarbon concentration (*ppmC*) of the oxygen interference check gas used in step (5)

(8) The percent of oxygen interference ($\%O_2I$) must be less than ±3% prior to testing.

(9) If the oxygen interference is greater than the specification, repair or replace the analyzer, change the FID fuel, or change the burner air to correct the interference problem prior to testing. Repeat this section after corrective action has been competed through repair or replacement of equipment or gases.

7.3.4 Initial and Periodic Calibration Procedure

(A) The HFID hydrocarbon analyzer shall be calibrated on all normally used ranges. Use the same flow rate and sample pressure as when analyzing samples.

(B) Calibration gases shall be introduced directly at the analyzer, unless the “overflow” calibration option 6.2.7(C)(2) for the HFID is exercised.

(C) The following calibration procedure shall be used (Reference 40 CFR 86.1321-94 [1]):

(1) Adjust the analyzer to optimize performance.

(2) Zero the hydrocarbon analyzer with zero-grade air.

(3) Calibrate on each used operating range with a minimum of 6, approximately equally spaced, propane-in-air calibration gases (e.g. 15, 30, 45, 60, 75 and 90 percent of that range). A gas divider may be used to provide the gas concentrations.

(4) For each range calibrated, if the deviation from a least-squares best-fit straight line is within ±2% of the value at each non-zero data point and within ±0.3% of full scale on the zero data point, then concentration values may be calculated by using the linear calibration equation for that range. If the deviation exceeds

these limits, then the best-fit non-linear equation which represents the data within these limits shall be used to determine concentration values [1].

7.3.5 HFID Response to Methane Procedure

(A) When the HFID analyzer is used for the analysis of natural gas-fueled vehicles, the methane response factor of the analyzer shall be established as follows (Reference 40 CFR 86.1321-94(d) [1]).

(1) To determine the total hydrocarbon HFID response to methane, known methane-in-air concentrations traceable to NIST shall be analyzed by the HFID.

(2) Several methane concentrations shall be analyzed by the FID in the range of concentrations in the exhaust sample.

(3) The HFID response to methane is calculated as follows:

$$r_{CH4} = FIDppm / SAMppm$$

$$where:$$

$$r_{CH4} = \text{FID response to methane}$$

$$FIDppm = \text{FID reading in ppmC}$$

$$SAMppm = \text{the known mehtane concentration in ppmC}$$

7.4 Carbon Monoxide Analyzer Calibration

7.4.1 Calibration Overview and Frequency

(A) The NDIR carbon monoxide analyzer shall receive the following initial and periodic calibration procedures:

(1) *Initial and Periodic Interference Check* – The NDIR carbon monoxide analyzer shall be checked for response to water vapor and CO_2:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) annually thereafter

(2) *Initial and Periodic Calibration* - The NDIR carbon monoxide analyzer shall be calibrated on the most appropriate instrument range(s) for the vehicle under test. Calibration should be conducted:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in the calibration gas source

(e) following any change in analyzer range

(f) at least monthly thereafter

7.4.2 Initial and Periodic Interference Check

(A) The following procedure shall be used (Reference 40 CFR 86.1322-84(a) [1]).

(1) Follow good engineering practices for instrument start-up and operation. Adjust the analyzer to optimize performance on the most sensitive range to be used following the manufacturer's recommended procedures.

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

(3) Introduce a mixture of 3% CO_2 in N_2 bubbled through water at room temperature into the analyzer and record analyzer response.

(4) An analyzer response of more than 1% of full scale for ranges above 300 ppm full scale or more than 3 ppm on ranges below 300 ppm full scale requires corrective action. (Use of conditioning columns or refrigerated driers are forms of corrective action that may be taken.)

7.4.3 Initial and Periodic Calibration Procedure

(A) The following calibration procedure shall be followed (Reference 40 CFR 86.1322-84 (b) [1]):

(1) Adjust the analyzer to optimize performance according to the manufacturer's recommended procedures.

(2) Zero the carbon monoxide analyzer with either zero-grade air of zero-grade nitrogen.

(3) Calibrate on each used operating range with a minimum of 6, approximately equally spaced, propane-in-air calibration gases (e.g. 15, 30, 45, 60, 75 and 90 percent of that range). A gas divider may be used to provide the gas concentrations.

(4) For each range calibrated, if the deviation from a least-squares best-fit straight line is within ±2% of the value at each non-zero data point and within ±0.3% of full scale on the zero data point, then concentration values may be calculated by using the linear calibration equation for that range. If the deviation exceeds these limits, then the best-fit non-linear equation which represents the data within these limits shall be used to determine concentration values [1].

7.5 Oxides of Nitrogen Analyzer Calibration

7.5.1 Calibration Overview and Frequency

(A) The chemiluminescent (CLD) oxides of nitrogen analyzer shall receive the following initial and periodic calibration procedures:

(1) *NO_2 to NO Converter Efficiency Check* – The chemiluminescent oxides of nitrogen analyzer must be checked for NO_2 to NO converter efficiency:

(a) Prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) at least monthly thereafter

(2) *Initial and Periodic Calibration* – The chemiluminescent oxides of nitrogen analyzer shall be calibrated on all normally used ranges:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in the calibration gas source

(e) following any change in analyzer range

(f) at least monthly thereafter

(3) *Chemiluminescent NOx Analyzer Quench Check* – CO_2 and Water vapor interfere with the response of a CLD by collisional quenching. The combined quench effect at their highest expected concentrations must be determined:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) once per year thereafter

7.5.2 NO_2 to NO Converter Efficiency Check

(A) The NO_2 to NO converter efficiency shall be verified by the following procedure (Reference 40 CFR 86.1323-2007(a) [1]):

(1) Follow good engineering practices for instrument start-up and operation. Adjust the analyzer to optimize performance.

(2) Zero the analyzer with zero-grade nitrogen.

(3) Set the oxides of nitrogen analyzer to the most common operating range

(4) Connect the outlet of the NOx generator Figure 7-4 to the sample inlet of the oxides of nitrogen analyzer.

(5) Introduce into the NOx generator-analyzer system and NO-in nitrogen mixture with an NO concentration equal to approximately 80 percent of the most common operating range. The NO_2 content of the gas mixture shall be less than 5 percent.

(6) With the oxides of nitrogen analyzer in the NO mode, record the concentration of NO indicated by the analyzer.

(7) Turn on the NOx generator O_2 supply and adjust the O_2 flow rater so that NO indicated by the analyzer I about 10 percent less than indicated in paragraph (6). Record the concentration on NO in this NO + O_2 mixture as value "***c***".

(8) Switch the NOx generator to the generation mode and adjust the generation rate so that the NO measured by the analyzer is 20 percent of that measured in paragraph (6). There must be at least 10% unreacted NO at this point. Record the concentration of residual NO as value “***d***”.

(9) Switch the oxides of nitrogen analyzer to NOx mode and measure the total NOx. Record this value as value “***a***”.

(10) Switch off the NOx generator but maintain gas flow through the system. The oxides of nitrogen analyzer will indicate the NOx in the NO + O_2 mixture. Record this value as value “***b***”.

(11) Turn off the NOx generator O_2 supply. The analyzer will now indicate the NOx in the original NO-in N_2 mixture. This value should be no more than 5 percent above the value indicated in paragraph (4).

(12) Calculate the efficiency of the NOx converter by substituting the concentrations obtained into the following equation.

$$\text{Percent Efficiency} = 1 + \frac{a-b}{c-d} x 100$$

(13) If the converter efficiency is not greater than 90 percent, repair the analyzer. The repaired analyzer must achieve converter efficiency greater than 90 percent before the analyzer may be used.

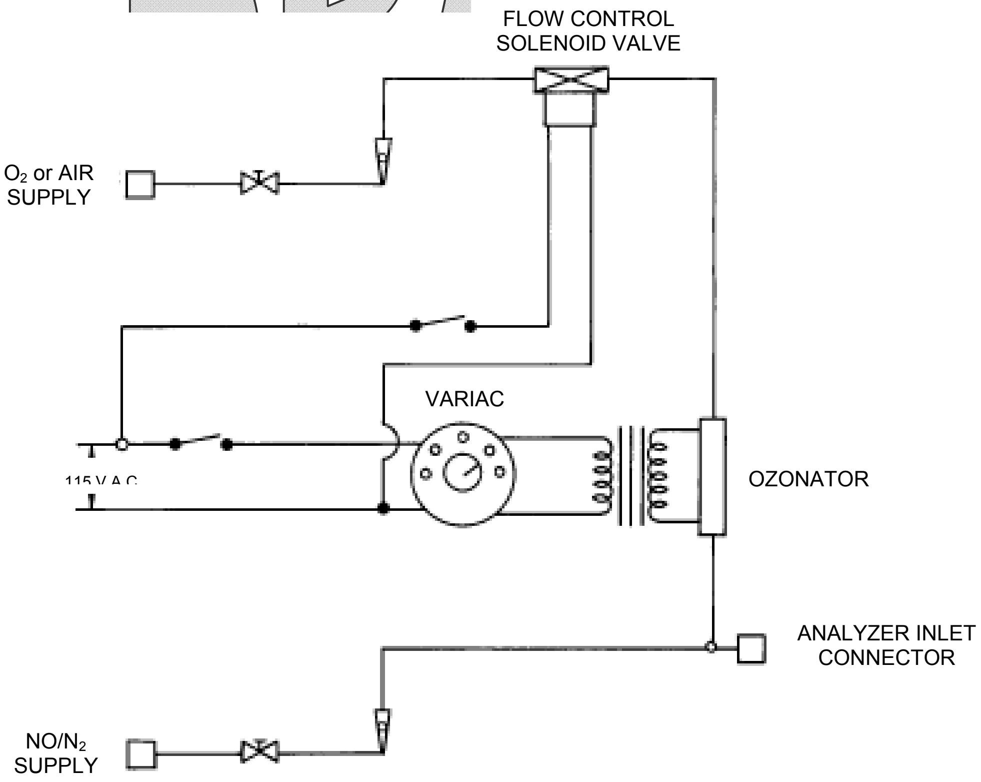

Figure 7-4: NOx Converter Efficiency Detector [1]

7.5.3 Initial and Periodic Calibration

(A) The following calibration procedure shall be followed (Reference 40 CFR 86.1323-2007(c) [1]):

(1) Adjust the analyzer to optimize performance.

