

# **WLTP Test Procedures**

**DRAFT**

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## **WLTP-DTP-01-02**

### **TESTING PROCEDURES**

#### **Equipment Specifications**

- 101 Overview.
- 110 Chassis Dynamometer
- 115 Driver's aid
- 140 Dilution for gaseous and PM constituents.
- 145 Gaseous and PM probes, transfer lines, and sampling system components.
- 150 Continuous sampling.
- 170 Batch sampling for gaseous and PM constituents. Including alcohol and carbonyls
- 190 PM-stabilization and weighing environments for gravimetric analysis.

#### **Measurement Instruments**

- 201 Overview and general provisions.
  - 202 Data updating, recording, and control.
  - 205 Performance specifications for measurement instruments.
- MEASUREMENT OF AMBIENT CONDITIONS

- 215 Pressure transducers, temperature sensors, and dewpoint sensors.

#### FLOW-RELATED MEASUREMENTS

- 240 Dilution air and diluted exhaust flow meters.
- 245 Sample flow meter for batch sampling.
- 248 Gas divider.

#### CO AND CO<sub>2</sub> MEASUREMENTS

- 250 Nondispersive infra-red analyzer.

#### HYDROCARBON MEASUREMENTS

- 260 Flame ionization detector.
- 265 Nonmethane cutter.
- 267 Gas chromatograph.

#### NO<sub>x</sub> AND N<sub>2</sub>O MEASUREMENTS

- 270 Chemiluminescent detector.
- 272 Nondispersive ultraviolet analyzer.
- 275 N<sub>2</sub>O measurement devices.

#### O<sub>2</sub> MEASUREMENTS

- 280 Paramagnetic and magnetopneumatic O<sub>2</sub> detection analyzers.

#### PM MEASUREMENTS

- 290 PM gravimetric balance.

GC for alcohol – Sampling is in 86 – Maybe reference ARB procedures?

HPLC for carbonyls – Same as above for GC.

#### **Calibrations and Verifications**

- 301 Overview and general provisions.
- 303 Summary of required calibration and verifications
- 305 Verifications for accuracy, repeatability, and noise.

- 307 Linearity verification.
- 308 Continuous gas analyzer system-response and updating-recording verification—for gas analyzers not continuously compensated for other gas species.
- 309 Continuous gas analyzer system-response and updating-recording verification—for gas analyzers continuously compensated for other gas species.

MEASUREMENT OF VEHICLE PARAMETERS AND AMBIENT CONDITIONS

- 310 Torque calibration.
- 315 Pressure, temperature, and dewpoint calibration.

FLOW-RELATED MEASUREMENTS

- 330 Exhaust-flow calibration.
- 340 Diluted exhaust flow (CVS) calibration.
- 341 CVS and batch sampler verification (propane check).
- 342 Sample dryer verification.
- 345 Vacuum-side leak verification.

CO AND CO<sub>2</sub> MEASUREMENTS

- 350 H<sub>2</sub>O interference verification for CO<sub>2</sub> NDIR analyzers.
- 355 H<sub>2</sub>O and CO<sub>2</sub> interference verification for CO NDIR analyzers.

HYDROCARBON MEASUREMENTS

- 360 FID optimization and verification.
- 362 Non-stoichiometric raw exhaust FID O<sub>2</sub> interference verification.
- 365 Nonmethane cutter penetration fractions.

NO<sub>x</sub> AND N<sub>2</sub>O MEASUREMENTS

- 370 CLD CO<sub>2</sub> and H<sub>2</sub>O quench verification.
- 372 NDUV analyzer HC and H<sub>2</sub>O interference verification.
- 376 Chiller NO<sub>2</sub> penetration.
- 375 Interference verification for N<sub>2</sub>O analyzers.
- 378 NO<sub>2</sub>-to-NO converter conversion verification.

PM MEASUREMENTS

- 390 PM balance verifications and weighing process verification.

**Performing an Emission Test in the Laboratory**

- 500 Performing Emission Tests.
- 510 Dynamometer procedure.
- 515 Pre-test checks.
- 520 Emission Test Sequence.
- 525 Vehicle starting and restarting.
- 545 Validation of proportional flow control for batch sampling.
- 546 Validation of minimum dilution ratio for PM batch sampling.
- 550 Gas analyzer range validation, drift validation.
- Validation of test driver power demand
- 590 PM sampling media (e.g., filters) preconditioning and tare weighing.
- 595 PM sample post-conditioning and total weighing.

## **WLTP-DTP-01-02**

Analysis for alcohol and carbonyls

### **Calculations and Data Requirements**

- 601 Overview.
- 602 Statistics.
- 630 1980 international gravity formula.
- 640 Flow meter calibration calculations.
- 642 SSV, CFV, and PDP molar flow rate calculations.
- 644 Vacuum-decay leak rate.
- 645 Amount of water in an ideal gas.
- 650 Emission calculations.
- 655 Chemical balances of fuel, intake air, and exhaust.
- 659 Removed water correction.
- 660 THC, NMHC, and CH<sub>4</sub> determination.
- 665 THCE and NMHCE determination.
- 667 Dilution air background emission correction.
- 670 NO<sub>x</sub> intake-air humidity and temperature corrections.
- 672 Drift correction.
- 675 CLD quench verification calculations.
- 690 Buoyancy correction for PM sample media.

### **Testing with Oxygenated Fuels**

- 805 Sampling system.
- 845 Response factor determination.
- 850 Calculations.

### **Definitions and Other Reference Information**

- 1001 Definitions.
- 1005 Symbols, abbreviations, acronyms, and units of measure.
- 1010 Reference materials.

## Equipment Specifications

### 101 Overview.

(a) This procedure specifies equipment, other than measurement instruments, related to emission testing. This equipment includes two broad categories—dynamometers and emission-sampling hardware.

(b) Other related subparts in this procedure identify measurement instruments, describe how to evaluate the performance of these instruments, and specify vehicle fluids and analytical gases.

### 110 Chassis Dynamometer

Dynamometers shall incorporate the following general features for testing vehicles:

- Accurate and precise road load determination (traceable to a recognized standards organization) and simulation that recreates the mechanical inertia and frictional forces that would be present on the road with electrically generated load forces based on specific equations, coefficients, and response characteristics.
- Vehicle loading applied to the tires by rolls connected to intermediate motor/absorbers that contacts vehicle drive tires.
- Capability of testing all light duty vehicles, medium-duty passenger vehicles and complete heavy duty vehicles on a Federal Test Register US06 Driving Trace which has a maximum acceleration rate of 8.0 MPH/second, in two wheel drive and four wheel drive configurations. Vehicle testing shall be accomplished by simulating all load conditions that the vehicle can experience on a dry smooth road.
- The dynamometer shall have a force measurement system to indicate the forces being applied by the dynamometer rolls to the vehicle tires. The load cell is the primary method of measuring force. This system shall be capable of indicating force readings to a resolution of 0.1% of rated output.

The load applied by the dynamometer shall model and simulate forces acting on the vehicle during normal road operation, including rolling resistance, aerodynamic drag, road grade, drive train losses and inertia forces according to the following formula:

$$FR = A + B * V + C * V^2 + D * W + M * dV / dt \quad (\text{See Note})$$

where:

FR= total vehicle road load force to be applied at the surfaces of the rolls

A = constant load term (friction)

B = load coefficient dependent on velocity (drag and rolling resistance)

C = load coefficient dependent on velocity squared (frontal windage and drag)

D = incline grade coefficient (-,+ ) = [ sin θ ] including variable grade mode D=f(t)

## WLTP-DTP-01-02

W = weight of vehicle

M = effective vehicle mass, taking into account the rotational masses of driven and non-driven power trains on both 2WD and 4WD vehicles

V = linear velocity at the roller surfaces =  $dX / dt$ , where X is a point on the roll surface

$dV / dt$  = acceleration rate of the roller surfaces

Note: The total force is the sum of the individual tractive forces applied at each roller surface.

The measured simulation error of the total road force, including the inertia force shall not exceed the greater of  $\pm 2.0$  pounds or  $\pm 1\%$  of the target value, according to the above force formula, under all operating conditions and at all velocities. This measurement shall utilize the 1-second average of force and speed when acquired at 10-Hz, or faster.

115 Driver's Aid

Place Holder

### **140 Dilution for gaseous and PM constituents.**

(a) General. You may dilute exhaust with ambient air, synthetic air, or nitrogen. For gaseous emission measurement the diluent must be at least 15 °C. Note that the composition of the diluent affects some gaseous emission measurement instruments' response to emissions. We recommend diluting exhaust at a location as close as possible to the location where ambient air dilution would occur in use.

(b) Dilution-air conditions and background concentrations. Before a diluent is mixed with exhaust, you may precondition it by increasing or decreasing its temperature or humidity. You may also remove constituents to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

(1) You may measure constituent concentrations in the diluent and compensate for background effects on test results. See 650 for calculations that compensate for background concentrations.

(2) Either measure these background concentrations the same way you measure diluted exhaust constituents, or measure them in a way that does not affect your ability to demonstrate compliance with the applicable standards. For example, you may use the following simplifications for background sampling:

(i) You may disregard any proportional sampling requirements.

(ii) You may use unheated gaseous sampling systems.

(iii) You may use unheated PM sampling systems.

(iv) You may use continuous sampling if you use batch sampling for diluted emissions.

(v) You may use batch sampling if you use continuous sampling for diluted emissions.

(3) For removing background PM, we recommend that you filter all dilution air, including primary full-flow dilution air, with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99.97 % (see §1001 for procedures related to HEPA-filtration efficiencies). Ensure that HEPA filters are installed properly so that

background PM does not leak past the HEPA filters. If you choose to correct for background PM without using HEPA filtration, demonstrate that the background PM in the dilution air contributes less than 50 % to the net PM collected on the sample filter. You may correct net PM without restriction if you use HEPA filtration.

(c) Full-flow dilution; constant-volume sampling (CVS). You may dilute the full flow of raw exhaust in a dilution tunnel that maintains a nominally constant volume flow rate, molar flow rate or mass flow rate of diluted exhaust, as follows:

(1) Construction. Use a tunnel with inside surfaces of 300 series stainless steel. Electrically ground the entire dilution tunnel. We recommend a thin-walled and insulated dilution tunnel to minimize temperature differences between the wall and the exhaust gases.

(2) Pressure control. Maintain static pressure at the location where raw exhaust is introduced into the tunnel within  $\pm 1.2$  kPa of atmospheric pressure. You may use a booster blower to control this pressure. If you test a vehicle using more careful pressure control and you show by engineering analysis or by test data that you require this level of control to demonstrate compliance at the applicable standards, we will maintain the same level of static pressure control when we test that vehicle.

(3) Mixing. Introduce raw exhaust into the tunnel by directing it downstream along the centerline of the tunnel. You may introduce a fraction of dilution air radially from the tunnel's inner surface to minimize exhaust interaction with the tunnel walls. You may configure the system with turbulence generators such as orifice plates or fins to achieve good mixing. We recommend a minimum Reynolds number,  $Re\#$ , of 4000 for the diluted exhaust stream, where  $Re\#$  is based on the inside diameter of the dilution tunnel.  $Re\#$  is defined in 640.

(4) Flow measurement preconditioning. You may condition the diluted exhaust before measuring its flow rate, as long as this conditioning takes place downstream of any heated HC or PM sample probes, as follows:

(i) You may use flow straighteners, pulsation dampeners, or both of these.

(ii) You may use a filter.

(iii) You may use a heat exchanger to control the temperature upstream of any flow meter, but you must take steps to prevent aqueous condensation as described in paragraph (c)(6) of this section.

(5) Flow measurement. Section 240 describes measurement instruments for diluted exhaust flow.

(6) Aqueous condensation. This paragraph (c)(6) describes how you must address aqueous condensation in the CVS. As described below, you may meet these requirements by preventing or limiting aqueous condensation in the CVS from the exhaust inlet to the last emission sample probe. See that paragraph for provisions related to the CVS between the last emission sample probe and the CVS flow meter. You may heat and/or insulate the dilution tunnel walls, as well as the bulk stream tubing downstream of the tunnel to prevent or limit aqueous condensation. Where we allow aqueous condensation to occur, use accepted measurement practices to ensure that the condensation does not affect your ability to demonstrate that your engines comply with the applicable standards.

(i) Preventing aqueous condensation. To prevent condensation, you must keep the temperature of internal surfaces, excluding any sample probes, above the dew point of the dilute exhaust passing through the CVS tunnel. Use accepted measurement practices to monitor temperatures

## WLTP-DTP-01-02

in the CVS. For the purposes of this paragraph (c)(6), assume that aqueous condensation is pure water condensate only, even though the definition of “aqueous condensation” in 1001 includes condensation of any constituents that contain water. No specific verification check is required under this paragraph (c)(6)(i), but we may ask you to show how you comply with this requirement. You may use engineering analysis, CVS tunnel design, alarm systems, measurements of wall temperatures, and calculation of water dew point to demonstrate compliance with this requirement. For optional CVS heat exchangers, you may use the lowest water temperature at the inlet(s) and outlet(s) to determine the minimum internal surface temperature.

(ii) Limiting aqueous condensation. This paragraph (c)(6)(ii) specifies limits of allowable condensation and requires you to verify that the amount of condensation that occurs during each test interval does not exceed the specified limits.

(A) Use chemical balance equations in 655 to calculate the mole fraction of water in the dilute exhaust continuously during testing. Alternatively, you may continuously measure the mole fraction of water in the dilute exhaust prior to any condensation during testing. Use accepted measurement practices to select, calibrate and verify water analyzers/detectors. The linearity verification requirements of §307 do not apply to water analyzers/detectors used to correct for the water content in exhaust samples.

(B) Use accepted measurement practices to select and monitor locations on the CVS tunnel walls prior to the last emission sample probe. If you are also verifying limited condensation from the last emission sample probe to the CVS flow meter, use accepted measurement practices to select and monitor locations on the CVS tunnel walls, optional CVS heat exchanger, and CVS flow meter. For optional CVS heat exchangers, you may use the lowest water temperature at the inlet(s) and outlet(s) to determine the minimum internal surface temperature. Identify the minimum surface temperature on a continuous basis.

(C) Identify the maximum potential mole fraction of dilute exhaust lost on a continuous basis during the entire test interval. This value must be less than or equal to 0.02 (i.e. 2 %). Calculate on a continuous basis the mole fraction of water that would be in equilibrium with liquid water at the measured minimum surface temperature. Subtract this mole fraction from the mole fraction of water that would be in the exhaust without condensation (either measured or from the chemical balance), and set any negative values to zero. This difference is the potential mole fraction of the dilute exhaust that would be lost due to water condensation on a continuous basis.

(D) Integrate the product of the molar flow rate of the dilute exhaust and the potential mole fraction of dilute exhaust lost, and divide by the totalized dilute exhaust molar flow over the test interval. This is the potential mole fraction of the dilute exhaust that would be lost due to water condensation over the entire test interval. Note that this assumes no re-evaporation. This value must be less than or equal to 0.005 (i.e. 0.5%).

(7) Flow compensation. Maintain nominally constant molar, volumetric or mass flow of diluted exhaust. You may maintain nominally constant flow by either maintaining the temperature and pressure at the flow meter or by directly controlling the flow of diluted exhaust. You may also directly control the flow of proportional samplers to maintain proportional sampling. For an individual test, validate proportional sampling as described in 545.

(d) Partial-flow dilution (PFD). You may dilute a partial flow of raw or previously diluted exhaust before measuring emissions. Section 240 describes PFD-related flow measurement instruments. PFD may consist of constant or varying dilution ratios as described in paragraphs (d)(2) and (3) of this section. An example of a constant dilution ratio PFD is a “secondary dilution PM” measurement system.

(1) Applicability. (i) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any test cycle.

(ii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous gaseous emission sampling over any transient duty cycle, any steady-state duty cycle, or any ramped-modal cycle.

(iii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous field-testing.

(iv) You may use PFD to extract a proportional diluted exhaust sample from a CVS for any batch or continuous emission sampling.

(v) You may use PFD to extract a constant raw or diluted exhaust sample for any continuous emission sampling.

(vi) You may use PFD to extract a constant raw or diluted exhaust sample for any steady-state emission sampling.

(2) Constant dilution-ratio PFD. Do one of the following for constant dilution-ratio PFD:

(i) Dilute an already proportional flow. For example, you may do this as a way of performing secondary dilution from a CVS tunnel to achieve overall dilution ratio for PM sampling.

(ii) Continuously measure constituent concentrations. For example, you might dilute to precondition a sample of raw exhaust to control its temperature, humidity, or constituent concentrations upstream of continuous analyzers. In this case, you must take into account the dilution ratio before multiplying the continuous concentration by the sampled exhaust flow rate.

(iii) Extract a proportional sample from a separate constant dilution ratio PFD system. For example, you might use a variable-flow pump to proportionally fill a gaseous storage medium such as a bag from a PFD system. In this case, the proportional sampling must meet the same specifications as varying dilution ratio PFD in paragraph (d)(3) of this section.

(3) Varying dilution-ratio PFD. All the following provisions apply for varying dilution-ratio PFD:

(i) Use a control system with sensors and actuators that can maintain exhaust flow and maintain proportional sampling over intervals as short as 200 ms (i.e., 5 Hz control).

(ii) Account for any emission transit time in the PFD system, as necessary.

(iii) You may not use a PFD system that requires preparatory tuning or calibration with a CVS or with the emission results from a CVS. Rather, you must be able to independently calibrate the PFD.

(e) Dilution air temperature, dilution ratio, residence time, and temperature control of PM samples. Dilute PM samples at least once upstream of transfer lines. You may dilute PM samples upstream of a transfer line using full-flow dilution, or partial-flow dilution immediately downstream of a PM probe. In the case of partial-flow dilution, you may have up to 26 cm of insulated length between the end of the probe and the dilution stage, but we recommend that the length be as short as practical. The intent of these specifications is to minimize heat transfer to

## WLTP-DTP-01-02

or from the emission sample before the final stage of dilution, other than the heat you may need to add to prevent aqueous condensation. This is accomplished by initially cooling the sample through dilution. Configure dilution systems as follows:

- (1) Set the diluent (i.e., dilution air) temperature to  $(25 \pm 5)$  °C. Measure this temperature as close as practical upstream of the point where diluent mixes with raw exhaust.
- (2) For any PM dilution system (i.e., CVS or PFD), dilute raw exhaust with diluent such that the minimum overall ratio of diluted exhaust to raw exhaust is within the range of (5:1 - 7:1) and is at least 2:1 for any primary dilution stage. Base this minimum value on the maximum vehicle exhaust flow rate for a given test interval. Either measure the maximum exhaust flow during a practice run of the test interval or estimate it based on accepted measurement practices (for example, you might rely on manufacturer-published literature).
- (3) Configure any PM dilution system to have an overall residence time of (1 to 5) s, as measured from the location of initial diluent introduction to the location where PM is collected on the sample media. Also configure the system to have a residence time of at least 0.5 s, as measured from the location of final diluent introduction to the location where PM is collected on the sample media. When determining residence times within sampling system volumes, use an assumed flow temperature of 25 °C and pressure of 101.325 kPa.
- (4) Control sample temperature to a  $(47 \pm 5)$  °C tolerance, as measured anywhere within 20 cm upstream or downstream of the PM storage media (such as a filter). Measure this temperature with a bare-wire junction thermocouple with wires that are  $(0.500 \pm 0.025)$  mm diameter, or with another suitable instrument that has equivalent performance.

### **145 Gaseous and PM probes, transfer lines, and sampling system components.**

(a) Continuous and batch sampling. Determine the total mass of each constituent with continuous or batch sampling. Both types of sampling systems have probes, transfer lines, and other sampling system components that are described in this section.

(c) Gaseous and PM sample probes. A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that its inside and outside surfaces are in contact with the exhaust. A sample is transported out of a probe into a transfer line, as described in paragraph (d) of this section. The following provisions apply to sample probes:

- (1) Probe design and construction. Use sample probes with inside surfaces of 300 series stainless steel or, for raw exhaust sampling, use any nonreactive material capable of withstanding raw exhaust temperatures. Locate sample probes where constituents are mixed to their mean sample concentration. Locate each probe to minimize interference with the flow to other probes. We recommend that all probes remain free from influences of boundary layers, wakes, and eddies—especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Make sure that purging or back-flushing of a probe does not influence another probe during testing. You may use a single probe to extract a sample of more than one constituent as long as the probe meets all the specifications for each constituent.
- (2) Gaseous sample probes. Use either single-port or multi-port probes for sampling gaseous emissions. You may orient these probes in any direction relative to the raw or diluted exhaust flow. For some probes, you must control sample temperatures, as follows:

- (i) For probes that extract  $\text{NO}_x$  from diluted exhaust, control the probe's wall temperature to prevent aqueous condensation.
- (ii) For probes that extract hydrocarbons for THC or NMHC analysis from the diluted exhaust of compression-ignition engines, heat the probe section to approximately  $190\text{ }^\circ\text{C}$  to minimize contamination.
- (3) PM sample probes. Use PM probes with a single opening at the end. Orient PM probes to face directly upstream. If you shield a PM probe's opening with a PM pre-classifier such as a hat, you may not use the preclassifier we specify in paragraph (f)(1) of this section.
- (d) Transfer lines. You may use transfer lines to transport an extracted sample from a probe to an analyzer, storage medium, or dilution system, noting certain restrictions for PM sampling in §140(e). Minimize the length of all transfer lines by locating analyzers, storage media, and dilution systems as close to probes as practical. Minimize the number of bends in transfer lines and maximize the radius of any unavoidable bend. Avoid using  $90^\circ$  elbows, tees, and cross-fittings in transfer lines. Where such connections and fittings are necessary you must meet the temperature tolerances in this paragraph (d). This may involve measuring temperature at various locations within transfer lines and fittings. You may use a single transfer line to transport a sample of more than one constituent, as long as the transfer line meets all the specifications for each constituent. The following construction and temperature tolerances apply to transfer lines:
  - (1) Gaseous samples. Use transfer lines with inside surfaces of 300 series stainless steel, PTFE, Viton<sup>TM</sup>, or any other material that you demonstrate has better properties for emission sampling. For raw exhaust sampling, use a non-reactive material capable of withstanding raw exhaust temperatures. You may use in-line filters if they do not react with exhaust constituents and if the filter and its housing meet the same temperature requirements as the transfer lines, as follows:
    - (i) For  $\text{NO}_x$  transfer lines upstream of either an  $\text{NO}_2$ -to- $\text{NO}$  converter that meets the specifications of 378 or a chiller that meets the specifications of 376, maintain a sample temperature that prevents aqueous condensation.
    - (ii) For THC transfer lines for testing compression-ignition engines, maintain a wall temperature tolerance throughout the entire line of  $(191 \pm 11)\text{ }^\circ\text{C}$ . If you sample from raw exhaust, you may connect an unheated, insulated transfer line directly to a probe. Design the length and insulation of the transfer line to cool the highest expected raw exhaust temperature to no lower than  $191\text{ }^\circ\text{C}$ , as measured at the transfer line's outlet. For dilute sampling, you may use a transition zone between the probe and transfer line of up to 92 cm to allow your wall temperature to transition to  $(191 \pm 11)\text{ }^\circ\text{C}$ .
  - (2) PM samples. Use heated transfer lines or a heated enclosure to minimize temperature differences between transfer lines and exhaust constituents. Use transfer lines made of 300 series stainless steel. Electrically ground the inside surface of PM transfer lines.
- (e) Optional sample-conditioning components for gaseous sampling. You may use the following sample-conditioning components to prepare gaseous samples for analysis, as long as you do not install or use them in a way that adversely affects your ability to show that your vehicles comply with all applicable gaseous emission standards.
  - (1)  $\text{NO}_2$ -to- $\text{NO}$  converter. You may use an  $\text{NO}_2$ -to- $\text{NO}$  converter that meets the converter conversion verification specified in 378 at any point upstream of a  $\text{NO}_x$  analyzer, sample bag, or other storage medium.

## WLTP-DTP-01-02

(2) Sample dryer. You may use either type of sample dryer described in this paragraph (e)(2) to decrease the effects of water on gaseous emission measurements. You may not use a chemical dryer, or use dryers upstream of PM sample filters.

(i) Osmotic-membrane. You may use an osmotic-membrane dryer upstream of any gaseous analyzer or storage medium, as long as it meets the temperature specifications in paragraph (d)(1) of this section. Because osmotic-membrane dryers may deteriorate after prolonged exposure to certain exhaust constituents, consult with the membrane manufacturer regarding your application before incorporating an osmotic-membrane dryer. Monitor the dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , downstream of an osmotic-membrane dryer. You may use continuously recorded values of  $T_{\text{dew}}$  and  $p_{\text{total}}$  in the amount of water calculations specified in 645. For our testing we may use average temperature and pressure values over the test interval or a nominal pressure value that we estimate as the dryer's average pressure expected during testing as constant values in the amount of water calculations specified in 645. For your testing, you may use the maximum temperature or minimum pressure values observed during a test interval or duty cycle or the high alarm temperature setpoint or low alarm pressure setpoint as constant values in the calculations specified in 645. For your testing, you may also use a nominal  $p_{\text{total}}$ , which you may estimate as the dryer's lowest absolute pressure expected during testing.

(ii) Thermal chiller. You may use a thermal chiller upstream of some gas analyzers and storage media. You may not use a thermal chiller upstream of a THC measurement system for compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW. If you use a thermal chiller upstream of an NO<sub>2</sub>-to-NO converter or in a sampling system without an NO<sub>2</sub>-to-NO converter, the chiller must meet the NO<sub>2</sub> loss-performance check specified in 376. Monitor the dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , downstream of a thermal chiller. You may use continuously recorded values of  $T_{\text{dew}}$  and  $p_{\text{total}}$  in the amount of water calculations specified in 645. If it is valid to assume the degree of saturation in the thermal chiller, you may calculate  $T_{\text{dew}}$  based on the known chiller performance and continuous monitoring of chiller temperature,  $T_{\text{chiller}}$ . If it is valid to assume a constant temperature offset between  $T_{\text{chiller}}$  and  $T_{\text{dew}}$ , due to a known and fixed amount of sample reheat between the chiller outlet and the temperature measurement location, you may factor in this assumed temperature offset value into emission calculations. If we ask for it, you must show by engineering analysis or by data the validity of any assumptions allowed by this paragraph (e)(2)(ii). For our testing we may use average temperature and pressure values over the test interval or a nominal pressure value that we estimate as the dryer's average pressure expected during testing as constant values in the calculations specified in 645. For your testing you may use the maximum temperature and minimum pressure values observed during a test interval or duty cycle or the high alarm temperature setpoint and the low alarm pressure setpoint as constant values in the amount of water calculations specified in 645. For your testing you may also use a nominal  $p_{\text{total}}$ , which you may estimate as the dryer's lowest absolute pressure expected during testing.

(3) Sample pumps. You may use sample pumps upstream of an analyzer or storage medium for any gas. Use sample pumps with inside surfaces of 300 series stainless steel, PTFE, or any other material that you demonstrate has better properties for emission sampling. For some sample pumps, you must control temperatures, as follows:

(i) If you use a NO<sub>x</sub> sample pump upstream of either an NO<sub>2</sub>-to-NO converter that meets 378 or a chiller that meets 376, it must be heated to prevent aqueous condensation.

(ii) For testing compression-ignition engines, if you use a THC sample pump upstream of a THC analyzer or storage medium, its inner surfaces must be heated to a tolerance of (191 ±11) °C.

(4) Ammonia Scrubber. You may use ammonia scrubbers for any or all gaseous sampling systems to prevent interference with NH<sub>3</sub>, poisoning of the NO<sub>2</sub>-to-NO converter, and deposits in the sampling system or analyzers. Follow the ammonia scrubber manufacturer's recommendations or use accepted measurement practices in applying ammonia scrubbers.

(f) Optional sample-conditioning components for PM sampling. You may use the following sample-conditioning components to prepare PM samples for analysis, as long as you do not install or use them in a way that adversely affects your ability to show that your engines comply with the applicable PM emission standards. You may condition PM samples to minimize positive and negative biases to PM results, as follows:

(1) PM preclassifier. You may use a PM preclassifier to remove large-diameter particles. The PM preclassifier may be either an inertial impactor or a cyclonic separator. It must be constructed of 300 series stainless steel. The preclassifier must be rated to remove at least 50 % of PM at an aerodynamic diameter of 10 µm and no more than 1 % of PM at an aerodynamic diameter of 1 µm over the range of flow rates for which you use it. Follow the preclassifier manufacturer's instructions for any periodic servicing that may be necessary to prevent a buildup of PM. Install the preclassifier in the dilution system downstream of the last dilution stage. Configure the preclassifier outlet with a means of bypassing any PM sample media so the preclassifier flow may be stabilized before starting a test. Locate PM sample media within 75 cm downstream of the preclassifier's exit. You may not use this preclassifier if you use a PM probe that already has a preclassifier. For example, if you use a hat-shaped preclassifier that is located immediately upstream of the probe in such a way that it forces the sample flow to change direction before entering the probe, you may not use any other preclassifier in your PM sampling system.

### **170 Batch sampling for gaseous and PM constituents.**

Batch sampling involves collecting and storing emissions for later analysis. Examples of batch sampling include collecting and storing gaseous emissions in a bag or collecting and storing PM on a filter. You may use batch sampling to store emissions that have been diluted at least once in some way, such as with CVS, PFD, or BMD. You may use batch-sampling to store undiluted emissions.

(a) Sampling methods. Sample at a flow rate proportional to the CVS as follows:

(1) Validate proportional sampling after an emission test as described in 545.

(2) Select storage media that will not significantly change measured emission levels (either up or down). For example, do not use sample bags for storing emissions if the bags are permeable with respect to emissions or if they off gas emissions to the extent that it affects your ability to demonstrate compliance with the applicable gaseous emission standards.

(3) You must follow the requirements in 140(e)(2) related to PM dilution ratios.

## WLTP-DTP-01-02

(b) Gaseous sample storage media. Store gas volumes in sufficiently clean containers that minimally off-gas or allow permeation of gases. Use accepted measurement practices to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, you may repeatedly purge and evacuate a container and you may heat it. Use a flexible container (such as a bag) within a temperature-controlled environment, or use a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement. Use containers meeting the specifications in the following table:

Table 1 of 170–Gaseous Batch Sampling Container Materials

Emissions	Engines	
	Compression-ignition	All other engines
CO, CO <sub>2</sub> , O <sub>2</sub> , CH <sub>4</sub> , C <sub>2</sub> H <sub>6</sub> , C <sub>3</sub> H <sub>8</sub> , NO, NO <sub>2</sub> <sup>1</sup>	Tedlar <sup>TM2</sup> , Kynar <sup>TM2</sup> , Teflon <sup>TM3</sup> , or 300 series stainless steel <sup>3</sup>	Tedlar <sup>TM2</sup> , Kynar <sup>TM2</sup> , Teflon <sup>TM3</sup> , or 300 series stainless steel <sup>3</sup>
THC, NMHC	Teflon <sup>TM4</sup> or 300 series stainless steel <sup>4</sup>	Tedlar <sup>TM2</sup> , Kynar <sup>TM2</sup> , Teflon <sup>TM3</sup> , or 300 series stainless steel <sup>3</sup>

<sup>1</sup>As long as you prevent aqueous condensation in storage container.

<sup>2</sup>Up to 40 °C.

<sup>3</sup>Up to 202 °C.

<sup>4</sup>Up to (191 ±11) °C.

(c) PM sample media. Apply the following methods for sampling particulate emissions:

(1) If you use filter-based sampling media to extract and store PM for measurement, your procedure must meet the following specifications:

(i) If you expect that a filter's total surface concentration of PM will exceed 400 µg, assuming a 38 mm diameter filter stain area, for a given test interval, you may use filter media with a minimum initial collection efficiency of 98 %; otherwise you must use a filter media with a minimum initial collection efficiency of 99.7 %.

(ii) The filter must be circular, with an overall diameter of 46.50 ±0.6 mm and an exposed diameter of at least 38 mm. See the cassette specifications in paragraph (c)(1)(vii) of this section.

(iii) Use a pure PTFE filter material that does not have any flow-through support bonded to the back and has an overall thickness of 40 ±20 µm. An inert polymer ring may be bonded to the periphery of the filter material for support and for sealing between the filter cassette parts. We consider Polymethylpentene (PMP) and PTFE inert materials for a support ring, but other inert materials may be used. See the cassette specifications in paragraph (c)(1)(vii) of this section. We allow the use of PTFE-coated glass fiber filter material, as long as this filter media selection does not affect your ability to demonstrate compliance with the applicable standards, which we base on a pure PTFE filter material.

(v) To minimize turbulent deposition and to deposit PM evenly on a filter, use a filter holder with a 12.5° (from center) divergent cone angle to transition from the transfer-line inside diameter to the exposed diameter of the filter face. Use 300 series stainless steel for this transition.

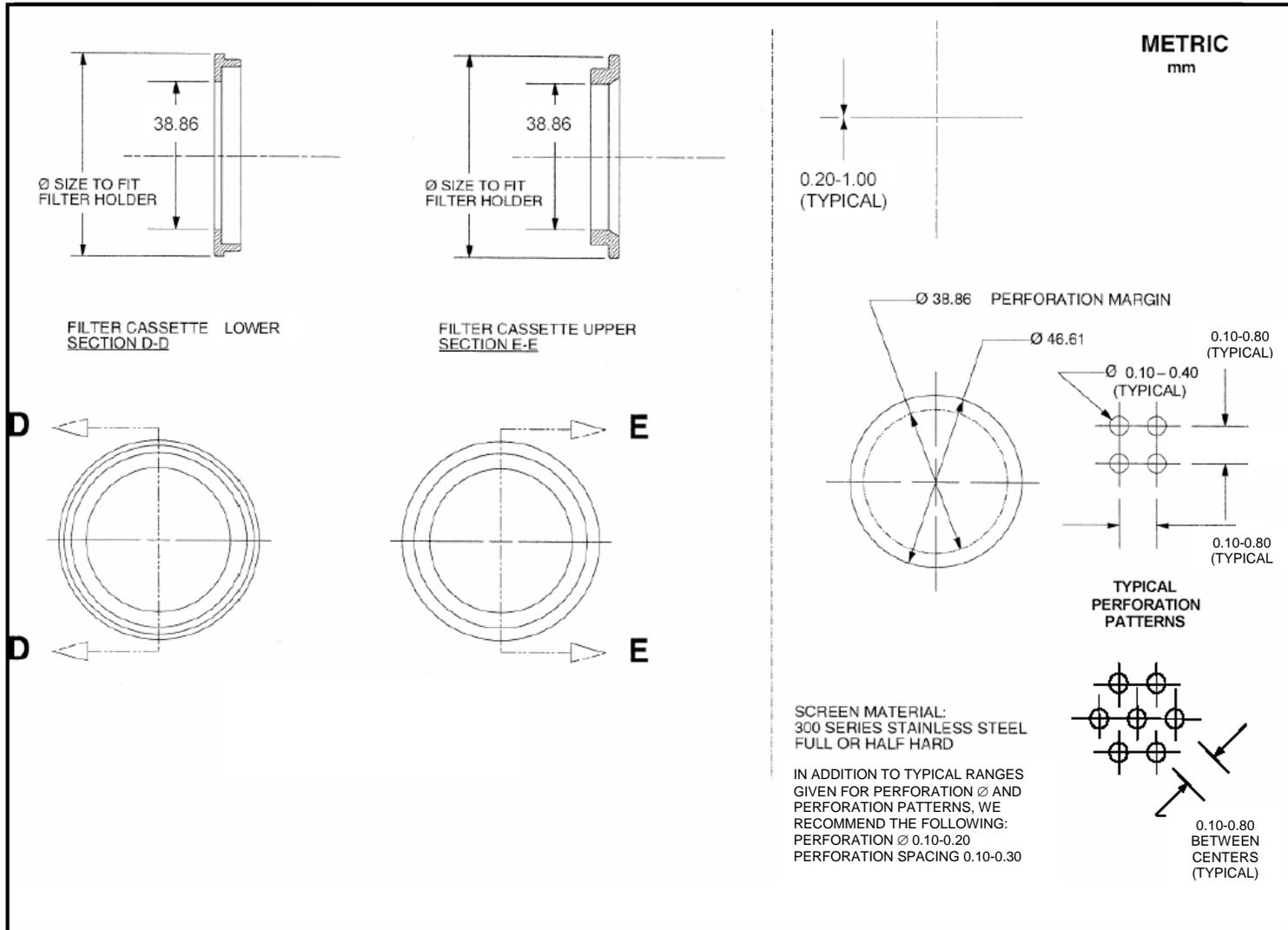
(vi) Maintain a filter face velocity near 100 cm/s with less than 5% of the recorded flow values exceeding 100 cm/s, unless you expect either the net PM mass on the filter to exceed 400 µg, assuming a 38 mm diameter filter stain area. Measure face velocity as the volumetric flow rate of the sample at the pressure upstream of the filter and temperature of the filter face as measured in 140(e), divided by the filter's exposed area. You may use the exhaust stack or CVS tunnel pressure for the upstream pressure if the pressure drop through the PM sampler up to the filter is less than 2 kPa.

(vii) Use a clean cassette designed to the specifications of Figure 1 of 170. In auto changer configurations, you may use cassettes of similar design. Cassettes must be made of one of the following materials: Delrin™, 300 series stainless steel, polycarbonate, acrylonitrile-butadiene-styrene (ABS) resin, or conductive polypropylene. We recommend that you keep filter cassettes clean by periodically washing or wiping them with a compatible solvent applied using a lint-free cloth. Depending upon your cassette material, ethanol (C<sub>2</sub>H<sub>5</sub>OH) might be an acceptable solvent. Your cleaning frequency will depend on your vehicle's PM and HC emissions.

(viii) If you keep the cassette in the filter holder after sampling, prevent flow through the filter until either the holder or cassette is removed from the PM sampler. If you remove the cassettes from filter holders after sampling, transfer the cassette to an individual container that is covered or sealed to prevent communication of semi-volatile matter from one filter to another. If you remove the filter holder, cap the inlet and outlet. Keep them covered or sealed until they return to the stabilization or weighing environments.

(ix) The filters should be loaded into cassettes, filter holders, or auto changer apparatus before removal from the PM stabilization and weighing environments.

Figure 1 of 170



**190 PM-stabilization and weighing environments for gravimetric analysis.**

(a) This section describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common space. These volumes may be one or more rooms, or they may be much smaller, such as a glove box or an automated weighing system consisting of one or more countertop-sized environments.

(b) Keep both the stabilization and the weighing environments free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples. We recommend that these environments conform with an “as-built” Class Six clean room specification according to ISO 14644-1. Deviate from ISO 14644-1 as necessary to minimize air motion that might affect weighing. We recommend maximum air-supply and air-return velocities of 0.05 m/s in the weighing environment.

(d) Maintain the following ambient conditions within the two environments during all stabilization and weighing:

(1) Ambient temperature and tolerances. Maintain the weighing environment at a tolerance of  $(22 \pm 1)$  °C. If the two environments share a common space, maintain both environments at a tolerance of  $(22 \pm 1)$  °C. If they are separate, maintain the stabilization environment at a tolerance of  $(22 \pm 3)$  °C.

(2) Dewpoint. Maintain a dewpoint of 9.5 °C in both environments. This dewpoint will control the amount of water associated with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) PM, such that 1.2216 grams of water will be associated with each gram of H<sub>2</sub>SO<sub>4</sub>.

(3) Dewpoint tolerances. If the expected fraction of sulfuric acid in PM is unknown, we recommend controlling dewpoint at within  $\pm 1$  °C tolerance. This would limit any dewpoint-related change in PM to less than  $\pm 2$  %, even for PM that is 50 % sulfuric acid. If you know your expected fraction of sulfuric acid in PM, we recommend that you select an appropriate dewpoint tolerance for showing compliance with emission standards using the following table as a guide:

Table 1 of 190—Dewpoint tolerance  
as a function of % PM change and % sulfuric acid PM

Expected sulfuric acid fraction of PM	$\pm 0.5$ % PM mass change	$\pm 1.0$ % PM mass change	$\pm 2.0$ % PM mass change
5 %	$\pm 3.0$ °C	$\pm 6.0$ °C	$\pm 12$ °C
50 %	$\pm 0.30$ °C	$\pm 0.60$ °C	$\pm 1.2$ °C
100 %	$\pm 0.15$ °C	$\pm 0.30$ °C	$\pm 0.60$ °C

(e) Verify the following ambient conditions using measurement instruments that meet the specifications in subpart C of this part:

(1) Continuously measure dewpoint and ambient temperature. Use these values to determine if the stabilization and weighing environments have remained within the tolerances specified in paragraph (d) of this section for at least 60 min before weighing sample media (e.g., filters).

## WLTP-DTP-01-02

(2) Continuously measure atmospheric pressure within the weighing environment. An acceptable alternative is to use a barometer that measures atmospheric pressure outside the weighing environment, as long as you can ensure that atmospheric pressure at the balance is always within  $\pm 100$  Pa of that outside environment during weighing operations. Record atmospheric pressure as you weigh filters, and use these pressure values to perform the buoyancy correction in 690.

(f) We recommend that you install a balance as follows:

(1) Install the balance on a vibration-isolation platform to isolate it from external noise and vibration.

(2) Shield the balance from convective airflow with a static-dissipating draft shield that is electrically grounded.

(3) Follow the balance manufacturer's specifications for all preventive maintenance.

(4) Operate the balance manually or as part of an automated weighing system.

(g) Minimize static electric charge in the balance environment, as follows:

(1) Electrically ground the balance.

(2) Use 300 series stainless steel tweezers if PM sample media (e.g., filters) must be handled manually.

(3) Ground tweezers with a grounding strap, or provide a grounding strap for the operator such that the grounding strap shares a common ground with the balance. Make sure grounding straps have an appropriate resistor to protect operators from accidental shock.

(4) Provide a static-electricity neutralizer that is electrically grounded in common with the balance to remove static charge from PM sample media (e.g., filters), as follows:

(i) You may use radioactive neutralizers such as a Polonium ( $^{210}\text{Po}$ ) source. Replace radioactive sources at the intervals recommended by the neutralizer manufacturer.

(ii) You may use other neutralizers, such as corona-discharge ionizers. If you use a corona-discharge ionizer, we recommend that you monitor it for neutral net charge according to the ionizer manufacturer's recommendations.

(5) We recommend that you use a device to monitor the static charge of PM sample media (e.g., filter) surface.

(6) We recommend that you neutralize PM sample media (e.g., filters) to within  $\pm 2.0$  V of neutral. Measure static voltages as follows:

(i) Measure static voltage of PM sample media (e.g., filters) according to the electrostatic voltmeter manufacturer's instructions.

(ii) Measure static voltage of PM sample media (e.g., filters) while the media is at least 15 cm away from any grounded surfaces to avoid mirror image charge interference.

**Measurement Instruments**

**201 Overview and general provisions.**

(a) Scope. This section specifies measurement instruments and associated system requirements related to emission testing in a laboratory or similar environment. This includes laboratory instruments for measuring test parameters, ambient conditions, flow-related parameters, and emission concentrations.

(b) Instrument types. You may use any of the specified instruments as described in this section to perform emission tests. Where we specify more than one instrument for a particular measurement, we may identify which instrument serves as the reference for comparing with an alternate procedure.

(d) Redundant systems. For all measurement instruments described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use accepted measurement practices to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements. This requirement applies whether or not you actually use the measurements in your calculations.

(e) Range. You may use an instrument’s response above 100 % of its operating range if this does not affect your ability to show that your emissions comply with the applicable emission standards. Note that we require additional testing and reporting if an analyzer responds above 100 % of its range. See 550. Auto-ranging analyzers do not require additional testing or reporting.

(f) Related subparts for laboratory testing. Section 300 of this part describes how to evaluate the performance of the measurement instruments in this subpart. In general, if an instrument is specified in a specific section of this subpart, its calibration and verifications are typically specified in a similarly numbered section in subpart D of this part. For example, 290 gives instrument specifications for PM balances and 390 describes the corresponding calibrations and verifications.

**202 Data updating, recording, and control.**

Your test system must be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Use data acquisition and control systems that can record at the specified minimum frequencies, as follows:

Table 1 of 202–Data recording and control minimum frequencies

Measured Values	Minimum Command and Control Frequency	Minimum Recording Frequency
Dynamometer	40 Hz	10 Hz
Continuous concentrations of raw or dilute analyzers	N/A	1 Hz
Batch concentrations of raw or dilute	N/A	1 mean value

## WLTP-DTP-01-02

analyzers		per test interval
Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	N/A	1 Hz
Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
Intake-air or raw-exhaust flow rate	N/A	1 Hz means
Dilution air if actively controlled	5 Hz	1 Hz means
Sample flow from a CVS that has a heat exchanger	1 Hz	1 Hz
Sample flow from a CVS does not have a heat exchanger	5 Hz	1 Hz mean

### **205 Performance specifications for measurement instruments.**

Your test system as a whole must meet all the applicable calibrations, verifications, and test-validation criteria specified.

(a) In order to ensure that your instruments will comply with the requirements of this test procedure, we recommend that your instruments meet the specifications in Table 1 of this section for all ranges you use for testing. Retain documentation you receive from instrument manufacturers showing that your instruments meet the specifications in Table 1 of this section.

(b) You may use a measurement instrument that does not meet the accuracy, repeatability, or noise specifications in Table 1 of 205, as long as you meet the following criteria:

(1) Your measurement systems meet all the other required calibration, verification, and validation specifications in subparts D and F of this part, as applicable.

(2) The measurement deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards.

**WLTP-DTP-01-02**

Table 1 of 205–Recommended performance specifications for measurement instruments

Measurement Instrument	Measured quantity symbol	Complete System Rise time ( $t_{10-90}$ ) and Fall time ( $t_{90-10}$ ) <sup>a</sup>	Recording update frequency	Accuracy <sup>b</sup>	Repeatability <sup>b</sup>	Noise <sup>b</sup>
General pressure transducer (not a part of another instrument)	$p$	5 s	1 Hz	2.0 % of pt. or 1.0 % of max.	1.0 % of pt. or 0.50 % of max.	0.1 % of max
Atmospheric pressure meter used for PM-stabilization and balance environments	$p_{\text{atmos}}$	50 s	5 times per hour	50 Pa	25 Pa	5 Pa
General purpose atmospheric pressure meter	$p_{\text{atmos}}$	50 s	5 times per hour	250 Pa	100Pa	50 Pa
Temperature sensor for PM-stabilization and balance environments	$T$	50 s	0.1 Hz	0.25 K	0.1 K	0.1 K
Other temperature sensor (not a part of another instrument)	$T$	10 s	0.5 Hz	0.4 % of pt. K or 0.2 % of max. K	0.2 % of pt. K or 0.1 % of max. K	0.1 % of max
Dewpoint sensor for intake air, PM-stabilization and balance environments	$T_{\text{dew}}$	50 s	0.1 Hz	0.25 K	0.1 K	0.02 K
Other dewpoint sensor	$T_{\text{dew}}$	50 s	0.1 Hz	1 K	0.5 K	0.1 K
Fuel flow meter (Fuel totalizer)	$\dot{m}$	5 s (N/A)	1 Hz (N/A)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	0.5 % of max.
Total diluted exhaust meter (CVS) (With heat exchanger before meter)	$\dot{n}$	1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	1.0 % of max.
Dilution air, inlet air, exhaust, and sample flow meters	$\dot{n}$	1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max.	1.25 % of pt. or 0.75 % of max.	1.0 % of max.
Continuous gas analyzer	$x$	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	1.0 % of max.
Batch gas analyzer	$x$	N/A	N/A	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	1.0 % of max.
Gravimetric PM balance	$m_{\text{PM}}$	N/A	N/A	See §790	0.5 µg	N/A

<sup>a</sup> The performance specifications identified in the table apply separately for rise time and fall time.

<sup>b</sup> Accuracy, repeatability, and noise are all determined with the same collected data, as described in §305, and based on absolute values. “pt.” refers to the overall flow-weighted mean value expected at the standard; “max.” refers to the peak value expected at the standard over any test interval, not the maximum of the instrument’s range; “meas” refers to the actual flow-weighted mean measured over any test interval.

## MEASUREMENT OF PARAMETERS AND AMBIENT CONDITIONS

### **215 Pressure transducers, temperature sensors, and dewpoint sensors.**

(a) Application. Use instruments as specified in this section to measure pressure, temperature, and dewpoint.

(c) Temperature. For PM-balance environments or other precision temperature measurements over a narrow temperature range, we recommend thermistors. For other applications we recommend thermocouples that are not grounded to the thermocouple sheath. You may use other temperature sensors, such as resistive temperature detectors (RTDs).

(d) Pressure. Pressure transducers must be located in a temperature-controlled environment, or they must compensate for temperature changes over their expected operating range. Transducer materials must be compatible with the fluid being measured. For atmospheric pressure or other precision pressure measurements, we recommend either capacitance-type, quartz crystal, or laser-interferometer transducers. For other applications, we recommend either strain gage or capacitance-type pressure transducers. You may use other pressure-measurement instruments, such as manometers, where appropriate.

(e) Dewpoint. For PM-stabilization environments, we recommend chilled-surface hygrometers, which include chilled mirror detectors and chilled surface acoustic wave (SAW) detectors. For other applications, we recommend thin-film capacitance sensors. You may use other dewpoint sensors, such as a wet-bulb/dry-bulb psychrometer, where appropriate.

### 230 CHASSIS DYNAMOMETER

(a) The dynamometer shall simulate the road load force and inertia specified for the vehicle being tested, and shall determine the distance traveled during each phase of the test procedure.

(2)(i) An electric dynamometer that has a single roll with a nominal diameter of 48 inches (1.20 to 1.25 meters).

(c) Other dynamometer configurations may be used for testing if it can be demonstrated that the simulated road load power and inertia are equivalent, and if approved in advance by the Administration.

(d) An electric dynamometer meeting the requirements of paragraph (b)(2) of this section, or a dynamometer approved as equivalent under paragraph

(c) of this section, must be used for all types of emission testing in the following situations.

(1)(i) Gasoline vehicles which are part of an engine family which is designated to meet the phase-in of SFTP compliance required under the implementation schedule of table A00-1 of § 86.000-08, or table A00-3, or table A00-5 of § 86.000-09.

(ii) Diesel LDVs and LDT1s which are part of an engine family which is designated to meet the phase-in of SFTP compliance required under the implementation schedule of table A00-1 of § 86.000-08, or table A00-3, or table A00-5 of § 86.000-09.

## FLOW-RELATED MEASUREMENTS

### **240 Dilution air and diluted exhaust flow meters.**

(a) Application. Use a diluted exhaust flow meter to determine instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval. You may use the difference between

## WLTP-DTP-01-02

a diluted exhaust flow meter and a dilution air meter to calculate raw exhaust flow rates or total raw exhaust flow over a test interval.

(b) Component requirements. Note that your overall system for measuring diluted exhaust flow must meet the linearity verification in 307 and the calibration and verifications in 340 and 341. You may use the following meters:

(1) For constant-volume sampling (CVS) of the total flow of diluted exhaust, you may use a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), or an ultrasonic flow meter (UFM). Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller in a CVS system. However, you may also combine any flow meter with any active flow control system to maintain proportional sampling of exhaust constituents. You may control the total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls to maintain proportional sampling. Ensure that any dilute exhaust flow measurement is immune to measurement performance degradation caused by pulsating exhaust flow.

(2) For any other dilution system, you may use a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer.

(c) Flow conditioning. For any type of diluted exhaust flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, you may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

(d) Exhaust cooling. You may cool diluted exhaust upstream of a dilute-exhaust flow meter, as long as you observe all the following provisions:

(1) Do not sample PM downstream of the cooling.

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines.

(3) If cooling causes aqueous condensation, do not sample NO<sub>x</sub> downstream of the cooling unless the cooler meets the performance verification in 376.

(4) If cooling causes aqueous condensation before the flow reaches a flow meter, measure dewpoint,  $T_{\text{dew}}$  and pressure,  $p_{\text{total}}$  at the flow meter inlet. Use these values in emission calculations according to 650.

### **245 Sample flow meter for batch sampling.**

(a) Application. Use a sample flow meter to determine sample flow rates or total flow sampled into a batch sampling system over a test interval.

(b) Component requirements. This may involve a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. For the special case where CFVs are used for both the diluted exhaust and sample-flow measurements and their upstream pressures and temperatures remain similar during

testing, you do not have to quantify the flow rate of the sample-flow CFV. In this special case, the sample-flow CFV inherently flow-weights the batch sample relative to the diluted exhaust CFV.

(c) Flow conditioning. For any type of sample flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, you may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

#### **248 Gas divider.**

(a) Application. You may use a gas divider to blend calibration gases.

(b) Component requirements. Use a gas divider that blends gases to the specifications of 750 and to the flow-weighted concentrations expected during testing. You may use critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers.

### CO AND CO<sub>2</sub> MEASUREMENTS

#### **250 Nondispersive infra-red analyzer.**

(a) Application. Use a nondispersive infra-red (NDIR) analyzer to measure CO and CO<sub>2</sub> concentrations in raw or diluted exhaust for either batch or continuous sampling.

(b) Component requirements. You may use an NDIR analyzer that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

### HYDROCARBON MEASUREMENTS

#### **260 Flame-ionization detector.**

(a) Application. Use a flame-ionization detector (FID) analyzer to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Determine hydrocarbon concentrations on a carbon number basis of one, C<sub>1</sub>. Determine methane and nonmethane hydrocarbon values as described in paragraph (e) of this section. See subpart I of this part for special provisions that apply to measuring hydrocarbons when testing with oxygenated fuels.

(b) Component requirements. You may use a FID that has compensation algorithms that are functions of other gaseous measurements and the vehicle's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

(c) Heated FID analyzers. For compression-ignition engines, you must use heated FID analyzers that maintain all surfaces that are exposed to emissions at a temperature of (191 ± 11) °C.

(d) FID fuel and burner air. Use FID fuel and burner air that meet the specifications of 750. Do not allow the FID fuel and burner air to mix before entering the FID analyzer to ensure that the FID analyzer operates with a diffusion flame and not a premixed flame.

## WLTP-DTP-01-02

(e) Methane. FID analyzers measure total hydrocarbons (THC). To determine nonmethane hydrocarbons (NMHC), quantify methane, CH<sub>4</sub>, either with a nonmethane cutter and a FID analyzer as described in 265, or with a gas chromatograph as described in 267. For a FID analyzer used to determine NMHC, determine its response factor to CH<sub>4</sub>,  $RF_{CH_4}$ , as described in 360. Note that NMHC-related calculations are described in 660.

### 265 Nonmethane cutter.

- (a) Application. You may use a nonmethane cutter to measure CH<sub>4</sub> with a FID analyzer. A nonmethane cutter oxidizes all nonmethane hydrocarbons to CO<sub>2</sub> and H<sub>2</sub>O. You may use a nonmethane cutter for raw or diluted exhaust for batch or continuous sampling.
- (b) System performance. Determine nonmethane-cutter performance as described in 365 and use the results to calculate NMHC emission in 660.
- (c) Configuration. Configure the nonmethane cutter with a bypass line if it is needed for the verification described in 365.
- (d) Optimization. Optimize a nonmethane cutter to maximize the penetration of CH<sub>4</sub> and the oxidation of all other hydrocarbons. You may humidify a sample and you may dilute a sample with purified air or upstream of the nonmethane cutter to optimize its performance. You must account for any sample humidification and dilution in emission calculations.

### 267 Gas chromatograph.

- (a) Application. You may use a gas chromatograph to measure CH<sub>4</sub> concentrations of diluted exhaust for batch sampling.

## NO<sub>x</sub> AND N<sub>2</sub>O MEASUREMENTS

### §270 Chemiluminescent detector.

- (a) Application. You may use a chemiluminescent detector (CLD) to measure NO<sub>x</sub> concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept a CLD for NO<sub>x</sub> measurement, even though it measures only NO and NO<sub>2</sub>, when coupled with an NO<sub>2</sub>-to-NO converter, since conventional engines and aftertreatment systems do not emit significant amounts of NO<sub>x</sub> species other than NO and NO<sub>2</sub>. Measure other NO<sub>x</sub> species if required by the standard-setting part.
- (b) Component requirements. You may use a heated or unheated CLD, and you may use a CLD that operates at atmospheric pressure or under a vacuum. You may use a CLD that has compensation algorithms that are functions of other gaseous measurements and the vehicle's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.
- (c) NO<sub>2</sub>-to-NO converter. Place upstream of the CLD an internal or external NO<sub>2</sub>-to-NO converter that meets the verification in 378. Configure the converter with a bypass line if it is needed to facilitate this verification.
- (d) Humidity effects. You must maintain all CLD temperatures to prevent aqueous condensation. If you remove humidity from a sample upstream of a CLD, use one of the following configurations:

- (1) Connect a CLD downstream of any dryer or chiller that is downstream of an NO<sub>2</sub>-to-NO converter that meets the verification in 378.
- (2) Connect a CLD downstream of any dryer or thermal chiller that meets the verification in §376.
- (e) Response time. You may use a heated CLD to improve CLD response time.

### **272 Nondispersive ultraviolet analyzer.**

- (a) Application. You may use a nondispersive ultraviolet (NDUV) analyzer to measure NO<sub>x</sub> concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept an NDUV for NO<sub>x</sub> measurement, even though it measures only NO and NO<sub>2</sub>, since conventional engines and aftertreatment systems do not emit significant amounts of other NO<sub>x</sub> species. Measure other NO<sub>x</sub> species if required by the standard-setting part.
- (b) Component requirements. You may use a NDUV analyzer that has compensation algorithms that are functions of other gaseous measurements and the vehicle's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.
- (c) NO<sub>2</sub>-to-NO converter. If your NDUV analyzer measures only NO, place upstream of the NDUV analyzer an internal or external NO<sub>2</sub>-to-NO converter that meets the verification in 378. Configure the converter with a bypass to facilitate this verification.
- (d) Humidity effects. You must maintain NDUV temperature to prevent aqueous condensation, unless you use one of the following configurations:
  - (1) Connect an NDUV downstream of any dryer or chiller that is downstream of an NO<sub>2</sub>-to-NO converter that meets the verification in 378.
  - (2) Connect an NDUV downstream of any dryer or thermal chiller that meets the verification in 376.

### **275 N<sub>2</sub>O measurement devices.**

- (a) General component requirements.
- (b) Instrument types. You may use any of the following analyzers to measure N<sub>2</sub>O:
  - (1) Nondispersive infra-red (NDIR) analyzer. You may use an NDIR analyzer that has compensation algorithms that are functions of other gaseous measurements and the vehicle's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.
  - (2) Fourier transform infra-red (FTIR) analyzer. You may use an FTIR analyzer that has compensation algorithms that are functions of other gaseous measurements and the vehicle's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias. Use appropriate analytical procedures for interpretation of infrared spectra.
  - (3) Photoacoustic analyzer. You may use a photoacoustic analyzer that has compensation algorithms that are functions of other gaseous measurements. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias. Use an optical wheel configuration that gives analytical priority to measurement of the least stable components in the sample. Select a sample integration time of at

## WLTP-DTP-01-02

least 5 seconds. Take into account sample chamber and sample line volumes when determining flush times for your instrument.

(4) Gas chromatograph analyzer. You may use a gas chromatograph with an electron-capture detector (GC-ECD) to measure N<sub>2</sub>O concentrations of diluted exhaust for batch sampling.

(i) You may use a packed or porous layer open tubular (PLOT) column phase of suitable polarity and length to achieve adequate resolution of the N<sub>2</sub>O peak for analysis. Examples of acceptable columns are a PLOT column consisting of bonded polystyrene-divinylbenzene or a Porapack Q packed column. Take the column temperature profile and carrier gas selection into consideration when setting up your method to achieve adequate N<sub>2</sub>O peak resolution.

(ii) Zero your instrument and correct for drift. You do not need to follow the specific procedures in 530 and 550(b) that would otherwise apply. For example, you may perform a span gas measurement before and after sample analysis without zeroing. Use the average area counts of the pre-span and post-span measurements to generate a response factor (area counts/span gas concentration), which you then multiply by the area counts from your sample to generate the sample concentration.

(c) Interference validation. Perform interference validation for NDIR, FTIR, and photoacoustic analyzers using the procedures of 375. Interference validation is not required for GC-ECD. Certain interference gases can positively interfere with NDIR, FTIR, and photoacoustic analyzers by causing a response similar to N<sub>2</sub>O. When running the interference verification for these analyzers, use interference gases as follows:

(1) The interference gases for NDIR analyzers are CO, CO<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub> and SO<sub>2</sub>. Note that interference species, with the exception of H<sub>2</sub>O, are dependent on the N<sub>2</sub>O infrared absorption band chosen by the instrument manufacturer and should be determined independently for each analyzer.

(2) Use accepted measurement practices to determine interference gases for FTIR. Note that interference species, with the exception of H<sub>2</sub>O, are dependent on the N<sub>2</sub>O infrared absorption band chosen by the instrument manufacturer and should be determined independently for each analyzer.

(3) The interference gases for photoacoustic analyzers are CO, CO<sub>2</sub>, and H<sub>2</sub>O or as recommended by the analyzer manufacturer.

## O<sub>2</sub> MEASUREMENTS

### **§280 Paramagnetic and magnetopneumatic O<sub>2</sub> detection analyzers.**

(a) Application. You may use a paramagnetic detection (PMD) or magnetopneumatic detection (MPD) analyzer to measure O<sub>2</sub> concentration in raw or diluted exhaust for batch or continuous sampling.

(b) Component requirements. You may use a PMD or MPD that has compensation algorithms that are functions of other gaseous measurements and the vehicle's known or assumed fuel properties. The target value for any compensation algorithm is 0.0 % (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

## PM MEASUREMENTS

**290 PM gravimetric balance.**

(a) Application. Use a balance to weigh net PM on a sample medium for laboratory testing.

(b) Component requirements. If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights must meet the specifications in 790.

(c) Pan design. Use a balance pan designed to minimize the effect of corner loading of the balance, as follows:

(1) Use a pan that centers the PM sample media (such as a filter) on the weighing pan. For example, use a pan in the shape of a cross that has upswept tips that center the PM sample media on the pan.

(2) Use a pan that positions the PM sample as low as possible.

(d) Balance configuration. Configure the balance for optimum settling time and stability at your location.

## **WLTP-DTP-01-02**

### **Calibrations and Verifications**

#### **301 Overview and general provisions.**

- (a) This subpart describes required and recommended calibrations and verifications of measurement systems. See section 200 for specifications that apply to individual instruments.
- (b) You must generally use complete measurement systems when performing calibrations or verification. For example, this would generally involve evaluating instruments based on values recorded with the complete system you use for recording test data, including analog-to-digital converters. For some calibrations and verifications, we may specify that you disconnect part of the measurement system to introduce a simulated signal.
- (c) If we do not specify a calibration or verification for a portion of a measurement system, calibrate that portion of your system and verify its performance at a frequency consistent with recommendations from the measurement-system manufacturer.
- (d) Use NIST-traceable standards to the tolerances we specify for calibrations and verifications. Where we specify the need to use NIST-traceable standards, you may alternatively ask for our approval to use international standards that are not NIST-traceable.

#### **303 Summary of required calibration and verifications**

The following table summarizes the required and recommended calibrations and verifications described in this subpart and indicates when these have to be performed:

Table 1 of 303—Summary of required calibration and verifications

Type of calibration or verification	Minimum frequency <sup>a</sup>
305: Accuracy, repeatability and noise	Accuracy: Not required, but recommended for initial installation. Repeatability: Not required, but recommended for initial installation. Noise: Not required, but recommended for initial installation.
307: Linearity verification	Dynamometer: Upon initial installation, within 370 days before testing and after major maintenance. Clean gas and diluted exhaust flows: Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Raw exhaust flow: Upon initial installation, within 185 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Gas dividers: Upon initial installation, within 370 days before testing, and after major maintenance. Gas analyzers: Upon initial installation, within 35 days before testing and after major maintenance. FTIR and photoacoustic analyzers: Upon initial installation, within 370 days before testing and after major maintenance. GC-ECD: Upon initial installation and after major maintenance. PM balance: Upon initial installation, within 370 days before testing and after major maintenance. Pressure, temperature, and dewpoint: Upon initial installation, within 370 days before testing and after major maintenance.
308: Continuous gas analyzer system response and updating-recording verification—for gas analyzers not continuously compensated for other gas species	Upon initial installation or after system modification that would affect response.
309: Continuous gas analyzer system-response and updating-recording verification—for gas analyzers continuously compensated for other gas species	Upon initial installation or after system modification that would affect response.
310: Dynamometer	Full transducer calibrations traceable to a recognized standards organization upon initial installation, within 370 days before testing, and after major maintenance. Dynamometer Parasitic loss: Upon initial installation and weekly. Dynamometer speed verifications: Upon initial installation and monthly. Dynamometer load curve coastdown: Upon initial installation and weekly.
315: Pressure, temperature, dewpoint	Upon initial installation and after major maintenance.
330: Exhaust flow	Upon initial installation and after major maintenance.
340: Diluted exhaust flow (CVS)	Upon initial installation and after major maintenance.
341: CVS and batch sampler verification <sup>b</sup>	Upon initial installation, within 35 days before testing, and after major maintenance.
342 Sample dryer verification	For thermal chillers: upon installation and after major maintenance. For osmotic membranes; upon installation, within 35 days of testing, and after major maintenance.
345: Vacuum leak	Within 8 hours before the start of the first test interval of each duty-cycle sequence, and after maintenance such as pre-filter changes.
350: CO <sub>2</sub> NDIR H <sub>2</sub> O interference	Upon initial installation and after major maintenance.
355: CO NDIR CO <sub>2</sub> and H <sub>2</sub> O interference	Upon initial installation, within 370 days before testing and after major maintenance.
360: FID calibration THC FID optimization, and THC FID verification.	Calibrate all FID analyzers: upon initial installation and after major maintenance. Optimize and determine CH <sub>4</sub> response for THC FID analyzers: upon initial installation and after major maintenance. Verify CH <sub>4</sub> response for THC FID analyzers: upon initial installation, within 185 days before testing, and after major maintenance.

## WLTP-DTP-01-02

362: Raw exhaust FID O <sub>2</sub> interference	For all FID analyzers: upon initial installation, and after major maintenance. For THC FID analyzers: upon initial installation, after major maintenance, and after FID optimization according to 360.
365: Nonmethane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
370: CLD CO <sub>2</sub> and H <sub>2</sub> O quench	Upon initial installation and after major maintenance.
372: NDUV HC and H <sub>2</sub> O interference	Upon initial installation and after major maintenance.
375: N <sub>2</sub> O analyzer interference	Upon initial installation and after major maintenance.
376: Chiller NO <sub>2</sub> penetration	Upon initial installation and after major maintenance.
378: NO <sub>2</sub> -to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
390: PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Zero, span, and reference sample verifications: within 12 hours of weighing, and after major maintenance.

<sup>a</sup>Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and accepted measurement practices.

<sup>b</sup>The CVS verification described in 341 is not required for systems that agree within  $\pm 2\%$  based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.

### 305 Verifications for accuracy, repeatability, and noise.

(a) This section describes how to determine the accuracy, repeatability, and noise of an instrument. Table 1 of 205 specifies recommended values for individual instruments.

(b) We do not require you to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

(c) In this section we use the letter “y” to denote a generic measured quantity, the superscript over-bar to denote an arithmetic mean (such as  $\bar{y}$ ), and the subscript “<sub>ref</sub>” to denote the reference quantity being measured.

(d) Conduct these verifications as follows:

(1) Prepare an instrument so it operates at its specified temperatures, pressures, and flows. Perform any instrument linearization or calibration procedures prescribed by the instrument manufacturer.

(2) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of 750.

(3) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of 750.

(4) Use the instrument to quantify a NIST-traceable reference quantity,  $y_{\text{ref}}$ . For gas analyzers the reference gas must meet the specifications of 750. Select a reference quantity near the mean value expected during testing. For all gas analyzers, use a quantity near the flow-weighted mean concentration expected at the standard. For noise verification, use the same zero gas from

paragraph (d)(2) of this section as the reference quantity. Use stabilization times equivalent to those used during regular testing.

(5) Sample and record values for 30 seconds (you may select a longer sampling period if the recording update frequency is less than 0.5 Hz), record the arithmetic mean,  $\bar{y}_i$  and record the standard deviation,  $\sigma_i$  of the recorded values. Refer to 602 for an example of calculating arithmetic mean and standard deviation.

(6) If the reference quantity is not absolutely constant, which might be the case with a reference flow, sample and record values of  $y_{refi}$  for 30 seconds and record the arithmetic mean of the values,  $\bar{y}_{ref}$ . Refer to §602 for an example of calculating arithmetic mean.

(7) Subtract the reference value,  $y_{ref}$  (or  $\bar{y}_{refi}$ ), from the arithmetic mean,  $\bar{y}_i$ . Record this value as the error,  $\varepsilon_i$ .

(8) Repeat the steps specified in paragraphs (d)(2) through (7) of this section until you have ten arithmetic means ( $\bar{y}_1, \bar{y}_2, \bar{y}_3, \dots, \bar{y}_{10}$ ), ten standard deviations, ( $\sigma_1, \sigma_2, \sigma_3, \dots, \sigma_{10}$ ), and ten errors ( $\varepsilon_1, \varepsilon_2, \varepsilon_3, \dots, \varepsilon_{10}$ ).

(9) Use the following values to quantify your measurements:

(i) Accuracy. Instrument accuracy is the absolute difference between the reference quantity,  $y_{ref}$  (or  $\bar{y}_{ref}$ ), and the arithmetic mean of the ten  $\bar{y}_i$  values,  $\bar{y}$ . Refer to the example of an accuracy calculation in 602.

(ii) Repeatability. Repeatability is two times the standard deviation of the ten errors (that is,  $\text{repeatability} = 2\sigma_\varepsilon$ ). Refer to the example of a standard-deviation calculation in 602.

(iii) Noise. Noise is two times the root-mean-square of the ten standard deviations (that is,  $\text{noise} = 2 \cdot \text{rms}_\sigma$ ) when the reference signal is a zero-quantity signal. Refer to the example of a root-mean-square calculation in 602.

### **307 Linearity verification.**

(a) Scope and frequency. Perform a linearity verification on each measurement system listed in Table 1 of this section at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations. Note that this linearity verification replaces requirements we previously referred to as “calibrations”. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification generally consists of introducing a series of at least 10 reference values to a measurement system. The measurement system quantifies each reference value. The measured values are then collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in Table 1 of this section.

(b) Performance requirements. If a measurement system does not meet the applicable linearity criteria in Table 1 of this section, correct the deficiency by re-calibrating, servicing, or replacing components as needed. Repeat the linearity verification after correcting the deficiency to ensure that the measurement system meets the linearity criteria. Before you may use a measurement system that does not meet linearity criteria, you must demonstrate to us that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards.

## WLTP-DTP-01-02

(c) Procedure. Use the following linearity verification protocol, or use accepted measurement practices to develop a different protocol that satisfies the intent of this section, as described in paragraph (a) of this section:

(1) In this paragraph (c), we use the letter “y” to denote a generic measured quantity, the superscript over-bar to denote an arithmetic mean (such as  $\bar{y}$ ), and the subscript “<sub>ref</sub>” to denote the known or reference quantity being measured.

(2) Precede the linearity verification with any adjustment or periodic calibration of the measurement system as required. Operate a measurement system at its specified temperatures, pressures, and flows.

(3) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of 750 and introduce it directly at the analyzer port.

(4) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of 750 and introduce it directly at the analyzer port.

(5) After spanning the instrument, check zero with the same signal you used in paragraph (c)(3) of this section. Based on the zero reading, determine whether or not to rezero and or re-span the instrument before proceeding to the next step.

(6) For all measured quantities, use instrument manufacturer recommendations and accepted measurement practices to select reference values,  $y_{refi}$ , that cover a range of values that encompasses the maximum values expected during emission testing. We recommend selecting a zero reference signal as one of the reference values of the linearity verification. For pressure, temperature, dewpoint, and GC-ECD linearity verifications, we recommend at least three reference values. For all other linearity verifications select at least ten reference values.

(7) Use instrument manufacturer recommendations and accepted measurement practices to select the order in which you will introduce the series of reference values. For example you may select the reference values randomly to avoid correlation with previous measurements, you may select reference values in ascending or descending order to avoid long settling times of reference signals, or as another example you may select values to ascend and then descend which might incorporate the effects of any instrument hysteresis into the linearity verification.

(8) Generate reference quantities as described in paragraph (d) of this section. For gas analyzers, use gas concentrations known to be within the specifications of 750 and introduce them directly at the analyzer port.

(9) Introduce a reference signal to the measurement instrument.

(10) Allow time for the instrument to stabilize while it measures the reference value. Stabilization time may include time to purge an instrument and time to account for its response.

(11) At a recording frequency of at least  $f$  Hz, specified in Table 1 of 205, measure the reference value for 30 seconds (you may select a longer sampling period if the recording update frequency is less than 0.5 Hz) and record the arithmetic mean of the recorded values,  $\bar{y}_i$ . Refer to §602 for an example of calculating an arithmetic mean.

(12) Repeat steps in paragraphs (c)(9) through (11) of this section until all reference quantities are measured.

(13) Use the arithmetic means,  $\bar{y}_i$ , and reference values,  $y_{\text{refi}}$ , to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table 1 of this section. Use the calculations described in 602. Using accepted measurement practices, you may weight the results of individual data pairs (i.e.  $(y_{\text{refi}}, \bar{y}_i)$ ), in the linear regression calculations.

(d) Reference signals. This paragraph (d) describes recommended methods for generating reference values for the linearity-verification protocol in paragraph (c) of this section. Use reference values that simulate actual values, or introduce an actual value and measure it with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems must be NIST-traceable. We recommend using calibration reference quantities that are NIST-traceable within 0.5 % uncertainty, if not specified otherwise in other sections of this part. Use the following recommended methods to generate reference values or use accepted measurement practices to select a different reference:

(1) Dynamometer. (a) Load cell calibration weight sets shall be certified traceable to international standards authority recognized as equivalent to NIST. Individual weights shall have an uncertainty of less than 0.05% of their labeled value. Individual weights shall weigh not more than 50 pounds, shall be corrosion resistant, and shall be permanently stamped with a unique serial number. Any other device whose physical attributes affect the forces applied to the load cell shall also be permanently marked with a unique device number. No physical alteration of any certified weight or device shall be made subsequent to certification.

(b) The dynamometer shall use an independent method or auxiliary piece of equipment for verifying the accuracy and precision of the speed measurement process, displays on each dynamometer, and both rolls as a synchronous pair. This method shall be useable during all steady speeds and accelerations. For example, a process that acquires speed data from a frequency standard at constant or varied rates that is independent of the encoder.

(c) The dynamometer shall use an independent international standards authority traceable method or auxiliary piece of equipment to verify that the mechanical roll speed matches the dynamometer displayed speed (i.e. photo-tachometer with reflective tape, etc.).

(2) Flow rates—dilution air, diluted exhaust, raw exhaust, or sample flow. Use a reference flow meter with a means of generating flows of the nature encountered during normal testing. Use the reference meter's response as the reference values.

(i) Reference flow meters. Because the flow range requirements for these various flows are large, we allow a variety of reference meters. For example, for diluted exhaust flow for a full-flow dilution system, we recommend a reference subsonic venturi flow meter with a restrictor valve and a blower to simulate flow rates. For inlet air, dilution air, diluted exhaust for partial-flow dilution, raw exhaust, or sample flow, we allow reference meters such as critical flow orifices, critical flow venturis, laminar flow elements, master mass flow standards, or Roots meters. Make sure the reference meter has been calibrated by a qualified calibration laboratory and its calibration is NIST-traceable. If you use the difference of two flow measurements to

## WLTP-DTP-01-02

determine a net flow rate, you may calibrate and use one of the measurements as a reference for the other.

(ii) Reference flow values. Sample and record reference values of  $\dot{n}_{\text{ref}}$  for 30 seconds and use the arithmetic mean of the values,  $\bar{\dot{n}}_{\text{ref}}$ , as the reference value. Refer to 602 for an example of calculating arithmetic mean.

(3) Gas division. Use one of the two reference signals:

(i) At the outlet of the gas-division system, connect a gas analyzer that meets the linearity verification described in this section that has not been linearized with the gas divider being verified. For example, verify the linearity of an analyzer using a series of reference analytical gases directly from compressed gas cylinders that meet the specifications of 750. We recommend using a FID analyzer or a PMD or MPD O<sub>2</sub> analyzer because of their inherent linearity. Operate this analyzer consistent with how you would operate it during an emission test. Connect a span gas to the gas-divider inlet. Use the gas-division system to divide the span gas with purified air or nitrogen. Select gas divisions that you typically use. Use a selected gas division as the measured value. Use the analyzer response divided by the span gas concentration as the reference gas-division value. Sample and record reference values of  $x_{\text{ref}}$  for 30 seconds and use the arithmetic mean of the values,  $\bar{x}_{\text{ref}}$ , as the reference value. Refer to 602 for an example of calculating arithmetic mean.

(ii) Using accepted measurement practices and gas divider manufacturer recommendations, use one or more reference flow meters to measure the flow rates of the gas divider and verify the gas-division value.

(4) Continuous constituent concentration. For reference values, use a series of gas cylinders of known gas concentration or use a gas-division system that is known to be linear with a span gas. Gas cylinders, gas-division systems, and span gases that you use for reference values must meet the specifications of 750.

(5) Temperature. You may perform the linearity verification for temperature measurement systems with thermocouples, RTDs, and thermistors by removing the sensor from the system and using a simulator in its place. Use a NIST-traceable simulator that is independently calibrated and, as appropriate, cold-junction compensated. The simulator uncertainty scaled to temperature must be less than 0.5 % of  $T_{\text{max}}$ . If you use this option, you must use sensors that the supplier states are accurate to better than 0.5 % of  $T_{\text{max}}$  compared with their standard calibration curve.

(e) Measurement systems that require linearity verification. Table 1 of this section indicates measurement systems that require linearity verifications, subject to the following provisions:

(1) Perform a linearity verification more frequently based on the instrument manufacturer's recommendation or accepted measurement practice.

(2) The expression " $x_{\text{min}}$ " refers to the reference value used during the linearity verification that is closest to zero. This is the value used to calculate the first tolerance in Table 1 of this section using the intercept,  $a_0$ . Note that this value may be zero, positive, or negative depending on the reference values. For example, if the reference values chosen to validate a pressure transducer vary from -10 to -1 kPa,  $x_{\text{min}}$  is -1 kPa. If the reference values used to validate a temperature device vary from 290 to 390 K,  $x_{\text{min}}$  is 290 K.

(3) The expression “max” generally refers to the absolute value of the reference value used during the linearity verification that is furthest from zero. This is the value used to scale the first and third tolerances in Table 1 of this section using  $a_0$  and  $SEE$ . For example, if the reference values chosen to validate a pressure transducer vary from -10 to -1 kPa, then  $p_{\max}$  is +10 kPa. If the reference values used to validate a temperature device vary from 290 to 390 K, then  $T_{\max}$  is 390 K. For gas dividers where “max” is expressed as,  $x_{\max}/x_{\text{span}}$ ;  $x_{\max}$  is the maximum gas concentration used during the verification,  $x_{\text{span}}$  is the undivided, undiluted, span gas concentration, and the resulting ratio is the maximum divider point reference value used during the verification (typically 1). The following are special cases where “max” refers to a different value:

(i) For linearity verification with a PM balance,  $m_{\max}$  refers to the typical mass of a PM filter.

(4) The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for  $a_1$  means  $0.98 \leq a_1 \leq 1.02$ .

(5) These linearity verifications are optional for systems that pass the flow-rate verification for diluted exhaust as described in 341 (the propane check) or for systems that agree within  $\pm 2\%$  based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust.

(6) You must meet the  $a_1$  criteria for these quantities only if the absolute value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.

(7) Linearity checks are required for the following temperature measurements:

(i) The following temperature measurements always require linearity checks:

(A) Dilution air for PM sampling, including CVS, double-dilution, and partial-flow systems.

(B) PM sample, if applicable.

(C) Chiller sample, for gaseous sampling systems that use thermal chillers to dry samples and use chiller temperature to calculate the dewpoint at the outlet of the chiller. For your testing, if you choose to use a high alarm temperature setpoint for the chiller temperature as a constant value in the amount of water calculations in 645, you may use accepted measurement practices to verify the accuracy of the high alarm temperature setpoint in lieu of the linearity verification on the chiller temperature. We recommend that you input a reference simulated temperature signal below the alarm trip point, increase this signal until the high alarm trips, and verify that the alarm trip point value is no less than 2.0 °C below the reference value at the trip point.

(8) Linearity checks are required for the following pressure measurements:

(i) The following pressure measurements always require linearity checks:

(A) Barometer.

(B) CVS inlet gage pressure.

(C) Pressure gauges used for determining flow.

(D) Sample dryer, for gaseous sampling systems that use either osmotic-membrane or thermal chillers to dry samples. For your testing, if you choose to use a low alarm pressure setpoint for the sample dryer pressure as a constant value in the amount of water calculations in 645, you may use accepted measurement practices to verify the accuracy of the low alarm pressure setpoint in lieu of the linearity verification on the sample dryer pressure. We recommend that you input a reference pressure signal above the alarm trip point, decrease this signal until the low alarm trips, and verify that the trip point value is no more than 4.0 kPa above the reference value at the trip point.

## WLTP-DTP-01-02

Table 1 of §307—Measurement systems that require linearity verifications

Measurement system	Quantity	Minimum verification frequency	Linearity criteria			
			$ x_{\min}(a_1-1)+a_0 $	$a_1$	$SEE$	$r^2$
Dynamometer	$f_n$	Within 370 days before testing	$\leq 0.05\% \cdot f_{n\max}$	0.98-1.02	$\leq 2\% \cdot f_{n\max}$	$\geq 0.990$
Dilution air flow rate	$\dot{n}$	Within 370 days before testing	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	$\geq 0.990$
Diluted exhaust flow rate	$\dot{n}$	Within 370 days before testing	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	$\geq 0.990$
Raw exhaust flow rate	$\dot{n}$	Within 185 days before testing	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	$\geq 0.990$
Batch sampler flow rates	$\dot{n}$	Within 370 days before testing	$\leq 1\% \cdot \dot{n}_{\max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{\max}$	$\geq 0.990$
Gas dividers	$x/x_{\text{span}}$	Within 370 days before testing	$\leq 0.5\% \cdot x_{\max}/x_{\text{span}}$	0.98-1.02	$\leq 2\% \cdot x_{\max}/x_{\text{span}}$	$\geq 0.990$
Gas analyzers for laboratory testing	$x$	Within 35 days before testing	$\leq 0.5\% \cdot x_{\max}$	0.99-1.01	$\leq 1\% \cdot x_{\max}$	$\geq 0.998$
Gas analyzers for field testing	$x$	Within 35 days before testing	$\leq 1\% \cdot x_{\max}$	0.99-1.01	$\leq 1\% \cdot x_{\max}$	$\geq 0.998$
PM balance	$m$	Within 370 days before testing	$\leq 1\% \cdot m_{\max}$	0.99-1.01	$\leq 1\% \cdot m_{\max}$	$\geq 0.998$
Pressures	$p$	Within 370 days before testing	$\leq 1\% \cdot p_{\max}$	0.99-1.01	$\leq 1\% \cdot p_{\max}$	$\geq 0.998$
Dewpoint for intake air, PM-stabilization and balance environments	$T_{\text{dew}}$	Within 370 days before testing	$\leq 0.5\% \cdot T_{\text{dewmax}}$	0.99-1.01	$\leq 0.5\% \cdot T_{\text{dewmax}}$	$\geq 0.998$
Other dewpoint measurements	$T_{\text{dew}}$	Within 370 days before testing	$\leq 1\% \cdot T_{\text{dewmax}}$	0.99-1.01	$\leq 1\% \cdot T_{\text{dewmax}}$	$\geq 0.998$
Analog-to-digital conversion of temperature signals	$T$	Within 370 days before testing	$\leq 1\% \cdot T_{\max}$	0.99-1.01	$\leq 1\% \cdot T_{\max}$	$\geq 0.998$

### 308 Continuous gas analyzer system-response and updating-recording verification—for gas analyzers not continuously compensated for other gas species.

(a) Scope and frequency. This section describes a verification procedure for system response and updating-recording frequency for continuous gas analyzers that output a gas species mole fraction (i.e., concentration) using a single gas detector, i.e., gas analyzers not continuously

compensated for other gas species measured with multiple gas detectors. See 309 for verification procedures that apply to continuous gas analyzers that are continuously compensated for other gas species measured with multiple gas detectors. Perform this verification to determine the system response of the continuous gas analyzer and its sampling system. This verification is required for continuous gas analyzers used for transient or ramped-modal testing. You need not perform this verification for batch gas analyzer systems or for continuous gas analyzer systems that are used only for discrete-mode testing. Perform this verification after initial installation (i.e., test cell commissioning) and after any modifications to the system that would change system response. For example, perform this verification if you add a significant volume to the transfer lines by increasing their length or adding a filter; or if you reduce the frequency at which the gas analyzer updates its output or the frequency at which you sample and record gas-analyzer concentrations.

(b) Measurement principles. This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyzers and their sampling systems must be optimized such that their overall response to a rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that the measurement system meets a minimum response time. You may use the results of this test to determine transformation time,  $t_{50}$ , for the purposes of time alignment of continuous data in accordance with 650(c)(2)(i). You may also use an alternate procedure to determine  $t_{50}$  in accordance with accepted measurement practices. Note that any such procedure for determining  $t_{50}$  must account for both transport delay and analyzer response time.

(c) System requirements. Demonstrate that each continuous analyzer has adequate update and recording frequencies and has a minimum rise time and a minimum fall time during a rapid change in gas concentration. You must meet one of the following criteria:

(1) The product of the mean rise time,  $t_{10-90}$ , and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time,  $t_{90-10}$ , and the frequency at which the system records an updated concentration must be at least 5. If the recording frequency is different than the analyzer's output update frequency, you must use the lower of these two frequencies for this verification, which is referred to as the updating-recording frequency. This verification applies to the nominal updating and recording frequencies. This criterion makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(2) The frequency at which the system records an updated concentration must be at least 5 Hz. This criterion assumes that the frequency content of significant changes in emission concentrations during emission testing do not exceed 1 Hz. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(3) You may use other criteria if we approve the criteria in advance.

(d) Procedure. Use the following procedure to verify the response of each continuous gas analyzer:

(1) Instrument setup. Follow the analyzer manufacturer's start-up and operating instructions. Adjust the measurement system as needed to optimize performance. Run this verification with

## WLTP-DTP-01-02

the analyzer operating in the same manner you will use for emission testing. If the analyzer shares its sampling system with other analyzers, and if gas flow to the other analyzers will affect the system response time, then start up and operate the other analyzers while running this verification test. You may run this verification test on multiple analyzers sharing the same sampling system at the same time. If you use any analog or real-time digital filters during emission testing, you must operate those filters in the same manner during this verification.

(2) Equipment setup. We recommend using minimal lengths of gas transfer lines between all connections and fast-acting three-way valves (2 inlets, 1 outlet) to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. Normally the gas flow rate is higher than the probe sample flow rate and the excess is overflowed out the inlet of the probe. If the gas flow rate is lower than the probe flow rate, the gas concentrations must be adjusted to account for the dilution from ambient air drawn into the probe. Select span gases for the species being measured. You may use binary or multi-gas span gases. You may use a gas blending or mixing device to blend span gases. A gas blending or mixing device is recommended when blending span gases diluted in N<sub>2</sub> with span gases diluted in air. You may use a multi-gas span gas, such as NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub>, to verify multiple analyzers at the same time. If you use standard binary span gases, you must run separate response tests for each analyzer. In designing your experimental setup, avoid pressure pulsations due to stopping the flow through the gas-blending device.

(3) Data collection. (i) Start the flow of zero gas.

(ii) Allow for stabilization, accounting for transport delays and the slowest analyzer's full response.

(iii) Start recording data. For this verification you must record data at a frequency greater than or equal to that of the updating-recording frequency used during emission testing. You may not use interpolation or filtering to alter the recorded values.

(iv) Switch the flow to allow the blended span gases to flow to the analyzer. If you intend to use the data from this test to determine  $t_{50}$  for time alignment, record this time as  $t_0$ .

(v) Allow for transport delays and the slowest analyzer's full response.

(vi) Switch the flow to allow zero gas to flow to the analyzer. If you intend to use the data from this test to determine  $t_{50}$  for time alignment, record this time as  $t_{100}$ .

(vii) Allow for transport delays and the slowest analyzer's full response.

(viii) Repeat the steps in paragraphs (d)(3)(iv) through (vii) of this section to record seven full cycles, ending with zero gas flowing to the analyzers.

(ix) Stop recording.

(e) Performance evaluation. (1) If you choose to demonstrate compliance with paragraph (c)(1) of this section, use the data from paragraph (d)(3) of this section to calculate the mean rise time,  $t_{10-90}$ , and mean fall time,  $t_{90-10}$ , for each of the analyzers being verified. You may use interpolation between recorded values to determine rise and fall times. If the recording frequency used during emission testing is different from the analyzer's output update frequency, you must use the lower of these two frequencies for this verification. Multiply these times (in seconds) by their respective updating-recording frequencies in Hertz (1/second). The resulting product must be at least 5 for both rise time and fall time. If either value is less than 5, increase the updating-recording frequency, or adjust the flows or design of the sampling system to

increase the rise time and fall time as needed. You may also configure analog or digital filters before recording to increase rise and fall times. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(2) If a measurement system fails the criterion in paragraph (e)(1) of this section, ensure that signals from the system are updated and recorded at a frequency of at least 5 Hz. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(3) If a measurement system fails the criteria in paragraphs (e)(1) and (2) of this section, you may use the measurement system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

(f) Transformation time,  $t_{50}$ , determination. If you choose to determine  $t_{50}$  for purposes of time alignment using data generated in paragraph (d)(3) of this section, calculate the mean  $t_{0-50}$  and the mean  $t_{100-50}$  from the recorded data. Average these two values to determine the final  $t_{50}$  for the purposes of time alignment in accordance with 650(c)(2)(i).

### **309 Continuous gas analyzer system-response and updating-recording verification—for gas analyzers continuously compensated for other gas species.**

(a) Scope and frequency. This section describes a verification procedure for system response and updating-recording frequency for continuous gas analyzers that output a single gas species mole fraction (i.e., concentration) based on a continuous combination of multiple gas species measured with multiple detectors (i.e., gas analyzers continuously compensated for other gas species). See 308 for verification procedures that apply to continuous gas analyzers that are not continuously compensated for other gas species or that use only one detector for gaseous species. Perform this verification to determine the system response of the continuous gas analyzer and its sampling system. This verification is required for continuous gas analyzers used for transient or ramped-modal testing. You need not perform this verification for batch gas analyzers or for continuous gas analyzers that are used only for discrete-mode testing. For this check we consider water vapor a gaseous constituent. This verification does not apply to any processing of individual analyzer signals that are time aligned to their  $t_{50}$  times and were verified according to §308. For example, this verification does not apply to correction for water removed from the sample done in post-processing according to 659 and it does not apply to NMHC determination from THC and CH<sub>4</sub> according to 660. Perform this verification after initial installation (i.e., test cell commissioning) and after any modifications to the system that would change the system response.

(b) Measurement principles. This procedure verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. It indirectly verifies the time-alignment and uniform response of all the continuous gas detectors used to generate a continuously combined/compensated concentration measurement signal. Gas analyzer systems must be optimized such that their overall response to rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that the measurement system meets a minimum response time. For this procedure, ensure that all compensation algorithms and humidity corrections are turned on. You may use the results of this test to determine transformation time,  $t_{50}$ , for the purposes of time alignment of continuous data in accordance with 650(c)(2)(i). You may also use an alternate procedure to determine  $t_{50}$  consistent with accepted measurement practices.

## WLTP-DTP-01-02

Note that any such procedure for determining  $t_{50}$  must account for both transport delay and analyzer response time.

(c) System requirements. Demonstrate that each continuously combined/compensated concentration measurement has adequate updating and recording frequencies and has a minimum rise time and a minimum fall time during a system response to a rapid change in multiple gas concentrations, including H<sub>2</sub>O concentration if H<sub>2</sub>O compensation is applied. You must meet one of the following criteria:

(1) The product of the mean rise time,  $t_{10-90}$ , and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time,  $t_{90-10}$ , and the frequency at which the system records an updated concentration must be at least 5. If the recording frequency is different than the update frequency of the continuously combined/compensated signal, you must use the lower of these two frequencies for this verification. This criterion makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(2) The frequency at which the system records an updated concentration must be at least 5 Hz. This criterion assumes that the frequency content of significant changes in emission concentrations during emission testing do not exceed 1 Hz. Also, the mean rise time must be at or below 10 seconds and the mean fall time must be at or below 10 seconds.

(3) You may use other criteria if we approve them in advance.

(d) Procedure. Use the following procedure to verify the response of each continuously compensated analyzer (verify the combined signal, not each individual continuously combined concentration signal):

(1) Instrument setup. Follow the analyzer manufacturer's start-up and operating instructions. Adjust the measurement system as needed to optimize performance. Run this verification with the analyzer operating in the same manner you will use for emission testing. If the analyzer shares its sampling system with other analyzers, and if gas flow to the other analyzers will affect the system response time, then start up and operate the other analyzers while running this verification test. You may run this verification test on multiple analyzers sharing the same sampling system at the same time. If you use any analog or real-time digital filters during emission testing, you must operate those filters in the same manner during this verification.

(2) Equipment setup. We recommend using minimal lengths of gas transfer lines between all connections and fast-acting three-way valves (2 inlets, 1 outlet) to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. Normally the gas flow rate is higher than the probe sample flow rate and the excess is overflowed out the inlet of the probe. If the gas flow rate is lower than the probe flow rate, the gas concentrations must be adjusted to account for the dilution from ambient air drawn into the probe. Select span gases for the species being continuously combined, other than H<sub>2</sub>O. Select concentrations of compensating species that will yield concentrations of these species at the analyzer inlet that covers the range of concentrations expected during testing. You may use binary or multi-gas span gases. You may use a gas blending or mixing device to blend span gases. A gas blending or mixing device is recommended when blending span gases diluted in N<sub>2</sub>

with span gases diluted in air. You may use a multi-gas span gas, such as NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub>, to verify multiple analyzers at the same time. In designing your experimental setup, avoid pressure pulsations due to stopping the flow through the gas blending device. If H<sub>2</sub>O correction is applicable, then span gases must be humidified before entering the analyzer; however, you may not humidify NO<sub>2</sub> span gas by passing it through a sealed humidification vessel that contains water. You must humidify NO<sub>2</sub> span gas with another moist gas stream. We recommend humidifying your NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub>, balance N<sub>2</sub> blended gas by flowing the gas mixture through a sealed vessel that humidifies the gas by bubbling it through distilled water and then mixing the gas with dry NO<sub>2</sub> gas, balance purified synthetic air. If your system does not use a sample dryer to remove water from the sample gas, you must humidify your span gas to the highest sample H<sub>2</sub>O content that you estimate during emission sampling. If your system uses a sample dryer during testing, it must pass the sample dryer verification check in 342, and you must humidify your span gas to an H<sub>2</sub>O content greater than or equal to the level determined in 145(e)(2). If you are humidifying span gases without NO<sub>2</sub>, use accepted measurement practices to ensure that the wall temperatures in the transfer lines, fittings, and valves from the humidifying system to the probe are above the dewpoint required for the target H<sub>2</sub>O content. If you are humidifying span gases with NO<sub>2</sub>, use accepted measurement practices to ensure that there is no condensation in the transfer lines, fittings, or valves from the point where humidified gas is mixed with NO<sub>2</sub> span gas to the probe. We recommend that you design your setup so that the wall temperatures in the transfer lines, fittings, and valves from the humidifying system to the probe are at least 5 °C above the local sample gas dewpoint. Operate the measurement and sample handling system as you do for emission testing. Make no modifications to the sample handling system to reduce the risk of condensation. Flow humidified gas through the sampling system before this check to allow stabilization of the measurement system's sampling handling system to occur, as it would for an emission test.

(3) Data collection. (i) Start the flow of zero gas.

(ii) Allow for stabilization, accounting for transport delays and the slowest analyzer's full response.

(iii) Start recording data. For this verification you must record data at a frequency greater than or equal to that of the updating-recording frequency used during emission testing. You may not use interpolation or filtering to alter the recorded values.

(iv) Switch the flow to allow the blended span gases to flow to the analyzer. If you intend to use the data from this test to determine  $t_{50}$  for time alignment, record this time as  $t_0$ .

(v) Allow for transport delays and the slowest analyzer's full response.

(vi) Switch the flow to allow zero gas to flow to the analyzer. If you intend to use the data from this test to determine  $t_{50}$  for time alignment, record this time as  $t_{100}$ .

(vii) Allow for transport delays and the slowest analyzer's full response.

(viii) Repeat the steps in paragraphs (d)(3)(iv) through (vii) of this section to record seven full cycles, ending with zero gas flowing to the analyzers.

(ix) Stop recording.

(e) Performance evaluations. (1) If you choose to demonstrate compliance with paragraph (c)(1) of this section, use the data from paragraph (d)(3) of this section to calculate the mean rise time,  $t_{10-90}$ , and mean fall time,  $t_{90-10}$ , for the continuously combined signal from each analyzer being verified. You may use interpolation between recorded values to determine rise and fall times. If

## WLTP-DTP-01-02

the recording frequency used during emission testing is different from the analyzer's output update frequency, you must use the lower of these two frequencies for this verification. Multiply these times (in seconds) by their respective updating-recording frequencies in Hz (1/second). The resulting product must be at least 5 for both rise time and fall time. If either value is less than 5, increase the updating-recording frequency or adjust the flows or design of the sampling system to increase the rise time and fall time as needed. You may also configure analog or digital filters before recording to increase rise and fall times. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(2) If a measurement system fails the criterion in paragraph (e)(1) of this section, ensure that signals from the system are updated and recorded at a frequency of at least 5 Hz. In no case may the mean rise time or mean fall time be greater than 10 seconds.