(2) Zero the oxides of nitrogen analyzer with zero-grade nitrogen.

(3) Calibrate all operating ranges with a minimum of nine (9) NO-in N_2 calibration gases (e.g., 10, 20, 30, 40, 50, 60, 70, 80, 90 percent of that range) and on one zero grade N_2 gas. A gas divider may be used to provide the gas concentrations.

(4) For each range calibrated, if the deviation from a least-squares best-fit straight line is within ±2% of the value at each non-zero data point and within ±0.3% of full scale on the zero data point, then concentration values may be calculated by using the linear calibration equation for that range. I the specified deviations are exceeded for ranges that have a minimum limit of 1 ppm or greater, then the best-fit non-linear equation that represents the data with in these deviations may be used to determine concentration values. For ranges that have a minimum limit less than 1 ppm, only a linear or second order non-linear equation that represents the data with in these deviations may be used to determine the concentration values [1].

7.5.4 Chemiluminescent NOx Analyzer Interference Check

(A) The quench check described in this section shall be performed on CLD NOx analyzers. The combined CO_2 and water quench effect at their highest expected concentrations shall not exceed 2 percent.

(B) *CO_2 Quench Check Procedure* – Reference 40 CFR 86.1323-2007 (d) [1].

(1) Variations in this procedure are acceptable provided they produce equivalent $\%CO_{2quench}$ results.

(2) Connect a pressure-regulated CO_2 span gas to one of the inlets of a three-way valve. The CO_2 concentration should be approximately twice the maximum concentration expected in the vehicle exhaust during testing. The valve must be leak free and its wetted parts must be made of stainless steel or other inert material.

(3) Connect a pressure-regulated zero-grade N_2 gas to the other inlet of the three way valve.

(4) Connect the single outlet of the valve to the balance-gas port of a properly operating gas divider.

(5) Connect a pressure-regulated NO span gas which has approximately twice the typical NO concentration expected during testing, to the span-port of the gas divider.

(6) Configure the gas divider such that nearly equal amounts of the span gas and the balance gas are blended with each other. Viscosity corrections shall be applied appropriately to ensure correct mass flow determinations.

(7) With the CO_2 flowing to the balance port and the NO flowing to the span port, measure a stable CO_2 concentration from the gas divider's outlet port with a properly calibrated NDIR CO_2 analyzer. Record this concentration in percent (%). This is "**$\%CO_2$**". This value is used in the water vapor quench check calculations described in paragraph (C) below.

(8) Measure the NO concentration at the gas divider outlet with the CLD analyzer in the NO mode. Record this concentration in ppm. This is "**NO_{CO2}**".

(9) Switch the three-way valve such that 100% N_2 flows to the balance port inlet of the gas divider. Monitor the CO_2 concentration of the gas dividers outlet until its concentration stabilizes at zero. Then measure the stable NO concentration from the gas divider's outlet. Record this value in ppm. This is "**NO_{N2}**".

(10) Calculate $\%CO_{2quench}$ as follows:

$$\%CO_{2quench} = (1.00 - (NO_{CO2} / NO_{N2}))x100$$

(C) *Water Vapor Quench Check Procedure* – Reference 40 CFR 86.1323-2007(d) [1]

(1) For all dry CLD analyzers it must be demonstrated that for the highest expected water vapor, the water removal technique maintains CLD humidity at less than or equal to 5 $g_{water}/kg_{dry\ air}$ (or about 0.008 percent H_2O), which is 100% RH at 3.9°C and 101.3 kPa. This humidity specification is also equivalent to about 25% RH at 25°C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD. Humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow out of the dehumidifier.

(2) For all ''wet'' CLD analyzers the following water vapor quench check procedure shall be followed.

(a) Measure an NO span gas, which has 90% to 100% of the typical NO expected during testing, using the CLD in the NO mode. Record this concentration in ppm; this is ''NO_{dry}''.

(b) Then bubble the same NO span gas through distilled water in a sealed vessel at 25°C ±10°C. This temperature specification is imposed to ensure that the H_2O_{vol} calculation returns an accurate result. To prevent subsequent condensation, this temperature must also be less than any temperature that the wetted sample will experience between the sealed vessel's outlet and the CLD. Record the vessel's water temperature in °C; this is ''T_{sat}''. Record the vessel's absolute pressure in kPa; this is ''P_{sat}''.

(c) Measure the wetted span gas with the CLD, and record this value in ppm; this is ''NO_{wet}''.

(3) Calculations for water quench must consider dilution of the NO span gas with water vapor and scaling of the water vapor concentration to that expected during testing.

  (a) Calculate the volume fraction of water vapor in the wetted span gas, as $H_2O_{vol} = (\exp(3.69-(81.28/T_{sat})) + 1.61)/P_{sat}$. This calculation approximates some of the thermodynamic properties of water based on the ''1995 Formulation for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use'', issued by The International Association for the Properties of Water and Steam (IAPWS). However, this approximation should only be used as prescribed in this section because it is an exponential fit that is accurate for data at 25°C ±10°C. Then, assuming a diesel fuel atomic hydrogen to carbon ratio of 1.8, and an intake and dilution air humidity of 75 grains (10.71 g_{water}/kg_{dry} air or 54.13 percent RH at 25°C and 101.3 kPa),

  (b) Calculate the maximum percent water vapor expected during testing; as $\%H_2O_{exp} = (0.90 \times \%CO_2) + 1.69$. $\%CO_2$ is the value measured during the $\%CO_2$ quench check.

  (c) Calculate the expected wet concentration of NO in ppm; as

$$NOexp = NO_{dry} \times (1.00-H_2O_{vol})$$

  (d) Calculate the percent water vapor quench as:

$$\%H_2O_{quench} = ((NO_{exp}-NO_{wet})/NO_{exp}) \times (\%H_2O_{exp}/H_2O_{vol})$$

7.6 Carbon Dioxide Analyzer Calibration

7.6.1 Calibration Overview and Frequency

(A) The NDIR carbon dioxide analyzer shall receive the following initial and periodic calibration procedures:

  (1) Initial and Periodic Calibration - The NDIR carbon dioxide analyzer shall be calibrated on the most appropriate instrument range(s) for the vehicle under test. Calibration should be conducted:

    (a) prior to introduction into service

    (b) at instrument start-up following any period of analyzer shutdown

    (c) following any analyzer maintenance

    (d) following any change in the calibration gas source

    (e) following any change in analyzer range

    (f) at least monthly thereafter

7.6.2 *Initial and Periodic Calibration*- Reference 40 CFR 86.124-78 [1]

(1) Adjust the analyzer to optimize performance according to the manufacturer's recommended procedures.

(2) Zero the carbon monoxide analyzer with either zero-grade air of zero-grade nitrogen.

(3) Calibrate on each used operating range with a minimum of 6, approximately equally spaced, propane-in-air calibration gases (e.g. 15, 30, 45, 60, 75 and 90 percent of that range). A gas divider may be used to provide the gas concentrations.

(4) For each range calibrated, if the deviation from a least-squares best-fit straight line is within ±2% of the value at each non-zero data point and within ±0.3% of full scale on the zero data point, then concentration values may be calculated by using the linear calibration equation for that range. If the deviation exceeds these limits, then the best-fit non-linear equation which represents the data within these limits shall be used to determine concentration values [1].

7.7 Methane Analyzer Calibration

7.7.1 Calibration Overview and Frequency

(A) The methane analyzer shall receive the following initial and periodic calibration procedures:

(1) *Initial and Periodic Calibration* – The methane analyzer shall be calibrated on the most appropriate instrument range(s) for the vehicle under test. Calibration should be conducted:

(a) prior to introduction into service

(b) at instrument start-up following any period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in FID fuel source

(e) following any change in the calibration gas source

(f) following any change in analyzer range

(g) at least monthly thereafter

7.7.2 Initial and Periodic Calibration

(A) The following calibration procedure shall be used (Reference 40 CFR 86.1325-94 [1]):

(1) Adjust the analyzer to optimize performance.