(3) If a measurement system fails the criteria in paragraphs (e)(1) and (2) of this section, you may use the measurement system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

(f) Transformation time,  $t_{50}$ , determination. If you choose to determine  $t_{50}$  for purposes of time alignment using data generated in paragraph (d)(3) of this section, calculate the mean  $t_{0-50}$  and the mean  $t_{100-50}$  from the recorded data. Average these two values to determine the final  $t_{50}$  for the purposes of time alignment in accordance with 650(c)(2)(i).

## 310 Dynamometer

### 315 Pressure, temperature, and dewpoint calibration.

(a) Calibrate instruments for measuring pressure, temperature, and dewpoint upon initial installation. Follow the instrument manufacturer's instructions and use accepted measurement practices to repeat the calibration, as follows:

(1) Pressure. We recommend temperature-compensated, digital-pneumatic, or deadweight pressure calibrators, with data-logging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within 0.5 % uncertainty.

(2) Temperature. We recommend digital dry-block or stirred-liquid temperature calibrators, with data logging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within 0.5 % uncertainty. You may perform the linearity verification for temperature measurement systems with thermocouples, RTDs, and thermistors by removing the sensor from the system and using a simulator in its place. Use a NIST-traceable simulator that is independently calibrated and, as appropriate, cold-junction compensated. The simulator uncertainty scaled to temperature must be less than 0.5 % of  $T_{\max}$ . If you use this option, you must use sensors that the supplier states are accurate to better than 0.5 % of  $T_{\max}$  compared with their standard calibration curve.

(3) Dewpoint. We recommend a minimum of three different temperature-equilibrated and temperature-monitored calibration salt solutions in containers that seal completely around the dewpoint sensor. We recommend using calibration reference quantities that are NIST-traceable within 0.5 % uncertainty.

(b) You may remove system components for off-site calibration. We recommend specifying calibration reference quantities that are NIST-traceable within 0.5 % uncertainty.

## FLOW-RELATED MEASUREMENTS

### **§330 Exhaust-flow calibration.**

(a) Calibrate exhaust-flow meters upon initial installation. Follow the instrument manufacturer's instructions and use accepted measurement practices to repeat the calibration. We recommend that you use a calibration subsonic venturi or ultrasonic flow meter and simulate exhaust temperatures by incorporating a heat exchanger between the calibration meter and the exhaust-flow meter. If you can demonstrate that the flow meter to be calibrated is insensitive to exhaust temperatures, you may use other reference meters such as laminar flow elements, which are not commonly designed to withstand typical raw exhaust temperatures. We recommend using calibration reference quantities that are NIST-traceable within 0.5 % uncertainty.

(b) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within 0.5 % uncertainty.

(c) If you use a subsonic venturi or ultrasonic flow meter for raw exhaust flow measurement, we recommend that you calibrate it as described in 340.

### **340 Diluted exhaust flow (CVS) calibration.**

(a) Overview. This section describes how to calibrate flow meters for diluted exhaust constant-volume sampling (CVS) systems. Calibrate CVS temperature and pressure instruments, as described in 315 before performing the flow calibration in this section.

(b) Scope and frequency. Perform this calibration while the flow meter is installed in its permanent position. Perform this calibration after you change any part of the flow configuration upstream or downstream of the flow meter that may affect the flow-meter calibration. Perform this calibration upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (i.e., propane check) in 341.

(c) Reference flow meter. 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  $\pm 1$  % uncertainty. Use this reference flow meter's response to flow as the reference value for CVS flow-meter calibration.

(d) Configuration. Do not use an upstream screen or other restriction that could affect the flow ahead of the reference flow meter, unless the flow meter has been calibrated with such a restriction.

(e) PDP calibration. Calibrate a positive-displacement pump (PDP) to determine a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Determine unique equation coefficients for each speed at which you operate the PDP. Calibrate a PDP flow meter as follows:

(1) Connect the system as shown in Figure 1 of this section.

## WLTP-DTP-01-02

- (2) Leaks between the calibration flow meter and the PDP must be less than 0.3 % of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point.
- (3) While the PDP operates, maintain a constant temperature at the PDP inlet within  $\pm 2$  % of the mean absolute inlet temperature,  $\bar{T}_{in}$ .
- (4) Set the PDP speed to the first speed point at which you intend to calibrate.
- (5) Set the variable restrictor to its wide-open position.
- (6) Operate the PDP for at least 3 min to stabilize the system. Continue operating the PDP and record the mean values of at least 30 seconds of sampled data of each of the following quantities:
  - (i) The mean flow rate of the reference flow meter,  $\bar{n}_{ref}$ . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating  $\bar{n}_{ref}$ .
  - (ii) The mean temperature at the PDP inlet,  $\bar{T}_{in}$ .
  - (iii) The mean static absolute pressure at the PDP inlet,  $\bar{p}_{in}$ .
  - (iv) The mean static absolute pressure at the PDP outlet,  $\bar{p}_{out}$ .
  - (v) The mean PDP speed,  $\bar{f}_{nPDP}$ .
- (7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the PDP,  $p_{in}$ .
- (8) Repeat the steps in paragraphs (e)(6) and (7) of this section to record data at a minimum of six restrictor positions reflecting the full range of possible in-use pressures at the PDP inlet.
- (9) Calibrate the PDP by using the collected data and the equations in 640.
- (10) Repeat the steps in paragraphs (e)(6) through (9) of this section for each speed at which you operate the PDP.
- (11) Use the equations in §642 to determine the PDP flow equation for emission testing.
- (12) Verify the calibration by performing a CVS verification (i.e., propane check) as described in §341.
- (13) Do not use the PDP below the lowest inlet pressure tested during calibration.
- (f) CFV calibration. Calibrate a critical-flow venturi (CFV) to verify its discharge coefficient,  $C_d$ , at the lowest expected static differential pressure between the CFV inlet and outlet. Calibrate a CFV flow meter as follows:
  - (1) Connect the system as shown in Figure 1 of this section.
  - (2) Start the blower downstream of the CFV.
  - (3) While the CFV operates, maintain a constant temperature at the CFV inlet within  $\pm 2$  % of the mean absolute inlet temperature,  $\bar{T}_{in}$ .
  - (4) Leaks between the calibration flow meter and the CFV must be less than 0.3 % of the total flow at the highest restriction.
  - (5) Set the variable restrictor to its wide-open position. Instead of a variable restrictor, you may alternately vary the pressure downstream of the CFV by varying blower speed or by introducing a controlled leak, but you must maintain choked flow conditions. Note that some blowers have limitations on nonloaded conditions.

- (6) Operate the CFV for at least 3 min 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:
- (i) The mean flow rate of the reference flow meter,  $\bar{n}_{\text{ref}}$ . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating  $\bar{n}_{\text{ref}}$ .
  - (ii) The mean dewpoint of the calibration air,  $\bar{T}_{\text{dew}}$ . See 640 for permissible assumptions during emission measurements.
  - (iii) The mean temperature at the venturi inlet,  $\bar{T}_{\text{in}}$ .
  - (iv) The mean static absolute pressure at the venturi inlet  $\bar{p}_{\text{in}}$ .
  - (v) The mean static differential pressure between the CFV inlet and the CFV outlet,  $\Delta\bar{p}_{\text{CFV}}$ .
- (7) Incrementally close the restrictor valve or decrease the downstream pressure to decrease the differential pressure across the CFV,  $\Delta\bar{p}_{\text{CFV}}$ .
- (8) Repeat the steps in paragraphs (f)(6) and (7) of this section to record mean data at a minimum of ten restrictor positions, such that you test the fullest practical range of  $\Delta\bar{p}_{\text{CFV}}$  expected during testing. We do not require that you remove calibration components or CVS components to calibrate at the lowest possible restrictions.
- (9) Determine  $C_d$  and the lowest allowable pressure ratio,  $r$ , according to 640.
- (10) Use  $C_d$  to determine CFV flow during an emission test. Do not use the CFV below the lowest allowed  $r$ , as determined in 640.
- (11) Verify the calibration by performing a CVS verification (i.e., propane check) as described in §341.
- (12) If your CVS is configured to operate more than one CFV at a time in parallel, calibrate your CVS by one of the following:
- (i) Calibrate every combination of CFVs according to this section and 640. Refer to 642 for instructions on calculating flow rates for this option.
  - (ii) Calibrate each CFV according to this section and 640. Refer to 642 for instructions on calculating flow rates for this option.
- (g) SSV calibration. Calibrate a subsonic venturi (SSV) to determine its calibration coefficient,  $C_d$ , for the expected range of inlet pressures. Calibrate an SSV flow meter as follows:
- (1) Connect the system as shown in Figure 1 of this section.
  - (2) Start the blower downstream of the SSV.
  - (3) Leaks between the calibration flow meter and the SSV must be less than 0.3 % of the total flow at the highest restriction.
  - (4) While the SSV operates, maintain a constant temperature at the SSV inlet within  $\pm 2$  % of the mean absolute inlet temperature,  $\bar{T}_{\text{in}}$ .
  - (5) Set the variable restrictor or variable-speed blower to a flow rate greater than the greatest flow rate expected during testing. You may not extrapolate flow rates beyond calibrated values, so we recommend that you make sure the Reynolds number,  $Re^\#$ , at the SSV throat at the greatest calibrated flow rate is greater than the maximum  $Re^\#$  expected during testing.

## WLTP-DTP-01-02

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

(i) The mean flow rate of the reference flow meter  $\bar{n}_{\text{ref}}$ . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating  $\bar{n}_{\text{ref}}$ .

(ii) Optionally, the mean dewpoint of the calibration air,  $\bar{T}_{\text{dew}}$ . See 640 for permissible assumptions.

(iii) The mean temperature at the venturi inlet,  $\bar{T}_{\text{dew}}$ .

(iv) The mean static absolute pressure at the venturi inlet,  $\bar{p}_{\text{in}}$ .

(v) Static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat,  $\Delta\bar{p}_{\text{SSV}}$ .

(7) Incrementally close the restrictor valve or decrease the blower speed to decrease the flow rate.

(8) Repeat the steps in paragraphs (g)(6) and (7) of this section to record data at a minimum of ten flow rates.

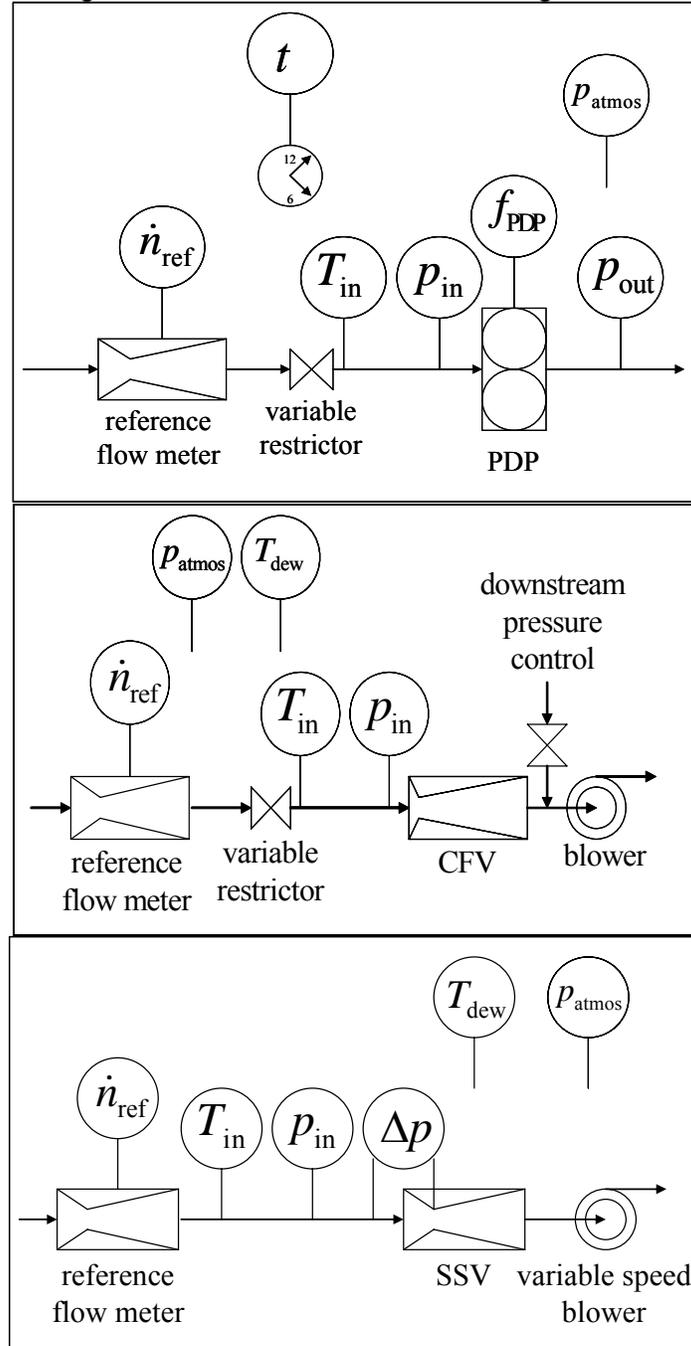
(9) Determine a functional form of  $C_d$  versus  $Re^{\#}$  by using the collected data and the equations in §640.

(10) Verify the calibration by performing a CVS verification (i.e., propane check) as described in §341 using the new  $C_d$  versus  $Re^{\#}$  equation.

(11) Use the SSV only between the minimum and maximum calibrated flow rates.

(12) Use the equations in 642 to determine SSV flow during a test.

Figure 1 of 340 CVS calibration configurations.



### 341 CVS and batch sampler verification (propane check).

(a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in paragraph (g) of this section. Using accepted measurement practices and safe practices, this check may be performed using a gas other than propane, such as

## WLTP-DTP-01-02

CO<sub>2</sub> or CO. A failed propane check might indicate one or more problems that may require corrective action, as follows:

- (1) Incorrect analyzer calibration. Re-calibrate, repair, or replace the FID analyzer.
- (2) Leaks. Inspect CVS tunnel, connections, fasteners, and HC sampling system, and repair or replace components.
- (3) Poor mixing. Perform the verification as described in this section while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyzer response indicates any deviation exceeding  $\pm 2$  % of the mean measured concentration, consider operating the CVS at a higher flow rate or installing a mixing plate or orifice to improve mixing.
- (4) Hydrocarbon contamination in the sample system. Perform the hydrocarbon-contamination verification as described in 520.
- (5) Change in CVS calibration. Perform an in-situ calibration of the CVS flow meter as described in 340.
- (6) Other problems with the CVS or sampling verification hardware or software. Inspect the CVS system, CVS verification hardware, and software for discrepancies.
  - (b) A propane check uses either a reference mass or a reference flow rate of C<sub>3</sub>H<sub>8</sub> as a tracer gas in a CVS. Note that if you use a reference flow rate, account for any non-ideal gas behavior of C<sub>3</sub>H<sub>8</sub> in the reference flow meter. Refer to 640 and 642, which describe how to calibrate and use certain flow meters. Do not use any ideal gas assumptions in 640 and 642. The propane check compares the calculated mass of injected C<sub>3</sub>H<sub>8</sub> using HC measurements and CVS flow rate measurements with the reference value.
  - (c) Prepare for the propane check as follows:
    - (1) If you use a reference mass of C<sub>3</sub>H<sub>8</sub> instead of a reference flow rate, obtain a cylinder charged with C<sub>3</sub>H<sub>8</sub>. Determine the reference cylinder's mass of C<sub>3</sub>H<sub>8</sub> within  $\pm 0.5$  % of the amount of C<sub>3</sub>H<sub>8</sub> that you expect to use.
    - (2) Select appropriate flow rates for the CVS and C<sub>3</sub>H<sub>8</sub>.
    - (3) Select a C<sub>3</sub>H<sub>8</sub> injection port in the CVS. Select the port location to be as close as practical to the location where you introduce vehicle exhaust into the CVS. Connect the C<sub>3</sub>H<sub>8</sub> cylinder to the injection system.
    - (4) Operate and stabilize the CVS.
    - (5) Preheat or pre-cool any heat exchangers in the sampling system.
    - (6) Allow heated and cooled components such as sample lines, filters, chillers, and pumps to stabilize at operating temperature.
    - (7) You may purge the HC sampling system during stabilization.
    - (8) If applicable, perform a vacuum side leak verification of the HC sampling system as described in 345.
    - (9) You may also conduct any other calibrations or verifications on equipment or analyzers.
  - (d) If you performed the vacuum-side leak verification of the HC sampling system as described in paragraph (c)(8) of this section, you may use the HC contamination procedure in 520(g) to verify HC contamination. Otherwise, zero, span, and verify contamination of the HC sampling system, as follows:
    - (1) Select the lowest HC analyzer range that can measure the C<sub>3</sub>H<sub>8</sub> concentration expected for the CVS and C<sub>3</sub>H<sub>8</sub> flow rates.

- (2) Zero the HC analyzer using zero air introduced at the analyzer port.
- (3) Span the HC analyzer using C<sub>3</sub>H<sub>8</sub> span gas introduced at the analyzer port.
- (4) Overflow zero air at the HC probe inlet or into a tee near the outlet of the probe.
- (5) Measure the stable HC concentration of the HC sampling system as overflow zero air flows. For batch HC measurement, fill the batch container (such as a bag) and measure the HC overflow concentration.
- (6) If the overflow HC concentration exceeds 2 μmol/mol, do not proceed until contamination is eliminated. Determine the source of the contamination and take corrective action, such as cleaning the system or replacing contaminated portions.
- (7) When the overflow HC concentration does not exceed 2 μmol/mol, record this value as  $x_{\text{THCinit}}$  and use it to correct for HC contamination as described in 660.
- (e) Perform the propane check as follows:
  - (1) For batch HC sampling, connect clean storage media, such as evacuated bags.
  - (2) Operate HC measurement instruments according to the instrument manufacturer's instructions.
  - (3) If you will correct for dilution air background concentrations of HC, measure and record background HC in the dilution air.
  - (4) Zero any integrating devices.
  - (5) Begin sampling, and start any flow integrators.
  - (6) Release the contents of the C<sub>3</sub>H<sub>8</sub> reference cylinder at the rate you selected. If you use a reference flow rate of C<sub>3</sub>H<sub>8</sub>, start integrating this flow rate.
  - (7) Continue to release the cylinder's contents until at least enough C<sub>3</sub>H<sub>8</sub> has been released to ensure accurate quantification of the reference C<sub>3</sub>H<sub>8</sub> and the measured C<sub>3</sub>H<sub>8</sub>.
  - (8) Shut off the C<sub>3</sub>H<sub>8</sub> reference cylinder and continue sampling until you have accounted for time delays due to sample transport and analyzer response.
  - (9) Stop sampling and stop any integrators.
- (f) Perform post-test procedure as follows:
  - (1) If you used batch sampling, analyze batch samples as soon as practical.
  - (2) After analyzing HC, correct for contamination and background.
  - (3) Calculate total C<sub>3</sub>H<sub>8</sub> mass based on your CVS and HC data as described in 650 and 660, using the molar mass of C<sub>3</sub>H<sub>8</sub>,  $M_{\text{C}_3\text{H}_8}$ , instead the effective molar mass of HC,  $M_{\text{HC}}$ .
  - (4) If you use a reference mass, determine the cylinder's propane mass within ±0.5 % and determine the C<sub>3</sub>H<sub>8</sub> reference mass by subtracting the empty cylinder propane mass from the full cylinder propane mass.
  - (5) Subtract the reference C<sub>3</sub>H<sub>8</sub> mass from the calculated mass. If this difference is within ±2.0 % of the reference mass, the CVS passes this verification. If not, take corrective action as described in paragraph (a) of this section.
- (g) You may repeat the propane check to verify a batch sampler, such as a PM secondary dilution system.
  - (1) Configure the HC sampling system to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, you may sample HC from the batch sampler pump's exhaust. Use caution when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flow meter will cause a false failure of the propane check.

## WLTP-DTP-01-02

- (2) Repeat the propane check described in this section, but sample HC from the batch sampler.
- (3) Calculate  $C_3H_8$  mass, taking into account any secondary dilution from the batch sampler.
- (4) Subtract the reference  $C_3H_8$  mass from the calculated mass. If this difference is within  $\pm 5\%$  of the reference mass, the batch sampler passes this verification. If not, take corrective action as described in paragraph (a) of this section.

### 342 Sample dryer verification.

- (a) Scope and frequency. If you use a sample dryer as allowed in 145(e)(2) to remove water from the sample gas, verify the performance upon installation, after major maintenance, for thermal chiller. For osmotic membrane dryers, verify the performance upon installation, after major maintenance, and within 35 days of testing.
- (b) Measurement principles. Water can inhibit an analyzer's ability to properly measure the exhaust component of interest and thus is sometimes removed before the sample gas reaches the analyzer. For example water can negatively interfere with a CLD's  $NO_x$  response through collisional quenching and can positively interfere with an NDIR analyzer by causing a response similar to CO.
- (c) System requirements. The sample dryer must meet the specifications as determined in 145(e)(2) for dewpoint,  $T_{dew}$ , and absolute pressure,  $p_{total}$ , downstream of the osmotic-membrane dryer or thermal chiller.
- (d) Sample dryer verification procedure. Use the following method to determine sample dryer performance. Run this verification with the dryer and associated sampling system operating in the same manner you will use for emission testing (including operation of sample pumps). You may run this verification test on multiple sample dryers sharing the same sampling system at the same time. You may run this verification on the sample dryer alone, but you must use the maximum gas flow rate expected during testing. You may use accepted measurement practices to develop a different protocol.
  - (1) Use PTFE or stainless steel tubing to make necessary connections.
  - (2) Humidify room air,  $N_2$ , or purified air by bubbling it through distilled water in a sealed vessel that humidifies the gas to the highest sample water content that you estimate during emission sampling.
  - (3) Introduce the humidified gas upstream of the sample dryer. You may disconnect the transfer line from the probe and introduce the humidified gas at the inlet of the transfer line of the sample system used during testing. You may use the sample pumps in the sample system to draw gas through the vessel.
  - (4) Maintain the sample lines, fittings, and valves from the location where the humidified gas water content is measured to the inlet of the sampling system at a temperature at least  $5\text{ }^\circ\text{C}$  above the local humidified gas dewpoint. For dryers used in  $NO_x$  sample systems, verify the sample system components used in this verification prevent aqueous condensation as required in 145(d)(1)(i). We recommend that the sample system components be maintained at least  $5\text{ }^\circ\text{C}$  above the local humidified gas dewpoint to prevent aqueous condensation.
  - (5) Measure the humidified gas dewpoint,  $T_{dew}$ , and absolute pressure,  $p_{total}$ , as close as possible to the inlet of the sample dryer or inlet of the sample system to verify the water content is at least as high as the highest value that you estimated during emission sampling. You may verify the

water content based on any humidity parameter (e.g. mole fraction water, local dewpoint, or absolute humidity).

(6) Measure the humidified gas dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , as close as possible to the outlet of the sample dryer. Note that the dewpoint changes with absolute pressure. If the dewpoint at the sample dryer outlet is measured at a different pressure, then this reading must be corrected to the dewpoint at the sample dryer absolute pressure,  $p_{\text{total}}$ .

(7) The sample dryer meets the verification if the dewpoint at the sample dryer pressure as measured in paragraph (d)(6) of this section is less than the dewpoint corresponding to the sample dryer specifications as determined in 145(e)(2) plus 2 °C or if the mole fraction of water as measured in (d)(6) is less than the corresponding sample dryer specifications plus 0.002 mol/mol.

(e) Alternate sample dryer verification procedure. The following method may be used in place of the sample dryer verification procedure in (d) of this section. If you use a humidity sensor for continuous monitoring of dewpoint at the sample dryer outlet you may skip the performance check in 342(d), but you must make sure that the dryer outlet humidity is at or below the minimum value used for quench, interference, and compensation checks.

### **345 Vacuum-side leak verification.**

(a) Scope and frequency. Verify that there are no significant vacuum-side leaks using one of the leak tests described in this section. For laboratory testing, perform the vacuum-side leak verification upon initial sampling system installation, within 12 hours before the start of the first interval of each test sequence, and after maintenance such as pre-filter changes. This verification does not apply to any full-flow portion of a CVS dilution system.

(b) Measurement principles. A leak may be detected either by measuring a small amount of flow when there should be zero flow, or by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system.

(c) Low-flow leak test. Test a sampling system for low-flow leaks as follows:

(1) Seal the probe end of the system by taking one of the following steps:

(i) Cap or plug the end of the sample probe.

(ii) Disconnect the transfer line at the probe and cap or plug the transfer line.

(iii) Close a leak-tight valve located in the sample transfer line within 92 cm of the probe.

(2) Operate all vacuum pumps. After stabilizing, verify that the flow through the vacuum-side of the sampling system is less than 0.5 % of the system's normal in-use flow rate. You may estimate typical analyzer and bypass flows as an approximation of the system's normal in-use flow rate.

(d) Dilution-of-span-gas leak test. You may use any gas analyzer for this test. If you use a FID for this test, correct for any HC contamination in the sampling system according to 660. To avoid misleading results from this test, we recommend using only analyzers that have a repeatability of 0.5% or better at the span gas concentration used for this test. Perform a vacuum-side leak test as follows:

(1) Prepare a gas analyzer as you would for emission testing.

(2) Supply span gas to the analyzer port and verify that it measures the span gas concentration within its expected measurement accuracy and repeatability.

## WLTP-DTP-01-02

(3) Route overflow span gas to the inlet of the sample probe or at a tee fitting in the transfer line near the exit of the probe. You may use a valve upstream of the overflow fitting to prevent overflow of span gas out of the inlet of the probe, but you must then provide an overflow vent in the overflow supply line.

(4) Verify that the measured overflow span gas concentration is within  $\pm 0.5\%$  of the span gas concentration. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyzer itself. A measured value higher than expected does not indicate a leak.

(e) Vacuum-decay leak test. To perform this test you must apply a vacuum to the vacuum-side volume of your sampling system and then observe the leak rate of your system as a decay in the applied vacuum. To perform this test you must know the vacuum-side volume of your sampling system to within  $\pm 10\%$  of its true volume. For this test you must also use measurement instruments that meet the specifications of subpart C of this part and of this subpart D. Perform a vacuum-decay leak test as follows:

(1) Seal the probe end of the system as close to the probe opening as possible by taking one of the following steps:

(i) Cap or plug the end of the sample probe.

(ii) Disconnect the transfer line at the probe and cap or plug the transfer line.

(iii) Close a leak-tight valve located in the sample transfer line within 92 cm of the probe.

(2) Operate all vacuum pumps. Draw a vacuum that is representative of normal operating conditions. In the case of sample bags, we recommend that you repeat your normal sample bag pump-down procedure twice to minimize any trapped volumes.

(3) Turn off the sample pumps and seal the system. Measure and record the absolute pressure of the trapped gas and optionally the system absolute temperature. Wait long enough for any transients to settle and long enough for a leak at 0.5% to have caused a pressure change of at least 10 times the resolution of the pressure transducer, then again record the pressure and optionally temperature.

(4) Calculate the leak flow rate based on an assumed value of zero for pumped-down bag volumes and based on known values for the sample system volume, the initial and final pressures, optional temperatures, and elapsed time. Using the calculations specified in 644, verify that the vacuum-decay leak flow rate is less than 0.5 % of the system's normal in-use flow rate.

## CO AND CO<sub>2</sub> MEASUREMENTS

### **350 H<sub>2</sub>O interference verification for CO<sub>2</sub> NDIR analyzers.**

(a) Scope and frequency. If you measure CO<sub>2</sub> using an NDIR analyzer, verify the amount of H<sub>2</sub>O interference after initial analyzer installation and after major maintenance.

(b) Measurement principles. H<sub>2</sub>O can interfere with an NDIR analyzer's response to CO<sub>2</sub>. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) System requirements. A CO<sub>2</sub> NDIR analyzer must have an H<sub>2</sub>O interference that is within within  $(0.0 \pm 0.2)$  mmol/mol.

(d) Procedure. Perform the interference verification as follows:

(1) Start, operate, zero, and span the CO<sub>2</sub> NDIR analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of 342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.

(2) Create a humidified test gas by bubbling zero gas that meets the specifications in 750 through distilled water in a sealed vessel. If the sample is not passed through a dryer during emission testing, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the maximum expected during emission testing. If the sample is passed through a dryer during emission testing, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the level determined in 145(e)(2) for that dryer.

(3) Introduce the humidified test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the water mole fraction,  $x_{\text{H}_2\text{O}}$ , of the humidified test gas, as close as possible to the inlet of the analyzer. For example, measure dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , to calculate  $x_{\text{H}_2\text{O}}$ . Verify that the water content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the water content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the water content (e.g., dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use accepted measurement practices to estimate the water content. For example, you may use previous direct measurements of water content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{O}}$  is measured to the analyzer. We recommend that you design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where  $x_{\text{H}_2\text{O}}$  is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) While the analyzer measures the sample's concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of this data. The analyzer meets the interference verification if this value is within  $(0 \pm 0.2)$  mmol/mol.

(e) Exceptions. The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO<sub>2</sub> sampling system and your emission-calculation procedures, the H<sub>2</sub>O interference for your CO<sub>2</sub> NDIR analyzer always affects your brake-specific emission results within  $\pm 0.5$  % of each of the applicable standards.

(2) You may use a CO<sub>2</sub> NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that vehicles comply with all applicable emission standards.

## WLTP-DTP-01-02

### 355 H<sub>2</sub>O and CO<sub>2</sub> interference verification for CO NDIR analyzers.

(a) Scope and frequency. If you measure CO using an NDIR analyzer, verify the amount of H<sub>2</sub>O and CO<sub>2</sub> interference after initial analyzer installation and after major maintenance.

(b) Measurement principles. H<sub>2</sub>O and CO<sub>2</sub> can positively interfere with an NDIR analyzer by causing a response similar to CO. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) System requirements. A CO NDIR analyzer must have combined H<sub>2</sub>O and CO<sub>2</sub> interference that is within  $\pm 1$  % of the flow-weighted mean concentration of CO expected at the standard.

(d) Procedure. Perform the interference verification as follows:

(1) Start, operate, zero, and span the CO NDIR analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of 342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.

(2) Create a humidified CO<sub>2</sub> test gas by bubbling a CO<sub>2</sub> span gas that meets the specifications in 750 through distilled water in a sealed vessel. If the sample is not passed through a dryer during emission testing, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the maximum expected during emission testing. If the sample is passed through a dryer during emission testing, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the level determined in 145(e)(2) for that dryer. Use a CO<sub>2</sub> span gas concentration at least as high as the maximum expected during testing.

(3) Introduce the humidified CO<sub>2</sub> test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the water mole fraction,  $x_{\text{H}_2\text{O}}$ , of the humidified CO<sub>2</sub> test gas as close as possible to the inlet of the analyzer. For example, measure dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , to calculate  $x_{\text{H}_2\text{O}}$ . Verify that the water content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the water content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the water content (e.g., dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use accepted measurement practices to estimate the water content. For example, you may use previous direct measurements of water content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test, use accepted measurement practices to prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{O}}$  is measured to the analyzer. We recommend that you design your system so that the wall temperatures in the transfer lines, fittings, and valves from the point where  $x_{\text{H}_2\text{O}}$  is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) While the analyzer measures the sample's concentration, record its output for 30 seconds. Calculate the arithmetic mean of this data.

(8) The analyzer meets the interference verification if the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(9) You may also run interference procedures for CO<sub>2</sub> and H<sub>2</sub>O separately. If the CO<sub>2</sub> and H<sub>2</sub>O levels used are higher than the maximum levels expected during testing, you may scale down each observed interference value by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. You may run separate interference concentrations of H<sub>2</sub>O (down to 0.025 mol/mol H<sub>2</sub>O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H<sub>2</sub>O interference by multiplying the observed interference by the ratio of the maximum expected H<sub>2</sub>O concentration value to the actual value used during this procedure. The sum of the two scaled interference values must meet the tolerance in paragraph (c) of this section.

(e) Exceptions. The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO sampling system and your emission-calculation procedures, the combined CO<sub>2</sub> and H<sub>2</sub>O interference for your CO NDIR analyzer always affects your brake-specific CO emission results within ±0.5 % of the applicable CO standard.

(2) You may use a CO NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that vehicles comply with all applicable emission standards.

## HYDROCARBON MEASUREMENTS

### **360 FID optimization and verification.**

(a) Scope and frequency. For all FID analyzers, calibrate the FID upon initial installation. Repeat the calibration as needed using accepted measurement practices. For a FID that measures THC, perform the following steps:

(1) Optimize the response to various hydrocarbons after initial analyzer installation and after major maintenance as described in paragraph (c) of this section.

(2) Determine the methane (CH<sub>4</sub>) response factor after initial analyzer installation and after major maintenance as described in paragraph (d) of this section.

(3) Verify the methane (CH<sub>4</sub>) response within 185 days before testing as described in paragraph (e) of this section.

(b) Calibration. Use accepted measurement practices to develop a calibration procedure, such as one based on the FID-analyzer manufacturer's instructions and recommended frequency for calibrating the FID. For a FID that measures THC, calibrate using C<sub>3</sub>H<sub>8</sub> calibration gases that meet the specifications of 750. For a FID that measures CH<sub>4</sub>, calibrate using CH<sub>4</sub> calibration gases that meet the specifications of 750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O<sub>2</sub> expected during testing. If you use a FID to measure methane (CH<sub>4</sub>) downstream of a nonmethane cutter, you may calibrate that FID using CH<sub>4</sub> calibration gases with the cutter. Regardless of the calibration gas composition, calibrate on a carbon number basis of one (C<sub>1</sub>). For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol. As another example, if you use a CH<sub>4</sub> span gas with a concentration of 200 µmol/mol, span the FID to respond with a value of 200 µmol/mol.

## WLTP-DTP-01-02

(c) THC FID response optimization. This procedure is only for FID analyzers that measure THC. Use instrument manufacturer's recommendations for initial instrument start-up and basic operating adjustment using FID fuel and zero air. Heated FIDs must be within their required operating temperature ranges. Optimize FID response at the most common analyzer range expected during emission testing. Optimization involves adjusting flows and pressures of FID fuel, burner air, and sample to minimize response variations to various hydrocarbon species in the exhaust. Use accepted measurement practices to trade off peak FID response to propane calibration gases to achieve minimal response variations to different hydrocarbon species. For an example of trading off response to propane for relative responses to other hydrocarbon species, see SAE 770141. Determine the optimum flow rates and/or pressures for FID fuel, burner air, and sample and record them for future reference.

(d) THC FID CH<sub>4</sub> response factor determination. This procedure is only for FID analyzers that measure THC. Since FID analyzers generally have a different response to CH<sub>4</sub> versus C<sub>3</sub>H<sub>8</sub>, determine each THC FID analyzer's CH<sub>4</sub> response factor,  $RF_{CH_4[THC-FID]}$ , after FID optimization. Use the most recent  $RF_{CH_4[THC-FID]}$  measured according to this section in the calculations for HC determination described in 660 to compensate for CH<sub>4</sub> response. Determine  $RF_{CH_4[THC-FID]}$  as follows, noting that you do not determine  $RF_{CH_4[THC-FID]}$  for FIDs that are calibrated and spanned using CH<sub>4</sub> with a nonmethane cutter:

- (1) Select a C<sub>3</sub>H<sub>8</sub> span gas concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of 750. Record the C<sub>3</sub>H<sub>8</sub> concentration of the gas.
- (2) Select a CH<sub>4</sub> span gas concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of 750. Record the CH<sub>4</sub> concentration of the gas.
- (3) Start and operate the FID analyzer according to the manufacturer's instructions.
- (4) Confirm that the FID analyzer has been calibrated using C<sub>3</sub>H<sub>8</sub>. Calibrate on a carbon number basis of one (C<sub>1</sub>). For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 μmol/mol, span the FID to respond with a value of 600 μmol/mol.
- (5) Zero the FID with a zero gas that you use for emission testing.
- (6) Span the FID with the C<sub>3</sub>H<sub>8</sub> span gas that you selected under paragraph (d)(1) of this section.
- (7) Introduce at the sample port of the FID analyzer, the CH<sub>4</sub> span gas that you selected under paragraph (d)(2) of this section.
- (8) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the analyzer and to account for its response.
- (9) While the analyzer measures the CH<sub>4</sub> concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.
- (10) Divide the mean measured concentration by the recorded span concentration of the CH<sub>4</sub> calibration gas. The result is the FID analyzer's response factor for CH<sub>4</sub>,  $RF_{CH_4[THC-FID]}$ .

(e) THC FID methane (CH<sub>4</sub>) response verification. This procedure is only for FID analyzers that measure THC. If the value of  $RF_{CH_4[THC-FID]}$  from paragraph (d) of this section is within ±5.0 % of its most recent previously determined value, the THC FID passes the methane response verification. For example, if the most recent previous value for  $RF_{CH_4[THC-FID]}$  was 1.05 and it changed by ±0.05 to become 1.10 or it changed by -0.05 to become 1.00, either case would be

acceptable because  $\pm 4.8\%$  is less than  $\pm 5.0\%$ . If you do not pass the response verification as stated above, verify  $RF_{CH_4[THC-FID]}$  as follows:

(1) First verify that the flow rates and/or pressures of FID fuel, burner air, and sample are each within  $\pm 0.5\%$  of their most recent previously recorded values, as described in paragraph (c) of this section. You may adjust these flow rates as necessary. Then determine the  $RF_{CH_4[THC-FID]}$  as described in paragraph (d) of this section and verify that it is within the tolerance specified in this paragraph (e).

(2) If  $RF_{CH_4[THC-FID]}$  is not within the tolerance specified in this paragraph (e), re-optimize the FID response as described in paragraph (c) of this section.

(3) Determine a new  $RF_{CH_4[THC-FID]}$  as described in paragraph (d) of this section. Use this new value of  $RF_{CH_4[THC-FID]}$  in the calculations for HC determination, as described in 660.

### **365 Nonmethane cutter penetration fractions.**

(a) Scope and frequency. If you use a FID analyzer and a nonmethane cutter (NMC) to measure methane ( $CH_4$ ), determine the nonmethane cutter's penetration fractions of methane,  $PF_{CH_4}$ , and ethane,  $PF_{C_2H_6}$ . As detailed in this section, these penetration fractions may be determined as a combination of NMC penetration fractions and FID analyzer response factors, depending on your particular NMC and FID analyzer configuration. Perform this verification after installing the nonmethane cutter. Repeat this verification within 185 days of testing to verify that the catalytic activity of the cutter has not deteriorated. Note that because nonmethane cutters can deteriorate rapidly and without warning if they are operated outside of certain ranges of gas concentrations and outside of certain temperature ranges, accepted measurement practices may dictate that you determine a nonmethane cutter's penetration fractions more frequently.

(b) Measurement principles. A nonmethane cutter is a heated catalyst that removes nonmethane hydrocarbons from an exhaust sample stream before the FID analyzer measures the remaining hydrocarbon concentration. An ideal nonmethane cutter would have a methane penetration fraction,  $PF_{CH_4}$ , of 1.000, and the penetration fraction for all other nonmethane hydrocarbons would be 0.000, as represented by  $PF_{C_2H_6}$ . The emission calculations in 660 use the measured values from this verification to account for less than ideal NMC performance.

(c) System requirements. We do not limit NMC penetration fractions to a certain range. However, we recommend that you optimize a nonmethane cutter by adjusting its temperature to achieve a  $PF_{CH_4} > 0.85$  and a  $PF_{C_2H_6} < 0.02$ , as determined by paragraphs (d), (e), or (f) of this section, as applicable. If we use a nonmethane cutter for testing, it will meet this recommendation. If adjusting NMC temperature does not result in achieving both of these specifications simultaneously, we recommend that you replace the catalyst material. Use the most recently determined penetration values from this section to calculate HC emissions according to 660 and 665 as applicable.

(d) Procedure for a FID calibrated with the NMC. The method described in this paragraph (d) is recommended over the procedures specified in paragraphs (e) and (f) of this section. If your FID arrangement is such that a FID is always calibrated to measure  $CH_4$  with the NMC, then span that FID with the NMC using a  $CH_4$  span gas, set the product of that FID's  $CH_4$  response factor and  $CH_4$  penetration fraction,  $RF_{PF_{CH_4[NMC-FID]}}$ , equal to 1.0 for all emission calculations, and determine its combined ethane ( $C_2H_6$ ) response factor and penetration fraction,  $RF_{PF_{C_2H_6[NMC-FID]}}$  as follows:

## WLTP-DTP-01-02

- (1) Select CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> analytical gas mixtures and ensure that both mixtures meet the specifications of 750. Select a CH<sub>4</sub> concentration that you would use for spanning the FID during emission testing and select a C<sub>2</sub>H<sub>6</sub> concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value.
- (2) Start, operate, and optimize the nonmethane cutter according to the manufacturer's instructions, including any temperature optimization.
- (3) Confirm that the FID analyzer meets all the specifications of 360.
- (4) Start and operate the FID analyzer according to the manufacturer's instructions.
- (5) Zero and span the FID with the nonmethane cutter as you would during emission testing. Span the FID through the cutter by using CH<sub>4</sub> span gas.
- (6) Introduce the C<sub>2</sub>H<sub>6</sub> analytical gas mixture upstream of the nonmethane cutter. Use accepted measurement practices to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.
- (7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.
- (8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.
- (9) Divide the mean C<sub>2</sub>H<sub>6</sub> concentration by the reference concentration of C<sub>2</sub>H<sub>6</sub>, converted to a C<sub>1</sub> basis. The result is the C<sub>2</sub>H<sub>6</sub> combined response factor and penetration fraction,  $RFPF_{C_2H_6[NMC-FID]}$ . Use this combined response factor and penetration fraction and the product of the CH<sub>4</sub> response factor and CH<sub>4</sub> penetration fraction,  $RFPF_{CH_4[NMC-FID]}$ , set to 1.0 in emission calculations according to 660(b)(2)(i), 660(c)(1)(i), or 665, as applicable.
- (e) Procedure for a FID calibrated with propane, bypassing the NMC. If you use a single FID for THC and CH<sub>4</sub> determination with an NMC that is calibrated with propane, C<sub>3</sub>H<sub>8</sub>, by bypassing the NMC, determine its penetration fractions,  $PF_{C_2H_6[NMC-FID]}$  and  $PF_{CH_4[NMC-FID]}$ , as follows:
  - (1) Select CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> analytical gas mixtures and ensure that both mixtures meet the specifications of 750. Select a CH<sub>4</sub> concentration that you would use for spanning the FID during emission testing and select a C<sub>2</sub>H<sub>6</sub> concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard and the C<sub>2</sub>H<sub>6</sub> concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value.
  - (2) Start and operate the nonmethane cutter according to the manufacturer's instructions, including any temperature optimization.
  - (3) Confirm that the FID analyzer meets all the specifications of 360.
  - (4) Start and operate the FID analyzer according to the manufacturer's instructions.
  - (5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the cutter and by using C<sub>3</sub>H<sub>8</sub> span gas. Note that you must span the FID on a C<sub>1</sub> basis. For example, if your span gas has a propane reference value of 100 μmol/mol, the correct FID response to that span gas is 300 μmol/mol because there are three carbon atoms per C<sub>3</sub>H<sub>8</sub> molecule.
  - (6) Introduce the C<sub>2</sub>H<sub>6</sub> analytical gas mixture upstream of the nonmethane cutter. Use accepted measurement practices to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.

- (7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.
  - (8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.
  - (9) Reroute the flow path to bypass the nonmethane cutter, introduce the C<sub>2</sub>H<sub>6</sub> analytical gas mixture, and repeat the steps in paragraphs (e)(7) through (8) of this section.
  - (10) Divide the mean C<sub>2</sub>H<sub>6</sub> concentration measured through the nonmethane cutter by the mean C<sub>2</sub>H<sub>6</sub> concentration measured after bypassing the nonmethane cutter. The result is the C<sub>2</sub>H<sub>6</sub> penetration fraction,  $PF_{C_2H_6[NMC-FID]}$ . Use this penetration fraction according to 660(b)(2)(ii), 660(c)(1)(ii), or 665, as applicable.
  - (11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH<sub>4</sub> analytical gas mixture instead of C<sub>2</sub>H<sub>6</sub>. The result will be the CH<sub>4</sub> penetration fraction,  $PF_{CH_4[NMC-FID]}$ . Use this penetration fraction according to 660(b)(2)(ii) or 665, as applicable.
- (f) Procedure for a FID calibrated with methane, bypassing the NMC. If you use a FID with an NMC that is calibrated with methane, CH<sub>4</sub>, by bypassing the NMC, determine its combined ethane (C<sub>2</sub>H<sub>6</sub>) response factor and penetration fraction,  $RFPF_{C_2H_6[NMC-FID]}$ , as well as its CH<sub>4</sub> penetration fraction,  $PF_{CH_4[NMC-FID]}$ , as follows:
- (1) Select CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> analytical gas mixtures and ensure that both mixtures meet the specifications of 750. Select a CH<sub>4</sub> concentration that you would use for spanning the FID during emission testing and select a C<sub>2</sub>H<sub>6</sub> concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to the THC analyzer's span value.
  - (2) Start and operate the nonmethane cutter according to the manufacturer's instructions, including any temperature optimization.
  - (3) Confirm that the FID analyzer meets all the specifications of 360.
  - (4) Start and operate the FID analyzer according to the manufacturer's instructions.
  - (5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the cutter and by using CH<sub>4</sub> span gas.
  - (6) Introduce the C<sub>2</sub>H<sub>6</sub> analytical gas mixture upstream of the nonmethane cutter. Use accepted measurement practices to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.
  - (7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.
  - (8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.
  - (9) Divide the mean C<sub>2</sub>H<sub>6</sub> concentration by the reference concentration of C<sub>2</sub>H<sub>6</sub>, converted to a C<sub>1</sub> basis. The result is the C<sub>2</sub>H<sub>6</sub> combined response factor and penetration fraction,  $RFPF_{C_2H_6[NMC-FID]}$ . Use this combined response factor and penetration fraction according to 660(b)(2)(iii), 660(c)(1)(iii), or 665, as applicable.
  - (10) Introduce the CH<sub>4</sub> analytical gas mixture upstream of the nonmethane cutter. Use accepted measurement practices to address the effect of hydrocarbon contamination if your point of introduction is vastly different from the point of zero/span gas introduction.
  - (11) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.

## WLTP-DTP-01-02

(12) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(13) Reroute the flow path to bypass the nonmethane cutter, introduce the CH<sub>4</sub> analytical gas mixture, and repeat the steps in paragraphs (e)(11) and (12) of this section.

(14) Divide the mean CH<sub>4</sub> concentration measured through the nonmethane cutter by the mean CH<sub>4</sub> concentration measured after bypassing the nonmethane cutter. The result is the CH<sub>4</sub> penetration fraction,  $PF_{CH_4[NMC-FID]}$ . Use this penetration fraction according to 660(b)(2)(iii), 660(c)(1)(iii), or 665, as applicable.

## NO<sub>x</sub> AND N<sub>2</sub>O MEASUREMENTS

### 370 CLD CO<sub>2</sub> and H<sub>2</sub>O quench verification.

(a) Scope and frequency. If you use a CLD analyzer to measure NO<sub>x</sub>, verify the amount of H<sub>2</sub>O and CO<sub>2</sub> quench after installing the CLD analyzer and after major maintenance.

(b) Measurement principles. H<sub>2</sub>O and CO<sub>2</sub> can negatively interfere with a CLD's NO<sub>x</sub> response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO<sub>x</sub>. This procedure and the calculations in 675 determine quench and scale the quench results to the maximum mole fraction of H<sub>2</sub>O and the maximum CO<sub>2</sub> concentration expected during emission testing. If the CLD analyzer uses quench compensation algorithms that utilize H<sub>2</sub>O and/or CO<sub>2</sub> measurement instruments, evaluate quench with these instruments active and evaluate quench with the compensation algorithms applied.

(c) System requirements. A CLD analyzer must have a combined H<sub>2</sub>O and CO<sub>2</sub> quench of  $\pm 2\%$  or less, though we strongly recommend a quench of  $\pm 1\%$  or less. Combined quench is the sum of the CO<sub>2</sub> quench determined as described in paragraph (d) of this section, plus the H<sub>2</sub>O quench determined in paragraph (e) of this section.

(d) CO<sub>2</sub> quench verification procedure. Use the following method to determine CO<sub>2</sub> quench by using a gas divider that blends binary span gases with zero gas as the diluent and meets the specifications in 248, or use accepted measurement practices to develop a different protocol:

(1) Use PTFE or stainless steel tubing to make necessary connections.

(2) Configure the gas divider such that nearly equal amounts of the span and diluent gases are blended with each other.

(3) If the CLD analyzer has an operating mode in which it detects NO-only, as opposed to total NO<sub>x</sub>, operate the CLD analyzer in the NO-only operating mode.

(4) Use a CO<sub>2</sub> span gas that meets the specifications of 750 and a concentration that is approximately twice the maximum CO<sub>2</sub> concentration expected during emission testing.

(5) Use an NO span gas that meets the specifications of 750 and a concentration that is approximately twice the maximum NO concentration expected during emission testing.

(6) Zero and span the CLD analyzer. Span the CLD analyzer with the NO span gas from paragraph (d)(5) of this section through the gas divider. Connect the NO span gas to the span port of the gas divider; connect a zero gas to the diluent port of the gas divider; use the same nominal blend ratio selected in paragraph (d)(2) of this section; and use the gas divider's output concentration of NO to span the CLD analyzer. Apply gas property corrections as necessary to ensure accurate gas division.

- (7) Connect the CO<sub>2</sub> span gas to the span port of the gas divider.
- (8) Connect the NO span gas to the diluent port of the gas divider.
- (9) While flowing NO and CO<sub>2</sub> through the gas divider, stabilize the output of the gas divider. Determine the CO<sub>2</sub> concentration from the gas divider output, applying gas property correction as necessary to ensure accurate gas division. Record this concentration,  $x_{\text{CO}_2\text{act}}$ , and use it in the quench verification calculations in 675. Alternatively, you may use a simple gas blending device and use an NDIR to determine this CO<sub>2</sub> concentration. If you use an NDIR, it must meet the requirements of this part for laboratory testing and you must span it with the CO<sub>2</sub> span gas from paragraph (d)(4) of this section.
- (10) Measure the NO concentration downstream of the gas divider with the CLD analyzer. Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response. While the analyzer measures the sample's concentration, record the analyzer's output for 30 seconds. Calculate the arithmetic mean concentration from these data,  $x_{\text{NOmeas}}$ . Record  $x_{\text{NOmeas}}$ , and use it in the quench verification calculations in 675.
- (11) Calculate the actual NO concentration at the gas divider's outlet,  $x_{\text{NOact}}$ , based on the span gas concentrations and  $x_{\text{CO}_2\text{act}}$  according to Equation 675-2. Use the calculated value in the quench verification calculations in Equation 675-1.
- (12) Use the values recorded according to this paragraph (d) and paragraph (e) of this section to calculate quench as described in 675.
- (e) H<sub>2</sub>O quench verification procedure. Use the following method to determine H<sub>2</sub>O quench, or use accepted measurement practices to develop a different protocol:
  - (1) Use PTFE or stainless steel tubing to make necessary connections.
  - (2) If the CLD analyzer has an operating mode in which it detects NO-only, as opposed to total NO<sub>x</sub>, operate the CLD analyzer in the NO-only operating mode.
  - (3) Use an NO span gas that meets the specifications of 750 and a concentration that is near the maximum concentration expected during emission testing.
  - (4) Zero and span the CLD analyzer. Span the CLD analyzer with the NO span gas from paragraph (e)(3) of this section, record the span gas concentration as  $x_{\text{NOdry}}$ , and use it in the quench verification calculations in 675.
  - (5) Humidify the NO span gas by bubbling it through distilled water in a sealed vessel. If the humidified NO span gas sample does not pass through a sample dryer for this verification test, control the vessel temperature to generate an H<sub>2</sub>O level approximately equal to the maximum mole fraction of H<sub>2</sub>O expected during emission testing. If the humidified NO span gas sample does not pass through a sample dryer, the quench verification calculations in 675 scale the measured H<sub>2</sub>O quench to the highest mole fraction of H<sub>2</sub>O expected during emission testing. If the humidified NO span gas sample passes through a dryer for this verification test, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the level determined in 145(e)(2). For this case, the quench verification calculations in 675 do not scale the measured H<sub>2</sub>O quench.
  - (6) Introduce the humidified NO test gas into the sample system. You may introduce it upstream or downstream of any sample dryer that is used during emission testing. Note that the sample dryer must meet the sample dryer verification check in 342.
  - (7) Measure the mole fraction of H<sub>2</sub>O in the humidified NO span gas downstream of the sample dryer,  $x_{\text{H}_2\text{Omeas}}$ . We recommend that you measure  $x_{\text{H}_2\text{Omeas}}$  as close as possible to the CLD

## WLTP-DTP-01-02

analyzer inlet. You may calculate  $x_{\text{H}_2\text{O}_{\text{meas}}}$  from measurements of dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ .

(8) Use accepted measurement practices to prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{O}_{\text{meas}}}$  is measured to the analyzer. We recommend that you design your system so the wall temperatures in the transfer lines, fittings, and valves from the point where  $x_{\text{H}_2\text{O}_{\text{meas}}}$  is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(9) Measure the humidified NO span gas concentration with the CLD analyzer. Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response. While the analyzer measures the sample's concentration, record the analyzer's output for 30 seconds. Calculate the arithmetic mean of these data,  $x_{\text{NO}_{\text{wet}}}$ . Record  $x_{\text{NO}_{\text{wet}}}$  and use it in the quench verification calculations in 675.

(f) Corrective action. If the sum of the H<sub>2</sub>O quench plus the CO<sub>2</sub> quench is less than -2 % or greater than +2 %, take corrective action by repairing or replacing the analyzer. Before running emission tests, verify that the corrective action successfully restored the analyzer to proper functioning.

(g) Exceptions. The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculation procedures, the combined CO<sub>2</sub> and H<sub>2</sub>O interference for your NO<sub>x</sub> CLD analyzer always affects your brake-specific NO<sub>x</sub> emission results within no more than ±1.0 % of the applicable NO<sub>x</sub> standard. If you certify to a combined emission standard (such as a NO<sub>x</sub> + NMHC standard), scale your NO<sub>x</sub> results to the combined standard based on the measured results (after incorporating deterioration factors, if applicable). For example, if your final NO<sub>x</sub> + NMHC value is half of the emission standard, double the NO<sub>x</sub> result to estimate the level of NO<sub>x</sub> emissions corresponding to the applicable standard.

(2) You may use a NO<sub>x</sub> CLD analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that vehicles comply with all applicable emission standards.

### **372 NDUV analyzer HC and H<sub>2</sub>O interference verification.**

(a) Scope and frequency. If you measure NO<sub>x</sub> using an NDUV analyzer, verify the amount of H<sub>2</sub>O and hydrocarbon interference after initial analyzer installation and after major maintenance.

(b) Measurement principles. Hydrocarbons and H<sub>2</sub>O can positively interfere with an NDUV analyzer by causing a response similar to NO<sub>x</sub>. If the NDUV analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct such measurements to test the algorithms during the analyzer interference verification.

(c) System requirements. A NO<sub>x</sub> NDUV analyzer must have combined H<sub>2</sub>O and HC interference within ±2 % of the flow-weighted mean concentration of NO<sub>x</sub> expected at the standard, though we strongly recommend keeping interference within ±1 %.

(d) Procedure. Perform the interference verification as follows:

(1) Start, operate, zero, and span the NO<sub>x</sub> NDUV analyzer according to the instrument manufacturer's instructions.

- (2) We recommend that you extract vehicle exhaust to perform this verification. Use a CLD that meets the specifications of subpart C of this part to quantify NO<sub>x</sub> in the exhaust. Use the CLD response as the reference value. Also measure HC in the exhaust with a FID analyzer that meets the specifications of subpart C of this part. Use the FID response as the reference hydrocarbon value.
  - (3) Upstream of any sample dryer, if one is used during testing, introduce the vehicle exhaust to the NDUV analyzer.
  - (4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.
  - (5) While all analyzers measure the sample's concentration, record 30 seconds of sampled data, and calculate the arithmetic means for the three analyzers.
  - (6) Subtract the CLD mean from the NDUV mean.
  - (7) Multiply this difference by the ratio of the flow-weighted mean HC concentration expected at the standard to the HC concentration measured during the verification. The analyzer meets the interference verification of this section if this result is within  $\pm 2$  % of the NO<sub>x</sub> concentration expected at the standard.
- (e) Exceptions. The following exceptions apply:
- (1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculations procedures, the combined HC and H<sub>2</sub>O interference for your NO<sub>x</sub> NDUV analyzer always affects your brake-specific NO<sub>x</sub> emission results by less than 0.5 % of the applicable NO<sub>x</sub> standard.
  - (2) You may use a NO<sub>x</sub> NDUV analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that vehicles comply with all applicable emission standards.

### **375 Interference verification for N<sub>2</sub>O analyzers.**

- (a) Scope and frequency. See 275 to determine whether you need to verify the amount of interference after initial analyzer installation and after major maintenance.
- (b) Measurement principles. Interference gasses can positively interfere with certain analyzers by causing a response similar to N<sub>2</sub>O. If the analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.
- (c) System requirements. Analyzers must have combined interference that is within  $(0.0 \pm 1.0)$   $\mu\text{mol/mol}$ . We strongly recommend a lower interference that is within  $(0.0 \pm 0.5)$   $\mu\text{mol/mol}$ .
- (d) Procedure. Perform the interference verification as follows:
  - (1) Start, operate, zero, and span the N<sub>2</sub>O analyzer as you would before an emission test. If the sample is passed through a dryer during emission testing, you may run this verification test with the dryer if it meets the requirements of 342. Operate the dryer at the same conditions as you will for an emission test. You may also run this verification test without the sample dryer.
  - (2) Create a humidified test gas by bubbling a multi component span gas that incorporates the target interference species and meets the specifications in 750 through distilled water in a sealed vessel. If the sample is not passed through a dryer during emission testing, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the maximum expected during emission

## WLTP-DTP-01-02

testing. If the sample is passed through a dryer during emission testing, control the vessel temperature to generate an H<sub>2</sub>O level at least as high as the level determined in 145(e)(2) for that dryer. Use interference span gas concentrations that are at least as high as the maximum expected during testing.

(3) Introduce the humidified interference test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) If the sample is not passed through a dryer during this verification test, measure the water mole fraction,  $x_{\text{H}_2\text{O}}$ , of the humidified interference test gas as close as possible to the inlet of the analyzer. For example, measure dewpoint,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , to calculate  $x_{\text{H}_2\text{O}}$ . Verify that the water content meets the requirement in paragraph (d)(2) of this section. If the sample is passed through a dryer during this verification test, you must verify that the water content of the humidified test gas downstream of the vessel meets the requirement in paragraph (d)(2) of this section based on either direct measurement of the water content (e.g., dewpoint and pressure) or an estimate based on the vessel pressure and temperature. Use accepted measurement practices to estimate the water content. For example, you may use previous direct measurements of water content to verify the vessel's level of saturation.

(5) If a sample dryer is not used in this verification test, use accepted measurement practices to prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{O}}$  is measured to the analyzer. We recommend that you design your system so that the wall temperatures in the transfer lines, fittings, and valves from the point where  $x_{\text{H}_2\text{O}}$  is measured to the analyzer are at least 5 °C above the local sample gas dewpoint.

(6) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(7) While the analyzer measures the sample's concentration, record its output for 30 seconds. Calculate the arithmetic mean of this data.

(8) The analyzer meets the interference verification if the result of paragraph (d)(7) of this section meets the tolerance in paragraph (c) of this section.

(9) You may also run interference procedures separately for individual interference gases. If the interference gas levels used are higher than the maximum levels expected during testing, you may scale down each observed interference value by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. You may run separate interference concentrations of H<sub>2</sub>O (down to 0.025 mol/mol H<sub>2</sub>O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H<sub>2</sub>O interference by multiplying the observed interference by the ratio of the maximum expected H<sub>2</sub>O concentration value to the actual value used during this procedure. The sum of the scaled interference values must meet the tolerance specified in paragraph (c) of this section.

### **376 Chiller NO<sub>2</sub> penetration.**

(a) Scope and frequency. If you use a chiller to dry a sample upstream of a NO<sub>x</sub> measurement instrument, but you don't use an NO<sub>2</sub>-to-NO converter upstream of the chiller, you must perform this verification for chiller NO<sub>2</sub> penetration. Perform this verification after initial installation and after major maintenance.

- (b) Measurement principles. A chiller removes water, which can otherwise interfere with a NO<sub>x</sub> measurement. However, liquid water remaining in an improperly designed chiller can remove NO<sub>2</sub> from the sample. If a chiller is used without an NO<sub>2</sub>-to-NO converter upstream, it could remove NO<sub>2</sub> from the sample prior NO<sub>x</sub> measurement.
- (c) System requirements. A chiller must allow for measuring at least 95 % of the total NO<sub>2</sub> at the maximum expected concentration of NO<sub>2</sub>.
- (d) Procedure. Use the following procedure to verify chiller performance:
- (1) Instrument setup. Follow the analyzer and chiller manufacturers' start-up and operating instructions. Adjust the analyzer and chiller as needed to optimize performance.
- (2) Equipment setup and data collection. (i) Zero and span the total NO<sub>x</sub> gas analyzer(s) as you would before emission testing.
- (ii) Select an NO<sub>2</sub> calibration gas, balance gas of dry air, that has an NO<sub>2</sub> concentration within ±5 % of the maximum NO<sub>2</sub> concentration expected during testing.
- (iii) Overflow this calibration gas at the gas sampling system's probe or overflow fitting. Allow for stabilization of the total NO<sub>x</sub> response, accounting only for transport delays and instrument response.
- (iv) Calculate the mean of 30 seconds of recorded total NO<sub>x</sub> data and record this value as  $x_{\text{NO}_x\text{ref}}$ .
- (v) Stop flowing the NO<sub>2</sub> calibration gas.
- (vi) Next saturate the sampling system by overflowing a dewpoint generator's output, set at a dewpoint of 50 °C, to the gas sampling system's probe or overflow fitting. Sample the dewpoint generator's output through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water.
- (vii) Immediately switch back to overflowing the NO<sub>2</sub> calibration gas used to establish  $x_{\text{NO}_x\text{ref}}$ . Allow for stabilization of the total NO<sub>x</sub> response, accounting only for transport delays and instrument response. Calculate the mean of 30 seconds of recorded total NO<sub>x</sub> data and record this value as  $x_{\text{NO}_x\text{meas}}$ .
- (viii) Correct  $x_{\text{NO}_x\text{meas}}$  to  $x_{\text{NO}_x\text{dry}}$  based upon the residual water vapor that passed through the chiller at the chiller's outlet temperature and pressure.
- (3) Performance evaluation. If  $x_{\text{NO}_x\text{dry}}$  is less than 95 % of  $x_{\text{NO}_x\text{ref}}$ , repair or replace the chiller.
- (e) Exceptions. The following exceptions apply:
- (1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculations procedures, the chiller always affects your brake-specific NO<sub>x</sub> emission results by less than 0.5 % of the applicable NO<sub>x</sub> standard.
- (2) You may use a chiller that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that vehicles comply with all applicable emission standards.

### **378 NO<sub>2</sub>-to-NO converter conversion verification.**

- (a) Scope and frequency. If you use an analyzer that measures only NO to determine NO<sub>x</sub>, you must use an NO<sub>2</sub>-to-NO converter upstream of the analyzer. Perform this verification after installing the converter, after major maintenance and within 35 days before an emission test. This verification must be repeated at this frequency to verify that the catalytic activity of the NO<sub>2</sub>-to-NO converter has not deteriorated.

## WLTP-DTP-01-02

(b) Measurement principles. An NO<sub>2</sub>-to-NO converter allows an analyzer that measures only NO to determine total NO<sub>x</sub> by converting the NO<sub>2</sub> in exhaust to NO.

(c) System requirements. An NO<sub>2</sub>-to-NO converter must allow for measuring at least 95 % of the total NO<sub>2</sub> at the maximum expected concentration of NO<sub>2</sub>.

(d) Procedure. Use the following procedure to verify the performance of a NO<sub>2</sub>-to-NO converter:

(1) Instrument setup. Follow the analyzer and NO<sub>2</sub>-to-NO converter manufacturers' start-up and operating instructions. Adjust the analyzer and converter as needed to optimize performance.

(2) Equipment setup. Connect an ozonator's inlet to a zero-air or oxygen source and connect its outlet to one port of a three-way tee fitting. Connect an NO span gas to another port, and connect the NO<sub>2</sub>-to-NO converter inlet to the last port.

(3) Adjustments and data collection. Perform this check as follows:

(i) Set ozonator air off, turn ozonator power off, and set the analyzer to NO mode. Allow for stabilization, accounting only for transport delays and instrument response.

(ii) Use an NO concentration that is representative of the peak total NO<sub>x</sub> concentration expected during testing. The NO<sub>2</sub> content of the gas mixture shall be less than 5 % of the NO concentration. Record the concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as  $x_{\text{NOref}}$ .

(iii) Turn on the ozonator O<sub>2</sub> supply and adjust the O<sub>2</sub> flow rate so the NO indicated by the analyzer is about 10 percent less than  $x_{\text{NOref}}$ . Record the concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as  $x_{\text{NO+O2mix}}$ .

(iv) Switch the ozonator on and adjust the ozone generation rate so the NO measured by the analyzer is 20 percent of  $x_{\text{NOref}}$ , while maintaining at least 10 percent unreacted NO. Record the concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as  $x_{\text{NOmeas}}$ .

(v) Switch the NO<sub>x</sub> analyzer to NO<sub>x</sub> mode and measure total NO<sub>x</sub>. Record the concentration of NO<sub>x</sub> by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as  $x_{\text{NOxmeas}}$ .

(vi) Switch off the ozonator but maintain gas flow through the system. The NO<sub>x</sub> analyzer will indicate the NO<sub>x</sub> in the NO + O<sub>2</sub> mixture. Record the concentration of NO<sub>x</sub> by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as  $x_{\text{NOx+O2mix}}$ .

(vii) Turn off the ozonator O<sub>2</sub> supply. The NO<sub>x</sub> analyzer will indicate the NO<sub>x</sub> in the original NO-in-N<sub>2</sub> mixture. Record the concentration of NO<sub>x</sub> by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as  $x_{\text{NOxref}}$ . This value should be no more than 5 percent above the  $x_{\text{NOref}}$  value.

(4) Performance evaluation. Calculate the efficiency of the NO<sub>x</sub> converter by substituting the concentrations obtained into the following equation:

$$\text{efficiency} = \left( 1 + \frac{x_{\text{NOxmeas}} - x_{\text{NOx+O2mix}}}{x_{\text{NO+O2mix}} - x_{\text{NOmeas}}} \right) \cdot 100 \%$$

(5) If the result is less than 95 %, repair or replace the NO<sub>2</sub>-to-NO converter.

(e) Exceptions. The following exceptions apply:

- (1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculations procedures, the converter always affects your brake-specific NO<sub>x</sub> emission results by less than 0.5 % of the applicable NO<sub>x</sub> standard.
- (2) You may use a converter that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that vehicles comply with all applicable emission standards.

## PM MEASUREMENTS

### **390 PM balance verifications and weighing process verification.**

(a) Scope and frequency. This section describes three verifications.

(1) Independent verification of PM balance performance within 370 days before weighing any filter.

(2) Zero and span the balance within 12 h before weighing any filter.

(3) Verify that the mass determination of reference filters before and after a filter weighing session are less than a specified tolerance.

(b) Independent verification. Have the balance manufacturer (or a representative approved by the balance manufacturer) verify the balance performance within 370 days of testing.

(c) Zeroing and spanning. You must verify balance performance by zeroing and spanning it with at least one calibration weight, and any weights you use must that meet the specifications in 790 to perform this verification.

(1) Use a manual procedure in which you zero the balance and span the balance with at least one calibration weight. If you normally use mean values by repeating the weighing process to improve the accuracy and precision of PM measurements, use the same process to verify balance performance.

(2) You may use an automated procedure to verify balance performance. For example many balances have internal calibration weights that are used automatically to verify balance performance. Note that if you use internal balance weights, the weights must meet the specifications in 790 to perform this verification.

(d) Reference sample weighing. Verify all mass readings during a weighing session by weighing reference PM sample media (e.g. filters) before and after a weighing session. A weighing session may be as short as desired, but no longer than 80 hours, and may include both pre-test and post-test mass readings. We recommend that weighing sessions be eight hours or less. Successive mass determinations of each reference PM sample media (e.g., filter) must return the same value within  $\pm 10 \mu\text{g}$  or  $\pm 10 \%$  of the net PM mass expected at the standard (if known), whichever is higher. If successive reference PM sample media (e.g. filter) weighing events fail this criterion, invalidate all individual test media (e.g., filter) mass readings occurring between the successive reference media (e.g., filter) mass determinations. You may reweigh these media (e.g. filter) in another weighing session. If you invalidate a pre-test media (e.g. filter) mass determination, that test interval is void. Perform this verification as follows:

(1) Keep at least two samples of unused PM sample media (e.g., filters) in the PM-stabilization environment. Use these as references. If you collect PM with filters, select unused filters of the same material and size for use as references. You may periodically replace references, using accepted measurement practices.

## WLTP-DTP-01-02

(2) Stabilize references in the PM stabilization environment. Consider references stabilized if they have been in the PM-stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of 190(d) for at least the preceding 60 min.

(3) Exercise the balance several times with a reference sample. We recommend weighing ten samples without recording the values.

(4) Zero and span the balance. Using accepted measurement practices, place a test mass such as a calibration weight on the balance, then remove it. After spanning, confirm that the balance returns to a zero reading within the normal stabilization time.

(5) Weigh each of the reference media (e.g. filters) and record their masses. We recommend using substitution weighing as described in 590(j). If you normally use mean values by repeating the weighing process to improve the accuracy and precision of the reference media (e.g. filter) mass, you must use mean values of sample media (e.g. filter) masses.

(6) Record the balance environment dewpoint, ambient temperature, and atmospheric pressure.

(7) Use the recorded ambient conditions to correct results for buoyancy as described in 690.

Record the buoyancy-corrected mass of each of the references.

(8) Subtract each reference media's (e.g. filter's) buoyancy-corrected reference mass from its previously measured and recorded buoyancy-corrected mass.

(9) If any of the reference filters' observed mass changes by more than that allowed under this paragraph, you must invalidate all PM mass determinations made since the last successful reference media (e.g. filter) mass validation. You may discard reference PM media (e.g. filters) if only one of the filter's mass changes by more than the allowable amount and you can positively identify a special cause for that filter's mass change that would not have affected other in-process filters. Thus, the validation can be considered a success. In this case, you do not have to include the contaminated reference media when determining compliance with paragraph (d)(10) of this section, but the affected reference filter must be immediately discarded and replaced prior to the next weighing session.

(10) If any of the reference masses change by more than that allowed under this paragraph (d), invalidate all PM results that were determined between the two times that the reference masses were determined. If you discarded reference PM sample media according to paragraph (d)(9) of this section, you must still have at least one reference mass difference that meets the criteria in this paragraph (d). Otherwise, you must invalidate all PM results that were determined between the two times that the reference media (e.g. filters) masses were determined.

## 500 Performing Emission Tests

The overall test consists of prescribed sequences of fueling, parking, and operating test conditions.

(a) Vehicles are tested for any or all of the following emissions:

(1) Gaseous exhaust THC, CO, NO<sub>x</sub>, CO<sub>2</sub> (for petroleum-fueled and gaseous-fueled vehicles), plus alcohol and carbonyls for alcohol-fueled vehicles, plus CH<sub>4</sub> (for vehicles subject to the NMHC and NMHCE standards).

(2) Particulates.

(b) Vehicles shall be operated during testing as follows.

(1) All test conditions, except as noted, shall be run according to the manufacturer's recommendations to the ultimate purchaser, provided that: Such recommendations are representative of what may reasonably be expected to be followed by the ultimate purchaser under in-use conditions.

(2) Vehicles equipped with features that preclude testing on a dynamometer shall be tested with these features modified according to the manufacturer's recommendations.

(3) 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, except for the first idle mode. The first idle mode and idle modes longer than one minute in length may be run with automatic transmissions in "Neutral;" manual transmissions may be in "Neutral" with the clutch engaged (clutch may be disengaged for engine start-up). If an automatic transmission is in "Neutral" during an idle mode, it shall be placed in "Drive" with the wheels braked at least 5 seconds before the end of the idle mode. If a manual transmission is in "Neutral" during an idle mode, it shall be placed in gear with the clutch disengaged at least 5 seconds before the end of the idle mode. If the vehicle cannot accelerate at the specified rate, the vehicle shall be operated at maximum available power until the vehicle speed reaches the value prescribed for that time in the driving schedule.

(4) The deceleration modes shall be run in gear using brakes or accelerator pedal as necessary to maintain the desired speed. Manual transmission vehicles shall have the clutch engaged and shall not change gears from the previous mode. For those modes which decelerate to zero, manual transmission clutches shall be depressed when the speed drops below 15 mph (24.1 km/h), when engine roughness is evident, or when engine stalling is imminent.

(5)(i) In the case of test vehicles equipped with manual transmissions, the transmission shall be shifted in accordance with procedures which are representative of shift patterns that may reasonably be expected to be followed by vehicles in use, in terms of such variables as vehicle speed or percent rated engine speed. At the Administrator's discretion, a test vehicle may also be shifted according to the shift procedures recommended by the manufacturer to the ultimate purchaser, if such procedures differ from those which are reasonably expected to be followed by vehicles in use.

(ii) A manufacturer may recommend to the ultimate purchaser shift procedures other than those used in testing by the EPA, provided that: All shift procedures (including multiple shift speeds) which the manufacturer proposes to supply to the ultimate purchaser are provided to the Administrator as part of the manufacturer's application for certification, or as an amendment to such application.

## WLTP-DTP-01-02

(6) Downshifting is allowed at the beginning of or during a power mode in accordance with the shift procedure determined in paragraph (5)(i) of this section.

Instantaneous drive trace limits (see current 86-B language).

(c) The [driving schedules] are listed in appendix [X] of this part. The driving schedules are defined by a smooth trace drawn through the specified speed vs. time relationships. They each consist of a distinct nonrepetitive series of idle, acceleration, cruise, and deceleration modes of various time sequences and rates.

(d) The driver should attempt to follow the target schedule as closely as possible (refer to paragraph b of this section for additional cycle driving instructions). The speed tolerance at any given time for these schedules, or for a driver's aid chart approved by the Administrator, are as follows:

(1) The upper limit is 2 mph (3.2 km/h) higher than the highest point on the trace within 1 second of the given time.

(2) The lower limit is 2 mph (3.2 km/h) lower than the lowest point on the trace within 1 second of the given time.

(3)(i) Speed variations greater than the tolerances (such as may occur during gear changes or braking spikes) are acceptable, provided they occur for less than 2 seconds on any occasion and are clearly documented as to the time and speed at that point of the driving schedule.

(ii) When conducted to meet the requirements of section 505 or 508, up to three additional occurrences of speed variations greater than the tolerance are acceptable, provided they occur for less than 15 seconds on any occasion, and are clearly documented as to the time and speed at that point of the driving schedule.

(4) Speeds lower than those prescribed are acceptable, provided the vehicle is operated at maximum available power during such occurrences.

(5) When conducted to meet the requirements of sections 505 and 506, the speed tolerance shall be as specified above, except that the upper and lower limits shall be 4 mph (6.4 km/h).

(e) Figures B78-4(a) and B78-4(b) show the range of acceptable speed tolerances for typical points. Figure B78-4(a) is typical of portions of the speed curve which are increasing or decreasing throughout the 2-second time interval. Figure B78-4(b) is typical of portions of the speed curve which include a maximum or minimum value.

(f) Overall driver accuracy is validated by comparing the expected power generated by the actual vehicle speed during the test to the theoretical power that would have been generated by driving exactly to the target trace.

505 Road load power, test weight, and inertia weight class determination. (129-94)

To determine road load power, test weight, and inertial weight class, follow SAE J2263, track road load determination and SAE J2264 dyno road load determination.

506 Vehicle Preparation 132

(a) Fuel tank cap(s) of gasoline- and methanol-fueled vehicles shall be removed during any period that the vehicle is parked outdoors awaiting testing, to prevent unusual loading of the canisters. During this time care must be taken to prevent entry of water or other contaminants

into the fuel tank. During storage in the test area while awaiting testing, the fuel tank cap(s) may be in place. The vehicle shall be moved into the test area and the following operations performed.

(b)(1) *Gasoline- and Methanol-Fueled Vehicles.* Drain the fuel tank(s) and fill with test fuel, as specified in § 86.113, to the “tank fuel volume” defined in § 86.082–2. The fuel cap(s) shall be installed within one minute after refueling.

(2) *Gaseous-Fueled Vehicles.* Vehicle fuel tanks to be filled with fuel that meets the specifications in § 86.113. Fuel tanks shall be filled to a minimum of 75% of service pressure for natural gas-fueled vehicles or a minimum of 75% of available fill volume for liquefied petroleum gas-fueled vehicles. Prior draining of the fuel tanks is not called for if the fuel in the tanks already meets the specifications in § 86.113.

(c)(1) Gasoline- and methanol-fueled vehicles shall be soaked for at least 6 hours after being refueled. Petroleumfueled diesel vehicles and gaseousfueled vehicles shall be soaked for at least 1 hour after being refueled. Following this soak period, the test vehicle shall be placed, either by being driven or pushed, on a dynamometer and operated through one Urban Dynamometer Driving Schedule (UDDS), specified in § 86.115 and appendix I of this part.

(2) Once a test vehicle has completed the refueling and vehicle soak steps specified in paragraphs (b) and (c)(1) of this section, these steps may be omitted in subsequent testing with the same vehicle and the same fuel specifications, provided the vehicle remains under laboratory ambient temperature conditions for at least 6 hours before starting the next test. In such cases, each subsequent test shall begin with the preconditioning drive specified in this paragraph. The test vehicle may not be used to set dynamometer horsepower.

(d) For unusual circumstances where the need for additional preconditioning is demonstrated by the manufacturer, such preconditioning may be allowed with the advance approval of the Administrator.

(e) The Administrator may also choose to conduct or require to be conducted additional preconditioning to ensure that the evaporative emission control system is stabilized in the case of gasoline-fueled and methanol-fueled vehicles, or to ensure that the exhaust system is stabilized in the case of petroleum- and methanol-fueled diesel vehicles. The preconditioning shall consist of one of the following:

(1) *For gasoline- and methanol-fueled vehicles.* (i) Additional preconditioning shall consist of no more than 50 miles of mileage accumulation under typical driving conditions, either on the road or on a dynamometer.

(ii) In the case of repeat testing on a flexible-fueled vehicle, in which the test fuel is changed, the following preconditioning procedure shall be used. This additional preconditioning allows the vehicle to adapt to the new fuel before the next test run.

(A) Purge the vehicle’s evaporative canister for 60 minutes at 0.8 cfm.

(B) Drain the fuel tank(s) and fill with 3 gallons of the test fuel.

(C) Start the vehicle and allow it to idle for 1 minute.

(D) Drain the fuel tank(s) and fill with the new test fuel to the “tank fuel volume” defined in § 86.082–2. The average temperature of the dispensed fuel shall be less than 60 °F.

(E) Conduct a heat build according to the procedure specified in § 86.133–90.

(F) The vehicle shall be placed, either by being driven or pushed, on a dynamometer and operated through one UDDS, specified in § 86.115 and appendix I of this part.

## WLTP-DTP-01-02

(G) Following the dynamometer drive, the vehicle shall be turned off for 5 minutes, then restarted and allowed to idle for 1 minute. The vehicle shall then be turned off for 1 minute, and allowed to idle again for 1 minute.

(H) After the vehicle is turned off the last time, it may be tested for evaporative and exhaust emissions, starting with paragraph (a) of this section.

(2) *For petroleum-fueled diesel, methanol-fueled diesel, and gaseous-fueled vehicles.* The preconditioning shall consist of either of the following:

(i) An initial one hour minimum soak and, one, two, or three driving cycles of the UDDS, as described in paragraph

(c) of this section, each followed by a soak of at least one hour with engine off, engine compartment cover closed and cooling fan off. The vehicle may be driven off the dynamometer following each UDDS for the soak period; or

(ii) For abnormally treated vehicles, as defined in § 86.085-2 or § 86.1803-01 as applicable, two Highway Fuel Economy Driving Schedules, found in 40 CFR part 600, appendix I, run in immediate succession, with the road load power set at twice the value obtained from § 86.129-80.

(f)(1) *Gasoline- and methanol-fueled vehicles.* After completion of the preconditioning drive, the vehicle shall be driven off the dynamometer. The vehicle's fuel tank(s) shall be drained and then filled with test fuel, as specified in § 86.113, to the "tank fuel volume" defined in § 86.082-2. The vehicle shall be refueled within 1 hour after completion of the preconditioning drive. The fuel cap(s) shall be installed within 1 minute after refueling. The vehicle shall be parked within five minutes after refueling.

(2) *Petroleum-fueled diesel vehicles.* Within five minutes after completion after the preconditioning drive, the vehicle shall be driven off the dynamometer and parked.

(3) *Gaseous-fueled vehicles.* After completion of the preconditioning drive, the vehicle shall be driven off the dynamometer. Vehicle fuel tanks shall be refilled with fuel that meets the specifications in § 86.113. Fuel tanks shall be filled to a minimum of 75% of service pressure for natural gas-fueled vehicles or a minimum of 75% of available fill volume for liquefied petroleum gas-fueled vehicles. Prior draining of the fuel tanks is not called for if the fuel in the tanks already meets the specifications in § 86.113. The vehicle shall be parked within five minutes after refueling, or, in the absence of refueling, within five minutes after completion of the preconditioning drive.

(g) The vehicle shall be soaked for not less than 12 hours nor more than 36 hours between the end of the refueling event and the beginning of the cold start exhaust emission test.

507 Fuel dispensing spitback procedure.

(a) The vehicle is fueled at a rate of 10 gal/min to test for fuel spitback emissions. All liquid fuel spitback emissions that occur during the test are collected in a bag made of a material impermeable to hydrocarbons or methanol. The bag shall be designed and used so that liquid fuel does not spit back onto the vehicle body, adjacent floor, etc., and it must not impede the free flow of displaced gasoline vapor from the orifice of the filler pipe. The bag must be designed to permit passage of the dispensing nozzle through the bag. If the bag has been used for previous

testing, sufficient time shall be allowed for the bag to dry out. The dispensing nozzle shall be a commercial model, not equipped with vapor recovery hardware.

(b) Ambient temperature levels encountered by the test vehicle shall be not less than 68 °F nor more than 86 °F. The temperatures monitored during testing must be representative of those experienced by the test vehicle. The vehicle shall be approximately level during all phases of the test sequence to prevent abnormal fuel distribution.

(c) Measure and record the mass of the bag to be used for collecting spitback emissions to the nearest 0.01 gram.

(d) Drain the fuel tank(s) and fill with test fuel, as specified in § 86.113, to 10 percent of the reported nominal fuel tank capacity. The fuel cap(s) shall be installed immediately after refueling.

(e) The vehicle shall be soaked at 80 ± 6 °F (27 ± 3 °C) for a minimum of six hours, then placed, either by being driven or pushed, on a dynamometer and operated through one Urban Dynamometer Driving Schedule (specified in § 86.115 and appendix I of this part). The test vehicle may not be used to set dynamometer horsepower.

(f) Following the preconditioning drive, the vehicle shall be moved or driven at minimum throttle to the refueling area.

(g) All areas in proximity to the vehicle fuel fill orifice and the dispenser nozzle itself shall be completely dry of liquid fuel.

(h) The fuel filler neck shall be snugly fitted with the vented bag to capture any fuel emissions. The fuel nozzle shall be inserted through the bag into the filler neck of the test vehicle to its maximum penetration. The plane of the nozzle's handle shall be perpendicular to the floor of the laboratory.

(i) The fueling procedure consists of dispensing fuel through a nozzle, interrupted by a series of automatic shutoffs. A minimum of 3 seconds shall elapse between any automatic shutoff and subsequent resumption of dispensing. Dispensing may not be manually terminated, unless the test vehicle has already clearly failed the test. The vehicle shall be fueled according to the following procedure:

(1) The fueling operation shall be started within 4 minutes after the vehicle is turned off and within 8 minutes after completion of the preconditioning drive. The average temperature of the dispensed fuel shall be 65 ± 5 °F (18 ± 3 °C).

(2) The fuel shall be dispensed at a rate of 9.8 ± 0.3 gallons/minute (37.1 ± 1.1 L/min) until the automatic shutoff is activated.

(3) If the automatic shutoff is activated before the nozzle has dispensed an amount of fuel equal to 70 percent of the tank's nominal capacity, the dispensing may be resumed at a reduced rate. Repeat as necessary until the nozzle has dispensed an amount of fuel equal to at least 70 percent of the tank's nominal capacity.

(4) Once the automatic shutoff is activated after the nozzle has dispensed an amount of fuel equal to 70 percent of the tank's nominal capacity, the fuel shall be dispensed at a rate of 5 ± 1 gallons/minute (19 ± 4 L/min) for all subsequent dispensing. Dispensing shall be restarted two additional times.

(5) If the nozzle has dispensed an amount of fuel less than 85 percent of the tank's nominal capacity after the two additional dispensing restarts, dispensing shall be resumed, and shall

## WLTP-DTP-01-02

continue through as many automatic shutoffs as necessary to achieve this level. This completes the fueling procedure.

(j) Withdraw the nozzle from the vehicle and the bag, holding the tip of the nozzle upward to avoid any dripping into the bag.

(k) Within 1 minute after completion of the fueling event, the bag shall be folded to minimize the vapor volume inside the bag. The bag shall be folded as quickly as possible to prevent evaporation of collected emissions.

(l) Within 5 minutes after completion of the fueling event, the mass of the bag and its contents shall be measured and recorded (consistent with paragraph (c) of this section). The bag shall be weighed as quickly as possible to prevent evaporation of collected emissions.

- Prep drive cycles
- Warm-up drive cycles

153 Vehicle and canister preconditioning; refueling test.

(a) *Vehicle and canister preconditioning.* Vehicles and vapor storage canisters shall be preconditioned in accordance with the preconditioning procedures for the supplemental two-diurnal evaporative emissions test specified in § 86.132–96 (a) through (j). For vehicles equipped with non-integrated refueling emission control systems, the canister must be loaded using the method involving butane loading to breakthrough (see § 86.132–96(j)(1)).

(b) *Seal test.* The Administrator may choose to omit certain canister load and purge steps, and replace them with a bench purge of the refueling canister(s), in order to verify the adequacy of refueling emission control system seals. Failure of this seal test shall constitute a failure of the refueling emission control test. For integrated systems, this bench purge may be performed after the exhaust testing in order to obtain exhaust emission test results. Non-integrated system seal testing shall be performed using paragraph (b)(1) of this section.

(1) *Without the exhaust emission test.* The Administrator may conduct the canister preconditioning by purging the canister(s) with at least 1200 canister bed volumes of ambient air (with humidity controlled to 50% ±25 grains of water vapor per pound of dry air) maintained at a nominal flow rate of 0.8 cfm directly following the preconditioning drive described in § 86.132–96 (c) through (e). In this case, the canister loading procedures and the vehicle driving procedures described in § 86.132–96 (f) through (j) and in paragraphs (c) through (d) of this section shall be omitted, and the 10 minute and 60 minute time requirements of paragraph (e) of this section shall apply to time after completion of the bench purge. In the case of multiple refueling canisters, each canister shall be purged separately.

(2) *With the exhaust emission test.* The Administrator may conduct the canister preconditioning by purging the canister(s) directly after the exhaust test (see paragraph (c)(1) of this section). The canister shall be purged with at least 1200 canister bed volumes of ambient air (with humidity controlled to 50% ±25 grains of water vapor per pound of dry air) maintained at a nominal flow rate of 0.8 cfm. In this case, the vehicle driving procedures described in paragraphs (c)(2) through (d) of this section shall be omitted, and the 10 minute and 60 minute time requirements of paragraph (e) of this section shall apply to time after completion of the bench purge. In the case of multiple refueling canisters, each canister shall be purged separately.

(c) *Canister purging; integrated systems.* (1) Vehicles to be tested for exhaust emissions only shall be processed according to §§ 86.135–94 through 86.137–96. Vehicles to be tested for

refueling emissions shall be processed in accordance with the procedures in §§ 86.135–94 through 86.137–96, followed by the procedures outlined in paragraph (c)(2) of this section.

(2) To provide additional opportunity for canister purge, conduct additional driving on a dynamometer, within one hour of completion of the hot start exhaust test, by operating the test vehicle through one UDDS, a 2 minute idle, two NYCCs, another 2 minute idle, another UDDS, then another 2 minute idle (see § 86.115–78 and appendix I of this part). Fifteen seconds after the engine starts, place the transmission in gear. Twenty seconds after the engine starts, begin the initial vehicle acceleration of the driving schedule. The transmission shall be operated according to the specifications of § 86.128–79 during the driving cycles. The vehicle’s air conditioner (if so equipped) shall be turned off. Ambient temperature shall be controlled as specified in § 86.151–98. It is not necessary to monitor and/or control in-tank fuel temperatures.

(i) The fixed-speed fan specified in § 86.135–94(b) may be used for engine cooling. If a fixed-speed fan is used, the vehicle’s hood shall be opened. (ii) Alternatively, the roadspeedmodulated fan specified in § 86.107–96(d)(1) may be used for engine cooling. If a road-speed modulated fan is used, the vehicle’s hood shall be closed.

(d) *Canister purging: non-integrated systems.* Within one hour of completion of canister loading to breakthrough, the fuel tank(s) shall be further filled to 95 percent of nominal tank capacity determined to the nearest one-tenth of a U.S. gallon (0.38 liter) with the fuel specified in § 86.113–94. During this fueling operation, the refueling emissions canister(s) shall be disconnected, unless the manufacturer specifies that the canister(s) should not be disconnected. Following completion of refueling, the refueling emissions canister(s) shall be reconnected, if the canister was disconnected during refueling. Special care shall be taken during this step to avoid damage to the components and the integrity of the fuel system. Vehicle driving to purge the refueling canister(s) shall be performed using either the chassis dynamometer procedure or the test track procedure, as described in paragraphs (d)(1) and (d)(2) of this section. The Administrator may choose to shorten the vehicle driving for a partial refueling test as described in paragraph (d)(3) of this section. For vehicles equipped with dual fuel tanks, the required volume of fuel shall be driven out of one tank, the second tank shall be selected as the fuel source, and the required volume of fuel shall be driven out of the second tank.

(1) *Chassis dynamometer procedure.* (i) Vehicle driving on a chassis dynamometer shall consist of repeated drives with the UDDS until 85 percent of fuel tank capacity has been consumed. Driving in testing performed by manufacturers may be terminated before 85 percent of the fuel tank capacity has been consumed, provided that driving is not terminated partway through a UDDS cycle. Driving in testing performed by the Administrator may be terminated after the same number of UDDS cycles as driven in the manufacturer’s certification testing.

(ii) Except with the advance approval of the Administrator, the number of UDDSs required to consume 85 percent of tank fuel capacity (total capacity of both tanks when the vehicle is equipped with dual fuel tanks) shall be determined from the fuel economy on the UDDS applicable to the test vehicle and from the number of gallons to the nearest 0.1 gallon (0.38 liter) that constitutes 85 percent of tank volume. If this “fuel consumed point” occurs partway through a UDDS cycle, the cycle shall be completed in its entirety.

(iii) For vehicles equipped with dual fuel tanks, fuel switching from the first tank to the second tank shall occur at the 10 percent volume of the first tank regardless of the point in the UDDS cycle at which this occurs.

## WLTP-DTP-01-02

(iv) If necessary to accommodate work schedules, the engine may be turned off and the vehicle parked on the dynamometer. The vehicle may be parked off of the dynamometer to facilitate maintenance or repairs if required.

(v) During the driving on the dynamometer, a cooling fan(s) shall be positioned as described in § 86.135–94(b).

(2) *Test track procedure.* (i) Vehicle driving on a test track shall consist of repeated drives with the UDDS until 85 percent of fuel tank capacity has been consumed. Driving performed by manufacturers may be terminated before 85 percent of the fuel tank capacity has been consumed, provided that driving is not terminated partway through a UDDS cycle. Driving performed by the Administrator may be terminated after the same number of UDDS cycles as driven in the manufacturer's certification testing.

(ii) If the distance from the emission laboratory to the test track is less than 5 miles (8.05 km) the vehicle may be driven to the test track at a speed not to exceed 25 mph. If the distance is greater than 5 miles (8.05 km) the vehicle shall be moved to the test track with the engine off.

(iii) Except with the advance approval of the Administrator, the number of UDDSs required to consume 85 percent of tank fuel capacity (total capacity of both tanks when the vehicle is equipped with dual fuel tanks) shall be determined from the fuel economy on the UDDS applicable to the test vehicle and from the number of gallons to the nearest 0.1 gallon (0.38 liter) that constitutes 85 percent of tank volume. If this "fuel consumed point" occurs partway through a UDDS cycle, the cycle shall be completed in its entirety.

(iv) The vehicle shall be driven at a speed not to exceed 25 mph from the test track to the laboratory provided the distance from the test track to the laboratory does not exceed 5 miles (8.05 km). If the distance from the test track to the emission laboratory is greater than 5 miles (8.05 km) the vehicle shall be moved from the test track with the engine off. (v) For vehicles equipped with dual fuel tanks, fuel switching from the first tank to the second tank shall occur at the 10 percent volume of the first tank regardless of the point in the UDDS cycle at which this occurs.

(vi) If necessary to accommodate work schedules, the engine may be turned off and the vehicle parked on the test track. The vehicle may be parked off of the test track to facilitate maintenance or repairs if required. If the vehicle is moved from the test track, it shall be returned to the track with the engine off when mileage accumulation is to be resumed.

(3) *Drive schedule for partial refueling test.* The Administrator may conduct a partial refueling test involving a shortening of the drive procedures described in paragraphs (d) (1) and (2) of this section and a modified soak and refueling procedure as described in paragraph (e) of this section and § 86.154–98(e)(7)(i). The drive shall be performed as described in paragraph (d) (1) or (2) of this section except that the drive shall be terminated when at least 10 percent but no more than 85 percent of the fuel tank nominal capacity has been consumed and not partway through a UDDS cycle. The amount of fuel consumed in the drive shall be determined by multiplying the number of UDDSs driven by the mileage accumulated per UDDS and dividing by the fuel economy for the UDDS applicable to the test vehicle.

(e) *Vehicle cool down*—(1) *Partial refueling test.* If the Administrator is conducting the non-integrated system partial refueling test, after the driving procedure specified in paragraph (d)(3)

of this section, the vehicle shall be parked (without starting the engine) and soaked at 80 ± 3 °F (27 ± 1.7 °C) for a minimum of 1 hour and a maximum of 6 hours.

(2) *For all other refueling emission tests.* Within 10 minutes of completion of refueling emissions canister stabilization (see paragraph (c) or (d) of this section), the refueling emissions canister(s) shall be disconnected, unless the manufacturer specifies that the refueling canister(s) should not be disconnected. Within 60 minutes of completion of refueling emissions canister stabilization (see paragraph (c) or (d) of this section), the vehicle fuel tank(s) shall be drained, the fuel tank(s) fueled to 10 percent of nominal tank capacity determined to the nearest one-tenth of a U.S. gallon (0.38 liter) with the specified fuel, and the vehicle parked (without starting the engine) and soaked at 80 ± 3 °F (27 ± 1.7 °C) for a minimum of 6 hours and a maximum of 24 hours.

#### Soak times

The testing sequence includes an approved preconditioning cycle, a 10 minute soak with the engine turned off.

#### **510 Dynamometer procedure.**

(a) *Overview.* The dynamometer run consists of [two] tests, a “cold” start test, after a minimum [12]-hour and a maximum [36]-hour soak, and a “hot” start test following the “cold” start by [10] minutes. Engine startup (with all accessories turned off), operation over the [drive cycle] and engine shutdown make a complete cold start test. [Engine startup and operation over the first 505 seconds of the driving schedule complete the hot start test.] The exhaust emissions are diluted with ambient air in the dilution tunnel. A dilution tunnel is not required for testing vehicles waived from the requirement to measure particulates. A minimum of [three] particulate samples are collected on filters for weighing; the first sample is collected during the first 505 seconds of the cold start test; the second sample is collected during the stabilized portion of the cold start test (including shutdown); the third sample is collected during the hot start test. Continuous proportional samples of gaseous emissions are collected for analysis during each test phase. Parallel bag samples of dilution air are analyzed for THC, CO, CO<sub>2</sub>, CH<sub>4</sub>, NOX, and N<sub>2</sub>O. Ethanol and carbonyls are analyzed if applicable.

(b) During dynamometer operation, a fixed speed cooling fan shall be positioned so as to direct cooling air to the vehicle in an appropriate manner with the engine compartment cover open. In the case of vehicles with front engine compartments, the fan shall be squarely positioned within 12 inches (30.5 centimeters) of the vehicle. In the case of vehicles with rear engine compartments (or if special designs make the above impractical), the cooling fan shall be placed in a position to provide sufficient air to maintain vehicle cooling. The fan capacity shall normally not exceed 5300 cfm (2.50 m<sup>3</sup>/s). If, however, the manufacturer can show that during field operation the vehicle receives additional cooling, and that such additional cooling is needed to provide a representative test, the fan capacity may be increased or additional fans used if approved in advance by the Administrator.