(2) Zero the methane analyzer with zero-grade air.

(3) Calibrate on each used operating range with a minimum of 6, approximately equally spaced, CH_4-in-air calibration gases (e.g., 15, 30, 45, 60, 75 and 90 percent of that range). A gas divider may be used to provide the gas concentrations.

(4) For each range calibrated, if the deviation from a least-squares best-fit straight line is within ±2% of the value at each non-zero data point and within ±0.3% of

full scale on the zero data point, then concentration values may be calculated by using the linear calibration equation for that range. If the deviation exceeds these limits, then the best-fit non-linear equation which represents the data within these limits shall be used to determine concentration values [1].

7.8 Microbalance Calibration

(A) Microbalance manufacturer specifications for calibration procedures shall be followed. All certification and calibration procedures shall be NIST traceable or traceable to an equivalent national standard. Calibration of Other Equipment.

7.9 Calibration of other equipment

7.9.1 Calibration Overview and Frequency

(A) Other test equipment shall receive the following initial and periodic calibration procedures (Reference 40 CFR 86.1326-90 [1]):

(1) *Initial and Periodic Calibration* – Other test equipment shall be calibrated on the most appropriate instrument range(s) for the vehicle under test. Calibration should be conducted:

(a) prior to introduction into service

(b) at instrument start-up following any extended period of analyzer shutdown

(c) following any analyzer maintenance

(d) following any change in the calibration gas source if applicable

(e) as often as required by the manufacturer or as necessary according to good practice.

7.9.2 Initial and Periodic Calibration

(A) Specific equipment requiring calibration

(1) Gas chromatograph

(2) Flame ionization detector used in measuring methanol

(3) High pressure liquid chromatograph (HPLC) and ultraviolet detector for measuring formaldehyde.

8. TEST PROCEDURES

8.1 Test Sequence

Figure 8-1 illustrates the generic test sequence.

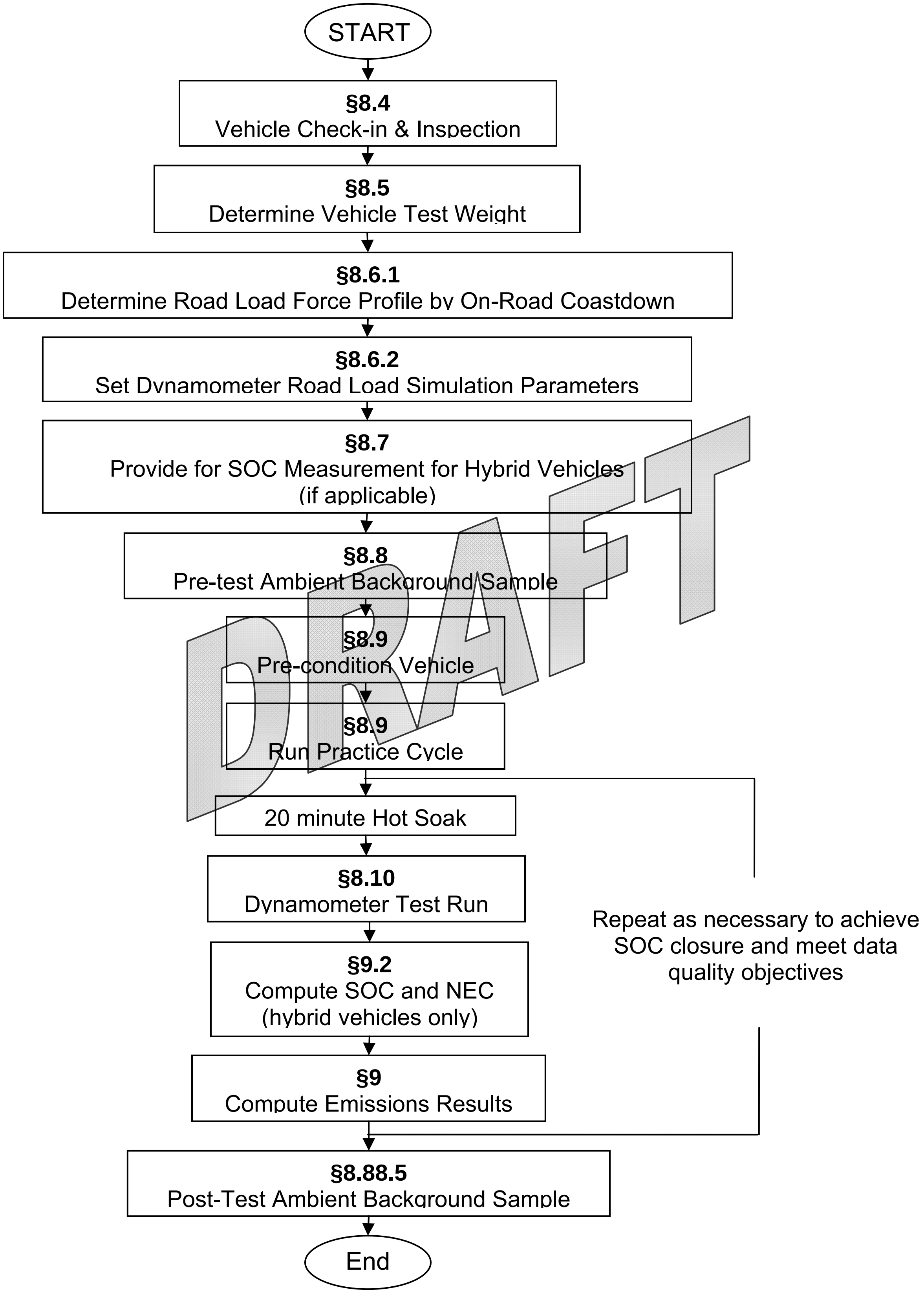

Figure 8-1: Generic Test Sequence

8.2 Test Conditions

8.2.1 Ambient Conditions

(B) Emissions testing is permissible under ambient conditions meeting one of the following criteria:

  (1) Emissions may be measured and reported without ambient corrections provided that the engine intake air temperature is within the range of 68°F to 86°F (20°C to 30°C) (40CFR 86.1330-90(b)[1]).

  (2) Emissions may be measured and reported with ambient corrections provided that the engine intake air temperature is within the range of 45°F to 100°F (7° to 38°C) (SAE 2711 §6.1 [2]). The measured emissions data shall be corrected base on the ambient conditions under which the test was conducted as follows:

    (a) NOx emissions shall be corrected for ambient air humidity to a standard humidity level of 50 grains (7.14 g/kg) if the humidity of the intake air was below 50 grains, or to 75 grains (10.71 g/kg) if above 75 grains (10.71 g/kg) (40 CFR 86.1370(e) [1]).

    (b) NOx and PM emissions shall be corrected for ambient air temperature to a temperature of 55 °F (12.8 °C) for ambient air temperatures below 55 °F or to 95 °F (35.0 °C) if the ambient air temperature is above 95 °F (40 CFR 86.1370(e) [1]).

    (c) No ambient air or humidity correction factors shall be used within the ranges of 50-75 grains or 55-95 °F (40 CFR 86.1370(e) [1]).

  (3) Where test conditions require such correction factors the following methods shall be used:

  [RESERVED]

(C) At a minimum, ambient temperatures must be recorded at the beginning and end of each chassis dynamometer test run.

8.2.2 Engine Cooling

(D) During operation of the vehicle on the chassis dynamometer, one or more cooling fans shall be positioned in a best faith effort to establish an equivalent air velocity of 10 mph (16.1 km/hr) beneath the bus and across any engine compartment intake of exhaust vent.

(E) The intention of the cooling fans is to prevent recirculation of stagnate hot air and not to augment the engine cooling.

8.3 Vehicle Configuration during Testing

8.3.1 General Provisions

(A) The intent of this protocol is to measure the emissions with the transit bus equipped and operated in the configuration in which it will be offered for sale.

(B) Certain aspects of buses such as hybrid drive and transmissions control algorithms may be customized to each individual transit agency’s requirements at the time of delivery and these customizations can have substantial impacts on vehicle performance, fuel economy and emissions. In some instances it may be adequate to perform the testing in the most common configuration while in other instances it may be necessary to perform testing in multiple configurations.

(C) Additional guidance as to bus model and configuration considerations is provided in Section 12 of this document.

8.3.2 General Vehicle Condition

(A) Vehicle Stabilization – Prior to testing, the vehicle shall be stabilized by operating to a distance of 4000 miles (SAE J2711 §6.3.2 [2]).

(B) State of Repair – The test vehicle should be in a good state of repair and have no known active engine and/or vehicle diagnostics/fault codes that may impact emissions.

(C) Engine Air Filter – The engine air filter should be reasonably clean. It is recommended that a fresh air filter be installed prior to emissions testing.

(D) Exhaust System – The vehicle exhaust system must be free of leaks. Exhaust aftertreatment systems should be installed and functioning as intended during normal service.