(c) The vehicle speed as measured from the dynamometer rolls shall be used. A speed vs. time recording, as evidence of dynamometer test validity, shall be supplied on request of the Administrator.

## WLTP-DTP-01-02

- (d) Practice runs over the prescribed driving schedule may be performed at test point, provided an emission sample is not taken, for the purpose of finding the appropriate throttle action to maintain the proper speed-time relationship, or to permit sampling system adjustment. Accelerator pedal movement shall be sufficient to closely follow micro-transient speed variations.
- (e) The drive wheel tires are to be inflated to the manufacturer recommended pressure. The drive wheel tire pressure must be the same as that utilized during dynamometer road load coefficient determination, and shall be reported with the test results.
- (f) If the dynamometer has not been operated immediately preceding the test, it shall be warmed up as recommended by the dynamometer manufacturer.
- (h) The driving distance, as measured by counting the number of dynamometer roll or shaft revolutions, shall be determined for the transient cold start, stabilized cold start, and transient hot start phases of the test. Driving distance may also be measured by integrating speed from high-resolution encoder system.
- (i) Four-wheel drive and all-wheel drive vehicles may be tested either in a four-wheel drive or a two-wheel drive mode of operation. In order to test in the two-wheel drive mode, four-wheel drive and all-wheel drive vehicles may have one set of drive wheels disengaged; four-wheel and all-wheel drive vehicles which can be shifted to a two wheel mode by the driver may be tested in a two-wheel drive mode of operation. This alternative may be used as long as emission results are not affected.

### 515 Pre-test checks.

- (g) Verify the amount of nonmethane contamination in the exhaust and background HC sampling systems within 8 hours before the start of the first test interval of each duty-cycle sequence for laboratory tests. You may verify the contamination of a background HC sampling system by reading the last bag fill and purge using zero gas. For any NMHC measurement system that involves separately measuring methane and subtracting it from a THC measurement, verify the amount of THC contamination using only the THC analyzer response. There is no need to operate any separate methane analyzer for this verification, however you may measure and correct for THC contamination in the CH<sub>4</sub> sample train for the cases where NMHC is determined by subtracting CH<sub>4</sub> from THC, using an NMC as configured in 365(d), (e), and (f); and the calculations in 660(b)(2). Perform this verification as follows:
  - (1) Select the HC analyzer range for measuring the flow-weighted mean concentration expected at the HC standard.
  - (2) Zero the HC analyzer at the analyzer zero or sample port. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of 750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O<sub>2</sub> expected during testing.
  - (3) Span the HC analyzer using span gas introduced at the analyzer span or sample port. Span on a carbon number basis of one (C<sub>1</sub>). For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.
  - (4) Overflow zero gas at the HC probe inlet or into a tee near the probe outlet.
  - (5) Measure the THC concentration in the sampling and background systems as follows:

- (i) For continuous sampling, record the mean THC concentration as overflow zero air flows.
- (ii) For batch sampling, fill the sample medium (e.g., bag) and record its mean THC concentration.
- (iii) For the background system, record the mean THC concentration of the last fill and purge.
- (6) Record this value as the initial THC concentration,  $x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$ , and use it to correct measured values as described in 660.
- (7) If any of the  $x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$  values exceed the greatest of the following values, determine the source of the contamination and take corrective action, such as purging the system during an additional preconditioning cycle or replacing contaminated portions:
  - (i) 2 % of the flow-weighted mean wet, net concentration expected at the HC (THC or NMHC) standard.
  - (ii) 2 % of the flow-weighted mean wet, net concentration of HC (THC or NMHC) measured during testing.
  - (iii) 2  $\mu\text{mol/mol}$ .

### **520 Emission Test Sequence.**

The following sequence shall be performed in conjunction with each series of measurements:

- (a) For CO, CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>x</sub>, and for Otto-cycle HC:
  - (1) Zero the analyzers and obtain a stable zero reading. (2) Introduce span gases and set instrument gains. In order to avoid errors, span and calibrate at the same flow rates used to analyze the test sample. Span gases should have concentrations equal to 75 to 100 percent of full scale.. Record observed concentrations.
  - (3) Check zeroes; repeat the procedure in paragraphs (a) (1) and (2) of this section if required.
  - (4) Check sample flow rates and/or pressures if not automatically monitored by the analytical system.
  - (5) Measure THC, CO, CO<sub>2</sub>, CH<sub>4</sub>, and NO<sub>x</sub> concentrations of samples. NOTE: In order to minimize errors, HFID flow rate and pressure during zero and span (and background bag reading) must be exactly the same as that used during testing.
  - (6) At the conclusion of the test, and optionally at intermediate points in the test check zero and span points. If difference is greater than 2 percent of full scale, repeat the procedure in paragraphs (a) (1) through (5) of this section.
- (b) For petroleum-fueled, natural gas-fueled and liquefied petroleum gas fueled (if HFID is used) diesel vehicle HC:
  - (1) Zero HFID analyzer and obtain a stable zero reading.
  - (2) Introduce span gas and set instrument gains. Span gas should have concentration equal to 75 to 100 percent of full scale.
  - (3) Check zero as in paragraph (b)(1) of this section.
  - (4) Introduction of zero and span gas into the analyzer can be accomplished by either of the following methods:
    - (i) Close heated valve in THC sample (see Figures B94–5 or B94–6) and allow gases to enter HFID.
    - (ii) Connect zero and span line directly to THC sample probe and introduce gases at a flow rate greater than 125 percent of the HFID flow rate with the CVS blower operating (see Figures B94–5 or B94–6). Excess flow must be allowed to exit probe inlet.

## **WLTP-DTP-01-02**

NOTE: In order to minimize errors, HFID flow rate and pressure during zero and span (and background bag reading) must be exactly the same as that used during testing.

(5) Continuously integrate dilute THC emission levels during test. Background samples are collected in sample bags and analyzed as in paragraphs

(b)(4) (i) or (ii) of this section.

(6) Check zero and span as in paragraphs (b) (1) through (4) of this section. If difference is greater than 2 percent of full scale, void test and check for THC “hangup” or electronic drift in analyzer.

(c) For CH<sub>4</sub> analysis:

(1) In the event that the procedure results in negative NMHC<sub>wm</sub> values (as may occur with high methane fractions), any negative NMHC<sub>wm</sub> value whose absolute value is less than 10 percent of the NMHC standard shall be rounded to zero. Negative NMHC<sub>wm</sub> values whose absolute value is more than 10 percent of the NMHC standard shall require sample remeasurement. If the 10 percent criterion cannot be met after remeasurement, the test will be void.

(2) Other sampling procedures may be used if shown to yield equivalent or superior results and if approved in advance by the Administrator.

### **525 Engine starting and restarting.**

(a) (Cold-start procedure)

(1) The engine shall be started according to the manufacturer’s recommended starting procedures in the owner’s manual. The initial idle period shall begin when the engine starts.

(2) The transmission shall be placed in gear 15 seconds after the engine is started. If necessary, braking may be employed to keep the drive wheels from turning.

(3) The operator may use the, accelerator pedal, etc., where necessary to keep the engine running.

(b) If the vehicle does not start after the manufacturer’s recommended cranking time (or 10 continuous seconds in the absence of a manufacturer’s recommendation), cranking shall cease for the period recommended by the manufacturer (or 10 seconds in the absence of a manufacturer’s recommendation). This may be repeated for up to three start attempts. If the vehicle does not start after three attempts, the reason for failure to start shall be determined. Sampling systems shall be shut off and either the CVS should be turned off, or the exhaust tube disconnected from the tailpipe during the diagnostic period. The vehicle shall be rescheduled for testing from a cold start.

(d) If the engine “false starts” the operator shall repeat the recommended starting procedure.

(e) Stalling. (1) If the engine stalls during an idle period, the engine shall be restarted immediately and the test continued. If the engine cannot be started soon enough to allow the vehicle to follow the next acceleration as prescribed, the driving schedule indicator shall be stopped. When the vehicle restarts, the driving schedule indicator shall be reactivated.

(2) If the engine stalls during some operating mode other than idle, the driving schedule indicator shall be stopped, the vehicle shall then be restarted and accelerated to the speed required at that point in the driving schedule and the test continued.

(3) If the vehicle will not restart within one minute, the test shall be voided, the vehicle removed from the dynamometer, corrective action taken, and the vehicle rescheduled for test. The reason for the malfunction (if determined) and the corrective action taken shall be reported to the Administrator.

#### **545 Validation of proportional flow control for batch sampling.**

For any proportional batch sample such as a bag or PM filter, demonstrate that proportional sampling was maintained using one of the following, noting that you may omit up to 5 % of the total number of data points as outliers:

(a) For any pair of flow meters, use recorded sample and total flow rates, where total flow rate means the raw exhaust flow rate for raw exhaust sampling and the dilute exhaust flow rate for CVS sampling, or their 1 Hz means with the statistical calculations in 602. Determine the standard error of the estimate, *SEE*, of the sample flow rate versus the total flow rate. For each test interval, demonstrate that *SEE* was less than or equal to 3.5 % of the mean sample flow rate.

(b) For any pair of flow meters, use recorded sample and total flow rates, where total flow rate means the raw exhaust flow rate for raw exhaust sampling and the dilute exhaust flow rate for CVS sampling, or their 1 Hz means to demonstrate that each flow rate was constant within  $\pm 2.5$  % of its respective mean or target flow rate. You may use the following options instead of recording the respective flow rate of each type of meter:

(1) Critical-flow venturi option. For critical-flow venturis, you may use recorded venturi-inlet conditions or their 1 Hz means. Demonstrate that the flow density at the venturi inlet was constant within  $\pm 2.5$  % of the mean or target density over each test interval. For a CVS critical-flow venturi, you may demonstrate this by showing that the absolute temperature at the venturi inlet was constant within  $\pm 4$  % of the mean or target absolute temperature over each test interval.

(2) Positive-displacement pump option. You may use recorded pump-inlet conditions or their 1 Hz means. Demonstrate that the flow density at the pump inlet was constant within  $\pm 2.5$  % of the mean or target density over each test interval. For a CVS pump, you may demonstrate this by showing that the absolute temperature at the pump inlet was constant within  $\pm 2$  % of the mean or target absolute temperature over each test interval.

(c) Using accepted measurement practices, demonstrate with an engineering analysis that the proportional-flow control system inherently ensures proportional sampling under all circumstances expected during testing. For example, you might use CFVs for both sample flow and total flow and demonstrate that they always have the same inlet pressures and temperatures and that they always operate under critical-flow conditions.

#### **546 Validation of minimum dilution ratio for PM batch sampling.**

Use continuous flows and/or tracer gas concentrations for transient and ramped modal cycles to validate the minimum dilution ratios for PM batch sampling as specified in 140(e)(2) over the test interval. You may use mode-average values instead of continuous measurements for discrete mode steady-state duty cycles. Determine the minimum primary and minimum overall dilution ratios using one of the following methods (you may use a different method for each stage of dilution):

(a) Determine minimum dilution ratio based on molar flow data. This involves determination of at least two of the following three quantities: raw exhaust flow (or previously diluted flow),

## WLTP-DTP-01-02

dilution air flow, and dilute exhaust flow. You may determine the raw exhaust flow rate based on the measured intake air molar flow rate and the chemical balance terms in 655. You may alternatively estimate the molar raw exhaust flow rate based on intake air, fuel rate measurements, and fuel properties, consistent with accepted measurement practices.

(b) Determine minimum dilution ratio based on tracer gas (e.g., CO<sub>2</sub>) concentrations in the raw (or previously diluted) and dilute exhaust corrected for any removed water.

(c) Use accepted measurement practices to develop your own method of determining dilution ratios.

### **550 Gas analyzer range validation, drift validation, and drift correction.**

(a) Range validation. If an analyzer operated above 100 % of its range at any time during the test, perform the following steps:

(1) For batch sampling, re-analyze the sample using the lowest analyzer range that results in a maximum instrument response below 100 %. Report the result from the lowest range from which the analyzer operates below 100 % of its range.

(2) For continuous sampling, repeat the entire test using the next higher analyzer range. If the analyzer again operates above 100 % of its range, repeat the test using the next higher range. Continue to repeat the test until the analyzer always operates at less than 100 % of its range.

(b) Drift validation and drift correction. Calculate two sets of brake-specific emission results for each test interval. Calculate one set using the data before drift correction and calculate the other set after correcting all the data for drift according to 672. Use the two sets of brake-specific emission results to validate the duty cycle for drift as follows:

(1) The duty cycle is validated for drift if you satisfy one of the following criteria:

(i) For each test interval of the duty cycle and for each measured exhaust constituent, the difference between the uncorrected and the corrected brake-specific emission values over the test interval is within  $\pm 4$  % of the uncorrected value or applicable emission standard, whichever is greater. This requirement also applies for CO<sub>2</sub>, whether or not an emission standard applies for CO<sub>2</sub>. Where no emission standard applies for CO<sub>2</sub>, the difference must be within  $\pm 4$  % of the uncorrected value. See paragraph (b)(4) of this section for exhaust constituents other than CO<sub>2</sub> for which no emission standard applies.

(ii) For the entire duty cycle and for each regulated pollutant, the difference between the uncorrected and corrected composite brake-specific emission values over the entire duty cycle is within  $\pm 4$  % of the uncorrected value or the applicable emission standard, whichever is greater. Note that for purposes of drift validation using composite brake-specific emission values over the entire duty cycle, leave unaltered any negative emission results over a given test interval (i.e., do not set them to zero). A third calculation of composite brake-specific emission values is required for final reporting. This calculation uses drift-corrected mass (or mass rate) values from each test interval and sets any negative mass (or mass rate) values to zero before calculating the composite brake-specific emission values over the entire duty cycle. This requirement also applies for CO<sub>2</sub>, whether or not an emission standard applies for CO<sub>2</sub>. Where no emission standard applies for CO<sub>2</sub>, the difference must be within  $\pm 4$  % of the uncorrected value. See paragraph (b)(4) of this section for exhaust constituents other than CO<sub>2</sub> for which no emission standard applies.

(2) If the test is not validated for drift, you may consider the test results for the duty cycle to be valid only if, using accepted measurement practices, the observed drift does not affect your ability to demonstrate compliance with the applicable emission standards. For example, if the drift-corrected value is less than the standard by at least two times the absolute difference between the uncorrected and corrected values, you may consider the data to be valid for demonstrating compliance with the applicable standard.

### **590 PM sampling media (e.g., filters) preconditioning and tare weighing.**

Before an emission test, take the following steps to prepare PM sampling media (e.g., filters) and equipment for PM measurements:

- (a) Make sure the balance and PM-stabilization environments meet the periodic verifications in 390.
- (b) Visually inspect unused sample media (e.g., filters) for defects and discard defective media.
- (d) Place unused sample media (e.g., filters) in one or more containers that are open to the PM-stabilization environment. If you are using filters, you may place them in the bottom half of a filter cassette.
- (e) Stabilize sample media (e.g., filters) in the PM-stabilization environment. Consider an unused sample medium stabilized as long as it has been in the PM-stabilization environment for a minimum of 30 min, during which the PM-stabilization environment has been within the specifications of 190.
- (f) Weigh the sample media (e.g., filters) automatically or manually, as follows:
  - (1) For automatic weighing, follow the automation system manufacturer's instructions to prepare samples for weighing. This may include placing the samples in a special container.
  - (2) For manual weighing, use accepted measurement practices to determine if substitution weighing is necessary to show that an engine meets the applicable standard. You may follow the substitution weighing procedure in paragraph (j) of this section, or you may develop your own procedure.
- (g) Correct the measured mass of each sample medium (e.g., filter) for buoyancy as described in 690. These buoyancy-corrected values are subsequently subtracted from the post-test mass of the corresponding sample media (e.g., filters) and collected PM to determine the mass of PM emitted during the test.
- (h) You may repeat measurements to determine the mean mass of each sample medium (e.g., filter). Use accepted measurement practices to exclude outliers from the calculation of mean mass values. At a minimum repeat the weighing for any excluded measurement.
- (i) If you use filters as sample media, load unused filters that have been tare-weighed into clean filter cassettes and place the loaded cassettes in a clean, covered or sealed container before removing them from the stabilization environment for transport to the test site for sampling.
- (j) Substitution weighing involves measurement of a reference weight before and after each weighing of PM sampling media (e.g., filters). While substitution weighing requires more measurements, it corrects for a balance's zero-drift and it relies on balance linearity only over a small range. This is most advantageous when quantifying net PM masses that are less than 0.1 % of the sample medium's mass. However, it may not be advantageous when net PM masses exceed 1 % of the sample medium's mass. If you utilize substitution weighing, it must be used for both pre-test and post-test weighing. The same substitution weight must be used for both

## **WLTP-DTP-01-02**

pre-test and post-test weighing. Correct the mass of the substitution weight for buoyancy if the density of the substitution weight is less than  $2.0 \text{ g/cm}^3$ . The following steps are an example of substitution weighing:

- (1) Use electrically grounded tweezers or a grounding strap, as described in 190.
- (2) Use a static neutralizer as described in 190 to minimize static electric charge on any object before it is placed on the balance pan.
- (3) Select a substitution weight that meets the requirements for calibration weights found in 790. The substitution weight must also have the same density as the weight you use to span the microbalance, and be similar in mass to an unused sample medium (e.g., filter). A 47 mm PTFE membrane filter will typically have a mass in the range of 80 to 100 mg.
- (4) Record the stable balance reading, then remove the calibration weight.
- (5) Weigh an unused sample medium (e.g., a new filter), record the stable balance reading and record the balance environment's dewpoint, ambient temperature, and atmospheric pressure.
- (6) Reweigh the calibration weight and record the stable balance reading.
- (7) Calculate the arithmetic mean of the two calibration-weight readings that you recorded immediately before and after weighing the unused sample. Subtract that mean value from the unused sample reading, then add the true mass of the calibration weight as stated on the calibration-weight certificate. Record this result. This is the unused sample's tare weight without correcting for buoyancy.
- (8) Repeat these substitution-weighing steps for the remainder of your unused sample media.
- (9) Once weighing is completed, follow the instructions given in paragraphs (g) through (i) of this section.

### **595 PM sample post-conditioning and total weighing.**

After testing is complete, return the sample media (e.g., filters) to the weighing and PM-stabilization environments.

- (a) Make sure the weighing and PM-stabilization environments meet the ambient condition specifications in 190(e)(1). If those specifications are not met, leave the test sample media (e.g., filters) covered until proper conditions have been met.
- (b) In the PM-stabilization environment, remove PM samples from sealed containers. If you use filters, remove the filter from its cassette or remove the top portion of the cassette before stabilization. When you remove a filter from a cassette, separate the top half of the cassette from the bottom half using a cassette separator designed for this purpose.
- (d) Visually inspect the sampling media (e.g., filters) and collected particulate. If either the sample media (e.g. filters) or particulate sample appear to have been compromised, or the particulate matter contacts any surface other than the filter, the sample may not be used to determine particulate emissions. In the case of contact with another surface, clean the affected surface before continuing.
- (e) To stabilize PM samples, place them in one or more containers that are open to the PM-stabilization environment, as described in 190. If you expect that a sample medium's (e.g., filter's) total surface concentration of PM will be less than  $400 \mu\text{g}$ , assuming a 38 mm diameter filter stain area, expose the filter to a PM-stabilization environment meeting the specifications of 190 for at least 30 minutes before weighing. If you expect a higher PM concentration or do not

know what PM concentration to expect, expose the filter to the stabilization environment for at least 60 minutes before weighing. Note that 400  $\mu\text{g}$  on sample media (e.g., filters) is an approximate net mass of 0.07 g/kW·hr for a hot-start test with compression-ignition engines or 50 mg/mile for light-duty vehicles.

(f) Repeat the procedures in 590(f) through (i) to determine post-test mass of the sample media (e.g., filters).

(g) Subtract each buoyancy-corrected tare mass of the sample medium (e.g., filter) from its respective buoyancy-corrected mass. The result is the net PM mass,  $m_{\text{PM}}$ . Use  $m_{\text{PM}}$  in emission calculations in 650.

Records required

## WLTP-DTP-01-02

### Calculations and Data Requirements

#### 601 Overview.

(a) This section describes how to—

(1) Use the signals recorded before, during, and after an emission test to calculate g/mile emissions of each regulated pollutant.

(2) Perform calculations for calibrations and performance checks.

(3) Determine statistical values.

(b) You may use data from multiple systems to calculate test results for a single emission test, consistent with accepted measurement practices. You may also make multiple measurements from a single batch sample, such as multiple weighings of a PM filter or multiple readings from a bag sample. You may not use test results from multiple emission tests to report emissions. We allow weighted means where appropriate. You may discard statistical outliers, but you must report all results.

#### 602 Statistics.

(a) Overview. This section contains equations and example calculations for statistics that are specified in this part. In this section we use the letter "y" to denote a generic measured quantity, the superscript over-bar "¯" to denote an arithmetic mean, and the subscript "ref" to denote the reference quantity being measured.

(b) Arithmetic mean. Calculate an arithmetic mean,  $\bar{y}$ , as follows:

$$\bar{y} = \frac{\sum_{i=1}^N y_i}{N}$$

Eq. 602-1

*Example:*

$$N = 3$$

$$y_1 = 10.60$$

$$y_2 = 11.91$$

$$y_N = y_3 = 11.09$$

$$\bar{y} = \frac{10.60 + 11.91 + 11.09}{3}$$

$$\bar{y} = 11.20$$

(c) Standard deviation. Calculate the standard deviation for a non-biased (e.g., N-1) sample,  $\sigma$ , as follows:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N-1)}}$$

Eq. 602-2

*Example:*

$$N = 3$$

$$y_1 = 10.60$$

$$y_2 = 11.91$$

$$y_N = y_3 = 11.09$$

$$\bar{y} = 11.20$$

$$\sigma_y = \sqrt{\frac{(10.60 - 11.2)^2 + (11.91 - 11.2)^2 + (11.09 - 11.2)^2}{2}}$$

$$\sigma_y = 0.6619$$

(d) Root mean square. Calculate a root mean square,  $rms_y$ , as follows:

$$rms_y = \sqrt{\frac{1}{N} \sum_{i=1}^N y_i^2}$$

Eq. 602-3

*Example:*

$$N = 3$$

$$y_1 = 10.60$$

$$y_2 = 11.91$$

$$y_N = y_3 = 11.09$$

$$rms_y = \sqrt{\frac{10.60^2 + 11.91^2 + 11.09^2}{3}}$$

$$rms_y = 11.21$$

(e) Accuracy. Determine accuracy as described in this paragraph (e).. Make multiple measurements of a standard quantity to create a set of observed values,  $y_i$ , and compare each observed value to the known value of the standard quantity. The standard quantity may have a single known value, such as a gas standard, or a set of known values of negligible range, such as a known applied pressure produced by a calibration device during repeated applications. The known value of the standard quantity is represented by  $y_{ref_i}$ . If you use a standard quantity with a single value,  $y_{ref_i}$  would be constant. Calculate an accuracy value as follows:

$$accuracy = \left| \frac{1}{N} \sum_{i=1}^N (y_i - y_{ref_i}) \right|$$

Eq. 602-4

*Example:*

$$y_{ref} = 1800.0$$

$$N = 3$$

$$y_1 = 1806.4$$

$$y_2 = 1803.1$$

$$y_3 = 1798.9$$

## WLTP-DTP-01-02

$$accuracy = \left| \frac{1}{3} \left( (1806.4 - 1800.0) + (1803.1 - 1800.0) + (1798.9 - 1800.0) \right) \right|$$

$$accuracy = \left| \frac{1}{3} \left( (6.4) + (3.1) + (-1.1) \right) \right|$$

$$accuracy = 2.8$$

(f) t-test. Determine if your data passes a *t*-test by using the following equations and tables:

(1) For an unpaired *t*-test, calculate the *t* statistic and its number of degrees of freedom,  $\nu$ , as follows:

$$t = \frac{|\bar{y}_{\text{ref}} - \bar{y}|}{\sqrt{\frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N}}}$$

Eq. 602-5

$$\nu = \frac{\left( \frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N} \right)^2}{\frac{(\sigma_{\text{ref}}^2/N_{\text{ref}})^2}{N_{\text{ref}}-1} + \frac{(\sigma_y^2/N)^2}{N-1}}$$

Eq. 602-6

*Example:*

$$\bar{y}_{\text{ref}} = 1205.3$$

$$\bar{y} = 1123.8$$

$$\sigma_{\text{ref}} = 9.399$$

$$\sigma_y = 10.583$$

$$N_{\text{ref}} = 11$$

$$N = 7$$

$$t = \frac{|1205.3 - 1123.8|}{\sqrt{\frac{9.399^2}{11} + \frac{10.583^2}{7}}}$$

$$t = 16.63$$

$$\sigma_{\text{ref}} = 9.399$$

$$\sigma_y = 10.583$$

$$N_{\text{ref}} = 11$$

$$N = 7$$

$$\nu = \frac{\left( \frac{9.399^2}{11} + \frac{10.583^2}{7} \right)^2}{\frac{(9.399^2/11)^2}{11-1} + \frac{(10.583^2/7)^2}{7-1}}$$

$$\nu = 11.76$$

(2) For a paired  $t$ -test, calculate the  $t$  statistic and its number of degrees of freedom,  $\nu$ , as follows, noting that the  $\varepsilon_i$  are the errors (e.g., differences) between each pair of  $y_{refi}$  and  $y_i$ :

$$t = \frac{|\bar{\varepsilon}| \cdot \sqrt{N}}{\sigma_{\varepsilon}}$$

Eq. 602-7

*Example:*

$$\bar{\varepsilon} = -0.12580$$

$$N = 16$$

$$\sigma_{\varepsilon} = 0.04837$$

$$t = \frac{|-0.12580| \cdot \sqrt{16}}{0.04837}$$

$$t = 10.403$$

$$\nu = N - 1$$

*Example:*

$$N = 16$$

$$\nu = 16 - 1$$

$$\nu = 15$$

(3) Use Table 1 of this section to compare  $t$  to the  $t_{crit}$  values tabulated versus the number of degrees of freedom. If  $t$  is less than  $t_{crit}$ , then  $t$  passes the  $t$ -test. The Microsoft Excel software package contains a TINV function that returns results equivalent to §602 Table 1 and may be used in place of Table 1.

Table 1 of 602–  
Critical  $t$  values versus number of degrees of freedom,  $\nu$ <sup>1</sup>

$\nu$	Confidence	
	90%	95%
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
18	1.734	2.101
20	1.725	2.086
22	1.717	2.074
24	1.711	2.064
26	1.706	2.056
28	1.701	2.048
30	1.697	2.042
35	1.690	2.030
40	1.684	2.021
50	1.676	2.009
70	1.667	1.994
100	1.660	1.984
1000+	1.645	1.960

<sup>1</sup> Use linear interpolation to establish values not shown here.

(g) F-test. Calculate the  $F$  statistic as follows:

$$F_y = \frac{\sigma_y^2}{\sigma_{\text{ref}}^2}$$

Eq. 602-8

*Example:*

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N-1)}} = 10.583$$

$$\sigma_{\text{ref}} = \sqrt{\frac{\sum_{i=1}^{N_{\text{ref}}} (y_{\text{ref}i} - \bar{y}_{\text{ref}})^2}{(N_{\text{ref}} - 1)}} = 9.399$$

$$F = \frac{10.583^2}{9.399^2}$$

$$F = 1.268$$

(1) For a 90 % confidence  $F$ -test, use Table 2 of this section to compare  $F$  to the  $F_{\text{crit}90}$  values tabulated versus  $(N-1)$  and  $(N_{\text{ref}} - 1)$ . If  $F$  is less than  $F_{\text{crit}90}$ , then  $F$  passes the  $F$ -test at 90 % confidence.

(2) For a 95 % confidence  $F$ -test, use Table 3 of this section to compare  $F$  to the  $F_{\text{crit}95}$  values tabulated versus  $(N-1)$  and  $(N_{\text{ref}} - 1)$ . If  $F$  is less than  $F_{\text{crit}95}$ , then  $F$  passes the  $F$ -test at 95 % confidence.

**WLTP-DTP-01-02**

Table 2 of 602–Critical  $F$  values,  $F_{crit90}$ , versus  $N-1$  and  $N_{ref}-1$  at 90 % confidence

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
$N_{ref}-1$																			
1	39.86	49.50	53.59	55.83	57.24	58.20	58.90	59.43	59.85	60.19	60.70	61.22	61.74	62.00	62.26	62.52	62.79	63.06	63.32
2	8.526	9.000	9.162	9.243	9.293	9.326	9.349	9.367	9.381	9.392	9.408	9.425	9.441	9.450	9.458	9.466	9.475	9.483	9.491
3	5.538	5.462	5.391	5.343	5.309	5.285	5.266	5.252	5.240	5.230	5.216	5.200	5.184	5.176	5.168	5.160	5.151	5.143	5.134
4	4.545	4.325	4.191	4.107	4.051	4.010	3.979	3.955	3.936	3.920	3.896	3.870	3.844	3.831	3.817	3.804	3.790	3.775	3.761
5	4.060	3.780	3.619	3.520	3.453	3.405	3.368	3.339	3.316	3.297	3.268	3.238	3.207	3.191	3.174	3.157	3.140	3.123	3.105
6	3.776	3.463	3.289	3.181	3.108	3.055	3.014	2.983	2.958	2.937	2.905	2.871	2.836	2.818	2.800	2.781	2.762	2.742	2.722
7	3.589	3.257	3.074	2.961	2.883	2.827	2.785	2.752	2.725	2.703	2.668	2.632	2.595	2.575	2.555	2.535	2.514	2.493	2.471
8	3.458	3.113	2.924	2.806	2.726	2.668	2.624	2.589	2.561	2.538	2.502	2.464	2.425	2.404	2.383	2.361	2.339	2.316	2.293
9	3.360	3.006	2.813	2.693	2.611	2.551	2.505	2.469	2.440	2.416	2.379	2.340	2.298	2.277	2.255	2.232	2.208	2.184	2.159
10	3.285	2.924	2.728	2.605	2.522	2.461	2.414	2.377	2.347	2.323	2.284	2.244	2.201	2.178	2.155	2.132	2.107	2.082	2.055
11	3.225	2.860	2.660	2.536	2.451	2.389	2.342	2.304	2.274	2.248	2.209	2.167	2.123	2.100	2.076	2.052	2.026	2.000	1.972
12	3.177	2.807	2.606	2.480	2.394	2.331	2.283	2.245	2.214	2.188	2.147	2.105	2.060	2.036	2.011	1.986	1.960	1.932	1.904
13	3.136	2.763	2.560	2.434	2.347	2.283	2.234	2.195	2.164	2.138	2.097	2.053	2.007	1.983	1.958	1.931	1.904	1.876	1.846
14	3.102	2.726	2.522	2.395	2.307	2.243	2.193	2.154	2.122	2.095	2.054	2.010	1.962	1.938	1.912	1.885	1.857	1.828	1.797
15	3.073	2.695	2.490	2.361	2.273	2.208	2.158	2.119	2.086	2.059	2.017	1.972	1.924	1.899	1.873	1.845	1.817	1.787	1.755
16	3.048	2.668	2.462	2.333	2.244	2.178	2.128	2.088	2.055	2.028	1.985	1.940	1.891	1.866	1.839	1.811	1.782	1.751	1.718
17	3.026	2.645	2.437	2.308	2.218	2.152	2.102	2.061	2.028	2.001	1.958	1.912	1.862	1.836	1.809	1.781	1.751	1.719	1.686
18	3.007	2.624	2.416	2.286	2.196	2.130	2.079	2.038	2.005	1.977	1.933	1.887	1.837	1.810	1.783	1.754	1.723	1.691	1.657
19	2.990	2.606	2.397	2.266	2.176	2.109	2.058	2.017	1.984	1.956	1.912	1.865	1.814	1.787	1.759	1.730	1.699	1.666	1.631
20	2.975	2.589	2.380	2.249	2.158	2.091	2.040	1.999	1.965	1.937	1.892	1.845	1.794	1.767	1.738	1.708	1.677	1.643	1.607
21	2.961	2.575	2.365	2.233	2.142	2.075	2.023	1.982	1.948	1.920	1.875	1.827	1.776	1.748	1.719	1.689	1.657	1.623	1.586
20	2.949	2.561	2.351	2.219	2.128	2.061	2.008	1.967	1.933	1.904	1.859	1.811	1.759	1.731	1.702	1.671	1.639	1.604	1.567
23	2.937	2.549	2.339	2.207	2.115	2.047	1.995	1.953	1.919	1.890	1.845	1.796	1.744	1.716	1.686	1.655	1.622	1.587	1.549
24	2.927	2.538	2.327	2.195	2.103	2.035	1.983	1.941	1.906	1.877	1.832	1.783	1.730	1.702	1.672	1.641	1.607	1.571	1.533
25	2.918	2.528	2.317	2.184	2.092	2.024	1.971	1.929	1.895	1.866	1.820	1.771	1.718	1.689	1.659	1.627	1.593	1.557	1.518
26	2.909	2.519	2.307	2.174	2.082	2.014	1.961	1.919	1.884	1.855	1.809	1.760	1.706	1.677	1.647	1.615	1.581	1.544	1.504
27	2.901	2.511	2.299	2.165	2.073	2.005	1.952	1.909	1.874	1.845	1.799	1.749	1.695	1.666	1.636	1.603	1.569	1.531	1.491
28	2.894	2.503	2.291	2.157	2.064	1.996	1.943	1.900	1.865	1.836	1.790	1.740	1.685	1.656	1.625	1.593	1.558	1.520	1.478
29	2.887	2.495	2.283	2.149	2.057	1.988	1.935	1.892	1.857	1.827	1.781	1.731	1.676	1.647	1.616	1.583	1.547	1.509	1.467
30	2.881	2.489	2.276	2.142	2.049	1.980	1.927	1.884	1.849	1.819	1.773	1.722	1.667	1.638	1.606	1.573	1.538	1.499	1.456
40	2.835	2.440	2.226	2.091	1.997	1.927	1.873	1.829	1.793	1.763	1.715	1.662	1.605	1.574	1.541	1.506	1.467	1.425	1.377
60	2.791	2.393	2.177	2.041	1.946	1.875	1.819	1.775	1.738	1.707	1.657	1.603	1.543	1.511	1.476	1.437	1.395	1.348	1.291
120	2.748	2.347	2.130	1.992	1.896	1.824	1.767	1.722	1.684	1.652	1.601	1.545	1.482	1.447	1.409	1.368	1.320	1.265	1.193

1000+	2.706	2.303	2.084	1.945	1.847	1.774	1.717	1.670	1.632	1.599	1.546	1.487	1.421	1.383	1.342	1.295	1.240	1.169	1.000
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Table 3 of 602–Critical  $F$  values,  $F_{\text{crit}95}$ , versus  $N-1$  and  $N_{\text{ref}}-1$  at 95 % confidence

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
$N_{\text{ref}}-1$																			
1	161.4	199.5	215.7	224.5	230.1	233.9	236.7	238.8	240.5	241.8	243.9	245.9	248.0	249.0	250.1	251.1	252.2	253.2	254.3
2	18.51	19.00	19.16	19.24	19.29	19.33	19.35	19.37	19.38	19.39	19.41	19.42	19.44	19.45	19.46	19.47	19.47	19.48	19.49
3	10.12	9.552	9.277	9.117	9.014	8.941	8.887	8.845	8.812	8.786	8.745	8.703	8.660	8.639	8.617	8.594	8.572	8.549	8.526
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094	6.041	5.999	5.964	5.912	5.858	5.803	5.774	5.746	5.717	5.688	5.658	5.628
5	6.608	5.786	5.410	5.192	5.050	4.950	4.876	4.818	4.773	4.735	4.678	4.619	4.558	4.527	4.496	4.464	4.431	4.399	4.365
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207	4.147	4.099	4.060	4.000	3.938	3.874	3.842	3.808	3.774	3.740	3.705	3.669
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787	3.726	3.677	3.637	3.575	3.511	3.445	3.411	3.376	3.340	3.304	3.267	3.230
8	5.318	4.459	4.066	3.838	3.688	3.581	3.501	3.438	3.388	3.347	3.284	3.218	3.150	3.115	3.079	3.043	3.005	2.967	2.928
9	5.117	4.257	3.863	3.633	3.482	3.374	3.293	3.230	3.179	3.137	3.073	3.006	2.937	2.901	2.864	2.826	2.787	2.748	2.707
10	4.965	4.103	3.708	3.478	3.326	3.217	3.136	3.072	3.020	2.978	2.913	2.845	2.774	2.737	2.700	2.661	2.621	2.580	2.538
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012	2.948	2.896	2.854	2.788	2.719	2.646	2.609	2.571	2.531	2.490	2.448	2.405
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913	2.849	2.796	2.753	2.687	2.617	2.544	2.506	2.466	2.426	2.384	2.341	2.296
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832	2.767	2.714	2.671	2.604	2.533	2.459	2.420	2.380	2.339	2.297	2.252	2.206
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764	2.699	2.646	2.602	2.534	2.463	2.388	2.349	2.308	2.266	2.223	2.178	2.131
15	4.543	3.682	3.287	3.056	2.901	2.791	2.707	2.641	2.588	2.544	2.475	2.403	2.328	2.288	2.247	2.204	2.160	2.114	2.066
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657	2.591	2.538	2.494	2.425	2.352	2.276	2.235	2.194	2.151	2.106	2.059	2.010
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614	2.548	2.494	2.450	2.381	2.308	2.230	2.190	2.148	2.104	2.058	2.011	1.960
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577	2.510	2.456	2.412	2.342	2.269	2.191	2.150	2.107	2.063	2.017	1.968	1.917
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544	2.477	2.423	2.378	2.308	2.234	2.156	2.114	2.071	2.026	1.980	1.930	1.878
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514	2.447	2.393	2.348	2.278	2.203	2.124	2.083	2.039	1.994	1.946	1.896	1.843
21	4.325	3.467	3.073	2.840	2.685	2.573	2.488	2.421	2.366	2.321	2.250	2.176	2.096	2.054	2.010	1.965	1.917	1.866	1.812
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464	2.397	2.342	2.297	2.226	2.151	2.071	2.028	1.984	1.938	1.889	1.838	1.783
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442	2.375	2.320	2.275	2.204	2.128	2.048	2.005	1.961	1.914	1.865	1.813	1.757
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423	2.355	2.300	2.255	2.183	2.108	2.027	1.984	1.939	1.892	1.842	1.790	1.733
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405	2.337	2.282	2.237	2.165	2.089	2.008	1.964	1.919	1.872	1.822	1.768	1.711
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388	2.321	2.266	2.220	2.148	2.072	1.990	1.946	1.901	1.853	1.803	1.749	1.691
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373	2.305	2.250	2.204	2.132	2.056	1.974	1.930	1.884	1.836	1.785	1.731	1.672
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359	2.291	2.236	2.190	2.118	2.041	1.959	1.915	1.869	1.820	1.769	1.714	1.654
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346	2.278	2.223	2.177	2.105	2.028	1.945	1.901	1.854	1.806	1.754	1.698	1.638
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334	2.266	2.211	2.165	2.092	2.015	1.932	1.887	1.841	1.792	1.740	1.684	1.622
40	4.085	3.232	2.839	2.606	2.450	2.336	2.249	2.180	2.124	2.077	2.004	1.925	1.839	1.793	1.744	1.693	1.637	1.577	1.509
60	4.001	3.150	2.758	2.525	2.368	2.254	2.167	2.097	2.040	1.993	1.917	1.836	1.748	1.700	1.649	1.594	1.534	1.467	1.389
120	3.920	3.072	2.680	2.447	2.290	2.175	2.087	2.016	1.959	1.911	1.834	1.751	1.659	1.608	1.554	1.495	1.429	1.352	1.254

**WLTP-DTP-01-02**

1000+	3.842	2.996	2.605	2.372	2.214	2.099	2.010	1.938	1.880	1.831	1.752	1.666	1.571	1.517	1.459	1.394	1.318	1.221	1.000
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(h) Slope. Calculate a least-squares regression slope,  $a_{1y}$ , as follows:

$$a_{1y} = \frac{\sum_{i=1}^N (y_i - \bar{y}) \cdot (y_{\text{ref}i} - \bar{y}_{\text{ref}})}{\sum_{i=1}^N (y_{\text{ref}i} - \bar{y}_{\text{ref}})^2}$$

Eq. 602-9

*Example:*

$$N = 6000$$

$$y_1 = 2045.8$$

$$\bar{y} = 1051.1$$

$$y_{\text{ref}1} = 2045.0$$

$$\bar{y}_{\text{ref}} = 1055.3$$

$$a_{1y} = \frac{(2045.8 - 1050.1) \cdot (2045.0 - 1055.3) + \dots + (y_{6000} - 1050.1) \cdot (y_{\text{ref}6000} - 1055.3)}{(2045.0 - 1055.3)^2 + \dots + (y_{\text{ref}6000} - 1055.3)^2}$$

$$a_{1y} = 1.0110$$

(i) Intercept. Calculate a least-squares regression intercept,  $a_{0y}$ , as follows:

$$a_{0y} = \bar{y} - (a_{1y} \cdot \bar{y}_{\text{ref}})$$

Eq. 602-10

*Example:*

$$\bar{y} = 1050.1$$

$$a_{1y} = 1.0110$$

$$\bar{y}_{\text{ref}} = 1055.3$$

$$a_{0y} = 1050.1 - (1.0110 \cdot 1055.3)$$

$$a_{0y} = -16.8083$$

(j) Standard estimate of error. Calculate a standard estimate of error,  $SEE$ , as follows:

$$SEE_y = \sqrt{\frac{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{\text{ref}i})]^2}{N - 2}}$$

Eq. 602-11

*Example:*

$$N = 6000$$

$$y_1 = 2045.8$$

$$a_{0y} = -16.8083$$

$$a_{1y} = 1.0110$$

$$y_{\text{ref}1} = 2045.0$$

## WLTP-DTP-01-02

$$SEE_y = \sqrt{\frac{[2045.8 - (-16.8083) - (1.0110 \cdot 2045.0)]^2 + \dots [y_{6000} - (-16.8083) - (1.0110 \cdot y_{\text{ref}6000})]^2}{6000 - 2}}$$

$$SEE_y = 5.348$$

(k) Coefficient of determination. Calculate a coefficient of determination,  $r^2$ , as follows:

$$r_y^2 = 1 - \frac{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{\text{ref}i})]^2}{\sum_{i=1}^N [y_i - \bar{y}]^2}$$

Eq. 602-12

*Example:*

$$N = 6000$$

$$y_l = 2045.8$$

$$a_{0y} = -16.8083$$

$$a_{1y} = 1.0110$$

$$y_{\text{ref}l} = 2045.0$$

$$\bar{y} = 1480.5$$

$$r_y^2 = 1 - \frac{[2045.8 - (-16.8083) - (1.0110 \times 2045.0)]^2 + \dots [y_{6000} - (-16.8083) - (1.0110 \cdot y_{\text{ref}6000})]^2}{[2045.8 - 1480.5]^2 + \dots [y_{6000} - 1480.5]^2}$$

$$r_y^2 = 0.9859$$

(l) Flow-weighted mean concentration. In some sections of this part, you may need to calculate a flow-weighted mean concentration to determine the applicability of certain provisions. A flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration because the CVS system itself flow-weights the bag concentration. You might already expect a certain flow-weighted mean concentration of an emission at its standard based on previous testing with similar vehicles or testing with similar equipment and instruments. If you need to estimate your expected flow-weighted mean concentration of an emission at its standard, we recommend using the following example as a guide for how to estimate the flow-weighted mean concentration expected at the standard. Note that this example is not exact and it contains assumptions that are not always valid.

(1) To estimate the flow-weighted mean THC concentration in a CVS from a naturally aspirated spark-ignition vehicle at a THC standard of 0.1 g/mile, you may do the following:

(i) Determine the distance driven over the test cycle,  $D_{\text{ref}}$ .

(ii) Multiply your CVS total molar flow rate by the time interval of the test cycle,  $\Delta t_{\text{testcycle}}$ . The result is the total diluted exhaust flow of the  $n_{\text{dexh}}$ .

(iii) Use your estimated values as described in the following example calculation:

$$\bar{x}_{\text{THC}} = \frac{e_{\text{std}} \cdot D_{\text{ref}}}{M \cdot \dot{n}_{\text{dexh}} \cdot \Delta t_{\text{testcycle}}}$$

Eq. 602-15

*Example:*

$$e_{\text{THC}} = 0.1 \text{ g/mile}$$

$$D_{\text{ref}} = 7.26 \text{ miles}$$

$$M_{\text{THC}} = 13.875389 \text{ g/mol} = 13.875389 \cdot 10^{-6} \text{ g/}\mu\text{mol}$$

$$\dot{n}_{\text{dexh}} = 6.021 \text{ mol/s}$$

$$\Delta t_{\text{testcycle}} = 30 \text{ min} = 1800 \text{ s}$$

$$\bar{x}_{\text{THC}} = \frac{0.1 \cdot 7.26}{13.875389 \cdot 10^{-6} \cdot 6.021 \cdot 1800}$$

$$\bar{x}_{\text{NMHC}} = 4.83 \mu\text{mol/mol}$$

### Dyno Road Load Derivation goes here??

#### §630 1980 international gravity formula.

The acceleration of Earth's gravity,  $a_g$ , varies depending on your location. Calculate  $a_g$  at your latitude, as follows:

$$a_g = 9.7803267715 \cdot [1 + 5.2790414 \cdot 10^{-3} \cdot \sin^2(\theta) + 2.32718 \cdot 10^{-5} \cdot \sin^4(\theta) + 1.262 \cdot 10^{-7} \cdot \sin^6(\theta) + 7 \cdot 10^{-10} \cdot \sin^8(\theta)]$$

Eq. 630-1

Where:

$\theta$  = Degrees north or south latitude.

*Example:*

$$\theta = 45^\circ$$

$$a_g = 9.7803267715 \cdot (1 + 5.2790414 \cdot 10^{-3} \cdot \sin^2(45) + 2.32718 \cdot 10^{-5} \cdot \sin^4(45) + 1.262 \cdot 10^{-7} \cdot \sin^6(45) + 7 \cdot 10^{-10} \cdot \sin^8(45))$$

$$a_g = 9.8178291229 \text{ m/s}^2$$

#### 640 Flow meter calibration calculations.

This section describes the calculations for calibrating various flow meters. After you calibrate a flow meter using these calculations, use the calculations described in §642 to calculate flow during an emission test. Paragraph (a) of this section first describes how to convert reference flow meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining paragraphs describe the calibration calculations that are specific to certain types of flow meters.

(a) Reference meter conversions. The calibration equations in this section use molar flow rate,  $\dot{n}_{\text{ref}}$ , as a reference quantity. If your reference meter outputs a flow rate in a different quantity, such as standard volume rate,  $\dot{V}_{\text{stdref}}$ , actual volume rate,  $\dot{V}_{\text{actref}}$ , or mass rate,  $\dot{m}_{\text{ref}}$ , convert your reference meter output to a molar flow rate using the following equations, noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may change during an emission test, you should ensure that they are as constant as practical for each individual set

## WLTP-DTP-01-02

point during a flow meter calibration:

$$\dot{n}_{\text{ref}} = \frac{\dot{V}_{\text{stdref}} \cdot P_{\text{std}}}{T_{\text{std}} \cdot R} = \frac{\dot{V}_{\text{actref}} \cdot P_{\text{act}}}{T_{\text{act}} \cdot R} = \frac{\dot{m}_{\text{ref}}}{M_{\text{mix}}}$$

Eq. 640-1

Where:

$\dot{n}_{\text{ref}}$  = reference molar flow rate.

$\dot{V}_{\text{stdref}}$  = reference volume flow rate, corrected to a standard pressure and a standard temperature.

$\dot{V}_{\text{actref}}$  = reference volume flow rate at the actual pressure and temperature of the flow rate.

$\dot{m}_{\text{ref}}$  = reference mass flow.

$P_{\text{std}}$  = standard pressure.

$P_{\text{act}}$  = actual pressure of the flow rate.

$T_{\text{std}}$  = standard temperature.

$T_{\text{act}}$  = actual temperature of the flow rate.

$R$  = molar gas constant.

$M_{\text{mix}}$  = molar mass of the flow rate.