8.3.3 Tires

(E) The vehicle will be tested using tires falling in that range of tire sizes recommended by the manufacturer.

(F) Tire should be in well used but in good condition. New tires are not recommended for dynamometer testing because they can delaminate and rupture due to excessive heat buildup. In cases where the as received tires are too green for chassis dynamometer testing, a suitable set of test tires of the same size should be mounted on the vehicle.

(G) Tire inflation pressure shall be adjusted to median of the range specified by the tire manufacturer and shall not exceed levels necessary for safe operation. During dynamometer testing the tires should be set at the same pressure used to determine dynamometer road-load coefficients.

8.3.4 Lubricants and Coolant

(H) Manufacturer recommended engine lubricating oil, coolant and transmission fluid should be used.

(I) Fluid levels should be within normal operating ranges.

(J) It is not recommended that emissions testing be conducted immediately following an engine oil change.

8.3.5 Fuel

(K) The fuel tank should be drained and filled with the required test fuel to ensure only test fuel is utilized. Alternatively a remote tank may be used.

(L) Fuel level (liquid fueled vehicles) or pressure (gaseous fueled vehicles) should be adequate to complete the required test cycles and sufficient to prevent excessive fuel heating (liquid fueled vehicles).

(M) If necessary an auxiliary fuel cooler may be used to maintain acceptable fuel temperature.

8.3.6 Air System

(A) All vehicles with air suspensions and/or air brakes shall have their air systems charged to normal operating pressure at the beginning of the test.

(B) Air systems may be charged from and external source prior to testing. After the air system has reached sufficient pressure to achieve proper suspension leveling and service brake operation, the external air source shall be disconnected and not be reconnected during actual emissions testing.

(C) External air should only be utilized prior to the first test and should not be utilized between testing events during the key off period.

8.3.7 Traction Control and ABS Braking Systems

(A) If the test vehicle is equipped with an Antilock Braking System (ABS) or a Traction Control System (TCS) and is tested on a two-wheel dynamometer, the vehicle's ABS or TCS may inadvertently interpret the non-movement of the (front) set of wheels as a malfunctioning system (SAE J2711 §6.3.7 [2]).

(B) Modifications to defeat the ABS or TCS shall be made to achieve normal operation of the remaining vehicle systems including the engine transmissions and regenerative braking system (SAE J2711 §6.3.7 [2]).

8.3.8 Transmission Operation

(A) For buses with automatic transmissions, the bus shall be tested with the automatic transmission control algorithm consistent with that intended for normal in-use operation.

  (1) The same transmission control software used for fuel economy testing shall be used for emissions testing.

  (2) If the bus is offered for sale with altered hardware and software, the test results do not extend to the altered configurations.

(B) The transmission shall be operated in a manner consistent with in-use operation. In the case of test vehicles equipped with manual transmissions, the transmission shall be shifted in accordance with procedures that are representative of normal use.

(C) Except for the first idle mode, idle modes less than one minute in length shall be run with automatic transmissions in “Drive” and the wheels braked; manual transmissions shall be in gear with the clutch disengaged (40 CFR 86.1228-85 [1]).

(D) The first idle mode and idle modes longer than one minute in length shall run with automatic transmissions in “Neutral,” and manual transmissions in “Neutral” with clutch engaged (40 CFR 86.1228-85 [1]).

(E) During decelerations to zero, manual transmissions clutches may be disengaged when vehicle speed drops below 15 mph (24.1 km/h), when engine roughness is evident or engine stall is imminent (40 CFR 86.1228-85 [1]).

(F) Devices that assist in decelerating the vehicle such as engine compression brakes, electrical retarders or other similar devices shall be disengaged during emissions testing. This stipulation does not apply to regenerative braking features of hybrid vehicles.

8.3.9 Hybrid Drive System Calibration

(A) Some hybrid drive buses may have features that may be calibrated at the time of delivery to meet the specific transit agency’s requirements. Such calibrations may significantly impact fuel consumption and emissions.

  (1) The bus shall be tested with the hybrid drive system hardware, software and calibration that reflect the most common configuration to be offered for sale.

  (2) Emissions testing shall be conducted with the same hybrid drive system, hardware, software and calibration use for fuel economy testing.

  (3) If the bus is offered for sale with altered hardware and software, the test results do not extend to the altered configurations.

8.3.10 Regenerative Braking

(A) Regenerative braking is a mechanism by which a portion of the energy normally dissipated in decelerating the vehicle is captured (e.g. by operating an electric motor-generator system) and stored in a rechargeable energy storage system (ESS) thereby returned to the vehicle propulsion system or available to operate onboard auxiliaries.

(B) If the vehicle has regenerative braking, the vehicle should be operated on the chassis dynamometer during emissions testing with the identical control strategy as used in service. Vehicles with regenerative braking ability on axles which are not rotated on the dynamometer at time of testing will not have the full potential of regenerative braking demonstrated by the test.

(C) During on-road and on-dynamometer coastdown procedures to establish dynamometer load coefficients that simulate road-load forces, the regenerative braking system must be disabled. Refer to Section 8.5 for detailed procedures.

8.3.11 Heating Ventilation and Air Conditioning

(A) Heating, ventilation and air conditioning (HVAC) in heavy-duty transit buses can be a significant consumer of on-board vehicle power and as a result can have a large impact on fuel consumption and emissions. A holistic view of vehicle efficiency and emissions inventory contribution should consider typical air conditioning load. However typical air conditioning load is not readily described and cannot be consistently achieved absent the availability of an environmental enclosure (SAE J2711 §7.8 [2]).

(B) The HVAC system shall be turned off during emissions testing conducted under this protocol.

8.3.12 Interior and Exterior Lighting and Onboard Accessories

(A) Interior and exterior lighting shall be switched off during emissions testing.

(B) All other non-propulsion related onboard accessories such as “Wi-FI” wireless internet technology etc. shall be switched off during emissions testing.

8.4 Pre-Test Vehicle Inspection

8.4.1 General Provisions

(A) The objectives of the pre-test vehicle inspection are as follows:

  (1) To thoroughly document the “as-tested” configuration and condition of the vehicle.

  (2) To identify and correct any vehicle maintenance issues that may affect accuracy and quality of the emissions test results.

  (3) To assure that the vehicle is in a safe condition for operation on the chassis dynamometer.

8.4.2 Documentation of Vehicle Configuration and Condition

The following vehicle information shall be documented prior to installation of the vehicle on the chassis dynamometer:

(B) General Information

  (1) Bus Type (e.g. articulated, coach, dual mode, trolleybus, intercity body on chassis, etc.)

  (2) Vehicle Identification Number (VIN)

  (3) Vehicle manufacturer

  (4) Vehicle model no.

  (5) Model year of the vehicle

  (6) Odometer meter reading

  (7) Hub odometer reading (if equipped)

  (8) Number of axles

(9) Number of drive axles

(10) Drive axle ratio (may not be appropriate for hybrid vehicles with wheel motor drives)

(11) Tire size and specification

(C) Vehicle Weight and Wheel Reactions

(1) Record the following vehicle weight ratings as provided by the vehicle manufacturer.

(a) Vehicle curb weight (CW)

(b) Gross Vehicle Weight Rating (GVWR)

(c) Gross Axle Weight Rating (GAWR) for the front, rear and middle axles (if applicable)

(d) Seated passenger capacity (including driver)

(2) Measure and record the individual (left and right) wheel reactions for each axle at each of the following vehicle load conditions:

(a) Curb weight

(b) One-half seated load weight

(3) Compute and record the vehicle test weight according to Section 8.5 of this document.

(D) Vehicle Dimensions

(1) Length

(2) Width

(3) Height

(E) Engine Information

(1) Engine type (e.g. compression ignition, spark ignition, dual-fuel, etc.)

(2) Engine manufacturer

(3) Engine family

(4) Engine model no.

(5) Engine serial no.

(6) Model year

(7) No. of cylinders

(8) Engine configuration (e.g. in-line 6 cylinder, V – 8 cylinder, etc.)

(9) Engine displacement (in^3 or Liters):

(10) Bore

(11) Stroke

(12) Compression ratio
(13) Engine rated power (hp@ rpm or kW@rpm)
(14) Engine peak torque (ft-lb@ rpm or Nm@rpm)
(15) Governed speed (rpm)
(16) Curb idle (rpm)
(17) High idle (rpm):
(18) Engine electronically controlled? Yes/No
    (a) ECU protocol (e.g. SAE J1922, J1587, J1939)
    (b) ECU manufacturer
    (c) ECU model no.
    (d) ECU serial no.
(19) Turbocharged? Yes/No
(20) Charge cooling? Yes/No
(21) Engine location (e.g. front, rear, other)
(22) Fuel type (e.g. gasoline, diesel, CNG, LNG, ethanol, etc.)
(23) Fuel induction type: (e.g. fuel injected, carburetion)
    (a) Fuel injector or carburetor manufacturer
    (b) Fuel injector or carburetor model no.
(24) Fuel pump:
    (a) Manufacturer
    (b) Model no.
(25) Engine compression brake:
    (a) Type
    (b) Manufacturer
    (c) Model no.