*Example 1:*

$$\dot{V}_{\text{stdref}} = 1000.00 \text{ ft}^3/\text{min} = 0.471948 \text{ m}^3/\text{s}$$

$$P = 29.9213 \text{ in Hg @ } 32 \text{ }^\circ\text{F} = 101325 \text{ Pa}$$

$$T = 68.0 \text{ }^\circ\text{F} = 293.15 \text{ K}$$

$$R = 8.314472 \text{ J}/(\text{mol}\cdot\text{K})$$

$$\dot{n}_{\text{ref}} = \frac{0.471948 \cdot 101325}{293.15 \cdot 8.314472}$$

$$\dot{n}_{\text{ref}} = 19.619 \text{ mol/s}$$

*Example 2:*

$$\dot{m}_{\text{ref}} = 17.2683 \text{ kg/min} = 287.805 \text{ g/s}$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol}$$

$$\dot{n}_{\text{ref}} = \frac{287.805}{28.7805}$$

$$\dot{n}_{\text{ref}} = 10.0000 \text{ mol/s}$$

(b) PDP calibration calculations. For each restrictor position, calculate the following values from the mean values determined in §340, as follows:

(1) PDP volume pumped per revolution,  $V_{rev}$  ( $\text{m}^3/\text{rev}$ ):

$$V_{rev} = \frac{\bar{n}_{ref} \cdot R \cdot \bar{T}_{in}}{\bar{P}_{in} \cdot \bar{f}_{nPDP}}$$

Eq. 640-2

*Example:*

$$\bar{n}_{ref} = 25.096 \text{ mol/s}$$

$$R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K})$$

$$\bar{T}_{in} = 299.5 \text{ K}$$

$$\bar{P}_{in} = 98290 \text{ Pa}$$

$$\bar{f}_{nPDP} = 1205.1 \text{ rev/min} = 20.085 \text{ rev/s}$$

$$V_{rev} = \frac{25.096 \cdot 8.314472 \cdot 299.5}{98290 \cdot 20.085}$$

$$V_{rev} = 0.03166 \text{ m}^3/\text{rev}$$

(2) PDP slip correction factor,  $K_s$  (s/rev):

$$K_s = \frac{1}{\bar{f}_{nPDP}} \cdot \sqrt{\frac{\bar{P}_{out} - \bar{P}_{in}}{\bar{P}_{out}}}$$

Eq. 640-3

*Example:*

$$\bar{f}_{nPDP} = 1205.1 \text{ rev/min} = 20.085 \text{ rev/s}$$

$$\bar{P}_{out} = 100.103 \text{ kPa}$$

$$\bar{P}_{in} = 98.290 \text{ kPa}$$

$$K_s = \frac{1}{20.085} \cdot \sqrt{\frac{100.103 - 98.290}{100.103}}$$

$$K_s = 0.006700 \text{ s/rev}$$

(3) Perform a least-squares regression of PDP volume pumped per revolution,  $V_{rev}$ , versus PDP slip correction factor,  $K_s$ , by calculating slope,  $a_1$ , and intercept,  $a_0$ , as described in 602.

(4) Repeat the procedure in paragraphs (b)(1) through (3) of this section for every speed that you run your PDP.

(5) The following example illustrates these calculations:

Table 1 of 640–

Example of PDP calibration data

$\bar{f}_{nPDP}$ (rev/min)	$a_1$ ( $\text{m}^3/\text{min}$ )	$a_0$ ( $\text{m}^3/\text{rev}$ )
-------------------------------	--------------------------------------	--------------------------------------

## WLTP-DTP-01-02

755.0	50.43	0.056
987.6	49.86	-0.013
1254.5	48.54	0.028
1401.3	47.30	-0.061

(6) For each speed at which you operate the PDP, use the corresponding slope,  $a_1$ , and intercept,  $a_0$ , to calculate flow rate during emission testing as described in 642.

(c) Venturi governing equations and permissible assumptions. This section describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio,  $r$  (i.e.,  $r_{SSV}$  versus  $r_{CFV}$ ). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In paragraph (c)(4) of this section, we describe other assumptions that you may make, depending upon how you conduct your emission tests. If we do not allow you to assume that the measured flow is an ideal gas, the governing equations include a first-order correction for the behavior of a real gas; namely, the compressibility factor,  $Z$ . If accepted measurement practices dictates using a value other than  $Z=1$ , you may either use an appropriate equation of state to determine values of  $Z$  as a function of measured pressures and temperatures, or you may develop your own calibration equations based on accepted measurement practices. Note that the equation for the flow coefficient,  $C_f$ , is based on the ideal gas assumption that the isentropic exponent,  $\gamma$ , is equal to the ratio of specific heats,  $C_p/C_v$ . If accepted measurement practices dictates using a real gas isentropic exponent, you may either use an appropriate equation of state to determine values of  $\gamma$  as a function of measured pressures and temperatures, or you may develop your own calibration equations based on accepted measurement practices. Calculate molar flow rate,  $\dot{n}$ , as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}$$

Eq. 640-4

Where:

$C_d$  = Discharge coefficient, as determined in paragraph (c)(1) of this section.

$C_f$  = Flow coefficient, as determined in paragraph (c)(2) of this section.

$A_t$  = Venturi throat cross-sectional area.

$p_{in}$  = Venturi inlet absolute static pressure.

$Z$  = Compressibility factor.

$M_{mix}$  = Molar mass of gas mixture.

$R$  = Molar gas constant.

$T_{in}$  = Venturi inlet absolute temperature.

(1) Using the data collected in 340, calculate  $C_d$  using the following equation:

$$C_d = \dot{n}_{\text{ref}} \cdot \frac{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}}{C_f \cdot A_t \cdot p_{\text{in}}} \quad \text{Eq. 640-5}$$

Where:

$\dot{n}_{\text{ref}}$  = A reference molar flow rate.

(2) Determine  $C_f$  using one of the following methods:

(i) For CFV flow meters only, determine  $C_{f\text{CFV}}$  from the following table based on your values for  $\beta$  and  $\gamma$ , using linear interpolation to find intermediate values:

Table 2 of 640–

$C_{f\text{CFV}}$  versus  $\beta$  and  $\gamma$  for CFV flow meters

$\beta$	$C_{f\text{CFV}}$	
	$\gamma_{\text{exh}} = 1.385$	$\gamma_{\text{dexh}} = \gamma_{\text{air}} = 1.399$
0.000	0.6822	0.6846
0.400	0.6857	0.6881
0.500	0.6910	0.6934
0.550	0.6953	0.6977
0.600	0.7011	0.7036
0.625	0.7047	0.7072
0.650	0.7089	0.7114
0.675	0.7137	0.7163
0.700	0.7193	0.7219
0.720	0.7245	0.7271
0.740	0.7303	0.7329
0.760	0.7368	0.7395
0.770	0.7404	0.7431
0.780	0.7442	0.7470
0.790	0.7483	0.7511
0.800	0.7527	0.7555
0.810	0.7573	0.7602
0.820	0.7624	0.7652
0.830	0.7677	0.7707
0.840	0.7735	0.7765
0.850	0.7798	0.7828

(ii) For any CFV or SSV flow meter, you may use the following equation to calculate  $C_f$ :

## WLTP-DTP-01-02

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

Eq. 640-6

Where:

$\gamma$  = isentropic exponent. For an ideal gas, this is the ratio of specific heats of the gas mixture,  $C_p/C_v$ .

$r$  = Pressure ratio, as determined in paragraph (c)(3) of this section.

$\beta$  = Ratio of venturi throat to inlet diameters.

(3) Calculate  $r$  as follows:

(i) For SSV systems only, calculate  $r_{SSV}$  using the following equation:

$$r_{SSV} = 1 - \frac{\Delta p_{SSV}}{P_{in}}$$

Eq. 640-7

Where:

$\Delta p_{SSV}$  = Differential static pressure; venturi inlet minus venturi throat.

(ii) For CFV systems only, calculate  $r_{CFV}$  iteratively using the following equation:

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left( \frac{\gamma-1}{2} \right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma+1}{2}$$

Eq. 640-8

(4) You may make any of the following simplifying assumptions of the governing equations, or you may use accepted measurement practices to develop more appropriate values for your testing:

(i) For emission testing over the full ranges of raw exhaust, diluted exhaust and dilution air, you may assume that the gas mixture behaves as an ideal gas:  $Z=1$ .

(ii) For the full range of raw exhaust you may assume a constant ratio of specific heats of  $\gamma=1.385$ .

(iii) For the full range of diluted exhaust and air (e.g., calibration air or dilution air), you may assume a constant ratio of specific heats of  $\gamma=1.399$ .

(iv) For the full range of diluted exhaust and air, you may assume the molar mass of the mixture is a function only of the amount of water in the dilution air or calibration air,  $x_{H_2O}$ , determined as described in 645, as follows:

$$M_{mix} = M_{air} \cdot (1 - x_{H_2O}) + M_{H_2O} \cdot x_{H_2O}$$

Eq. 640-9

*Example:*

$$M_{air} = 28.96559 \text{ g/mol}$$

$$x_{H_2O} = 0.0169 \text{ mol/mol}$$

$$M_{H_2O} = 18.01528 \text{ g/mol}$$

$$M_{mix} = 28.96559 \cdot (1 - 0.0169) + 18.01528 \cdot 0.0169$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol}$$

(v) For the full range of diluted exhaust and air, you may assume a constant molar mass of the mixture,  $M_{\text{mix}}$ , for all calibration and all testing as long as your assumed molar mass differs no more than  $\pm 1\%$  from the estimated minimum and maximum molar mass during calibration and testing. You may assume this, using accepted measurement practices, if you sufficiently control the amount of water in calibration air and in dilution air or if you remove sufficient water from both calibration air and dilution air. The following table gives examples of permissible ranges of dilution air dewpoint versus calibration air dewpoint:

Table 3 of 640–  
Examples of dilution air and calibration air  
dewpoints at which you may assume a constant  $M_{\text{mix}}$ .

If calibration $T_{\text{dew}}$ (°C) is...	assume the following constant $M_{\text{mix}}$ (g/mol)...	for the following ranges of $T_{\text{dew}}$ (°C) during emission tests <sup>a</sup>
dry	28.96559	dry to 18
0	28.89263	dry to 21
5	28.86148	dry to 22
10	28.81911	dry to 24
15	28.76224	dry to 26
20	28.68685	-8 to 28
25	28.58806	12 to 31
30	28.46005	23 to 34

<sup>a</sup> Range valid for all calibration and emission testing over the atmospheric pressure range (80.000 to 103.325) kPa.

(5) The following example illustrates the use of the governing equations to calculate the discharge coefficient,  $C_d$  of an SSV flow meter at one reference flow meter value. Note that calculating  $C_d$  for a CFV flow meter would be similar, except that  $C_f$  would be determined from Table 2 of this section or calculated iteratively using values of  $\beta$  and  $\gamma$  as described in paragraph (c)(2) of this section.

*Example:*

$$\dot{m}_{\text{ref}} = 57.625 \text{ mol/s}$$

$$Z = 1$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$$

$$T_{\text{in}} = 298.15 \text{ K}$$

$$A_t = 0.01824 \text{ m}^2$$

$$p_{\text{in}} = 99132.0 \text{ Pa}$$

$$\gamma = 1.399$$

$$\beta = 0.8$$

$$\Delta p = 2.312 \text{ kPa}$$

## WLTP-DTP-01-02

$$r_{\text{SSV}} = 1 - \frac{2.312}{99.132} = 0.977$$

$$C_f = \left[ \frac{2 \cdot 1.399 \cdot \left( 0.977^{\frac{1.399-1}{1.399}} - 1 \right)}{(1.399-1) \cdot \left( 0.8^4 - 0.977^{\frac{-2}{1.399}} \right)} \right]^{\frac{1}{2}}$$

$$C_f = 0.274$$

$$C_d = 57.625 \cdot \frac{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}{0.274 \cdot 0.01824 \cdot 99132.0}$$

$$C_d = 0.982$$

(d) SSV calibration. Perform the following steps to calibrate an SSV flow meter:

(1) Calculate the Reynolds number,  $Re^{\#}$ , for each reference molar flow rate, using the throat diameter of the venturi,  $d_t$ . Because the dynamic viscosity,  $\mu$ , is needed to compute  $Re^{\#}$ , you may use your own fluid viscosity model to determine  $\mu$  for your calibration gas (usually air), using accepted measurement practices. Alternatively, you may use the Sutherland three-coefficient viscosity model to approximate  $\mu$ , as shown in the following sample calculation for  $Re^{\#}$ :

$$Re^{\#} = \frac{4 \cdot M_{\text{mix}} \cdot \dot{n}_{\text{ref}}}{\pi \cdot d_t \cdot \mu}$$

Eq. 640-10

Where, using the Sutherland three-coefficient viscosity model:

$$\mu = \mu_0 \cdot \left( \frac{T_{\text{in}}}{T_0} \right)^{\frac{3}{2}} \cdot \left( \frac{T_0 + S}{T_{\text{in}} + S} \right)$$

Eq. 640-11

Where:

$\mu$  = Dynamic viscosity of calibration gas.

$\mu_0$  = Sutherland reference viscosity.

$T_0$  = Sutherland reference temperature.

$S$  = Sutherland constant.

Table 4 of 640–  
Sutherland three-coefficient viscosity model parameters

Gas <sup>a</sup>	$\mu_0$	$T_0$	$S$	Temp range within $\pm 2$ % error	Pressure limit
	kg/(m·s)	K	K	K	kPa
Air	$1.716 \cdot 10^{-5}$	273	111	170 to 1900	$\leq 1800$
CO <sub>2</sub>	$1.370 \cdot 10^{-5}$	273	222	190 to 1700	$\leq 3600$
H <sub>2</sub> O	$1.12 \cdot 10^{-5}$	350	1064	360 to 1500	$\leq 10000$
O <sub>2</sub>	$1.919 \cdot 10^{-5}$	273	139	190 to 2000	$\leq 2500$
N <sub>2</sub>	$1.663 \cdot 10^{-5}$	273	107	100 to 1500	$\leq 1600$

<sup>a</sup>Use tabulated parameters only for the pure gases, as listed. Do not combine parameters in calculations to calculate viscosities of gas mixtures.

*Example:*

$$\mu_0 = 1.716 \cdot 10^{-5} \text{ kg/(m·s)}$$

$$T_0 = 273.11 \text{ K}$$

$$S = 110.56 \text{ K}$$

$$\mu = 1.716 \cdot 10^{-5} \cdot \left( \frac{298.15}{273.11} \right)^2 \cdot \left( \frac{273.11 + 110.56}{298.15 + 110.56} \right)$$

$$\mu = 1.837 \cdot 10^{-5} \text{ kg/(m·s)}$$

$$M_{\text{mix}} = 28.7805 \text{ g/mol}$$

$$\dot{n}_{\text{ref}} = 57.625 \text{ mol/s}$$

$$d_t = 152.4 \text{ mm}$$

$$T_{\text{in}} = 298.15 \text{ K}$$

$$Re^{\#} = \frac{4 \cdot 28.7805 \cdot 57.625}{3.14159 \cdot 152.4 \cdot 1.837 \cdot 10^{-5}}$$

$$Re^{\#} = 7.541 \cdot 10^5$$

(2) Create an equation for  $C_d$  versus  $Re^{\#}$ , using paired values of  $(Re^{\#}, C_d)$ . For the equation, you may use any mathematical expression, including a polynomial or a power series. The following equation is an example of a commonly used mathematical expression for relating  $C_d$  and  $Re^{\#}$ :

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}}$$

Eq. 640-12

(3) Perform a least-squares regression analysis to determine the best-fit coefficients to the equation and calculate the equation's regression statistics,  $SEE$  and  $r^2$ , according to 602.

## WLTP-DTP-01-02

- (4) If the equation meets the criteria of  $SEE \leq 0.5 \% \cdot \dot{n}_{\text{refmax}}$  and  $r^2 \geq 0.995$ , you may use the equation to determine  $C_d$  for emission tests, as described in 642.
- (5) If the  $SEE$  and  $r^2$  criteria are not met, you may use accepted measurement practices to omit calibration data points to meet the regression statistics. You must use at least seven calibration data points to meet the criteria.
- (6) If omitting points does not resolve outliers, take corrective action. For example, select another mathematical expression for the  $C_d$  versus  $Re^\#$  equation, check for leaks, or repeat the calibration process. If you must repeat the process, we recommend applying tighter tolerances to measurements and allowing more time for flows to stabilize.
- (7) Once you have an equation that meets the regression criteria, you may use the equation only to determine flow rates that are within the range of the reference flow rates used to meet the  $C_d$  versus  $Re^\#$  equation's regression criteria.
- (e) CFV calibration. Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flow meters that consist of multiple venturis, either calibrate each venturi independently to determine a separate discharge coefficient,  $C_d$ , for each venturi, or calibrate each combination of venturis as one venturi. In the case where you calibrate a combination of venturis, use the sum of the active venturi throat areas as  $A_t$ , the square root of the sum of the squares of the active venturi throat diameters as  $d_t$ , and the ratio of the venturi throat to inlet diameters as the ratio of the square root of the sum of the active venturi throat diameters ( $d_t$ ) to the diameter of the common entrance to all of the venturis ( $D$ ). To determine the  $C_d$  for a single venturi or a single combination of venturis, perform the following steps:
- (1) Use the data collected at each calibration set point to calculate an individual  $C_d$  for each point using Eq. 640-4.
  - (2) Calculate the mean and standard deviation of all the  $C_d$  values according to Eqs. 602-1 and 602-2.
  - (3) If the standard deviation of all the  $C_d$  values is less than or equal to 0.3 % of the mean  $C_d$ , use the mean  $C_d$  in Eq 642-6, and use the CFV only down to the lowest  $r$  measured during calibration using the following equation:

$$r = 1 - \frac{\Delta p_{\text{CFV}}}{p_{\text{in}}}$$

Eq. 640-13

Where:

$\Delta p_{\text{CFV}}$  = Differential static pressure; venturi inlet minus venturi outlet.

- (4) If the standard deviation of all the  $C_d$  values exceeds 0.3 % of the mean  $C_d$ , omit the  $C_d$  values corresponding to the data point collected at the lowest  $r$  measured during calibration.
- (5) If the number of remaining data points is less than seven, take corrective action by checking your calibration data or repeating the calibration process. If you repeat the calibration process, we recommend checking for leaks, applying tighter tolerances to measurements and allowing more time for flows to stabilize.
- (6) If the number of remaining  $C_d$  values is seven or greater, recalculate the mean and standard deviation of the remaining  $C_d$  values.
- (7) If the standard deviation of the remaining  $C_d$  values is less than or equal to 0.3 % of the

mean of the remaining  $C_d$ , use that mean  $C_d$  in Eq 642-6, and use the CFV values only down to the lowest  $r$  associated with the remaining  $C_d$ .

(8) If the standard deviation of the remaining  $C_d$  still exceeds 0.3 % of the mean of the remaining  $C_d$  values, repeat the steps in paragraph (e)(4) through (8) of this section.

## MOLAR BASED CALCULATIONS

### 642 SSV, CFV, and PDP molar flow rate calculations.

This section describes the equations for calculating molar flow rates from various flow meters. After you calibrate a flow meter according to 640, use the calculations described in this section to calculate flow during an emission test.

(a) PDP molar flow rate. Based upon the speed at which you operate the PDP for a test interval, select the corresponding slope,  $a_1$ , and intercept,  $a_0$ , as calculated in 640, to calculate molar flow rate,  $\dot{n}$  as follows:

$$\dot{n} = f_{\text{nPDP}} \cdot \frac{p_{\text{in}} \cdot V_{\text{rev}}}{R \cdot T_{\text{in}}} \quad \text{Eq. 642-1}$$

Where:

$$V_{\text{rev}} = \frac{a_1}{f_{\text{nPDP}}} \cdot \sqrt{\frac{p_{\text{out}} - p_{\text{in}}}{p_{\text{out}}}} + a_0 \quad \text{Eq. 642-2}$$

*Example:*

$$a_1 = 50.43 \text{ (m}^3\text{/min)} = 0.8405 \text{ (m}^3\text{/s)}$$

$$\bar{f}_{\text{nPDP}} = 755.0 \text{ rev/min} = 12.58 \text{ rev/s}$$

$$p_{\text{out}} = 99950 \text{ Pa}$$

$$p_{\text{in}} = 98575 \text{ Pa}$$

$$a_0 = 0.056 \text{ (m}^3\text{/rev)}$$

$$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$$

$$T_{\text{in}} = 323.5 \text{ K}$$

$$C_p = 1000 \text{ (J/m}^3\text{)/kPa}$$

$$C_t = 60 \text{ s/min}$$

$$V_{\text{rev}} = \frac{0.8405}{12.58} \cdot \sqrt{\frac{99950 - 98575}{99950}} + 0.056$$

$$V_{\text{rev}} = 0.06383 \text{ m}^3\text{/rev}$$

$$\dot{n} = 12.58 \cdot \frac{98575 \cdot 0.06383}{8.314472 \cdot 323.5}$$

$$\dot{n} = 29.428 \text{ mol/s}$$

(b) SSV molar flow rate. Based on the  $C_d$  versus  $Re^{\#}$  equation you determined according to

## WLTP-DTP-01-02

§640, calculate SSV molar flow rate,  $\dot{n}$  during an emission test as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}$$

Eq. 642-3

*Example:*

$$A_t = 0.01824 \text{ m}^2$$

$$p_{in} = 99132 \text{ Pa}$$

$$Z = 1$$

$$M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$$

$$T_{in} = 298.15 \text{ K}$$

$$Re^\# = 7.232 \cdot 10^5$$

$$\gamma = 1.399$$

$$\beta = 0.8$$

$$\Delta p = 2.312 \text{ kPa}$$

Using Eq. 640-7,

$$r_{ssv} = 0.997$$

Using Eq. 640-6,

$$C_f = 0.274$$

Using Eq. 640-5,

$$C_d = 0.990$$

$$\dot{n} = 0.990 \cdot 0.274 \cdot \frac{0.01824 \cdot 99132}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}$$

$$\dot{n} = 58.173 \text{ mol/s}$$

(c) CFV molar flow rate. Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. If you use multiple venturis and you calibrated each venturi independently to determine a separate discharge coefficient,  $C_d$ , for each venturi, calculate the individual molar flow rates through each venturi and sum all their flow rates to determine  $\dot{n}$ . If you use multiple venturis and you calibrated each combination of venturis, calculate  $\dot{n}$  using the sum of the active venturi throat areas as  $A_t$ , the sum of the active venturi throat diameters as  $d_t$ , and the ratio of venturi throat to inlet diameters as the ratio of the sum of the active venturi throat diameters to the diameter of the common entrance to all of the venturis. To calculate the molar flow rate through one venturi or one combination of venturis, use its respective mean  $C_d$  and other constants you determined according to 640 and calculate its molar flow rate  $\dot{n}$  during an emission test, as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}$$

Eq. 642-4

*Example:*

$$C_d = 0.985$$

$$C_f = 0.7219$$

$$A_t = 0.00456 \text{ m}^2$$

$$p_{in} = 98836 \text{ Pa}$$

$$Z = 1$$

$$M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$$

$$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$$

$$T_{in} = 378.15 \text{ K}$$

$$\dot{n} = 0.985 \cdot 0.7219 \cdot \frac{0.00456 \cdot 98836}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 378.15}}$$

$$\dot{n} = 33.690 \text{ mol/s}$$

#### §644 Vacuum-decay leak rate.

This section describes how to calculate the leak rate of a vacuum-decay leak verification, which is described in §345(e). Use Eq. 644-1 to calculate the leak rate,  $\dot{n}_{leak}$ , and compare it to the criterion specified in §345(e).

$$\dot{n}_{leak} = \frac{V_{vac}}{R} \cdot \frac{\left( \frac{p_2}{T_2} - \frac{p_1}{T_1} \right)}{(t_2 - t_1)}$$

Eq. 644-1

Where:

$V_{vac}$  = geometric volume of the vacuum-side of the sampling system.

$R$  = molar gas constant.

$p_2$  = Vacuum-side absolute pressure at time  $t_2$ .

$T_2$  = Vacuum-side absolute temperature at time  $t_2$ .

$p_1$  = Vacuum-side absolute pressure at time  $t_1$ .

$T_1$  = Vacuum-side absolute temperature at time  $t_1$ .

$t_2$  = time at completion of vacuum-decay leak verification test.

$t_1$  = time at start of vacuum-decay leak verification test.

*Example:*

$$V_{vac} = 2.0000 \text{ L} = 0.00200 \text{ m}^3$$

$$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$$

$$p_2 = 50.600 \text{ kPa} = 50600 \text{ Pa}$$

$$T_2 = 293.15 \text{ K}$$

$$p_1 = 25.300 \text{ kPa} = 25300 \text{ Pa}$$

## WLTP-DTP-01-02

$$T_1 = 293.15 \text{ K}$$

$$t_2 = 10:57:35 \text{ AM}$$

$$t_1 = 10:56:25 \text{ AM}$$

$$\dot{n}_{\text{leak}} = \frac{0.0002}{8.314472} \cdot \frac{\left( \frac{50600}{293.15} - \frac{25300}{293.15} \right)}{(10:57:35 - 10:56:25)}$$

$$\dot{n}_{\text{leak}} = \frac{0.00200}{8.314472} \cdot \frac{86.304}{70}$$

$$\dot{n}_{\text{leak}} = 0.00030 \text{ mol/s}$$

### 645 Amount of water in an ideal gas.

This section describes how to determine the amount of water in an ideal gas, which you need for various performance verifications and emission calculations. Use the equation for the vapor pressure of water in paragraph (a) of this section or another appropriate equation and, depending on whether you measure dewpoint or relative humidity, perform one of the calculations in paragraph (b) or (c) of this section.

(a) Vapor pressure of water. Calculate the vapor pressure of water for a given saturation temperature condition,  $T_{\text{sat}}$ , as follows, or use accepted measurement practices to use a different relationship of the vapor pressure of water to a given saturation temperature condition:

(1) For humidity measurements made at ambient temperatures from (0 to 100) °C, or for humidity measurements made over super-cooled water at ambient temperatures from (-50 to 0) °C, use the following equation:

$$\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left( 1 - \frac{273.16}{T_{\text{sat}}} \right) - 5.02800 \cdot \log_{10} \left( \frac{T_{\text{sat}}}{273.16} \right) + 1.50475 \cdot 10^{-4} \cdot \left( 1 - 10^{-8.2969 \cdot \left( \frac{T_{\text{sat}}}{273.16} - 1 \right)} \right) \\ + 0.42873 \cdot 10^{-3} \cdot \left( 10^{4.76955 \cdot \left( 1 - \frac{273.16}{T_{\text{sat}}} \right)} - 1 \right) - 0.2138602$$

Eq. 645-1

Where:

$p_{\text{H}_2\text{O}}$  = vapor pressure of water at saturation temperature condition, kPa.

$T_{\text{sat}}$  = saturation temperature of water at measured conditions, K.

*Example:*

$$T_{\text{sat}} = 9.5 \text{ °C}$$

$$T_{\text{dsat}} = 9.5 + 273.15 = 282.65 \text{ K}$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left(1 - \frac{273.16}{282.65}\right) - 5.02800 \cdot \log_{10}\left(\frac{282.65}{273.16}\right) + 1.50475 \cdot 10^{-4} \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{282.65}{273.16} - 1\right)}\right)$$

$$+ 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{282.65}\right)} - 1\right) - 0.2138602$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = 0.074297$$

$$p_{\text{H}_2\text{O}} = 10^{0.074297} = 1.186581 \text{ kPa}$$

(2) For humidity measurements over ice at ambient temperatures from (-100 to 0) °C, use the following equation:

$$\log_{10}(p_{\text{sat}}) = -9.096853 \cdot \left(\frac{273.16}{T_{\text{sat}}} - 1\right) - 3.566506 \cdot \log_{10}\left(\frac{273.16}{T_{\text{sat}}}\right)$$

$$+ 0.876812 \cdot \left(1 - \frac{T_{\text{sat}}}{273.16}\right) - 0.2138602$$

Eq. 645-2

*Example:*

$$T_{\text{ice}} = -15.4 \text{ °C}$$

$$T_{\text{ice}} = -15.4 + 273.15 = 257.75 \text{ K}$$

$$\log_{10}(p_{\text{sat}}) = -9.096853 \cdot \left(\frac{273.16}{257.75} - 1\right) - 3.566506 \cdot \log_{10}\left(\frac{273.16}{257.75}\right)$$

$$+ 0.876812 \cdot \left(1 - \frac{257.75}{273.16}\right) - 0.2138602$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = -0.798207$$

$$p_{\text{H}_2\text{O}} = 10^{0.79821} = 0.159145 \text{ kPa}$$

(b) Dewpoint. If you measure humidity as a dewpoint, determine the amount of water in an ideal gas,  $x_{\text{H}_2\text{O}}$ , as follows:

$$x_{\text{H}_2\text{O}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}}$$

Eq. 645-3

Where:

$x_{\text{H}_2\text{O}}$  = amount of water in an ideal gas.

$p_{\text{H}_2\text{O}}$  = water vapor pressure at the measured dewpoint,  $T_{\text{sat}} = T_{\text{dew}}$ .

$p_{\text{abs}}$  = wet static absolute pressure at the location of your dewpoint measurement.

*Example:*

## WLTP-DTP-01-02

$$p_{\text{abs}} = 99.980 \text{ kPa}$$

$$T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ }^\circ\text{C}$$

Using Eq. 645-1,

$$p_{\text{H}_2\text{O}} = 1.186581 \text{ kPa}$$

$$x_{\text{H}_2\text{O}} = 1.186581 / 99.980$$

$$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$$

(c) Relative humidity. If you measure humidity as a relative humidity,  $RH \%$ , determine the amount of water in an ideal gas,  $x_{\text{H}_2\text{O}}$ , as follows:

$$x_{\text{H}_2\text{O}} = \frac{RH \% \cdot p_{\text{H}_2\text{O}}}{p_{\text{abs}}}$$

Eq. 645-4

Where:

$x_{\text{H}_2\text{O}}$  = amount of water in an ideal gas.

$RH \%$  = relative humidity.

$p_{\text{H}_2\text{O}}$  = water vapor pressure at 100 % relative humidity at the location of your relative humidity measurement,  $T_{\text{sat}} = T_{\text{amb}}$ .

$p_{\text{abs}}$  = wet static absolute pressure at the location of your relative humidity measurement.

*Example:*

$$RH \% = 50.77 \%$$

$$p_{\text{abs}} = 99.980 \text{ kPa}$$

$$T_{\text{sat}} = T_{\text{amb}} = 20 \text{ }^\circ\text{C}$$

Using Eq. 645-1,

$$p_{\text{H}_2\text{O}} = 2.3371 \text{ kPa}$$

$$x_{\text{H}_2\text{O}} = (50.77 \% \cdot 2.3371) / 99.980$$

$$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$$

### 650 Emission calculations.

(a) General. Calculate emissions over each applicable test cycle. For test cycles with multiple test intervals, calculate the cycle specific emissions using the appropriate weighting factors.

(b) For light-duty vehicles and light duty trucks:

$$e_{[\text{emission}]_{\text{composite}}} = WF_1 \times \frac{\sum (m_{\text{ct}} + m_s)}{\sum (D_{\text{ct}} + D_s)} + WF_2 \times \frac{\sum (m_{\text{ht}} + m_s)}{\sum (D_{\text{ht}} + D_s)}$$

Eq. 650-1

Where:

$E_{[\text{emission}]_{\text{composite}}}$  = Weighted mass emissions of each pollutant, i.e., THC, CO, THCE, NMHC, NMHCE, CH<sub>4</sub>, NO<sub>x</sub>, or CO<sub>2</sub>, in grams per vehicle mile.

$m_{\text{ct}}$  = Mass emissions as calculated from the “transient” phase of the cold start test, in grams per test phase.

$m_{ht}$  = Mass emissions as calculated from the “transient” phase of the hot start test, in grams per test phase.

$m_s$  = Mass emissions as calculated from the “stabilized” phase of the cold start test, in grams per test phase.

$D_{ct}$  = The measured driving distance from the “transient” phase of the cold start test, in miles.

$D_{ht}$  = The measured distance from the “transient” phase of the hot start test, in miles.

$D_s$  = The measured driving distance from the “stabilized” phase of the cold start test, in miles.

*Example:*

$WF_1 = 0.43$

$WF_2 = 0.57$

$M_{NOxct} = 3.125 \text{ g}$

$M_{NOxs} = 2.975 \text{ g}$

$M_{NOxht} = 1.253 \text{ g}$

$D_{ct} = 7.26 \text{ miles}$

$D_s = 12.43 \text{ miles}$

$D_{ht} = 7.26 \text{ miles}$

$$e_{NOxcomposite} = 0.43 \times \frac{3(3.125 + 2.975) \frac{\text{g}}{\text{mi}}}{6(7.26 + 12.43) \frac{\text{mi}}{\text{hr}}} + 0.57 \times \frac{3(1.253 + 2.975) \frac{\text{g}}{\text{mi}}}{6(7.26 + 12.43) \frac{\text{mi}}{\text{hr}}}$$

$$e_{NOxcomposite} = 0.256 \text{ g/mile}$$

(c) Total mass of emissions over a test cycle. To calculate the total mass of an emission, multiply a concentration by its respective flow. For all systems, make preliminary calculations as described in paragraph (c)(1) of this section, then use the method in paragraphs (c)(2) through (4) of this section that is appropriate for your system. Calculate the total mass of emissions as follows:

(1) Concentration corrections. Perform the following sequence of preliminary calculations on recorded concentrations:

(i) Correct all THC and CH<sub>4</sub> concentrations, including continuous readings, sample bags readings, and dilution air background readings, for initial contamination, as described in 660(a).

(ii) Correct all concentrations measured on a “dry” basis to a “wet” basis, including dilution air background concentrations, as described in 659.

(iii) Calculate all THC and NMHC concentrations, including dilution air background concentrations, as described in 660.

(iv) For emission testing with an oxygenated fuel, calculate any HC concentrations, including dilution air background concentrations, as described in 665. See section 700 of this part for testing with oxygenated fuels.

(v) Correct all the NO<sub>x</sub> concentrations, including dilution air background concentrations, for intake-air humidity as described in 670.

(vi) Compare the background corrected mass of NMHC to background corrected mass of THC. If the background corrected mass of NMHC is greater than 0.98 times the background corrected mass of THC, take the background corrected mass of NMHC to be 0.98 times the background corrected mass of THC. If you omit the NMHC calculations as described in 660(b)(1), take the background corrected mass of NMHC to be 0.98 times the background corrected mass of THC.

## WLTP-DTP-01-02

(vii) Calculate brake-specific emissions before and after correcting for drift, including dilution air background concentrations, according to 672.

(2) Continuous sampling. For continuous sampling, you must frequently record a continuously updated concentration signal. You may measure this concentration from a changing flow rate or a constant flow rate, as follows:

(i) Varying flow rate. If you continuously sample from a changing exhaust flow rate, time align and then multiply concentration measurements by the flow rate from which you extracted it. Use accepted measurement practices to time-align flow and concentration data to match transformation time,  $t_{50}$ , to within  $\pm 1$  s. We consider the following to be examples of changing flows that require a continuous multiplication of concentration times molar flow rate: raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. This multiplication results in the flow rate of the emission itself. Integrate the emission flow rate over a test interval to determine the total emission. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass,  $M$ . The result is the mass of the emission,  $m$ . Calculate  $m$  for continuous sampling with variable flow using the following equations:

$$m = M \cdot \sum_{i=1}^N x_i \cdot \dot{n}_i \cdot \Delta t$$

Eq. 650-2

Where:

$$\Delta t = 1/f_{\text{record}} \quad \text{Eq. 650-3}$$

*Example:*

$$M_{\text{NMHC}} = 13.875389 \text{ g/mol}$$

$$N = 1200$$

$$x_{\text{NMHC1}} = 84.5 \text{ } \mu\text{mol/mol} = 84.5 \cdot 10^{-6} \text{ mol/mol}$$

$$x_{\text{NMHC2}} = 86.0 \text{ } \mu\text{mol/mol} = 86.0 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{\text{exh1}} = 2.876 \text{ mol/s}$$

$$\dot{n}_{\text{exh2}} = 2.224 \text{ mol/s}$$

$$f_{\text{record}} = 1 \text{ Hz}$$

Using Eq. 650-3,

$$\Delta t = 1/1 = 1 \text{ s}$$

$$m_{\text{NMHC}} = 13.875389 \cdot (84.5 \cdot 10^{-6} \cdot 2.876 + 86.0 \cdot 10^{-6} \cdot 2.224 + \dots + x_{\text{NMHC1200}} \cdot \dot{n}_{\text{exh}}) \cdot 1$$

$$m_{\text{NMHC}} = 25.23 \text{ g}$$

(ii) Constant flow rate. If you continuously sample from a constant exhaust flow rate, use the same emission calculations described in paragraph (c)(2)(i) of this section or calculate the mean or flow-weighted concentration recorded over the test interval and treat the mean as a batch sample, as described in paragraph (c)(3)(ii) of this section. We consider the following to be

examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both.

(3) Batch sampling. For batch sampling, the concentration is a single value from a proportionally extracted batch sample (such as a bag, filter, impinger, or cartridge). In this case, multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. You may calculate total flow by integrating a changing flow rate or by determining the mean of a constant flow rate, as follows:

(i) Varying flow rate. If you collect a batch sample from a changing exhaust flow rate, extract a sample proportional to the changing exhaust flow rate. We consider the following to be examples of changing flows that require proportional sampling: raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. Integrate the flow rate over a test interval to determine the total flow from which you extracted the proportional sample. Multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass,  $M$ . The result is the mass of the emission,  $m$ . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of sample,  $\bar{M}_{\text{PM}}$ , simply multiply it by the total flow. The result is the total mass of PM,  $m_{\text{PM}}$ . Calculate  $m$  for batch sampling with variable flow using the following equation:

$$m = M \cdot \bar{x} \cdot \sum_{i=1}^N \dot{n}_i \cdot \Delta t$$

Eq. 650-4

*Example:*

$$M_{\text{NO}_x} = 46.0055 \text{ g/mol}$$

$$N = 9000$$

$$\bar{x}_{\text{NO}_x} = 85.6 \text{ } \mu\text{mol/mol} = 85.6 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{\text{dexh1}} = 25.534 \text{ mol/s}$$

$$\dot{n}_{\text{dexh2}} = 26.950 \text{ mol/s}$$

$$f_{\text{record}} = 5 \text{ Hz}$$

Using Eq. 650-3,

$$\Delta t = 1/5 = 0.2$$

$$m_{\text{NO}_x} = 46.0055 \cdot 85.6 \cdot 10^{-6} \cdot (25.534 + 26.950 + \dots + \dot{n}_{\text{exh9000}}) \cdot 0.2$$

$$m_{\text{NO}_x} = 4.201 \text{ g}$$

(ii) Constant flow rate. If you batch sample from a constant exhaust flow rate, extract a sample at a proportional or constant flow rate. We consider the following to be examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both. Determine the mean molar flow rate from which you extracted the constant flow rate sample. Multiply the mean concentration of the batch sample by the mean molar flow rate of the exhaust from which the sample was extracted, and multiply the result by the time of the test interval. If the total emission is a molar quantity, convert this

## WLTP-DTP-01-02

quantity to a mass by multiplying it by its molar mass,  $M$ . The result is the mass of the emission,  $m$ . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of sample,  $\bar{M}_{\text{PM}}$ , simply multiply it by the total flow, and the result is the total mass of PM,  $m_{\text{PM}}$ . Calculate  $m$  for sampling with constant flow using the following equations:

$$m = M \cdot \bar{x} \cdot \bar{n} \cdot \Delta t$$

Eq. 650-5

and for PM or any other analysis of a batch sample that yields a mass per mole of sample,

$$\bar{M} = M \cdot \bar{x}$$

Eq. 650-6

*Example:*

$$\bar{M}_{\text{PM}} = 144.0 \text{ } \mu\text{g/mol} = 144.0 \cdot 10^{-6} \text{ g/mol}$$

$$\bar{n}_{\text{dexh}} = 57.692 \text{ mol/s}$$

$$\Delta t = 1200 \text{ s}$$

$$m_{\text{PM}} = 144.0 \cdot 10^{-6} \cdot 57.692 \cdot 1200$$

$$m_{\text{PM}} = 9.9692 \text{ g}$$

(4) Additional provisions for diluted exhaust sampling; continuous or batch. The following additional provisions apply for sampling emissions from diluted exhaust:

(i) For sampling with a constant dilution ratio ( $DR$ ) of diluted exhaust versus exhaust flow (e.g., secondary dilution for PM sampling), calculate  $m$  using the following equation:

$$m = m_{\text{dil}} \cdot (DR)$$

Eq. 650-7

*Example:*

$$m_{\text{PMdil}} = 6.853 \text{ g}$$

$$DR = 6:1$$

$$m_{\text{PM}} = 6.853 \cdot (6)$$

$$m_{\text{PM}} = 41.118 \text{ g}$$

(ii) For continuous or batch sampling, you may measure background emissions in the dilution air. You may then subtract the measured background emissions, as described in 667.

(h) Rounding. Round the final mass per mile values to be compared to the applicable standard only after all calculations are complete (including any drift correction, applicable deterioration factors, adjustment factors, and allowances) and the result is in g/mile or units equivalent to the units of the standard, such as g/km. See the definition of “Round” in §1001.

### 655 Chemical balances of fuel, intake air, and exhaust.

(a) General. Chemical balances of fuel, intake air, and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. With one flow rate of either fuel, intake air, or exhaust, you may use chemical balances to determine the flows of the other two. For example, you may use chemical balances along with either intake air or fuel flow to determine raw exhaust flow.

(b) Procedures that require chemical balances. We require chemical balances when you determine the following:

(1) A value proportional to total distance when you choose to determine g/mile emissions as

described in 650(e).

(2) The amount of water in a raw or diluted exhaust flow,  $x_{\text{H}_2\text{O}_{\text{exh}}}$ , when you do not measure the amount of water to correct for the amount of water removed by a sampling system. Correct for removed water according to 659(c)(2).

(3) The flow-weighted mean fraction of dilution air in diluted exhaust,  $x_{\text{dil/exh}}$ , when you do not measure dilution air flow to correct for background emissions as described in 667(c). Note that if you use chemical balances for this purpose, you are assuming that your exhaust is stoichiometric, even if it is not.

(c) Chemical balance procedure. The calculations for a chemical balance involve a system of equations that require iteration. We recommend using a computer to solve this system of equations. You must guess the initial values of up to three quantities: the amount of water in the measured flow,  $x_{\text{H}_2\text{O}_{\text{exh}}}$ , fraction of dilution air in diluted exhaust,  $x_{\text{dil/exh}}$ , and the amount of products on a  $C_1$  basis per dry mole of dry measured flow,  $x_{\text{C}_{\text{comb}}\text{dry}}$ . You may use time-weighted mean values of combustion air humidity and dilution air humidity in the chemical balance; as long as your combustion air and dilution air humidities remain within tolerances of  $\pm 0.0025$  mol/mol of their respective mean values over the test interval. For each emission concentration,  $x$ , and amount of water,  $x_{\text{H}_2\text{O}_{\text{exh}}}$ , you must determine their completely dry concentrations,  $x_{\text{dry}}$  and  $x_{\text{H}_2\text{O}_{\text{exhdry}}}$ . You must also use your fuel's atomic hydrogen-to-carbon ratio,  $\alpha$ , oxygen-to-carbon ratio,  $\beta$ , sulfur-to-carbon ratio,  $\gamma$ , and nitrogen-to-carbon ratio,  $\delta$ . You may measure  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  or you may use default values for a given fuel as described in 655(d). Use the following steps to complete a chemical balance:

(1) Convert your measured concentrations such as,  $x_{\text{CO}_2\text{meas}}$ ,  $x_{\text{NO}_{\text{meas}}}$ , and  $x_{\text{H}_2\text{O}_{\text{int}}}$ , to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example:  $x_{\text{H}_2\text{O}_x\text{CO}_2\text{meas}}$ ,  $x_{\text{H}_2\text{O}_x\text{NO}_{\text{meas}}}$ , and  $x_{\text{H}_2\text{O}_{\text{int}}}$ . If the amount of water present during a "wet" measurement is the same as the unknown amount of water in the exhaust flow,  $x_{\text{H}_2\text{O}_{\text{exh}}}$ , iteratively solve for that value in the system of equations. If you measure only total  $\text{NO}_x$  and not NO and  $\text{NO}_2$  separately, use accepted measurement practices to estimate a split in your total  $\text{NO}_x$  concentration between NO and  $\text{NO}_2$  for the chemical balances. For example, if you measure emissions from a stoichiometric spark-ignition engine, you may assume all  $\text{NO}_x$  is NO. For a compression-ignition engine, you may assume that your molar concentration of  $\text{NO}_x$ ,  $x_{\text{NO}_x}$ , is 75 % NO and 25 %  $\text{NO}_2$ . For  $\text{NO}_2$  storage aftertreatment systems, you may assume  $x_{\text{NO}_x}$  is 25 % NO and 75 %  $\text{NO}_2$ . Note that for calculating the mass of  $\text{NO}_x$  emissions, you must use the molar mass of  $\text{NO}_2$  for the effective molar mass of all  $\text{NO}_x$  species, regardless of the actual  $\text{NO}_2$  fraction of  $\text{NO}_x$ .

(2) Enter the equations in paragraph (c)(4) of this section into a computer program to iteratively solve for  $x_{\text{H}_2\text{O}_{\text{exh}}}$ ,  $x_{\text{C}_{\text{comb}}\text{dry}}$ , and  $x_{\text{dil/exh}}$ . Use accepted measurement practices to guess initial values for  $x_{\text{H}_2\text{O}_{\text{exh}}}$ ,  $x_{\text{C}_{\text{comb}}\text{dry}}$ , and  $x_{\text{dil/exh}}$ . We recommend guessing an initial amount of water that is about twice the amount of water in your intake or dilution air. We recommend guessing an initial value of  $x_{\text{C}_{\text{comb}}\text{dry}}$  as the sum of your measured  $\text{CO}_2$ , CO, and THC values. We also recommend guessing an initial  $x_{\text{dil/exh}}$  between 0.75 and 0.95, such as 0.8. Iterate values in the system of equations until the most recently updated guesses are all within  $\pm 1$  % of their respective most recently calculated values.

(3) Use the following symbols and subscripts in the equations for this paragraph (c):

$x_{\text{dil/exh}}$  = amount of dilution gas or excess air per mole of exhaust.

$x_{\text{H}_2\text{O}_{\text{exh}}}$  = amount of water in exhaust per mole of exhaust.

## WLTP-DTP-01-02

$x_{C_{comb}dry}$  = amount of carbon from fuel in the exhaust per mole of dry exhaust.

$x_{H_2dry}$  = amount of  $H_2$  in exhaust per amount of dry exhaust.

$K_{H_2O_{gas}}$  = water-gas reaction equilibrium coefficient. You may use 3.5 or calculate your own value using accepted measurement practices.

$x_{H_2O_{exhdry}}$  = amount of water in exhaust per dry mole of dry exhaust.

$x_{prod/intdry}$  = amount of dry stoichiometric products per dry mole of intake air.

$x_{dil/exhdry}$  = amount of dilution gas and/or excess air per mole of dry exhaust.

$x_{int/exhdry}$  = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust.

$x_{raw/exhdry}$  = amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust.

$x_{O_2int}$  = amount of intake air  $O_2$  per mole of intake air.

$x_{CO_2intdry}$  = amount of intake air  $CO_2$  per mole of dry intake air. You may use  $x_{CO_2intdry} = 375 \mu\text{mol/mol}$ , but we recommend measuring the actual concentration in the intake air.

$x_{H_2Ointdry}$  = amount of intake air  $H_2O$  per mole of dry intake air.

$x_{CO_2int}$  = amount of intake air  $CO_2$  per mole of intake air.

$x_{CO_2dil}$  = amount of dilution gas  $CO_2$  per mole of dilution gas.

$x_{CO_2dildry}$  = amount of dilution gas  $CO_2$  per mole of dry dilution gas. If you use air as diluent, you may use  $x_{CO_2dildry} = 375 \mu\text{mol/mol}$ , but we recommend measuring the actual concentration in the intake air.

$x_{H_2Odildry}$  = amount of dilution gas  $H_2O$  per mole of dry dilution gas.

$x_{H_2Odil}$  = amount of dilution gas  $H_2O$  per mole of dilution gas.

$x_{[emission]meas}$  = amount of measured emission in the sample at the respective gas analyzer.

$x_{[emission]dry}$  = amount of emission per dry mole of dry sample.

$x_{H_2O[emission]meas}$  = amount of water in sample at emission-detection location. Measure or estimate these values according to 145(e)(2).

$x_{H_2Oint}$  = amount of water in the intake air, based on a humidity measurement of intake air.