(F) Aftertreatment Devices

For each aftertreatment device present on the vehicle document the following information:

(1) Type of aftertreatment device (e.g. oxidation catalyst, 3-way catalyst, particulate filter, SCR catalyst etc.)
(2) Manufacturer
(3) Model no.
(4) Serial no.

  - (5) Active or passive system (describe)
- (G) Transmission Information
  - (1) Transmissions type (e.g. manual, automatic, hybrid etc.)
    - (a) If hybrid, describe its architecture
  - (2) Manufacturer
  - (3) Model no.
  - (4) Serial no.
  - (5) Number of Speeds
  - (6) Control type (e.g. mechanical, electrical etc.)
  - (7) Torque Converter
    - (a) Manufacturer
    - (b) Model no.
    - (c) Serial no.
  - (8) Retarder
    - (a) Type
    - (b) Manufacturer
    - (c) Model no.
    - (d) Serial no.
- (H) Heating, Ventilation and Air Conditioning (HVAC)
  - (1) Heating system type (e.g. air, water, other)
    - (a) Capacity (BTU/hr or kW/hr)
  - (2) Air Conditioning (Yes/No)
    - (a) Capacity (BTU/hr or kW/hr)

8.4.3 Vehicle Inspection

The following vehicle components and subsystems should be inspected for integrity and safety prior to installation of the test vehicle on the dynamometer.

- (A) Engine Compartment
  - (1) All fluid levels shall be within manufacturers specification
  - (2) Belts and hoses shall be in good condition
  - (3) The engine air filter should be clean. Installation of a new air filter is recommended prior to emissions testing.
  - (4) The integrity of the lines between the turbocharger and intercooler and intercooler and engine intake shall be verified.

(5) The presence of the manifold air pressure sensor (MAP) and integrity of wiring connection shall be inspected (applies to most electronic engines).

(6) The presence of the manifold air temperature sensor (MAT) and integrity of wiring connection shall be inspected (applies to most electronic engines).

(7) The integrity of the wiring harness and connections to the engine controller should be inspected (applies to all electronic engines).

(8) The integrity of the wastegate/boost control or variable geometry control on the turbocharger shall be inspected.

(9) The condition of the intercooler if visible shall be inspected.

(10) The integrity of linkages and fuel lines surrounding the fuel injection pump or breakage of the seal on the fuel injection pump shall be inspected (if equipped).

(11) Any visible fluid leaks shall be noted.

(12) The exhaust system shall be inspected for leak and all leaks repaired prior to emissions testing.

(B) Transmission and Driveline

(1) Transmission fluid and differential fluid levels shall be within manufacturer's specification.

(2) All driveline components shall be visually inspected for integrity and safety.

(3) Any visible fluid leaks shall be noted.

(C) Brakes and Tires.

(1) The service brakes shall be in good condition and properly adjusted.

(2) Tires shall be inspected to verify that they are within the size and specification specified by the manufacture and are in good condition.

8.5 Vehicle Test Weight Determination

(A) For transit buses, the dynamometer equipment shall be set to simulate a transient inertial load equivalent to the curb weight of the bus plus the weight of the driver and one half of the seated passenger load. For purposes of this calculation an average weight of 150 lbs (68 kg) per passenger shall be used. The curb weight of the bus shall include the weight of a full fuel load.

$$Inertial\ Weight = curb\ weight + 150 + \frac{1}{2}(seated\ \ passenger\ load) * (150)\ lb$$

8.6 Vehicle Road Load Determination and Simulation

(A) Determination and simulation of the test vehicle road load on the chassis dynamometer requires two procedures.

(1) The first procedure involves performing a coastdown of the vehicle on a suitable road surface or test track to determine the road load force encountered by the vehicle over the speed range spanned by the test cycles.

(2) The second procedure involves performing a series of coastdown runs of the vehicle on the dynamometer to calibrate and verify the dynamometer road load coefficients.

8.6.1 Road Load Measurement by On-Track Coastdown Technique

(A) Road load force is the total force encountered by the vehicle due to motion on a level, smooth surface, defined as road load. The road load force includes aerodynamic and mechanical drag components expressed as a function of vehicle speed.

(B) The vehicle road load force shall be measured by the coastdown method on a suitable road surface or test track according to the procedures outlined in SAE J2263 Surface Vehicle Recommended Practice Road Load Measurement Using Onboard Anemometry and Coastdown Techniques [11] with the following provisions.

  (1) The vehicle shall be loaded to the correct dynamometer test weight as determined in Section 8.5 of this document.

  (2) The road load force shall be determined as a function of vehicle speed from 5 mph to 45 mph (8 km/h to 72 km/hr).

  (3) Regenerative braking systems (if equipped) shall be disabled during the deceleration portion of the cost down.

    (a) If the regenerative braking system is actuated only by the brake pedal, no action is required.

    (b) If the regenerative braking system is actuated in part when the brake pedal is not depressed (e.g. pedal-off regeneration), shall have the regenerative braking system disabled preferably through a deactivation switch or temporary modification to the vehicle control software (SAE 2711 §6.5.6 [2]).

8.6.2 Chassis Dynamometer Simulation of Road Load

(A) The chassis dynamometer shall be calibrated to provide accurate simulation of the road load force which must be overcome by the vehicle propulsion system to maintain steady speed on a flat road surface according to the procedures outline in SAE J2264 Surface Vehicle Recommended Practice Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques [12].

  (1) Regenerative braking systems should be disabled during coastdowns on the dynamometer for road load coefficient determination.

  (2) Vehicle configuration and operating conditions should be the same as those used during the on-road coastdown procedure.

  (3) It is preferable that the dynamometer system provide the appropriate retarding force at all speeds, rather than simply matching the coastdown time between the two specified speeds ((SAE 2711 §6.5.7 [2]).

8.7 Energy Storage System State of Charge Provisions for Hybrid Buses

(A) When a conventional vehicle is exercised through a test cycle on a chassis dynamometer, the total energy necessary to complete the test run is equal to the energy provided by the internal combustion engine. There is no energy storage on board the vehicle other than the consumable fuel and no state of charge correction is necessary (SAE J2711 §4.0 [2]).

(B) In a hybrid vehicle, a significant amount of motive energy may be stored onboard within the ESS and over the relatively short duration of the test cycle the amount if energy stored in the ESS may increase or decrease. Therefore the fuel consumption and emissions data must be corrected so that the net energy change in the ESS is essentially zero (SAE J2711 §4.0 [2]).

(C) Provision must be made to measure the State or Charge (SOC) at the beginning of and end of a drive cycle/test run and calculate the Net Energy Change (NEC) by difference. Specific procedures for each type of ESS are described in the following sections.

8.7.1 Batteries

(A) Provision must be made to measure continuously (using a totalizing ammeter) the flow of current into and out of the battery.

(B) The integrated (totalized) value with the appropriate conversion factors applied is the NEC.

8.7.2 Capacitors

(A) Provision must be made to measure the voltage across the capacitor pack at the beginning and end of each test run.

(B) The NEC can be readily calculated by determining the difference of the starting and ending SOC.

8.7.3 Electromechanical Flywheels

(A) Provision must be made to measure to measure the speed of the flywheel (revolutions per minute) at the beginning and end of each test run.

(B) The NEC is calculated by determining the difference of the starting and ending SOC.

8.7.4 Hydraulic Accumulators

(A) Provision must be made to measure the accumulator pressure at the beginning and end of each test run.

(B) The NEC is calculated by determining the difference in starting and ending SOC.

8.8 Ambient Background Sampling

(A) Measured vehicle emissions shall be corrected to account for trace levels exhaust constituents in the dilution air.

(B) Bag samples of the dilution air for background correction of gaseous emissions (THC, NMHC, NOx, CO, CO_2) may be collected simultaneously during a test run from a point immediately downstream of the dilution air filter and upstream of the point where the engine exhaust enters the dilution tunnel. Equipment for collection of bag samples is described in Section 6.3.

(C) Primary dilution air may be sampled to determine background particulate levels simultaneously during a test run from a point immediately downstream of the dilution air filter and upstream of the point where the engine exhaust enters the dilution tunnel.

(D) Alternatively, samples to determine background particulate levels may be taken via the same sample system used to collect exhaust particulate samples. In this approach PM samples are collected while the CVS system is operated with the test vehicle's engine shut off. This approach may be desirable if shedding of particulate matter from the dilution tunnel walls is of concern.

8.9 Vehicle Preconditioning Procedures and Practice Test Runs

(A) Vehicle preconditioning procedures have the following objectives:

(1) To precondition the engine and exhaust emissions control equipment.

(2) To establish an "equilibrium" SOC in the ESS of hybrid vehicles so that initial and final SOC during the subsequent test runs will be within the required tolerance.

(3) To familiarize the driver with the test cycle and the vehicle's driving characteristics.

(4) To verify the suitability of the selected operating ranges of gas analyzers.

(B) Once the vehicle has reached operating temperature and the appropriate vehicle preconditioning requirements have been met, the vehicle shall be returned to the "key off" condition in preparation for the subsequent test run.