$\alpha$  = atomic hydrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$\beta$  = atomic oxygen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$\gamma$  = atomic sulfur-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$\delta$  = atomic nitrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

(4) Use the following equations to iteratively solve for  $x_{dil/exh}$ ,  $x_{H_2O_{exh}}$ , and  $x_{C_{comb}dry}$ :

$$x_{dil/exh} = 1 - \frac{x_{raw/exhdry}}{1 + x_{H_2O_{exhdry}}} \quad \text{Eq. 655-1}$$

$$x_{H_2O_{exh}} = \frac{x_{H_2O_{exhdry}}}{1 + x_{H_2O_{exhdry}}} \quad \text{Eq. 655-2}$$

$$x_{C_{comb}dry} = x_{CO_2dry} + x_{COdry} + x_{THCdry} - x_{CO_2dil} \cdot x_{dil/exhdry} - x_{CO_2int} \cdot x_{int/exhdry}$$

Eq. 655-3

$$x_{\text{H}_2\text{dry}} = \frac{x_{\text{COdry}} \cdot (x_{\text{H}_2\text{Oexhdry}} - x_{\text{H}_2\text{Odil}} \cdot x_{\text{dil/exhdry}})}{K_{\text{H}_2\text{O-gas}} \cdot (x_{\text{CO}_2\text{dry}} - x_{\text{CO}_2\text{dil}} \cdot x_{\text{dil/exhdry}})}$$

Eq. 655-4

$$x_{\text{H}_2\text{Oexhdry}} = \frac{\alpha}{2} (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + x_{\text{H}_2\text{Odil}} \cdot x_{\text{dil/exhdry}} + x_{\text{H}_2\text{Oint}} \cdot x_{\text{int/exhdry}} - x_{\text{H}_2\text{dry}}$$

Eq. 655-5

$$x_{\text{dil/exhdry}} = \frac{x_{\text{dil/exh}}}{1 - x_{\text{H}_2\text{Oexh}}}$$

Eq. 655-6

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O}_2\text{int}}} \left( \left( \frac{\alpha}{2} - \beta + 2 + 2\gamma \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) - (x_{\text{COdry}} - x_{\text{NOdry}} - 2x_{\text{NO}_2\text{dry}} + x_{\text{H}_2\text{dry}}) \right)$$

Eq. 655-7

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left( \left( \frac{\alpha}{2} + \beta + \delta \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + (2x_{\text{THCdry}} + x_{\text{COdry}} - x_{\text{NO}_2\text{dry}} + x_{\text{H}_2\text{dry}}) \right) + x_{\text{int/exhdry}}$$

Eq. 655-8

$$x_{\text{O}_2\text{int}} = \frac{0.209820 - x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}}$$

Eq. 655-9

$$x_{\text{CO}_2\text{int}} = \frac{x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}}$$

Eq. 655-10

$$x_{\text{H}_2\text{Ointdry}} = \frac{x_{\text{H}_2\text{Oint}}}{1 - x_{\text{H}_2\text{Oint}}}$$

Eq. 655-11

$$x_{\text{CO}_2\text{dil}} = \frac{x_{\text{CO}_2\text{dildry}}}{1 + x_{\text{H}_2\text{Odildry}}}$$

Eq. 655-12

$$x_{\text{H}_2\text{Odildry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}}$$

Eq. 655-13

## WLTP-DTP-01-02

$$x_{\text{COdry}} = \frac{x_{\text{COmeas}}}{1 - x_{\text{H}_2\text{OCOmeas}}}$$

Eq. 655-14

$$x_{\text{CO}_2\text{dry}} = \frac{x_{\text{CO}_2\text{meas}}}{1 - x_{\text{H}_2\text{OCO}_2\text{meas}}}$$

Eq. 655-15

$$x_{\text{NOdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H}_2\text{ONomeas}}}$$

Eq. 655-16

$$x_{\text{NO}_2\text{dry}} = \frac{x_{\text{NO}_2\text{meas}}}{1 - x_{\text{H}_2\text{ONO}_2\text{meas}}}$$

Eq. 655-17

$$x_{\text{THCdry}} = \frac{x_{\text{THCmeas}}}{1 - x_{\text{H}_2\text{O}^+\text{THCmeas}}}$$

Eq. 655-18

(5) The following example is a solution for  $x_{\text{dil/exh}}$ ,  $x_{\text{H}_2\text{Oexh}}$ , and  $x_{\text{Ccombdry}}$  using the equations in paragraph (c)(4) of this section:

$$x_{\text{dil/exh}} = 1 - \frac{0.184}{1 + \frac{35.38}{1000}} = 0.822 \text{ mol/mol}$$

$$x_{\text{H}_2\text{Oexh}} = \frac{35.38}{1 + \frac{35.38}{1000}} = 34.18 \text{ mmol/mol}$$

$$x_{\text{Ccombdry}} = 0.025 + \frac{29.3}{1000000} + \frac{47.6}{1000000} - \frac{0.371}{1000} \cdot 0.851 - \frac{0.369}{1000} \cdot 0.172 = 0.0249 \text{ mol/mol}$$

$$x_{\text{H}_2\text{dry}} = \frac{29.3 \cdot (0.034 - 0.012 \cdot 0.851)}{3.5 \cdot \left( \frac{25.2}{1000} - \frac{0.371}{1000} \cdot 0.851 \right)} = 8.5 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{Oexhdry}} = \frac{1.8}{2} \left( 0.0249 - \frac{47.6}{1000000} \right) + 0.018 \cdot 0.851 + 0.017 \cdot 0.172 - \frac{8.5}{1000000} = 0.0353 \text{ mol/mol}$$

$$x_{\text{dil/exhdry}} = \frac{0.822}{1 - 0.034} = 0.851 \text{ mol/mol}$$

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot 0.206} \left( \left( \frac{1.8}{2} - 0.050 + 2 + 2 \cdot 0.0003 \right) \left( 0.0249 - \frac{47.6}{1000000} \right) - \left( \frac{29.3}{1000000} - \frac{50.4}{1000000} - 2 \cdot \frac{12.1}{1000000} + \frac{8.5}{1000000} \right) \right) = 0.172 \text{ mol/mol}$$

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left( \left( \frac{1.8}{2} + 0.050 + 0.0001 \right) \left( 0.0249 - \frac{47.6}{1000000} \right) + \left( 2 \cdot \frac{47.6}{1000000} + \frac{29.3}{1000000} - \frac{12.1}{1000000} + \frac{8.5}{1000000} \right) \right) + 0.172 = 0.184 \text{ mol/mol}$$

$$x_{\text{O2int}} = \frac{0.209820 - 0.000375}{1 + \frac{17.22}{1000}} = 0.206 \text{ mol/mol}$$

$$x_{\text{CO2int}} = \frac{0.000375 \cdot 1000}{1 + \frac{17.22}{1000}} = 0.369 \text{ mmol/mol}$$

$$x_{\text{H2Ointdry}} = \frac{16.93}{1 - \frac{16.93}{1000}} = 17.22 \text{ mmol/mol}$$

$$x_{\text{CO2dil}} = \frac{0.375}{1 + \frac{12.01}{1000}} = 0.371 \text{ mmol/mol}$$

$$x_{\text{H2Odildry}} = \frac{11.87}{1 - \frac{11.87}{1000}} = 12.01 \text{ mmol/mol}$$

$$x_{\text{COdry}} = \frac{29.0}{1 - \frac{8.601}{1000}} = 29.3 \text{ mmol/mol}$$

$$x_{\text{CO2dry}} = \frac{24.98}{1 - \frac{8.601}{1000}} = 25.2 \text{ mmol/mol}$$

$$x_{\text{NOdry}} = \frac{50.0}{1 - \frac{8.601}{1000}} = 50.4 \text{ mmol/mol}$$

## WLTP-DTP-01-02

$$x_{\text{NO}_{2\text{dry}}} = \frac{12.0}{1 - \frac{8.601}{1000}} = 12.1 \text{ mmol/mol}$$

$$x_{\text{THC}_{\text{dry}}} = \frac{46}{1 - \frac{34.18}{1000}} = 47.6 \text{ mmol/mol}$$

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

(d) Carbon mass fraction. Determine carbon mass fraction of fuel,  $w_c$ , using one of the following methods:

(1) You may calculate  $w_c$  as described in this paragraph (d)(1) based on measured fuel properties. To do so, you must determine values for  $\alpha$  and  $\beta$  in all cases, but you may set  $\gamma$  and  $\delta$  to zero if the default value listed in Table 1 of this section is zero. Calculate  $w_c$  using the following equation:

$$w_c = \frac{1 \cdot M_C}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 655-19

Where:

$w_c$  = carbon mass fraction of fuel.

$M_C$  = molar mass of carbon.

$\alpha$  = atomic hydrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_H$  = molar mass of hydrogen.

$\beta$  = atomic oxygen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_O$  = molar mass of oxygen.

$\gamma$  = atomic sulfur-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_S$  = molar mass of sulfur.

$\delta$  = atomic nitrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_N$  = molar mass of nitrogen.

*Example:*

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

$$M_C = 12.0107$$

$$M_H = 1.01$$

$$M_O = 15.9994$$

$$M_S = 32.065$$

$$M_N = 14.0067$$

$$w_c = \frac{1 \cdot 12.0107}{1 \cdot 12.0107 + 1.8 \cdot 1.01 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$$w_c = 0.8205$$

(2) You may use the default values in the following table to determine  $w_c$  for a given fuel:

Table 1 of §655–Default values of  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ , and  $w_c$  for various fuels

Fuel	Atomic hydrogen, oxygen, sulfur, and nitrogen-to-carbon ratios $CH_\alpha O_\beta S_\gamma N_\delta$	Carbon mass fraction, $w_c$ g/g
Gasoline	$CH_{1.85}O_0S_0N_0$	0.866
#2 Diesel	$CH_{1.80}O_0S_0N_0$	0.869
#1 Diesel	$CH_{1.93}O_0S_0N_0$	0.861
Liquefied Petroleum Gas	$CH_{2.64}O_0S_0N_0$	0.819
Natural gas	$CH_{3.78}O_{0.016}S_0N_0$	0.747
Ethanol	$CH_3O_{0.5}S_0N_0$	0.521
Methanol	$CH_4O_1S_0N_0$	0.375

### 659 Removed water correction.

(a) If you remove water upstream of a concentration measurement,  $x$ , or upstream of a flow measurement,  $n$ , correct for the removed water. Perform this correction based on the amount of water at the concentration measurement,  $x_{H_2O[emission]meas}$ , and at the flow meter,  $x_{H_2Oexh}$ , whose flow is used to determine the concentration's total mass over a test interval.

(b) When using continuous analyzers downstream of a sample dryer for transient and ramped-modal testing, you must correct for removed water using signals from other continuous analyzers. When using batch analyzers downstream of a sample dryer, you must correct for removed water by using signals either from other batch analyzers or from the flow-weighted average concentrations from continuous analyzers. Downstream of where you removed water, you may determine the amount of water remaining by any of the following:

(1) Measure the dewpoint and absolute pressure downstream of the water removal location and calculate the amount of water remaining as described in 645.

(2) When saturated water vapor conditions exist at a given location, you may use the measured temperature at that location as the dewpoint for the downstream flow. If we ask, you must demonstrate how you know that saturated water vapor conditions exist. Use accepted measurement practices to measure the temperature at the appropriate location to accurately reflect the dewpoint of the flow. Note that if you use this option and the water correction in

## WLTP-DTP-01-02

paragraph (d) of this section results in a corrected value that is greater than the measured value, your saturation assumption is invalid and you must determine the water content according to paragraph (b)(1) of this section.

(3) You may also use a nominal value of absolute pressure based on an alarm set point, a pressure regulator set point, or accepted measurement practices.

(4) Set  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$  equal to that of the measured upstream humidity condition if it is lower than the dryer saturation conditions.

(c) For a corresponding concentration or flow measurement where you did not remove water, you may determine the amount of initial water by any of the following:

(1) Use any of the techniques described in paragraph (b) of this section.

(2) If the measurement comes from raw exhaust, you may determine the amount of water based on intake-air humidity, plus a chemical balance of fuel, intake air and exhaust as described in 655.

(3) If the measurement comes from diluted exhaust, you may determine the amount of water based on intake-air humidity, dilution air humidity, and a chemical balance of fuel, intake air, and exhaust as described in 655.

(d) Perform a removed water correction to the concentration measurement using the following equation:

$$x = x_{[\text{emission}]_{\text{meas}}} \cdot \left[ \frac{1 - x_{\text{H}_2\text{Oexh}}}{1 - x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}} \right]$$

Eq. 659-1

*Example:*

$$x_{\text{CO}_{\text{meas}}} = 29.0 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{OCO}_{\text{meas}}} = 8.601 \text{ mmol/mol} = 0.008601 \text{ mol/mol}$$

$$x_{\text{H}_2\text{Oexh}} = 34.04 \text{ mmol/mol} = 0.03404 \text{ mol/mol}$$

$$x_{\text{CO}} = 29.0 \cdot \left[ \frac{1 - 0.03404}{1 - 0.008601} \right]$$

$$x_{\text{CO}} = 28.3 \text{ } \mu\text{mol/mol}$$

### 660 THC, NMHC, and CH<sub>4</sub> determination.

(a) THC determination and THC/CH<sub>4</sub> initial contamination corrections. (1) If we require you to determine THC emissions, calculate  $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  using the initial THC contamination concentration  $x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$  from 520 as follows:

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = x_{\text{THC}[\text{THC-FID}]_{\text{uncor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{init}}}$$

Eq. 660-1

*Example:*

$$x_{\text{THC}_{\text{uncor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}_{\text{init}}} = 1.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}_{\text{cor}}} = 150.3 - 1.1$$

$$x_{\text{THC}_{\text{cor}}} = 149.2 \text{ } \mu\text{mol/mol}$$

(2) For the NMHC determination described in paragraph (b) of this section, correct  $x_{\text{THC}[\text{THC-FID}]}$

for initial HC contamination using Eq. 660-1. You may correct  $x_{\text{THC}[\text{NMC-FID}]}$  for initial contamination of the CH<sub>4</sub> sample train using Eq. 660-1, substituting in CH<sub>4</sub> concentrations for THC.

(3) For the CH<sub>4</sub> determination described in paragraph (c) of this section, you may correct  $x_{\text{THC}[\text{NMC-FID}]}$  for initial contamination of the CH<sub>4</sub> sample train using Eq. 660-1, substituting in CH<sub>4</sub> concentrations for THC.

(b) **NMHC determination.** Use one of the following to determine NMHC concentration,  $x_{\text{NMHC}}$ :

(1) If you do not measure CH<sub>4</sub>, you may determine NMHC concentrations as described in 650(c)(1)(vi).

(2) For nonmethane cutters, calculate  $x_{\text{NMHC}}$  using the nonmethane cutter's penetration fractions (*PF*) of CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> from 365, and using the HC contamination and dry-to-wet corrected THC concentration  $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  as determined in paragraph (a) of this section.

(i) Use the following equation for penetration fractions determined using an NMC configuration as outlined in 365(d):

$$x_{\text{NMHC}} = \frac{x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} - x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}{1 - RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}$$

Eq. 660-2

Where:

$x_{\text{NMHC}}$  = concentration of NMHC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC FID to CH<sub>4</sub>, according to 360(d).

$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = nonmethane cutter combined ethane response factor and penetration fraction, according to 365(d).

*Example:*

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 20.5 \text{ } \mu\text{mol/mol}$$

$$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} = 0.019$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 1.05$$

$$x_{\text{NMHC}} = \frac{150.3 - 20.5 \cdot 1.05}{1 - 0.019 \cdot 1.05}$$

$$x_{\text{NMHC}} = 131.4 \text{ } \mu\text{mol/mol}$$

(ii) For penetration fractions determined using an NMC configuration as outlined in section §365(e), use the following equation:

$$x_{\text{NMHC}} = \frac{x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot PF_{\text{CH}_4[\text{NMC-FID}]} - x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}}{PF_{\text{CH}_4[\text{NMC-FID}]} - PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}}$$

Eq. 660-3

Where:

$x_{\text{NMHC}}$  = concentration of NMHC.

## WLTP-DTP-01-02

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{\text{CH}_4[\text{NMC-FID}]}$  = nonmethane cutter  $\text{CH}_4$  penetration fraction, according to 365(e).

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = nonmethane cutter ethane penetration fraction, according to 365(e).

*Example:*

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$PF_{\text{CH}_4[\text{NMC-FID}]} = 0.990$$

$$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 20.5 \text{ } \mu\text{mol/mol}$$

$$PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} = 0.020$$

$$x_{\text{NMHC}} = \frac{150.3 \cdot 0.990 - 20.5}{0.990 - 0.020}$$

$$x_{\text{NMHC}} = 132.3 \text{ } \mu\text{mol/mol}$$

(iii) For penetration fractions determined using an NMC configuration as outlined in section 365(f), use the following equation:

$$x_{\text{NMHC}} = \frac{x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot PF_{\text{CH}_4[\text{NMC-FID}]} - x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}{PF_{\text{CH}_4[\text{NMC-FID}]} - RF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]_{\text{cor}}}}$$

Eq. 660-4

Where:

$x_{\text{NMHC}}$  = concentration of NMHC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{\text{CH}_4[\text{NMC-FID}]}$  = nonmethane cutter  $\text{CH}_4$  penetration fraction, according to 365(f).

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$RF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = nonmethane cutter  $\text{CH}_4$  combined ethane response factor and penetration fraction, according to 365(f).

$RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC FID to  $\text{CH}_4$ , according to 360(d).

*Example:*

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$PF_{\text{CH}_4[\text{NMC-FID}]} = 0.990$$

$$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 20.5 \text{ } \mu\text{mol/mol}$$

$$RF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} = 0.019$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 0.980$$

$$x_{\text{NMHC}} = \frac{150.3 \cdot 0.990 - 20.5 \cdot 0.980}{0.990 - 0.019 \cdot 0.980}$$

$$x_{\text{NMHC}} = 132.5 \text{ } \mu\text{mol/mol}$$

(3) For a gas chromatograph, calculate  $x_{\text{NMHC}}$  using the THC analyzer's response factor ( $RF$ ) for  $\text{CH}_4$ , from 360, and the HC contamination and dry-to-wet corrected initial THC concentration

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  as determined in paragraph (a) of this section as follows:

$$x_{\text{NMHC}} = x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} - RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4}$$

Eq. 660-5

Where:

$x_{\text{NMHC}}$  = concentration of NMHC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID.

$x_{\text{CH}_4}$  = concentration of CH<sub>4</sub>, HC contamination (optional) and dry-to-wet corrected, as measured by the gas chromatograph FID.

$RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC-FID to CH<sub>4</sub>.

*Example:*

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 145.6 \text{ } \mu\text{mol/mol}$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 0.970$$

$$x_{\text{CH}_4} = 18.9 \text{ } \mu\text{mol/mol}$$

$$x_{\text{NMHC}} = 145.6 - 0.970 \cdot 18.9$$

$$x_{\text{NMHC}} = 127.3 \text{ } \mu\text{mol/mol}$$

(c) CH<sub>4</sub> determination. Use one of the following methods to determine CH<sub>4</sub> concentration,  $x_{\text{CH}_4}$ :

(1) For nonmethane cutters, calculate  $x_{\text{CH}_4}$  using the nonmethane cutter's penetration fractions (*PF*) of CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> from 365, using the dry-to-wet corrected CH<sub>4</sub> concentration  $x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  as determined in paragraph (a) of this section and optionally using the CH<sub>4</sub> contamination correction under paragraph (a) of this section.

(i) Use the following equation for penetration fractions determined using an NMC configuration as outlined in 365(d):

$$x_{\text{CH}_4} = \frac{x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot RF_{\text{CH}_4[\text{THC-FID}]} \cdot RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}}{1 - RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}$$

Eq. 660-6

Where:

$x_{\text{CH}_4}$  = concentration of CH<sub>4</sub>.

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = the combined ethane response factor and penetration fraction of the nonmethane cutter, according to 365(d).

$RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC FID to CH<sub>4</sub>, according to 360(d).

*Example:*

$$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 10.4 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} = 0.019$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 1.05$$

## WLTP-DTP-01-02

$$x_{\text{CH}_4} = \frac{10.4 - 150.3 \cdot 0.019}{1 - 0.019 \cdot 1.05}$$
$$x_{\text{CH}_4} = 7.69 \text{ } \mu\text{mol/mol}$$

(ii) For penetration fractions determined using an NMC configuration as outlined in 365(e), use the following equation:

$$x_{\text{CH}_4} = \frac{x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}}{RF_{\text{CH}_4[\text{THC-FID}]} \cdot (PF_{\text{CH}_4[\text{NMC-FID}]} - PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]})}$$

Eq. 660-7

Where:

$x_{\text{CH}_4}$  = concentration of  $\text{CH}_4$ .

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = nonmethane cutter ethane penetration fraction, according to 365(e).

$RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC FID to  $\text{CH}_4$ , according to 360(d).

$PF_{\text{CH}_4[\text{NMC-FID}]}$  = nonmethane cutter  $\text{CH}_4$  penetration fraction, according to 365(e).

*Example:*

$$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} = 10.4 \text{ } \mu\text{mol/mol}$$

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$PF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} = 0.020$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 1.05$$

$$PF_{\text{CH}_4[\text{NMC-FID}]} = 0.990$$

$$x_{\text{CH}_4} = \frac{10.4 - 150.3 \cdot 0.020}{1.05 \cdot (0.990 - 0.020)}$$

$$x_{\text{CH}_4} = 7.25 \text{ } \mu\text{mol/mol}$$

(iii) For penetration fractions determined using an NMC configuration as outlined in §365(f), use the following equation:

$$x_{\text{CH}_4} = \frac{x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}} - x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}}{PF_{\text{CH}_4[\text{NMC-FID}]} - RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}$$

Eq. 660-8

Where:

$x_{\text{CH}_4}$  = concentration of  $\text{CH}_4$ .

$x_{\text{THC}[\text{NMC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = the combined ethane response factor and penetration fraction of the nonmethane cutter, according to 365(f).

$PF_{CH_4[NMC-FID]}$  = nonmethane cutter  $CH_4$  penetration fraction, according to 365(f).

$RF_{CH_4[THC-FID]}$  = response factor of THC FID to  $CH_4$ , according to 360(d).

*Example:*

$$x_{THC[NMC-FID]_{cor}} = 10.4 \text{ } \mu\text{mol/mol}$$

$$x_{THC[THC-FID]_{cor}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$RFPF_{C_2H_6[NMC-FID]} = 0.019$$

$$PF_{CH_4[NMC-FID]} = 0.990$$

$$RF_{CH_4[THC-FID]} = 1.05$$

$$x_{CH_4} = \frac{10.4 - 150.3 \cdot 0.019}{0.990 - 0.019 \cdot 1.05}$$

$$x_{CH_4} = 7.78 \text{ } \mu\text{mol/mol}$$

(2) For a gas chromatograph,  $x_{CH_4}$  is the actual dry-to-wet corrected  $CH_4$  concentration as measured by the analyzer.

### 665 THCE and NMHCE determination.

(a) If you measured an oxygenated hydrocarbon's mass concentration, first calculate its molar concentration in the exhaust sample stream from which the sample was taken (raw or diluted exhaust), and convert this into a  $C_1$ -equivalent molar concentration. Add these  $C_1$ -equivalent molar concentrations to the molar concentration of NOTHC. The result is the molar concentration of THCE. Calculate THCE concentration using the following equations, noting that equation 665-3 is only required if you need to convert your OHC concentration from mass to moles:

$$x_{THCE} = x_{NOTHC} + \sum_{i=1}^N (x_{OHCi} - x_{OHCi-init})$$

Eq. 665-1

$$x_{NOTHC} = x_{THC[THC-FID]_{cor}} - \sum_{i=1}^N (x_{OHCi} \cdot RF_{OHCi[THC-FID]})$$

Eq. 665-2

$$x_{OHCi} = \frac{\frac{m_{dexhOHCi}}{M_{OHCi}}}{\frac{m_{dexh}}{M_{dexh}}} = \frac{n_{dexhOHCi}}{n_{dexh}}$$

Eq. 665-3

Where:

$x_{THCE}$  = The  $C_1$ -equivalent sum of the concentration of carbon mass contributions of non-oxygenated hydrocarbons, alcohols, and aldehydes.

$x_{NOTHC}$  = The  $C_1$ -equivalent sum of the concentration of nonoxygenated THC.

$x_{OHCi}$  = The  $C_1$ -equivalent concentration of oxygenated species  $i$  in diluted exhaust, not corrected for initial contamination.

$x_{OHCi-init}$  = The  $C_1$ -equivalent concentration of the initial system contamination (optional) of

## WLTP-DTP-01-02

oxygenated species  $i$ , dry-to-wet corrected.

$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = The C<sub>1</sub>-equivalent response to NOTHC and all OHC in diluted exhaust, HC contamination and dry-to-wet corrected, as measured by the THC-FID.

$RF_{\text{OHC}i[\text{THC-FID}]}$  = The response factor of the FID to species  $i$  relative to propane on a C<sub>1</sub>-equivalent basis.

$C^{\#}$  = the mean number of carbon atoms in the particular compound.

$M_{\text{dexh}}$  = The molar mass of diluted exhaust as determine in §340.

$m_{\text{dexhOHC}i}$  = The mass of oxygenated species  $i$  in dilute exhaust.

$M_{\text{OHC}i}$  = The C<sub>1</sub>-equivalent molecular weight of oxygenated species  $i$ .

$m_{\text{dexh}}$  = The mass of diluted exhaust

$n_{\text{dexhOHC}i}$  = The number of moles of oxygenated species  $i$  in total diluted exhaust flow.

$n_{\text{dexh}}$  = The total diluted exhaust flow.

(b) If we require you to determine NMHCE, use the following equation:

$$x_{\text{NMHCE}} = x_{\text{THCE}} - RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4}$$

Eq..665-4

Where:

$x_{\text{NMHCE}}$  = The C<sub>1</sub>-equivalent sum of the concentration of carbon mass contributions of non-oxygenated NMHC, alcohols, and aldehydes.

$RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC-FID to CH<sub>4</sub>.

$x_{\text{CH}_4}$  = concentration of CH<sub>4</sub>, HC contamination (optional) and dry-to-wet corrected, as measured by the gas chromatograph FID.

(c) The following example shows how to determine NMHCE emissions based on ethanol (C<sub>2</sub>H<sub>5</sub>OH), methanol (CH<sub>3</sub>OH), acetaldehyde (C<sub>2</sub>H<sub>4</sub>O), and formaldehyde (HCHO) as C<sub>1</sub>-equivalent molar concentrations:

$$x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} = 145.6 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CH}_4} = 18.9 \text{ } \mu\text{mol/mol}$$

$$x_{\text{C}_2\text{H}_5\text{OH}} = 100.8 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CH}_3\text{OH}} = 1.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{C}_2\text{H}_4\text{O}} = 19.1 \text{ } \mu\text{mol/mol}$$

$$x_{\text{HCHO}} = 1.3 \text{ } \mu\text{mol/mol}$$

$$RF_{\text{CH}_4[\text{THC-FID}]} = 1.07$$

$$RF_{\text{C}_2\text{H}_5\text{OH}[\text{THC-FID}]} = 0.76$$

$$RF_{\text{CH}_3\text{OH}[\text{THC-FID}]} = 0.74$$

$$RF_{\text{H}_2\text{H}_4\text{O}[\text{THC-FID}]} = 0.50$$

$$RF_{\text{HCHO}[\text{THC-FID}]} = 0.0$$

$$x_{\text{NMHCE}} = x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} - (x_{\text{C}_2\text{H}_5\text{OH}} \cdot RF_{\text{C}_2\text{H}_5\text{OH}[\text{THC-FID}]} + x_{\text{CH}_3\text{OH}} \cdot RF_{\text{CH}_3\text{OH}[\text{THC-FID}]} + x_{\text{C}_2\text{H}_4\text{O}} \cdot RF_{\text{C}_2\text{H}_4\text{O}[\text{THC-FID}]} + x_{\text{HCHO}} \cdot RF_{\text{HCHO}[\text{THC-FID}]}) + x_{\text{C}_2\text{H}_5\text{OH}} + x_{\text{CH}_3\text{OH}} + x_{\text{C}_2\text{H}_4\text{O}} + x_{\text{HCHO}} - (RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4})$$

$$x_{\text{NMHCE}} = 145.6 - (100.8 \cdot 0.76 + 1.1 \cdot 0.74 + 19.1 \cdot 0.50 + 1.3 \cdot 0) + 100.8 + 1.1 + 19.1 + 1.3 - (1.07 \cdot 18.9)$$

$$x_{\text{NMHCE}} = 160.71 \text{ } \mu\text{mol/mol}$$

### §667 Dilution air background emission correction.

(a) To determine the mass of background emissions to subtract from a diluted exhaust sample, first determine the total flow of dilution air,  $n_{\text{dil}}$ , over the test interval. This may be a measured quantity or a quantity calculated from the diluted exhaust flow and the flow-weighted mean fraction of dilution air in diluted exhaust,  $\bar{x}_{\text{dil/exh}}$ . Multiply the total flow of dilution air by the mean concentration of a background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). The product of  $n_{\text{dil}}$  and the mean concentration of a background emission is the total amount of a background emission. If this is a molar quantity, convert it to a mass by multiplying it by its molar mass,  $M$ . The result is the mass of the background emission,  $m$ . In the case of PM, where the mean PM concentration is already in units of mass per mole of sample,  $\bar{M}_{\text{PM}}$ , multiply it by the total amount of dilution air, and the result is the total background mass of PM,  $m_{\text{PM}}$ . Subtract total background masses from total mass to correct for background emissions.

(b) You may determine the total flow of dilution air by a direct flow measurement. In this case, calculate the total mass of background as described in 650(c), using the dilution air flow,  $n_{\text{dil}}$ . Subtract the background mass from the total mass. Use the result in brake-specific emission calculations.

(c) You may determine the total flow of dilution air from the total flow of diluted exhaust and a chemical balance of the fuel, intake air, and exhaust as described in 655. In this case, calculate the total mass of background as described in 650(c), using the total flow of diluted exhaust,  $n_{\text{dexh}}$ , then multiply this result by the flow-weighted mean fraction of dilution air in diluted exhaust,  $\bar{x}_{\text{dil/exh}}$ . Calculate  $\bar{x}_{\text{dil/exh}}$  using flow-weighted mean concentrations of emissions in the chemical balance, as described in 655. You may assume that your engine operates stoichiometrically, even if it is a lean-burn engine, such as a compression-ignition engine. Note that for lean-burn engines this assumption could result in an error in emission calculations. This error could occur because the chemical balances in 655 correct excess air passing through a lean-burn engine as if it was dilution air. If an emission concentration expected at the standard is about 100 times its dilution air background concentration, this error is negligible. However, if an emission concentration expected at the standard is similar to its background concentration, this error could be significant. If this error might affect your ability to show that your vehicles comply with applicable standards, we recommend that you remove background emissions from dilution air by HEPA filtration, chemical adsorption, or catalytic scrubbing. You might also consider using a partial-flow dilution technique such as a bag mini-diluter, which uses purified air as the dilution air.

(d) The following is an example of using the flow-weighted mean fraction of dilution air in diluted exhaust,  $\bar{x}_{\text{dil/exh}}$ , and the total mass of background emissions calculated using the total flow of diluted exhaust,  $n_{\text{dexh}}$ , as described in 650(c):

$$m_{\text{bknd}} = \bar{x}_{\text{dil/exh}} \cdot m_{\text{bknddexh}}$$

Eq. 667-1

$$m_{\text{bknddexh}} = M \cdot \bar{x}_{\text{bknd}} \cdot n_{\text{dexh}}$$

Eq. 667-2

## WLTP-DTP-01-02

*Example:*

$$M_{\text{NO}_x} = 46.0055 \text{ g/mol}$$

$$\bar{x}_{\text{bkgn}} = 0.05 \text{ } \mu\text{mol/mol} = 0.05 \cdot 10^{-6} \text{ mol/mol}$$

$$n_{\text{dexh}} = 23280.5 \text{ mol}$$

$$\bar{x}_{\text{dil/exh}} = 0.843 \text{ mol/mol}$$

$$m_{\text{bkgnNO}_x\text{dexh}} = 46.0055 \cdot 0.05 \cdot 10^{-6} \cdot 23280.5$$

$$m_{\text{bkgnNO}_x\text{dexh}} = 0.0536 \text{ g}$$

$$m_{\text{bkgnNO}_x} = 0.843 \cdot 0.0536$$

$$m_{\text{bkgnNO}_x} = 0.0452 \text{ g}$$

(e) The following is an example of using the fraction of dilution air in diluted exhaust,  $x_{\text{dil/exh}}$ , and the mass rate of background emissions calculated using the flow rate of diluted exhaust,  $\dot{n}_{\text{dexh}}$ , as described in §650(c) :

$$\dot{m}_{\text{bkgn}} = x_{\text{dil/exh}} \cdot \dot{m}_{\text{bkgn dexh}}$$

Eq. 667-3

$$\dot{m}_{\text{bkgn dexh}} = M \cdot x_{\text{bkgn}} \cdot \dot{n}_{\text{dexh}}$$

Eq. 667-4

*Example:*

$$M_{\text{NO}_x} = 46.0055 \text{ g/mol}$$

$$x_{\text{bkgn}} = 0.05 \text{ } \mu\text{mol/mol} = 0.05 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{\text{dexh}} = 23280.5 \text{ mol/s}$$

$$x_{\text{dil/exh}} = 0.843 \text{ mol/mol}$$

$$\dot{m}_{\text{bkgnNO}_x\text{dexh}} = 46.0055 \cdot 0.05 \cdot 10^{-6} \cdot 23280.5$$

$$\dot{m}_{\text{bkgnNO}_x\text{dexh}} = 0.0536 \text{ g/hr}$$

$$\dot{m}_{\text{bkgnNO}_x} = 0.843 \cdot 0.0536$$

$$\dot{m}_{\text{bkgnNO}_x} = 0.0452 \text{ g/hr}$$

### 670 NO<sub>x</sub> intake-air humidity and temperature corrections.

First apply any NO<sub>x</sub> corrections for background emissions and water removal from the exhaust sample, then correct NO<sub>x</sub> concentrations for intake-air humidity. You may use a time-weighted mean combustion air humidity to calculate this correction if your combustion air humidity remains within a tolerance of ±0.0025 mol/mol of the mean value over the test interval. For intake-air humidity correction, use one of the following approaches:

(a) For compression-ignition engines, correct for intake-air humidity using the following equation:

$$x_{\text{NO}_x\text{cor}} = x_{\text{NO}_x\text{uncor}} \cdot (9.953 \cdot x_{\text{H}_2\text{O}} + 0.832)$$

Eq. 670-1

*Example:*

$$x_{\text{NOxuncor}} = 700.5 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{O}} = 0.022 \text{ mol/mol}$$

$$x_{\text{NOxcor}} = 700.5 \cdot (9.953 \cdot 0.022 + 0.832)$$

$$x_{\text{NOxcor}} = 736.2 \text{ } \mu\text{mol/mol}$$

(b) For spark-ignition engines, correct for intake-air humidity using the following equation:

$$x_{\text{NOxcor}} = x_{\text{NOxuncor}} \cdot (18.840 \cdot x_{\text{H}_2\text{O}} + 0.68094)$$

Eq. 670-2

*Example:*

$$x_{\text{NOxuncor}} = 154.7 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{O}} = 0.022 \text{ mol/mol}$$

$$x_{\text{NOxcor}} = 154.7 \cdot (18.840 \cdot 0.022 + 0.68094)$$

$$x_{\text{NOxcor}} = 169.5 \text{ } \mu\text{mol/mol}$$

## 672 Drift correction.

(a) Scope and frequency. Perform the calculations in this section to determine if gas analyzer drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, correct that test interval's gas analyzer responses for drift according to this section. Use the drift-corrected gas analyzer responses in all subsequent emission calculations. Note that the acceptable threshold for gas analyzer drift over a test interval is specified in 550 for both laboratory testing and field testing.

(b) Correction principles. The calculations in this section utilize a gas analyzer's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analyzer's responses that were recorded during a test interval. The correction is based on an analyzer's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validate and correct for drift as follows:

(c) Drift validation. After applying all the other corrections—except drift correction—to all the gas analyzer signals, calculate brake-specific emissions according to 650. Then correct all gas analyzer signals for drift according to this section. Recalculate brake-specific emissions using all of the drift-corrected gas analyzer signals. Validate and report the brake-specific emission results before and after drift correction according to 550.

(d) Drift correction. Correct all gas analyzer signals as follows:

(1) Correct each recorded concentration,  $x_i$ , for continuous sampling or for batch sampling,  $\bar{x}$ .

(2) Correct for drift using the following equation:

$$x_{\text{idriftcorrected}} = x_{\text{refzero}} + (x_{\text{refspan}} - x_{\text{refzero}}) \cdot \frac{2x_i - (x_{\text{prezero}} + x_{\text{postzero}})}{(x_{\text{prespan}} + x_{\text{postspan}}) - (x_{\text{prezero}} + x_{\text{postzero}})}$$

Eq. 672-1

Where:

$x_{\text{idriftcorrected}}$  = concentration corrected for drift.

$x_{\text{refzero}}$  = reference concentration of the zero gas, which is usually zero unless known to be otherwise.

$x_{\text{refspan}}$  = reference concentration of the span gas.

$x_{\text{prespan}}$  = pre-test interval gas analyzer response to the span gas concentration.

## WLTP-DTP-01-02

$x_{\text{postspan}}$  = post-test interval gas analyzer response to the span gas concentration.

$x_i$  or  $\bar{x}$  = concentration recorded during test, before drift correction.

$x_{\text{prezero}}$  = pre-test interval gas analyzer response to the zero gas concentration.

$x_{\text{postzero}}$  = post-test interval gas analyzer response to the zero gas concentration.

### Example:

$x_{\text{refzero}} = 0 \text{ } \mu\text{mol/mol}$

$x_{\text{refspan}} = 1800.0 \text{ } \mu\text{mol/mol}$

$x_{\text{prespan}} = 1800.5 \text{ } \mu\text{mol/mol}$

$x_{\text{postspan}} = 1695.8 \text{ } \mu\text{mol/mol}$

$x_i$  or  $\bar{x} = 435.5 \text{ } \mu\text{mol/mol}$

$x_{\text{prezero}} = 0.6 \text{ } \mu\text{mol/mol}$

$x_{\text{postzero}} = -5.2 \text{ } \mu\text{mol/mol}$

$$x_{\text{idriftcorrected}} = 0 + (1800.0 - 0) \cdot \frac{2 \cdot 435.5 - (0.6 + (-5.2))}{(1800.5 + 1695.8) - (0.6 + (-5.2))}$$

$x_{\text{idriftcorrected}} = 450.2 \text{ } \mu\text{mol/mol}$

(3) For any pre-test interval concentrations, use concentrations determined most recently before the test interval. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals.

(4) For any post-test interval concentrations, use concentrations determined most recently after the test interval. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals.

(5) If you do not record any pre-test interval analyzer response to the span gas concentration,  $x_{\text{prespan}}$ , set  $x_{\text{prespan}}$  equal to the reference concentration of the span gas:  $x_{\text{prespan}} = x_{\text{refspan}}$ .

(6) If you do not record any pre-test interval analyzer response to the zero gas concentration,  $x_{\text{prezero}}$ , set  $x_{\text{prezero}}$  equal to the reference concentration of the zero gas:  $x_{\text{prezero}} = x_{\text{refzero}}$ .

(7) Usually the reference concentration of the zero gas,  $x_{\text{refzero}}$ , is zero:  $x_{\text{refzero}} = 0 \text{ } \mu\text{mol/mol}$ .

However, in some cases you might know that  $x_{\text{refzero}}$  has a non-zero concentration. For example, if you zero a CO<sub>2</sub> analyzer using ambient air, you may use the default ambient air concentration of CO<sub>2</sub>, which is 375  $\mu\text{mol/mol}$ . In this case,  $x_{\text{refzero}} = 375 \text{ } \mu\text{mol/mol}$ . Note that when you zero an analyzer using a non-zero  $x_{\text{refzero}}$ , you must set the analyzer to output the actual  $x_{\text{refzero}}$  concentration. For example, if  $x_{\text{refzero}} = 375 \text{ } \mu\text{mol/mol}$ , set the analyzer to output a value of 375  $\mu\text{mol/mol}$  when the zero gas is flowing to the analyzer.

### §675 CLD quench verification calculations.

Perform CLD quench-check calculations as follows:

(a) Perform a CLD analyzer quench verification test as described in 370.

(b) Estimate the maximum expected mole fraction of water during emission testing,  $x_{\text{H}_2\text{Oexp}}$ . Make this estimate where the humidified NO span gas was introduced in 370(e)(6). When estimating the maximum expected mole fraction of water, consider the maximum expected water content in combustion air, fuel combustion products, and dilution air (if applicable). If you introduced the humidified NO span gas into the sample system upstream of a sample dryer during the verification test, you need not estimate the maximum expected mole fraction of water

and you must set  $x_{\text{H}_2\text{Oexp}}$  equal to  $x_{\text{H}_2\text{Omeas}}$ .

(c) Estimate the maximum expected  $\text{CO}_2$  concentration during emission testing,  $x_{\text{CO}_2\text{exp}}$ . Make this estimate at the sample system location where the blended NO and  $\text{CO}_2$  span gases are introduced according to 370(d)(10). When estimating the maximum expected  $\text{CO}_2$  concentration, consider the maximum expected  $\text{CO}_2$  content in fuel combustion products and dilution air.

(d) Calculate quench as follows:

$$\text{quench} = \left( \left( \frac{x_{\text{NOwet}}}{1 - x_{\text{H}_2\text{Omeas}}} - 1 \right) \cdot \frac{x_{\text{H}_2\text{Oexp}}}{x_{\text{H}_2\text{Omeas}}} + \left( \frac{x_{\text{NOmeas}}}{x_{\text{NOact}}} - 1 \right) \cdot \frac{x_{\text{CO}_2\text{exp}}}{x_{\text{CO}_2\text{act}}} \right) \cdot 100 \%$$

Eq. 675-1

Where:

*quench* = amount of CLD quench.

$x_{\text{NOdry}}$  = concentration of NO upstream of a bubbler, according to 370(e)(4).

$x_{\text{NOwet}}$  = measured concentration of NO downstream of a bubbler, according to 370(e)(9).

$x_{\text{H}_2\text{Oexp}}$  = maximum expected mole fraction of water during emission testing, according to paragraph (b) of this section.

$x_{\text{H}_2\text{Omeas}}$  = measured mole fraction of water during the quench verification, according to 370(e)(7).

$x_{\text{NOmeas}}$  = measured concentration of NO when NO span gas is blended with  $\text{CO}_2$  span gas, according to 370(d)(10).

$x_{\text{NOact}}$  = actual concentration of NO when NO span gas is blended with  $\text{CO}_2$  span gas, according to 370(d)(11) and calculated according to Equation 675-2.

$x_{\text{CO}_2\text{exp}}$  = maximum expected concentration of  $\text{CO}_2$  during emission testing, according to paragraph (c) of this section.

$x_{\text{CO}_2\text{act}}$  = actual concentration of  $\text{CO}_2$  when NO span gas is blended with  $\text{CO}_2$  span gas, according to 370(d)(9).

$$x_{\text{NOact}} = \left( 1 - \frac{x_{\text{CO}_2\text{act}}}{x_{\text{CO}_2\text{span}}} \right) \cdot x_{\text{NOspan}}$$

Eq. 675-2

Where:

$x_{\text{NOspan}}$  = the NO span gas concentration input to the gas divider, according to 370(d)(5).

$x_{\text{CO}_2\text{span}}$  = the  $\text{CO}_2$  span gas concentration input to the gas divider, according to 370(d)(4).

*Example:*

$x_{\text{NOdry}} = 1800.0 \mu\text{mol/mol}$

$x_{\text{NOwet}} = 1729.6 \mu\text{mol/mol}$

$x_{\text{H}_2\text{Oexp}} = 0.030 \text{ mol/mol}$

$x_{\text{H}_2\text{Omeas}} = 0.030 \text{ mol/mol}$

$x_{\text{NOmeas}} = 1495.2 \mu\text{mol/mol}$

## WLTP-DTP-01-02

$$x_{\text{NOspan}} = 3001.6 \text{ } \mu\text{mol/mol}$$

$$x_{\text{CO2exp}} = 3.2 \%$$

$$x_{\text{CO2span}} = 6.00 \%$$

$$x_{\text{CO2act}} = 2.98 \%$$

$$x_{\text{NOact}} = \left(1 - \frac{2.98}{6.00}\right) \cdot 3001.6 = 1510.8 \text{ } \mu\text{mol/mol}$$

$$\text{quench} = \left( \left( \frac{1729.6}{1 - 0.030} - 1 \right) \cdot \frac{0.030}{0.030} + \left( \frac{1495.2}{1510.8} - 1 \right) \cdot \frac{3.2}{2.98} \right) \cdot 100 \%$$

$$\text{quench} = (-0.00939 - 0.01109) \cdot 100\% = -2.0048 \% = -2 \%$$

### 690 Buoyancy correction for PM sample media.

(a) General. Correct PM sample media for their buoyancy in air if you weigh them on a balance. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0.01 to 0.10) % of the total weight. A correction to this small fraction of mass would be at the most 0.010 %.

(b) PM sample media density. Different PM sample media have different densities. Use the known density of your sample media, or use one of the densities for some common sampling media, as follows:

(1) For PTFE-coated borosilicate glass, use a sample media density of 2300 kg/m<sup>3</sup>.

(2) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95 % of the media mass, use a sample media density of 920 kg/m<sup>3</sup>.

(3) For PTFE membrane (film) media with an integral support ring of PTFE, use a sample media density of 2144 kg/m<sup>3</sup>.

(c) Air density. Because a PM balance environment must be tightly controlled to an ambient temperature of (22 ± 1) °C and humidity has an insignificant effect on buoyancy correction, air density is primarily a function of atmospheric pressure. Therefore you may use nominal constant values for temperature and humidity in the buoyancy correction equation in Eq. 690-2.

(d) Calibration weight density. Use the stated density of the material of your metal calibration weight. The example calculation in this section uses a density of 8000 kg/m<sup>3</sup>, but you should know the density of your weight from the calibration weight supplier or the balance manufacturer if it is an internal weight.

(e) Correction calculation. Correct the PM sample media for buoyancy using the following equations:

$$m_{\text{cor}} = m_{\text{uncor}} \cdot \left[ \frac{1 - \frac{\rho_{\text{air}}}{\rho_{\text{weight}}}}{1 - \frac{\rho_{\text{air}}}{\rho_{\text{media}}}} \right]$$

Eq. 690-1

Where:

$m_{\text{cor}}$  = PM mass corrected for buoyancy.

$m_{\text{uncor}}$  = PM mass uncorrected for buoyancy.

$\rho_{\text{air}}$  = density of air in balance environment.

$\rho_{\text{weight}}$  = density of calibration weight used to span balance.

$\rho_{\text{media}}$  = density of PM sample media, such as a filter.

$$\rho_{\text{air}} = \frac{p_{\text{abs}} \cdot M_{\text{mix}}}{R \cdot T_{\text{amb}}}$$

Eq. 690-2

Where:

$p_{\text{abs}}$  = absolute pressure in balance environment.

$M_{\text{mix}}$  = molar mass of air in balance environment.

$R$  = molar gas constant.

$T_{\text{amb}}$  = absolute ambient temperature of balance environment.

*Example:*

$p_{\text{abs}} = 99.980 \text{ kPa}$

$T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ }^\circ\text{C}$

Using Eq. 645-1,

$p_{\text{H}_2\text{O}} = 1.1866 \text{ kPa}$

Using Eq. 645-3,

$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$

Using Eq. 640-9,

$M_{\text{mix}} = 28.83563 \text{ g/mol}$

$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$

$T_{\text{amb}} = 20 \text{ }^\circ\text{C}$

$$\rho_{\text{air}} = \frac{99.980 \cdot 28.83563}{8.314472 \cdot 293.15}$$

$\rho_{\text{air}} = 1.18282 \text{ kg/m}^3$

$m_{\text{uncorr}} = 100.0000 \text{ mg}$

$\rho_{\text{weight}} = 8000 \text{ kg/m}^3$

$\rho_{\text{media}} = 920 \text{ kg/m}^3$

$$m_{\text{cor}} = 100.0000 \cdot \left[ \frac{1 - \frac{1.18282}{8000}}{1 - \frac{1.18282}{920}} \right]$$

$m_{\text{cor}} = 100.1139 \text{ mg}$

## WLTP-DTP-01-02

### MASS BASED CALCULATIONS

#### Calculations; exhaust emissions.

The final reported test results shall be computed by use of the following formula:

(a) For light-duty vehicles and light duty trucks:

$$Y_{wm} = 0.43 \times \frac{\sum (Y_{ct} + Y_s) \frac{\ddot{O}}{i}}{\sum (D_{ct} + D_s) \frac{\ddot{O}}{i}} + 0.57 \times \frac{\sum (Y_{ht} + Y_s) \frac{\ddot{O}}{i}}{\sum (D_{ht} + D_s) \frac{\ddot{O}}{i}}$$

Where:

(1)  $Y_{wm}$  = Weighted mass emissions of each pollutant, *i.e.*, THC, CO, THCE, NMHC, NMHCE, CH<sub>4</sub>, NO<sub>x</sub>, or CO<sub>2</sub>, in grams per vehicle mile.

(2)  $Y_{ct}$  = Mass emissions as calculated from the “transient” phase of the cold start test, in grams per test phase.

(3)  $Y_{ht}$  = Mass emissions as calculated from the “transient” phase of the hot start test, in grams per test phase.