8.9.1 Preconditioning of Conventional (non-hybrid) Vehicles

(A) Vehicles with conventional drivetrains shall be operated at least once through the drive cycle.

(B) The first test run shall commence no more than 20 minutes after the practice run.

8.9.2 Preconditioning of Charge-Depleting Hybrid Electric Vehicles

(A) The ESS of charge depleting hybrid-electric vehicles should be fully charged prior to testing.

8.9.3 Preconditioning of Hybrid-Electric Vehicles with Batteries

(A) Off-vehicle charging allowed for battery conditioning of vehicles with charge-sustaining rechargeable energy storage systems (RESS). It is necessary to establish an "equilibrium" state of charge prior to testing. A stable SOC ensures that the energy stored in the RESS will not fluctuate during the test. [**Error! Reference source not found.**]

(B) To measure vehicle representative emissions during the test, the change in energy stored in the RESS should be less than ± 1% of the total fuel energy consumed during a test cycle. [**Error! Reference source not found.**]

(C) To accomplish a stable SOC, the vehicle will be operated at least twice through the drive cycle that will be used during the test in order to verify that the initial and final SOC values are within the above tolerance. [**Error! Reference source not found.**] These initial drive cycle runs can count toward any required warm up runs, provided they are completed within the required time.

(D) If the initial drive cycle runs result in a net increase or decrease in SOC, then the initial SOC of the RESS may be adjusted using procedures detailed in Section X.X. [**Error! Reference source not found.**]

8.9.4 Preconditioning of Hybrid-Electric Vehicles with Capacitors

(A) Hybrid electric vehicles with capacitors follow a preconditioning procedure similar to hydraulic hybrid vehicles described below. [**Error! Reference source not found.**]

8.9.5 Preconditioning of Hybrid Vehicles with Electromechanical Flywheels

(A) Hybrid vehicles with electromechanical flywheels follow a preconditioning procedure similar to hydraulic hybrid vehicles described below. [**Error! Reference source not found.**]

8.9.6 Preconditioning of Hybrid-Electric Vehicles with Capacitors

[RESERVED]

8.9.7 Preconditioning of Hybrid Vehicles with Electromechanical Flywheels

[RESERVED]

8.9.8 Preconditioning of Hydraulic Hybrid Vehicles

(A) The goal of preconditioning for hydraulic hybrid vehicles is that the accumulator pressure at the end of the test run be equal to the accumulator pressure at the start of the test run. Hydraulic accumulators can usually store only as much energy as is generated during a typical stop. The accumulator pressure is dependent on the last few acceleration and decelerating events of the drive cycle.

(B) Vehicles with hydraulic hybrid drivetrains shall be operated at least once through the drive cycles.

(C) The first test run shall commence no more than 20 minutes after the practice run.

8.10 Chassis Dynamometer Test Procedures

8.10.1 Engine Starting, Restarting Procedures

(A) The engine shall be started according to the manufacturer's recommended starting procedures in the owner's manual. A minimum initial idle period of 20 seconds shall be observed prior to the first acceleration event of the drive cycle.

(B) The vehicle transmissions shall be placed into gear within 15 seconds after the engine is started. If necessary the vehicles brakes may be applied to keep the drive wheels from turning.

(C) If the engine does not start after the manufacture's recommended cranking time (or 10 seconds in the absence of a manufacturers recommendation), cranking shall cease for the period recommended by the manufacturer (or 10 seconds in the absence of a manufacturers recommendation). Three attempts may be employed to start the engine. After three attempts, the reason for failure to start must be determined.

(D) If the engine stalls during an idle period, the engine shall be restarted immediately and the test continued. If the engine cannot be restarted soon enough to allow the vehicle to follow the next prescribed acceleration the test run shall be aborted.

(E) If the engine stalls during a portion of the driving cycle other than idle the test shall be aborted.

(F) If the vehicle will not restart and corrective action is not accomplished within 30 minutes of aborting the prior test run then the preconditioning procedures described in Section 8.9 must be repeated.

8.10.2 Driving Cycles

(A) Emissions and fuel consumption shall be measured while the transit bus is operated on a chassis dynamometer over two specific driving cycles; the Manhattan Bus Cycle and the Orange County Bus Cycle (OCTA) representing urban and suburban transit service respectively. A visual display of the desired and actual vehicle speed will be provided to the driver to allow the driver to operate the vehicle over the prescribed cycle.

(1) The Manhattan Bus Cycle was developed by West Virginia University based on actual observed driving patters of buses in the Manhattan core of New York City [5]. The Manhattan Bus Cycle is characterized by frequent stops and very low speed. The maximum speed is 25.4 mph (40.1 km/hr) and the average speed is 6.8 mph (11.0 km/hr). The original Manhattan Cycle is only 18 minutes in duration. For the purposes of this protocol the Manhattan cycle must be run twice back-to-back. Speed-time points for the Double Manhattan Cycle (Figure 8-2) are provided in Appendix A.

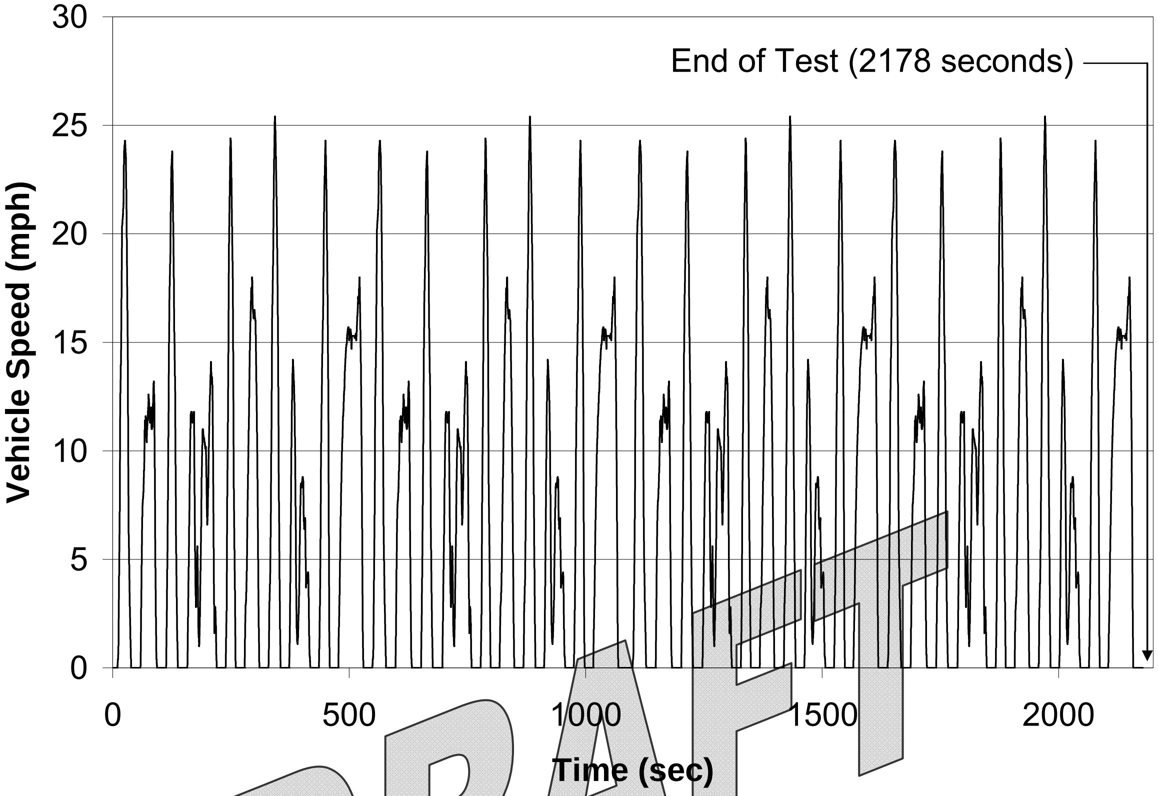

Figure 8-2: Double Manhattan Bus Cycle

(2) The Orange County Bus Cycle (Figure 8-3) was developed by West Virginia University based on driving patterns of urban transit buses in the Los Angeles area [6]. The maximum speed is 41.4 mph (65.4 km/hr) and the average speed is 12.5 mph (19.9 km/hr). Speed-time points are provided in Appendix A.

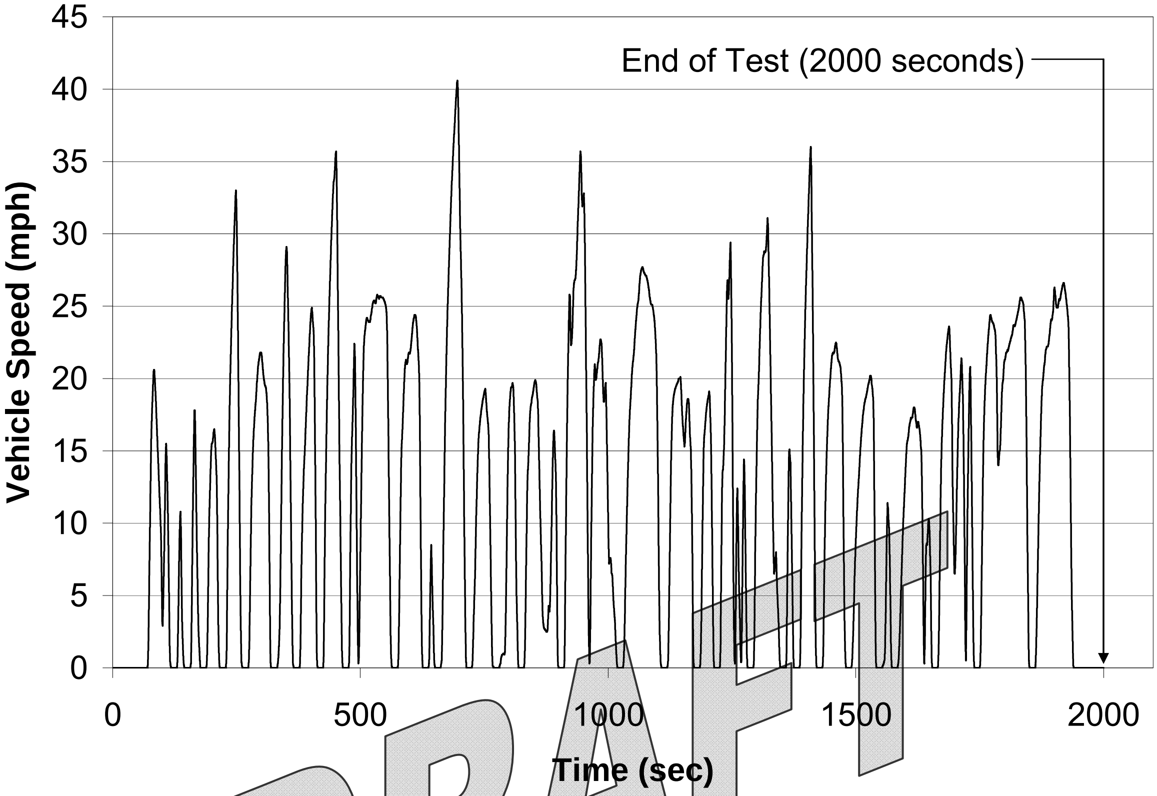

Figure 8-3: Orange County Bus Cycle

(B) Evaluation of charge-sustaining hybrid-electric transit buses requires longer test runs, because a short drive cycle is unlikely to affect the state-of-charge (SOC) at a level sufficient enough to cause the hybrid management system to provide additional power to the energy storage system (ESS). The use of a longer cycle increases the probability of a smaller net energy change (NEC) over the duration of the test run. Test cycles should be approximately 30 minutes in duration (SAE J2711 §5.2 [2]).

8.10.3 Dynamometer Test Run

(A) Engine startup, operation over the test cycle and engine shut-down shall comprise a completed test run.

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

(1) Position and switch on the engine compartment cooling fans.

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

(3) Start the CVS system (if not already on) and the gaseous emissions sample pumps (the PM sample pump must remain off at this time).

(4) The heat exchanger of the CVS (if used) and the heated components of any continuous sampling systems shall be preheated to their designated operating temperature before the test begins.

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

(6) For vehicles tested for particulate emissions, carefully load clean particulate sample filters into the filter holders. It is recommended that filters be loaded into the filter holder within the filter stabilization environment, with both ends of the filter holder assembly plugged during transport to the sampling system. The filters must be handled only with forceps. Rough filter handling will result in erroneous weight determination. Install the filter holder assembly into the sampling system.

(7) Position gas sample valves to direct sample flow into the ambient background and dilute exhaust (if applicable) sample bags.

(8) Start the exhaust, dilution air and particulate sample systems simultaneously with the driver command to start the engine. Begin sampling and integrating the continuous THC, NMHC, NOx (and CO and CO_2 if continuous) concentrations and turn on the particulate sample pump and begin integrating the particulate sample flow.

(9) Fifteen seconds after the engine starts place the transmission in gear.

(10) No sooner than 25 seconds after the engine starts begin the initial vehicle acceleration event of the driving cycle.

(11) Operate the vehicle according to the prescribed drive cycle.

(12) During the test run the particulate sampling, it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ±5.0% of its set point value (except for the first 10 seconds of sampling). For double dilution operation, sample flow is the net difference between the flow rate through the sample filters and the secondary dilution air flow rate (40 CFR 86.1337-2007 [1]).

(13) If the set particulate sample flow rate cannot be maintained because of high particulate loading on the filter, the test shall be terminated and rerun using a lower sample flow rate or greater dilution (40 CFR 86.1337-2007 [1]).

(14) The test run shall terminate on the last record of the cycle. However, sufficient idle time should be included at the end of the cycle, such that the analyzers are not missing emissions that are still in the sample train. Test cycles should have a minimum of one minute of idle and the end of the cycle.

(15) On the last record of the test cycle, cease sampling, turn off the particulate sample pump, gas flow measuring devices, and continuous analyzer integrators.

(16) Immediately turn of the engine and start the hot soak timer in preparation for the next test run.

(17) Immediately after the engine is turned off, turn off the engine compartment ventilation fans.

(18) Process the dilute exhaust and dilution air bag samples.

(19) Carefully remove the particulate sample filter holder from the sample train and transfer the sample filters back to the filter stabilization environment. It is recommended that filters be unloaded from the filter holder within the filter stabilization environment, with both ends of the filter holder assembly plugged during transport. Filters may be stabilized in the Petri dishes while still within the filter cartridges, or the cartridge tops may be removed, or the filters may be entirely removed from the filter cartridges and stabilized in Petri dishes alone. Removal of the filters from the filter cartridges shall only take place with in the stabilization environment (40 CFR 86.1337-2007 [1].

(20) Allow the engine to soak for 20 minutes but no longer than 30 minutes prior to initiating the next test run.

8.10.4 Inter-Test Pauses

(A) Between consecutive test runs, the vehicle shall dwell for 20-30 minutes with the key switch in the “key off” position, and the brake pedal not depressed.

(B) During the inter-test pauses, engine compartment ventilation fans shall be switched off.

(C) For hybrid-electric vehicles, the ESS may or may not be charged from an off-vehicle electric energy source based on the following:

(1) For charge-depleting hybrid vehicles, the ESS shall be charged between test runs and their energy economy determined with the ESS starting from 100% SOC.

(2) For charge sustaining hybrid vehicles the ESS shall not be charged between test runs.

(3) For vehicles that are proclaimed by the manufacturer to be charge-sustaining but which consistently exhibit charge depleting behavior over a particular test cycle, the vehicle may not be tested as a charge-sustaining hybrid vehicle over that particular test cycle and shall be treated as a charge-depleting vehicle.

8.11 Particulate Filter Handling and Weighing Procedures

The following procedures shall be followed in handling and weighing particulate sample filters (Reference 40 CFR 86.1312-2007(c) [1]).

8.11.1 Static Charge Precautions

(A) Care should be taken to prevent contamination of the sample filters and to prevent a buildup of static charge on the filters that could interfere with filter weighing.

(B) Static neutralizers, such as Po-210 sources, shall be used to neutralize charge on a filter prior to each weighing. The static neutralizer shall be replaced at the interval recommended by the manufacturer, or when it is no longer able to reduce static charge on a filter to less than ±2 VDC as measured with an electrostatic monitor at the microbalance workstation.

(C) The person weighing the filter shall be grounded with respect to the microbalance to prevent imparting a static charge on the filters. This can be accomplished safely by using a grounding strap such as the wrist straps that are commonly used in the microelectronics industry. To prevent electrical shock, a 1-megaohm resistor should be installed in series with the between the person weighing the filter and ground.

8.11.2 Filter Pre-conditioning and Pre-weighing

(A) Within the filter stabilization environment, a pair of clean and electrically conductive tweezers shall be used to place a filter in the lower half of a filter cassette and the cassette shall be placed in a partially open glass petri dish. The petri dish lid should extend over the filter to prevent gross contamination, but it should be left slightly open on one edge to permit stabilization with the environment.

(B) Each filter shall be stabilized for at least 30 minutes.

(C) After at least 30 minutes of stabilization, each filter shall be weighed using the specified microbalance. The process of weighing a filter may be repeated an a statistical mean weight of a single filter may be calculated. Sound engineering judgment shall dictate the use of statistics to discard outliers and the weighting of averages. For a clean filter its single weight or statistical mean weight shall be considered the uncorrected tare weight of the filter. The uncorrected tare weight of the filter shall be corrected for filter buoyancy in air as described in Section 8.11.4 below.

(D) The uncorrected weight, corrected weight, barometric pressure, temperature and humidity of the filer shall be recorded.

(E) After the filter has been weighed, it shall be returned to the lower half of the filter cassette, and the upper half of the cassette shall be set in place. The cassette with filter shall be stored in a covered glass petri dish or sealed (i.e. ends plugged) filter holder assembly with in the filter stabilization environment until needed for testing.

8.11.3 Post-conditioning and Post-weighing

(A) After the emission test, the filter cassette shall be removed from the filter assembly. If the removal is performed in the filter stabilization environment then the upper half of the cassette shall be removed using a properly designed separator tool. The lower half of the cassette with the filter shall be placed in a partially covered petri dish, and allowed to stabilize for at least 30 minutes. Otherwise, the cassette and filter shall be placed in a closed petri dish until it can be returned to the filter stabilization environment.

(B) After at least 30 minutes but no more than 60 hours of stabilization, each filter may be weighed using the specified microbalance as described previously in Section 8.11.2(C).

(C) The uncorrected weight, corrected weight, barometric pressure, temperature and humidity of the filer shall be recorded.

(D) The net particulate matter weight (P_f) of each filter shall be equal to the corrected gross filter weight minus corrected tare filter weight.

(E) Should the particulate matter on the filters contact the petri dish, tweezers, microbalance or any other surface, the data with respect to that filter is void.

8.11.4 Correction for Filter Buoyancy in Air

(A) All filter weights shall be corrected for filter buoyancy in air as follows (Reference 40 CFR 86.1312-2007 [1]).

(B) Barometric pressure of the microbalance environment shall be measured with and instrument that exhibits ±0.01% full-scale accuracy and 0.01% per year full-scale stability, and the full-scale value used for such a specification shall not exceed 200 kPa.

(C) Buoyancy correction calculation:

(1) Calculate vapor pressure of liquid water using the dewpoint temperature in the Magnus formula:

$$P_W = 0.6113x10^{((7.5xT_{dp})/(237.3+T_{dp}))}$$

Where:

P_w = vapor pressure of liquid water, kPa.

T_{dp} = dewpoint temperature, °C

(2) Calculate air density using the ideal gas relationship and molecular weights of standard aid and water:

$$A = (3.424xP - 1.317xP_W)/(T + 273.15)$$

Where:

A = air density, kg/m^3

P = barometric pressure, kPa

P_w = vapor pressure of liquid water, kPa

T = temperature °C

(3) Calculate the buoyancy correction:

$$M = Rx(1-(A/\rho_w))/(1-(A/\rho_s))$$

Where:

M = corrected mass in units of the microbalance display

R = uncorrected filter weight in units of the microbalance display

A calculated air density, kg/m^3

ρ_w = density calibration weight used to calibrate the microbalance, kg/m^3

ρ_s = density of filter material used to sample PM emissions, kg/m^3

(D) For determining ρ_s, note that PFTE and borosilicate glass both have densities in the range of 2,200 to 2,400 kg/m^3. An acceptable ρ_s is 2300 kg/m^3. Because Teflon PTFE membrane filters have an integral polymethylpentene support ring that accounts for 95% of the filter mass, an acceptable ρ_s for these filters is 920 kg/m^3. Other filter densities may be determined similarly. Information about ρ_w should be available from the calibration weight manufacturer.

8.12 Emissions Measurement Accuracy

(a) Minimum limit. (1) The minimum limit of an analyzer must be equal to or less than one-half of the average diluted concentration for an engine emitting the maximum amount of the applicable pollutant allowed by the applicable standard. For example, if with a given dilution and sampling system, an engine emitting NO$_X$ at the level of the standard (e.g., 0.20 g/bhp-hr NO$_X$) would result in an average NO$_X$ concentration of 1.0 ppm in the diluted sample, then the minimum limit for the NO$_X$ analyzer must be less than or equal to 0.5 ppm. (2) For the purpose of this section, ‘‘minimum limit’’ means the lowest of the following levels: (i) The lowest NOX concentration in the calibration curve for which an accuracy of ±2 percent of point has been demonstrated as specified in paragraph (a)(3) of this section; or (ii) Any NOX concentration for which the test facility has demonstrated sufficient accuracy to the Administrator’s satisfaction prior to the start of testing, such that it will allow a meaningful determination of compliance with respect to the applicable standard. (3) For determination of the analyzer’s minimum limit, a NO$_X$ concentration that is less than or equal to one-half of the average NO$_X$ concentration determined in paragraph (a)(1) of this section shall be measured by the oxides of nitrogen analyzer following the analyzer’s monthly periodic calibration. This measurement must be made to ensure the accuracy of the calibration curve to within ±2 percent of point accuracy of the appropriate least-squares fit, at less than or equal to one half of the average expected diluted NO$_X$ concentration determined in paragraph (a)(1) of this section. (b) Measurement accuracy—Bag sampling. Analyzers used for bag analysis must be operated such that the measured concentration falls between 15 and 100 percent of full scale, with the following exception: concentrations below 15 percent of full scale may be used if the minimum limit of the analyzer within the range meets the requirement of paragraph (a) of this section. (c) Measurement accuracy—Continuous measurement. (1) Analyzers used for continuous analysis must be operated such that the measured concentration falls between 15 and 100 percent of full scale, with the following exceptions: (i) Concentrations below 15 percent of full scale may be used if the minimum limit of the analyzer within the range meets the requirement of paragraph (a) of this section. (ii) Analyzer response over 100% of full scale may be used if it can be shown that readings in this range are accurate.

(2) If the analyzer response exceeds the level allowed by paragraph (c)(1)(ii) of this section, the test must be repeated using a higher range and both results must be reported. The Administrator may waive this requirement. (d) If a gas divider is used, the gas divider shall conform to the accuracy requirements specified in § 86.1314–84(g),

and shall be used according to the procedures contained in paragraphs (a) and (b) of this section.

8.13 Exhaust Sample Analysis

[Reserved]

8.14 Test Validation Criteria

A minimum of three valid test runs of each drive cycle are required. Additional test runs may be required to meet SOC requirements and run-to-run variability targets.

8.14.1 Drive Trace Accuracy

(A) At the conclusion of each test run, the total distance traveled by the vehicle over the test run will be noted.

(B) Adherence to the test cycle target speeds will be evaluated by regression analysis to compare actual speeds to target speeds on a second by second basis. Actual speed will be plotted against target speed in 1 Hz increments and a best fit linear trend line with zero intercept determined.

(C) The test run shall be declared invalid if the slope of the trend line varies from unity by more than 10% or R^2 or the linear best fit is less than 0.8 (SAE J2711 §7.10 [2]).

8.14.2 SOC Variation

(A) For hybrid vehicles, the SOC correction shall be computed first for the emission species as described in Section 9.2. The R^2 of the linear best fit must be greater than 0.8 (SAE J2711 §7.10 [2]).

(B) If three valid test runs with less than 1% NEC delta are achieved then the data may be considered valid and the results can be treated the same as a conventional vehicle. Under these circumstances the R^2 criteria can be ignored as the best fit would be poor since the data points are essentially on the same axis (0% SOC correction) (SAE J2711 §7.10 [2]).

8.14.3 Coefficient of Variance of Emissions Results

(A) The coefficient of variation (COV) shall be determined for each emissions species. If the COV is poor, additional test runs should be performed until acceptable repeatability of emissions value is achieved.

(B) When evaluating the COV for hybrid vehicles, the SOC corrected emissions values should be used.

(C) Limits on the COV that are indicative of acceptable repeatability are difficult to define. The following guidance should be considered:

  (1) The COV on CO_2 emissions of 2% or less is generally achievable and should not exceed 5%.

  (2) The COV on fuel consumption of 2% or less is generally achievable and should not exceed 5%.

(3) A COV on NOx emissions of 5% or less should generally be achievable.

(4) The distance traveled over consecutive runs of the same test cycle should generally be less than 2%.

9. EXHAUST EMISSIONS CALCULATIONS

9.1 Emissions Calculations

[RESERVED] Will follow 40 CFR Part 86 Subpart N

9.2 State of Charge Correction for Hybrid Vehicles

[RESERVED] Will follow SAE J2711 Protocol

10. DATA QUALITY ASSURANCE AND CONTROL PROCEDURES

10.1 Data Quality Objectives

10.1.1 Program Quality Objectives

[RESERVED]

10.1.2 Measurement Performance Criteria

[RESERVED]

10.2 QA Chain of Command

10.2.1 Authority of the QA/QC Manager

[RESERVED]

10.2.2 Roles and Responsibilities of Key QA/QC Personnel

[RESERVED]

10.2.3 Personnel Organization Chart

[RESERVED]

10.2.4 Personnel Training

[RESERVED]

10.3 QA/QC Documentation

10.3.1 List of Test Equipment and Instrumentation

10.3.2 Equipment Maintenance and Calibration Records

10.3.3 Calibration Gas Certification Records

10.3.4 Test Fuel Handling and Analysis Records

10.3.5 Test Logs and Sample Collection Records

10.3.6 Sample Chain of Custody Records

10.4 Data Review and Validation

10.4.1 Data Review Process

10.4.2 Corrective Actions Report

10.4.3 Data Archival Process

11. DATA REPORTING

[RESERVED]

12. BUS MODEL CONSIDERATIONS

[RESERVED]

13. BUS MODEL MODIFICATIONS NECESSITATING AN EMISSIONS RETEST

[RESERVED]

14. REFERENCES

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Appendix A: Drive Cycle Speed-Time Points