(4)  $Y_s$  = Mass emissions as calculated from the “stabilized” phase of the cold start test, in grams per test phase.

(5)  $D_{ct}$  = The measured driving distance from the “transient” phase of the cold start test, in miles.

(6)  $D_{ht}$  = The measured distance from the “transient” phase of the hot start test, in miles.

(7)  $D_s$  = The measured driving distance from the “stabilized” phase of the cold start test, in miles.

(b) The mass of each pollutant for each phase of both the cold start test and the hot start test is determined from the following:

(1) Total hydrocarbon mass:

$$HC_{mass} = V_{mix} \cdot \text{Density}_{HC} \cdot (HC_{conc} / 1,000,000)$$

(2) Oxides of nitrogen mass:

$$NOx_{mass} = V_{mix} \cdot \text{Density}_{NO2} \cdot KH \cdot (NOx_{conc} / 1,000,000)$$

(3) Carbon monoxide mass:

$$CO_{mass} = V_{mix} \cdot \text{Density}_{CO} \cdot (CO_{conc} / 1,000,000)$$

(4) Carbon dioxide mass:

$$CO_{2mass} = V_{mix} \cdot \text{Density}_{CO2} \cdot (CO_{2conc} / 100)$$

(5) Methanol mass:

$$CH_3OH_{mass} = V_{mix} \cdot \text{Density}_{CH_3OH} \cdot (CH_3OH_{conc} / 1,000,000)$$

(6) Formaldehyde mass:

$$HCHO_{mass} = V_{mix} \cdot \text{Density}_{HCHO} \cdot (HCHO_{conc} / 1,000,000)$$

(7) Total hydrocarbon equivalent mass:

$$THCE_{mass} = HC_{mass} + 13.8756/32.042 \cdot (CH_3OH_{mass}) + 13.8756/32.0262 \cdot (HCHO_{mass})$$

(8) Non-methane hydrocarbon mass:

$$NMHC_{mass} = V_{mix} \cdot \text{Density}_{NMHC} \cdot (NMHC_{conc} / 1,000,000)$$

(9) Non-methane hydrocarbon equivalent mass:

$$NMHCE_{mass} = NMHC_{mass} + 13.8756/32.042 \cdot (CH_3OH_{mass}) + 13.8756/30.0262 \cdot (HCHO_{mass})$$

(10) Methane mass:

$$\text{CH}_{4\text{mass}} = V_{\text{mix}} = \text{Density}_{\text{CH}_4} = (\text{CH}_{4\text{conc}} / 1,000,00)$$

(c) Meaning of symbols:

(1)(i)  $\text{HC}_{\text{mass}}$  = Total hydrocarbon emissions, in grams per test phase.

(ii)  $\text{Density}_{\text{HC}}$  = Density of total hydrocarbon.

(A) *For gasoline-fuel, diesel-fuel and methanol fuel;*  $\text{Density}_{\text{HC}} = 16.33 \text{ g/ft}^3$  - carbon atom (0.5768 kg/m<sup>3</sup> - carbon atom), assuming an average carbon to hydrogen ratio of 1:1.85, at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(B) *For natural gas and liquefied petroleum gas-fuel;*  $\text{Density}_{\text{HC}} = 1.1771 (12.011 + \text{H/C} (1.008)) \text{ g/ft}^3$  - carbon atom (0.04157(12.011+H/C (1.008))kg/m<sup>3</sup> - carbon atom), where H/C is the hydrogen to carbon ratio of the hydrocarbon components of the test fuel, at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(iii)(A)  $\text{HC}_{\text{conc}}$  = Total hydrocarbon concentration of the dilute exhaust sample corrected for background, in ppm carbon equivalent, i.e., equivalent propane · 3.

(B)  $\text{HC}_{\text{conc}} = \text{HC}_e - \text{HC}_d(1 - 1/\text{DF})$ .

Where:

(iv)(A)  $\text{HC}_e$  = Total hydrocarbon concentration of the dilute exhaust sample or, for diesel-cycle (or methanol-fueled vehicles, if selected), average hydrocarbon concentration of the dilute exhaust sample as calculated from the integrated THC traces, in ppm carbon equivalent.

(B)  $\text{HC}_e = \text{FID HC}_e - (r)\text{CCH}_3\text{OH}_e$ .

(v)  $\text{FID HC}_e$  = Concentration of total hydrocarbon plus methanol in dilute exhaust as measured by the FID, ppm carbon equivalent.

(vi)  $r$  = FID response to methanol.

(vii)  $\text{CCH}_3\text{OH}_e$  = Concentration of methanol in dilute exhaust as determined from the dilute exhaust methanol sample in ppm carbon. For vehicles not fueled with methanol,  $\text{CCH}_3\text{OH}_e$  equals zero.

(viii)(A)  $\text{HC}_d$  = Total hydrocarbon concentration of the dilution air as measured, in ppm carbon equivalent.

(B)  $\text{HC}_d = \text{FID HC}_d - (r)\text{CCH}_3\text{OH}_d$ .

(ix)  $\text{FID HC}_d$  = Concentration of total hydrocarbon plus methanol in dilution air as measured by the FID, ppm carbon equivalent.

(x)  $\text{CCH}_3\text{OH}_d$  = Concentration of methanol in dilution air as determined from dilution air methanol sample in ppm carbon. For vehicles not fueled with methanol,  $\text{CCH}_3\text{OH}_d$  equals zero.

(2)(i)  $\text{NO}_{\text{xmass}}$  = Oxides of nitrogen emissions, in grams per test phase.

(ii)  $\text{Density}_{\text{NO}_2}$  = Density of oxides of nitrogen is 54.16 g/ft<sup>3</sup> (1.913 kg/m<sup>3</sup>) assuming they are in the form of nitrogen dioxide, at 68 °F (20 °C) and 760 mm Hg (101.3kPa) pressure.

(iii)(A)  $\text{NO}_{\text{xconc}}$  = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, in ppm.

(B)  $\text{NO}_{\text{xconc}} = \text{NO}_{\text{xe}} - \text{NO}_{\text{xd}}(1 - (1/\text{DF}))$ .

Where:

(iv)  $\text{NO}_{\text{xe}}$  = Oxides of nitrogen concentration of the dilute exhaust sample as measured, in ppm.

(v)  $\text{NO}_{\text{xd}}$  = Oxides of nitrogen concentration of the dilution air as measured, in ppm.

(3)(i)  $\text{CO}_{\text{mass}}$  = Carbon monoxide emissions, in grams per test phase.

(ii)  $\text{Density}_{\text{CO}}$  = Density of carbon monoxide is 32.97 g/ft<sup>3</sup> (1.164 kg/m<sup>3</sup>), at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

## WLTP-DTP-01-02

(iii)(A)  $CO_{conc}$  = Carbon monoxide concentration of the dilute exhaust sample corrected for background, water vapor, and  $CO_2$  extraction, in ppm.

(B)  $CO_{conc} = CO_e - CO_d(1 - (1/DF))$ .

Where:

(iv)(A)  $CO_e$  = Carbon monoxide concentration of the dilute exhaust volume corrected for water vapor and carbon dioxide extraction, in ppm.

(B)  $CO_e = (1 - 0.01925CO_{2e} - 0.000323R)CO_{em}$  for petroleum fuel with hydrogen to carbon ratio of 1.85:1.

(C)  $CO_e = [1 - (0.01 + 0.005HCR)CO_{2e} - 0.000323R]CO_{em}$  for methanol-fuel or natural gas-fuel or liquefied petroleum gas-fuel, where HCR is hydrogen-to-carbon ratio as measured for the fuel used.

(v)  $CO_{em}$  = Carbon monoxide concentration of the dilute exhaust sample as measured, in ppm.

(vi)  $CO_{2e}$  = Carbon dioxide concentration of the dilute exhaust sample, in percent.

(vii) R = Relative humidity of the dilution air, in percent (see § 86.142(n)).

(viii)(A)  $CO_d$  = Carbon monoxide concentration of the dilution air corrected for water vapor extraction, in ppm.

(B)  $CO_d = (1 - 0.000323R)CO_{dm}$ .

Where:

(ix)  $CO_{dm}$  = Carbon monoxide concentration of the dilution air sample as measured, in ppm.

(4)(i)  $CO_{2mass}$  = Carbon dioxide emissions, in grams per test phase.

(ii) Density  $CO_2$  = Density of carbon dioxide is 51.81 g/ft<sup>3</sup> (1.830 kg/m<sup>3</sup>), at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(iii)(A)  $CO_{2conc}$  = Carbon dioxide concentration of the dilute exhaust sample corrected for background, in percent.

(B)  $CO_{2conc} = CO_{2e} - CO_{2d}(1 - (1/DF))$ .

Where:

(iv)  $CO_{2d}$  = Carbon dioxide concentration of the dilution air as measured, in percent.

(5)(i)  $CH_3OH_{mass}$  = Methanol emissions corrected for background, in grams per test phase.

(ii) Density  $CH_3OH$  = Density of methanol is 37.71 g/ft<sup>3</sup>-carbon atom (1.332 kg/m<sup>3</sup>-carbon atom), at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(iii)(A)  $CH_3OH_{conc}$  = Methanol concentration of the dilute exhaust corrected for background, ppm.

(B)  $CH_3OH_{conc} = CCH_3OH_e - CCH_3OH_d(1 - (1/DF))$ .

Where:

(iv)(A)  $CCH_3OH_e$  = Methanol concentration in the dilute exhaust, ppm.

(B)

$$C_{CH_3OH_e} = \frac{3.813 \times 10^{-2} \times T_{EM} [(C_{S1} \times AV_{S1}) + (C_{S2} \times AV_{S2})]}{P_B \times V_{EM}}$$

(v)(A)  $CCH_3OH_d$  = Methanol concentration in the dilution air, ppm.

(B)

$$C_{\text{CH}_3\text{OHd}} = \frac{3.813 \times 10^{-2} \times T_{\text{DM}} [(C_{\text{D1}} \times AV_{\text{D1}}) + (C_{\text{D2}} \times AV_{\text{D2}})]}{P_{\text{B}} \times V_{\text{DM}}}$$

- (vi) TEM=Temperature of methanol sample withdrawn from dilute exhaust, °R.  
 (vii) TDM = Temperature of methanol sample withdrawn from dilution air, °R.  
 (viii) PB = Barometric pressure during test, mm Hg.  
 (ix) VEM = Volume of methanol sample withdrawn from dilute exhaust, ft<sup>3</sup>.  
 (x) VDM = Volume of methanol sample withdrawn from dilution air, ft<sup>3</sup>.  
 (xi) CS = GC concentration of sample drawn from dilute exhaust, g/ml.  
 (xii) CD = GC concentration of sample drawn from dilution air, g/ml.  
 (xiii) AVS = Volume of absorbing reagent (deionized water) in impinger through which methanol sample from dilute exhaust is drawn, ml.  
 (xiv) AVD = Volume of absorbing reagent (deionized water) in impinger through which methanol sample from dilution air is drawn, ml.  
 (xv) 1=first impinger.  
 (xvi) 2=second impinger.  
 (xvii) 1 = first impinger.  
 (xviii) 2 = second impinger.  
 (6)(i) HCHO<sub>mass</sub> = Formaldehyde emissions corrected for background, in grams per test phase.  
 (ii) Density<sub>HCHO</sub>=Density of formaldehyde is 35.36 g/ft<sup>3</sup>- carbon atom (1.249 kg/m<sup>3</sup>-carbon atom), at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.  
 (iii)(A) HCHO<sub>conc</sub> = Formaldehyde concentration of the dilute exhaust corrected for background, in ppm.  
 (B) HCHO<sub>conc</sub> = CHCHO<sub>e</sub> - CHCHO<sub>d</sub> (1 - (1/DF)).  
 Where:  
 (iv)(A) CHCHO<sub>e</sub> = Formaldehyde concentration in dilute exhaust, in ppm.  
 (B)

$$C_{\text{HCHOe}} = \frac{4.069 \times 10^{-2} \times C_{\text{FDE}} \times V_{\text{AE}} \times Q \times T_{\text{EF}}}{V_{\text{SE}} \times P_{\text{B}}}$$

- (v)(A) CHCHO<sub>d</sub> = Formaldehyde concentration in dilution air in ppm.  
 (B)

$$C_{\text{HCHOd}} = \frac{4.069 \times 10^{-2} \times C_{\text{FDA}} \times V_{\text{AA}} \times Q \times T_{\text{DF}}}{V_{\text{SA}} \times P_{\text{B}}}$$

- (vi) CFDE = Concentration of DNPH derivative of formaldehyde from dilute exhaust sample in sampling solution, µg/ml.  
 (vii) VAE = Volume of sampling solution for dilute exhaust formaldehyde sample, ml.  
 (viii)(A) Q = Ratio of molecular weights of formaldehyde to its DNPH derivative.  
 (B) Q = 0.1429.

## WLTP-DTP-01-02

- (ix) TEF = Temperature of formaldehyde sample withdrawn from dilute exhaust, °R.  
(x) VSE = Volume of formaldehyde sample withdrawn from dilute exhaust, ft<sup>3</sup>.  
(xi) PB = Barometric pressure during test, mm Hg.  
(xii) CFDA = Concentration of DNPH derivative of formaldehyde from dilution air sample in sampling solution, µg/ml.  
(xiii) VAA = Volume of sampling solution for dilution air formaldehyde sample, ml.  
(xiv) TDF = Temperature of formaldehyde sample withdrawn from dilution air, °R.  
(xv) VSA = Volume of formaldehyde sample withdrawn from dilution air, ft<sup>3</sup>.  
(7)(i) DF =  $13.4/[\text{CO}_{2e}+(\text{HC}_e+\text{CO}_e)\cdot 10^{-4}]$  for petroleum-fueled vehicles.  
(ii) For methanol-fueled vehicles, where fuel composition is C<sub>x</sub>H<sub>y</sub>O<sub>z</sub> as measured, or calculated, for the fuel used:

$$\text{DF} = \frac{(100) \frac{x}{x + y/2 + 3.76(x + y/2 - z/2)}}{\text{CO}_{2e} + (\text{HC}_e + \text{CO}_e + \text{CH}_3\text{OH}_e + \text{HCHO}_e) \times 10^{-4}}$$

(iii)

$$\text{DF} = \frac{100 \times \frac{x}{x + y/2 + 3.76(x + y/4)}}{\text{CO}_{2e} + (\text{NMHC}_e + \text{CH}_{4e} + \text{CO}_e) \times 10^{-4}}$$

for natural gas-fueled or liquefied petroleum gas-fueled vehicles where fuel composition is C<sub>x</sub>H<sub>y</sub> as measured for the fuel used.

(iv)(A) KH = Humidity correction factor.

(B) KH =  $1/[1-0.0047(H-75)]$ .

(C) For SI units, KH =  $1/[1-0.0329(H\cdot 10.71)]$ .

Where:

(v)(A) H = Absolute humidity in grains (grams) of water per pound (kilogram) of dry air.

(B) H =  $[(43.478)Ra \cdot Pd]/[PB - (Pd \cdot Ra/ 100)]$ .

(C) For SI units, H =  $[(6.211)Ra \cdot Pd]/ [PB\cdot(Pd \cdot Ra/100)]$ .

(vi) Ra = Relative humidity of the ambient air, percent.

(vii) Pd = Saturated vapor pressure, mm Hg (kPa) at the ambient dry bulb temperature.

(viii) PB = Barometric pressure, mm Hg (kPa).

(ix)(A) V<sub>mix</sub> = Total dilute exhaust volume in cubic feet per test phase corrected to standard conditions (528°R (293 °K) and 760 mm Hg (101.3 kPa)).

(B) For PDP-CVS, V<sub>mix</sub> is:

$$V_{\text{mix}} = \frac{V_O \times N \times (P_B - P_4) \times 528}{760 \times T_P}$$

(C) For SI units,

$$V_{\text{mix}} = \frac{V_o \times N \times (P_B - P_4) \times 293}{101.3 \times T_p}$$

Where:

(x)  $V_o$  = Volume of gas pumped by the positive displacement pump, in cubic feet ( $\text{m}^3$ ) per revolution. This volume is dependent on the pressure differential across the positive displacement pump.

(xi)  $N$  = Number of revolutions of the positive displacement pump during the test phase while samples are being collected.

(xii)  $P_B$  = Barometric pressure, mm Hg (kPa).

(xiii)  $P_4$  = Pressure depression below atmospheric measured at the inlet to the positive displacement pump, in mm Hg (kPa) (during an idle mode).

(xiv)  $T_p$  = Average temperature of dilute exhaust entering positive displacement pump during test, °R(°K).

(8)(i)  $\text{NMHC}_{\text{conc}} = \text{HC}_{\text{conc}} - (r\text{CH}_4 \cdot \text{CH}_{4\text{conc}})$ .

(ii)  $\text{Density}_{\text{NMHC}}$  = The density of nonmethane hydrocarbon.

(A) For gasoline-fuel and diesel-fuel;  $\text{Density}_{\text{NMHC}} = 16.33 \text{ g/ft}^3$ -carbon atom ( $0.5768 \text{ kg/m}^3$ -carbon atom), assuming an average carbon to hydrogen ratio of 1:1.85 at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(B) For natural gas and liquefied petroleum gas fuel;  $\text{Density}_{\text{NMHC}} = 1.1771(12.011 + \text{H/C}(1.008)) \text{ g/ft}^3$ -carbon atom ( $0.04157(12.011 + \text{H/C}(1.008)) \text{ kg/m}^3$ -carbon atom), where H/C is the hydrogen to carbon ratio of the non-methane hydrocarbon components of the test fuel, at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(iii)(A)  $\text{CH}_{4\text{conc}}$  = Methane concentration of the dilute exhaust sample corrected for background, in ppm carbon equivalent.

(B)  $\text{CH}_{4\text{conc}} = \text{CH}_{4e} - \text{CH}_{4d}(1 - 1/\text{DF})$

Where:

(iv)  $\text{CH}_{4e}$  = Methane exhaust bag concentration in ppm carbon equivalent.

(v)  $\text{CH}_{4d}$  = Methane concentration of the dilution air in ppm carbon equivalent.

(vi)  $r\text{CH}_4$  = HC FID response to methane as measured in.

(9)(i)  $\text{CH}_{4\text{mass}}$  = Methane emissions, in grams per test phase.

(ii)  $\text{Density}_{\text{CH}_4}$  = Density of methane is  $18.89 \text{ g/ft}^3$ -carbon atom ( $0.6672 \text{ kg/m}^3$ -carbon atom), at 68 °F (20 °C) and 760 mm Hg (101.3 kPa) pressure.

(d) For petroleum-fueled vehicles, example calculation of mass values of exhaust emissions using positive displacement pump:

(1) For the “transient” phase of the cold start test assume the following:  $V_o = 0.29344 \text{ ft}^3/\text{rev}$ ;  $N = 10,485$ ;  $R = 48.0 \text{ pct}$ ;  $R_a = 48.2 \text{ percent}$ ;  $P_B = 762 \text{ mm Hg}$ ;  $P_d = 22.225 \text{ mm Hg}$ ;  $P_4 = 70 \text{ mm Hg}$ ;  $T_p = 570 \text{ }^\circ\text{R}$ ;  $\text{HC}_e = 105.8 \text{ ppm}$ , carbon equivalent;  $\text{NO}_{\text{xe}} = 11.2 \text{ ppm}$ ;  $\text{CO}_{\text{em}} = 306.6 \text{ ppm}$ ;  $\text{CO}_{2e} = 1.43 \text{ percent}$ ;  $\text{CH}_{4e} = 10.74 \text{ ppm}$ ;  $\text{HC}_d = 12.1 \text{ ppm}$ ;  $\text{NO}_{\text{xd}} = 0.8 \text{ ppm}$ ;  $\text{CO}_{\text{dm}} = 15.3 \text{ ppm}$ ;  $\text{CO}_{2d} = 0.032 \text{ percent}$ ;  $\text{CH}_{4d} = 2.20 \text{ ppm}$ ;  $D_{\text{ct}} = 3.598 \text{ miles}$ .

Then:

(i)  $V_{\text{mix}} = (0.29344)(10,485)(762-70)(528) / (760)(570) = 2595.0 \text{ ft}^3$  per test phase.

(ii)  $H = (43.478)(48.2)(22.225) / 762 - (22.225)(48.2 / 100) = 62 \text{ grains of water per pound of dry air}$ .

## WLTP-DTP-01-02

- (iii)  $KH = 1/[1 - 0.0047(62-75)] = 0.9424$ .
- (iv)  $CO_e = [1 - 0.01925(1.43) - 0.000323(48)](306.6) = 293.4$  ppm.
- (v)  $CO_d = [1 - 0.000323(48)](15.3) = 15.1$  ppm.
- (vi)  $DF = 13.4/[1.43 + 10^{-4}(105.8 + 293.4)] = 9.116$ .
- (vii)  $HC_{conc} = 105.8 - 12.1(1 - 1/9.116) = 95.03$  ppm.
- (viii)  $HC_{mass} = (2595)(16.33)(95.03/1,000,000) = 4.027$  grams per test phase.
- (ix)  $NO_{xconc} = 11.2 - 0.8(1 - 1/9.116) = 10.49$  ppm.
- (x)  $NO_{xmass} = (2595)(54.16)(10.49/1,000,000)(0.9424) = 1.389$  grams per test phase.
- (xi)  $CO_{conc} = 293.4 - 15.1(1 - 1/9.116) = 280.0$  ppm.
- (xii)  $CO_{mass} = (2595)(32.97)(280/1,000,000) = 23.96$  grams per test phase.
- (xiii)  $CO_{2conc} = 1.43 - 0.032(1 - 1/9.116) = 1.402$  percent.
- (xiv)  $CO_{2mass} = (2595.0)(51.85)(1.402/100) = 1886$  grams per test phase.
- (xv)  $CH_{4conc} = 10.74 - 2.2(1 - 1/9.116) = 8.78$  ppm.
- (xvi)  $NMHC_{conc} = 95.03 - 8.78 = 86.25$  ppm.
- (xvii)  $NMHC_{mass} = (2595)(16.33)(86.25)/1,000,000 = 3.655$  grams per test phase.
- (2) For the stabilized portion of the cold start test assume that similar calculations resulted in the following:
- (i)  $HC_{mass} = 0.62$  gram per test phase.
- (ii)  $NO_{xmass} = 1.27$  grams per test phase.
- (iii)  $CO_{mass} = 5.98$  grams per test phase.
- (iv)  $CO_{2mass} = 2346$  grams per test phase.
- (v)  $D_s = 3.902$  miles.
- (vi)  $NMHC_{mass} = 0.50$  gram per test phase.
- (3) For the “transient” portion of the hot start test assume that similar calculations resulted in the following:
- (i)  $HC_{mass} = 0.51$  gram per test phase.
- (ii)  $NO_{xmass} = 1.38$  grams per test phase.
- (iii)  $CO_{mass} = 5.01$  grams per test phase.
- (iv)  $CO_{2mass} = 1758$  grams per test phase.
- (v)  $D_{ht} = 3.598$  miles.
- (vi)  $NMHC_{mass} = 0.44$  grams per test phase.
- (4) Weighted mass emission results:
- (i)  $HC_{wm} = 0.43[(4.027 + 0.62)/(3.598 + 3.902)] + 0.57[(0.51 + 0.62)/(3.598 + 3.902)] = 0.352$  gram per vehicle mile.
- (ii)  $NO_{xwm} = 0.43[(1.389 + 1.27)/(3.598 + 3.902)] + 0.57[(1.38 + 1.27)/(3.598 + 3.902)] = 0.354$  gram per vehicle mile.
- (iii)  $CO_{wm} = 0.43[(23.96 + 5.98)/(3.598 + 3.902)] + 0.57[(5.01 + 5.98)/(3.598 + 3.902)] = 2.55$  grams per vehicle mile.
- (iv)  $CO_{2wm} = 0.43[(1886 + 2346)/(3.598 + 3.902)] + 0.57[(1758 + 2346)/(3.598 + 3.902)] = 555$  gram per vehicle mile.
- (v)  $NMHC_{wm} = 0.43[(3.655 + 0.50)/(3.598 + 3.902)] + 0.57[(0.44 + 0.50)/(3.598 + 3.902)] = 0.310$  gram per vehicle mile.
- (e) For methanol-fueled vehicles with measured fuel composition of CH 3.487 O 0.763, example calculation of exhaust emissions using positive displacement pump:

(1) For the “transient” phase of the cold start test assume the following:

$V_0 = 0.29344 \text{ ft}^3 \text{ rev}$ ;  $N = 25,801$ ;  $R = 37.5 \text{ pct}$ ;  $R_a = 37.5 \text{ percent}$ ;  $P_B = 725.42 \text{ mm Hg}$ ;  $P_d = 22.02 \text{ mm Hg}$ ;  $P_4 = 70 \text{ mm Hg}$ ;  $T_p = 570 \text{ deg.R}$ ;  $\text{FID HC}_e = 14.65 \text{ ppm}$ , carbon equivalent;  $r = 0.788$ ;  $\text{TEM} = 527.67 \text{ deg.R}$ ;  $\text{VEM} = 0.2818 \text{ ft}^3$ ;  $\text{CS}_1 = 7.101$ ;  $\text{AVS}_1 = 15.0 \text{ ml}$ ;  $\text{CS}_2 = 0.256$ ;  $\text{AVS}_2 = 15.0 \text{ ml}$ ;  $\text{TDM} = 527.67 \text{ deg.R}$ ;  $\text{VDM} = 1.1389 \text{ ft}^3$ ;  $\text{CD}_1 = 0.439$ ;  $\text{AVD}_1 = 15.0 \text{ ml}$ ;  $\text{CD}_2 = 0.0$ ;  $\text{AVD}_2 = 15.0 \text{ ml}$ ;  $\text{CFDE} = 8.970 \text{ } \mu\text{g/ml}$ ;  $\text{VAE} = 5.0 \text{ ml}$ ;  $Q = 0.1429$ ;  $\text{TEF} = 527.67 \text{ deg.R}$ ;  $\text{VSE} = 0.2857 \text{ ft}^3$ ;  $\text{CFDA} = 0.39 \text{ } \mu\text{g/ml}$ ;  $\text{VAA} = 5.0 \text{ ml}$ ;  $\text{TDF} = 527.67 \text{ deg.R}$ ;  $\text{VSA} = 1.1043 \text{ ft}^3$ ;  $\text{NO}_X = 5.273 \text{ ppm}$ ;  $\text{CO}_{em} = 98.8 \text{ ppm}$ ;  $\text{CO}_{2e} = 0.469 \text{ pct}$ ;  $\text{CH}_{4e} = 2.825 \text{ ppm}$ ;  $\text{FID HC}_d = 2.771 \text{ ppm}$ ;  $\text{NO}_X = 0.146 \text{ ppm}$ ;  $\text{CO}_{dm} = 1.195 \text{ ppm}$ ;  $\text{CO}_{2d} = 0.039 \text{ percent}$ ;  $\text{CH}_{4d} = 2.019 \text{ ppm}$ ;  $D_{ct} = 3.583 \text{ miles}$ .

Then:

(i)  $V_{mix} = (0.29344)(25,801)(725.42-70)(528) / (760)(570) = 6048.10 \text{ ft}^3 \text{ per test phase}$ .

(ii)  $H = (43.478)(37.5)(22.02) / [725.42 - (22.02 \cdot 37.5 / 100)] = 50 \text{ grains of water per pound of dry air}$ .

(iii)  $\text{KH} = 1 / [1 - 0.0047(50 - 75)] = 0.8951$ .

(iv)  $C_{oe} = [1 - (0.01 + 0.005 \cdot 3.487) \cdot 0.469] - 0.000323(37.5) \cdot 98.8 = 96.332 \text{ ppm}$ .

(v)  $C_{od} = (1 - 0.000323(37.5)) \cdot 1.195 = 1.181 \text{ ppm}$ .

(vi)  $\text{CCH}_3\text{OH}_e = (3.813 \cdot 10^{-2})(527.67) [(7.101)(15.0) + (0.256)(15.0)] / (725.42)(0.2818) = 10.86 \text{ ppm}$ .

(vii)  $\text{HC}_e = 14.65 - (0.788)(10.86) = 6.092$ .

(viii)  $\text{DF} = 100(1 / [1 + (3.487/2) + 3.76(1 + (3.487/4) - (0.763/2))]) / 0.469 + (6.092 + 96.332 + 10.86 + 0.664)(10^{-4}) = 24.939$ .

(ix)  $\text{CCH}_3\text{OH}_d = (3.813 \cdot 10^{-2})(527.67) [(0.439)(15.0) + (0.0)(15.0)] / (725.42)(1.1389) = 0.16 \text{ ppm}$ .

(x)  $\text{CH}_3\text{OH}_{conc} = 10.86 - 0.16(1 - 1/24.939) = 10.71 \text{ ppm}$ .

(xi)  $\text{CH}_3\text{OH}_{mass} = 6048.1 \cdot 37.71 \cdot (10.71 / 1,000,000) = 2.44 \text{ grams per test phase}$ .

(xii)  $\text{HC}_{conc} = [14.65 - (0.788)(10.86)] - [2.771 - (0.788)(0.16)] (1 - 1/24.94) = 3.553 \text{ ppm}$ .

(xiii)  $\text{HC}_{mass} = (6048.1)(16.33)(3.553 / 1,000,000) = 0.35 \text{ grams per test phase}$ .

(xiv)  $\text{CHCHO}_e = 4.069 \cdot 10^{-2}(8.970)(5.0)(0.1429)(527.67) / (0.2857)(725.42) = 0.664 \text{ ppm}$ .

(xv)  $\text{CHCHO}_d = 4.069 \cdot 10^{-2}(0.39)(5.0)(0.1429)(527.67) / (1.1043)(725.42) = 0.0075 \text{ ppm}$ .

(xvi)  $\text{HCHO}_{conc} = 0.664 - 0.0075(1 - 1/24.939) = 0.6568 \text{ ppm}$ .

(xvii)  $\text{HCHO}_{mass} = (6048.1)(35.36)(0.6568 / 1,000,000) = 0.1405 \text{ grams per test phase}$ .

(xviii)  $\text{THCE} = 0.35 + (13.8756 / 32.042)(2.44) + (13.8756 / 30.0262)(0.1405) = 1.47 \text{ grams per test phase}$ .

(xix)  $\text{NO}_{Xconc} = 5.273 - (0.146)(1 - 1/24.939) = 5.13 \text{ ppm}$ .

(xx)  $\text{NO}_{Xmass} = (6048.1)(54.16)(5.13 / 1,000,000)(0.8951) = 1.505 \text{ grams per test phase}$ .

(xxi)  $\text{CO}_{conc} = 96.332 - 1.181(1 - 1/24.939) = 95.2 \text{ ppm}$ .

(xxii)  $\text{CO}_{mass} = (6048.1)(32.97)(95.2 / 1,000,000) = 18.98 \text{ grams per test phase}$ .

(xxiii)  $\text{CO}_{2conc} = 0.469 - 0.039(1 - 1/24.939) = 0.432 \text{ percent}$ .

(xxiv)  $\text{CO}_{2mass} = (6048.1)(51.85)(0.432 / 100) = 1353 \text{ grams}$ .

(xxv)  $\text{CH}_{4conc} = 2.825 - 2.019(1 - 1/24.939) = 0.89 \text{ ppm}$ .

(xxvi)  $\text{NMHC}_{conc} = 3.553 \text{ ppm} - 0.89 \text{ ppm} = 2.67 \text{ ppm}$ .

(xxvii)  $\text{NMHC}_{mass} = (6048.1)(16.33)(2.67 / 1,000,000) = 0.263 \text{ grams per test phase}$ .

(xxviii)  $\text{NMHCE}_{mass} = 0.263 + (13.8756 / 32.042)(2.44) + (13.8756 / 30.0262)(0.1405) = 1.39 \text{ grams per test phase}$ .

## WLTP-DTP-01-02

(2) For the stabilized portion of the cold start test assume that similar calculations resulted in the following:

- (i) THCE = 0.143 grams per test phase.
- (ii)  $\text{NO}_{x\text{mass}}$  = 0.979 grams per test phase.
- (iii)  $\text{CO}_{\text{mass}}$  = 0.365 grams per test phase.
- (iv)  $\text{CO}_{2\text{mass}}$  = 1467 grams per test phase.
- (v)  $D_s$  = 3.854 miles.
- (vi) NMHCE = 0.113 grams per test phase.

(3) For the “transient” portion of the hot start test assume that similar calculations resulted in the following:

- (i) THCE = 0.488 grams as carbon equivalent per test phase.
- (ii)  $\text{NO}_{x\text{mass}}$  = 1.505 grams per test phase.
- (iii)  $\text{CO}_{\text{mass}}$  = 3.696 grams per test phase.
- (iv)  $\text{CO}_{2\text{mass}}$  = 1179 grams per test phase.
- (v)  $D_{\text{ht}}$  = 3.577 miles.
- (vi) NMHCE = 0.426 grams per test phase.

(4) Weighted emission results:

- (i)  $\text{THCE}_{\text{wm}} = (0.43) \cdot (1.473 + 0.143) / (3.583 + 3.854) + (0.57) \cdot (0.488 + 0.143) / (3.577 + 3.854) = 0.142$  grams as carbon equivalent per mile.
- (ii)  $\text{NO}_{x\text{wm}} = (0.43) \cdot (1.505 + 0.979) / (3.583 + 3.854) + (0.57) \cdot (1.505 + 0.979) / (3.577 + 3.854) = 0.344$  grams per mile.
- (iii)  $\text{CO}_{\text{wm}} = (0.43) \cdot (18.983 + 0.365) / (3.583 + 3.854) + (0.57) \cdot (3.696 + 0.365) / (3.577 + 3.854) = 1.43$  grams per mile.
- (iv)  $\text{CO}_{2\text{wm}} = (0.43) \cdot (1353 + 1467) / (3.583 + 3.854) + (0.57) \cdot (1179 + 1467) / (3.577 + 3.854) = 366$  grams per mile.
- (v)  $\text{NMHCE}_{\text{wm}} = (0.43) \cdot (1.386 + 0.113) / (3.583 + 3.854) + (0.57) \cdot (0.426 + 0.113) / (3.577 + 3.854) = 0.128$  grams per mile.

### Calculations; particulate emissions.

(a) The final reported test results for the mass particulate (Mp) in grams/ mile shall be computed as follows.  $\text{Mp} = 0.43(\text{Mp}_1 + \text{Mp}_2) / (D_{\text{ct}} + D_s) + 0.57(\text{Mp}_3 + \text{Mp}_2) / (D_{\text{ht}} + D_s)$

where:

- (1)  $\text{Mp}_1$  = Mass of particulate determined from the “transient” phase of the cold start test, in grams per test phase.
- (2)  $\text{Mp}_2$  = Mass of particulate determined from the “stabilized” phase of the cold start test, in grams per test phase.
- (3)  $\text{Mp}_3$  = Mass of particulate determined from the “transient” phase of the hot start test, in grams per test phase.
- (4)  $D_{\text{ct}}$  = The measured driving distance from the “transient” phase of the cold start test, in miles.
- (5)  $D_s$  = The measured driving distance from the “stabilized” phase of the cold start test, in miles.
- (6)  $D_{\text{ht}}$  = The measured driving distance from the “transient” phase of the hot start test, in miles.

(b) The mass of particulate for each phase of testing is determined as follows:

$$M_{pj} = \left[ V_{mix} + V_{epi} \right] \left[ \frac{P_{ei}}{V_{epi}} - \frac{P_b}{V_{bp}} (1 - 1/DF) \right]$$

where:

(1)  $j = 1, 2$  or  $3$  depending on which phase the mass of particulate is being determined for (i.e., the “transient” phase of the cold start test, the “stabilized” phase of the cold start test, or the “transient” phase of the hot start test).

(2)  $V_{mix}$  = Total dilute exhaust volume in cubic meters per test, corrected to standard conditions 528°R (293K) and 29.92 in Hg (101.3 kPa).

(3)  $P_e$  = mass of particulate per test on the exhaust filter(s), grams.

(4)  $P_b$  = mass of particulate on the “background” filter, grams.

(i) The background particulate level,  $P_b$ , inside the dilution air filter box at EPA is very low.  $P_b$  will be assumed = 0, and background particulate samples will not be taken with each exhaust sample. It is recommended that background particulate checks be made periodically to verify the low level.

(ii) Any manufacturer may make the same assumption without prior EPA approval.

(iii) If  $P_b$  is assumed = 0, then no background correction is made. The equation for particulate mass emissions then reduces to:

$$M_{pj} = \frac{V_{mix_i} + V_{epi} \times P_{ei}}{V_{epi}}$$

(6)  $V_{ep}$  = total volume of sample pulled through the filter, cubic feet at standard conditions.

$$V_{ep} = \frac{V_{ap} \times (P_{bar} + P_{ip}) \times 528}{T_{ip} \times 29.92}$$

where:

(i)  $V_{ap}$  = corrected dilute exhaust sample volume, cubic feet.

(ii)  $P_{bar}$  = barometric pressure, in Hg.

(iii)  $P_{ip}$  = pressure elevation above ambient measured at the inlet to the dilute exhaust sample gas meter or flow instrument, in Hg. (For most gas meters with unrestricted discharge  $P_{ip}$  is negligible and can be assumed = 0.)

(iv)  $T_{ip}$  = average temperature of the dilute exhaust sample at the inlet to the gas meter or flow instrument, °R.

(7)  $V_{bp}$  = total volume of the background sample, cubic feet at standard conditions. ( $V_{bp}$  is not required if  $P_b$  is assumed = 0.) It is calculated using the following formula:

$$V_{bp} = \frac{V_{ap} \times (P_{bar} + P_{ib}) \times 528}{T_{ib} \times 29.92}$$

## WLTP-DTP-01-02

where:

- (i)  $V_{ab}$  = corrected background sample volume, cubic feet.
- (ii)  $P_{bar}$  = barometric pressure, in. Hg.
- (iii)  $P_{ib}$  = pressure elevation above ambient measured at the inlet to the background gas meter or flow instrument, in Hg. (For most gas meters with unrestricted discharge  $P_{ib}$  is negligible and can be assumed = 0.)
- (iv)  $T_{ib}$  = average temperature of the background sample at the inlet to the gas meter or flow instrument, °R.
- (8) DF = dilution factor. (DF is not required if  $P_b$  is assumed = 0.)

### Analytical Gases and Other Calibration Standards

#### 750 Analytical Gases.

Analytical gases must meet the accuracy and purity specifications of this section, unless you can show that other specifications would not affect your ability to show that your vehicles comply with all applicable emission standards.

(a) Parts of this test procedure refer to the following gas specifications:

(1) Use purified gases to zero measurement instruments and to blend with calibration gases. Use gases with contamination no higher than the highest of the following values in the gas cylinder or at the outlet of a zero-gas generator:

(i) 2 % contamination, measured relative to the flow-weighted mean concentration expected at the standard. For example, if you would expect a flow-weighted CO concentration of 100.0  $\mu\text{mol/mol}$ , then you would be allowed to use a zero gas with CO contamination less than or equal to 2.000  $\mu\text{mol/mol}$ .

(ii) Contamination as specified in the following table:

Table 1 of 750—General specifications for purified gases

Constituent	Purified Synthetic Air <sup>1</sup>	Purified N <sub>2</sub> <sup>1</sup>
THC (C <sub>1</sub> equivalent)	≤ 0.05 $\mu\text{mol/mol}$	≤ 0.05 $\mu\text{mol/mol}$
CO	≤ 1 $\mu\text{mol/mol}$	≤ 1 $\mu\text{mol/mol}$
CO <sub>2</sub>	≤ 10 $\mu\text{mol/mol}$	≤ 10 $\mu\text{mol/mol}$
O <sub>2</sub>	0.205 to 0.215 mol/mol	≤ 2 $\mu\text{mol/mol}$
NO <sub>x</sub>	≤ 0.02 $\mu\text{mol/mol}$	≤ 0.02 $\mu\text{mol/mol}$
N <sub>2</sub> O <sup>2</sup>	≤ 0.05 $\mu\text{mol/mol}$	≤ 0.05 $\mu\text{mol/mol}$

<sup>1</sup>We do not require these levels of purity to be NIST-traceable.

<sup>2</sup>The N<sub>2</sub>O limit applies only if you are required to report N<sub>2</sub>O.

(2) Use the following gases with a FID analyzer:

(i) FID fuel. Use FID fuel with a stated H<sub>2</sub> concentration of (0.39 to 0.41) mol/mol, balance He, and a stated total hydrocarbon concentration of 0.05  $\mu\text{mol/mol}$  or less.

(ii) FID burner air. Use FID burner air that meets the specifications of purified air in paragraph (a)(1) of this section. For field testing, you may use ambient air.

(iii) FID zero gas. Zero flame-ionization detectors with purified gas that meets the specifications in paragraph (a)(1) of this section, except that the purified gas O<sub>2</sub> concentration may be any value. Note that FID zero balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer zero gases that contain approximately the expected flow-weighted mean concentration of O<sub>2</sub> in the exhaust sample during testing.

(iv) FID propane span gas. Span and calibrate THC FID with span concentrations of propane, C<sub>3</sub>H<sub>8</sub>. Calibrate on a carbon number basis of one (C<sub>1</sub>). For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 μmol/mol, span a FID to respond with a value of 600 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the flow-weighted mean concentration of O<sub>2</sub> expected during testing. If the expected O<sub>2</sub> concentration in the exhaust sample is zero, we recommend using a balance gas of purified nitrogen.

(v) FID methane span gas. If you always span and calibrate a CH<sub>4</sub> FID with a nonmethane cutter, then span and calibrate the FID with span concentrations of methane, CH<sub>4</sub>. Calibrate on a carbon number basis of one (C<sub>1</sub>). For example, if you use a CH<sub>4</sub> span gas of concentration 200 μmol/mol, span a FID to respond with a value of 200 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the expected flow-weighted mean concentration of O<sub>2</sub> in the exhaust sample during testing. If the expected O<sub>2</sub> concentration in the exhaust sample is zero, we recommend using a balance gas of purified nitrogen.

(3) Use the following gas mixtures, with gases traceable within ±1.0 % of the NIST-accepted value or other gas standards we approve:

- (i) CH<sub>4</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable).
- (ii) C<sub>2</sub>H<sub>6</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable).
- (iii) C<sub>3</sub>H<sub>8</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable).
- (iv) CO, balance purified N<sub>2</sub>.
- (v) CO<sub>2</sub>, balance purified N<sub>2</sub>.
- (vi) NO, balance purified N<sub>2</sub>.
- (vii) NO<sub>2</sub>, balance purified synthetic air.
- (viii) O<sub>2</sub>, balance purified N<sub>2</sub>.
- (ix) C<sub>3</sub>H<sub>8</sub>, CO, CO<sub>2</sub>, NO, balance purified N<sub>2</sub>.
- (x) C<sub>3</sub>H<sub>8</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>, NO, balance purified N<sub>2</sub>.
- (xi) N<sub>2</sub>O, balance purified synthetic air.

(4) You may use gases for species other than those listed in paragraph (a)(3) of this section (such as methanol in air, which you may use to determine response factors), as long as they are traceable to within ±3.0 % of the NIST-accepted value or other similar standards we approve, and meet the stability requirements of paragraph (b) of this section.

(5) You may generate your own calibration gases using a precision blending device, such as a gas divider, to dilute gases with purified N<sub>2</sub> or purified synthetic air. If your gas dividers meet the specifications in 248, and the gases being blended meet the requirements of paragraphs (a)(1) and (3) of this section, the resulting blends are considered to meet the requirements of this paragraph (a).

(b) Record the concentration of any calibration gas standard and its expiration date specified by the gas supplier.

## **WLTP-DTP-01-02**

- (1) Do not use any calibration gas standard after its expiration date, except as allowed by paragraph (b)(2) of this section.
- (2) Calibration gases may be relabeled and used after their expiration date as follows:
  - (i) Alcohol/carbonyl calibration gases used to determine response factors according to subpart I of this part may be relabeled as specified in subpart I of this part.
  - (ii) Other gases may be relabeled and used after the expiration date only if we approve it in advance.
- (c) Transfer gases from their source to analyzers using components that are dedicated to controlling and transferring only those gases. For example, do not use a regulator, valve, or transfer line for zero gas if those components were previously used to transfer a different gas mixture. We recommend that you label regulators, valves, and transfer lines to prevent contamination. Note that even small traces of a gas mixture in the dead volume of a regulator, valve, or transfer line can diffuse upstream into a high-pressure volume of gas, which would contaminate the entire high-pressure gas source, such as a compressed-gas cylinder.
- (d) To maintain stability and purity of gas standards, use accepted measurement practices and follow the gas standard supplier's recommendations for storing and handling zero, span, and calibration gases. For example, it may be necessary to store bottles of condensable gases in a heated environment.

### **790 Mass standards.**

- (a) PM balance calibration weights. Use PM balance calibration weights that are certified as NIST-traceable within 0.1 % uncertainty. Calibration weights may be certified by any calibration lab that maintains NIST-traceability. Make sure your lowest calibration weight has no greater than ten times the mass of an unused PM-sample medium.

## Testing with Oxygenated Fuels

### §805 Sampling system.

- (a) Dilute vehicle exhaust, and use batch sampling to collect proportional flow-weighted dilute samples of the applicable alcohols and carbonyls. You may not use raw sampling for alcohols and carbonyls.
- (b) You may collect background samples for correcting dilution air for background concentrations of alcohols and carbonyls. You collect one background over an entire exhaust emission test, rather than for each individual test phase for this purpose.
- (c) Maintain sample temperatures and dilution rates within the dilution system, probes, and sample lines high enough to prevent aqueous condensation up to the point where a sample is collected to prevent loss of the alcohols and carbonyls by dissolution in condensed water. Use accepted measurement practices to ensure that surface reactions of alcohols and carbonyls do not occur, as surface decomposition of methanol has been shown to occur at temperatures greater than 120 °C in exhaust from methanol-fueled vehicles.
- (d) You may bubble a sample of the exhaust through water to collect alcohols for later analysis. You may also use a photo-acoustic analyzer to quantify ethanol and methanol in an exhaust sample.
- (e) Sample the exhaust through cartridges impregnated with 2,4-dinitrophenylhydrazine to collect carbonyls for later analysis. If the standard specifies a duty cycle that has multiple test intervals (such as multiple engine starts or an engine-off soak phase), you may proportionally collect a single carbonyl sample for the entire duty cycle. For example, if the standard-setting part specifies a six-to-one weighting of hot-start to cold-start emissions, you may collect a single carbonyl sample for the entire duty cycle by using a hot-start sample flow rate that is six times the cold-start sample flow rate.
- (f) You may sample alcohols or carbonyls using "California Non-Methane Organic Gas Test Procedures". If you use this method, follow its calculations to determine the mass of the alcohol/carbonyl in the exhaust sample, but follow subpart G of this part for all other calculations.

### §845 Response factor determination.

Since FID analyzers generally have an incomplete response to alcohols and carbonyls, determine each FID analyzer's alcohol/carbonyl response factor (such as  $RF_{MeOH}$ ) after FID optimization to subtract those responses from the FID reading. You are not required to determine the response factor for a compound unless you will subtract its response to compensate for a response. Formaldehyde response is assumed to be zero and does not need to be determined. Use the most recent alcohol/carbonyl response factors to compensate for alcohol/carbonyl response.

(a) Determine the alcohol/carbonyl response factors as follows:

- (1) Select a  $C_3H_8$  span gas that meets the specifications of 750. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of 750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of  $O_2$  expected during testing. Record the  $C_3H_8$  concentration of the gas.

## WLTP-DTP-01-02

- (2) Select or prepare an alcohol/carbonyl calibration gas that meets the specifications of 750 and has a concentration typical of the peak concentration expected at the hydrocarbon standard. Record the calibration concentration of the gas.
  - (3) Start and operate the FID analyzer according to the manufacturer's instructions.
  - (4) Confirm that the FID analyzer has been calibrated using  $C_3H_8$ . Calibrate on a carbon number basis of one ( $C_1$ ). For example, if you use a  $C_3H_8$  span gas of concentration  $200 \mu\text{mol/mol}$ , span the FID to respond with a value of  $600 \mu\text{mol/mol}$ .
  - (5) Zero the FID. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of 750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of  $O_2$  expected during testing.
  - (6) Span the FID with the  $C_3H_8$  span gas that you selected under paragraph (a)(1) of this section.
  - (7) Introduce at the inlet of the FID analyzer the alcohol/carbonyl calibration gas that you selected under paragraph (a)(2) of this section.
  - (8) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the analyzer and to account for its response.
  - (9) While the analyzer measures the alcohol/carbonyl concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.
  - (10) Divide the mean measured concentration by the recorded span concentration of the alcohol/carbonyl calibration gas. The result is the FID analyzer's response factor for alcohol/carbonyl,  $RF_{MeOH}$ .
- (b) Alcohol/carbonyl calibration gases must remain within  $\pm 2\%$  of the labeled concentration. You must demonstrate the stability based on a quarterly measurement procedure with a precision of  $\pm 2\%$  percent or another method that we approve. Your measurement procedure may incorporate multiple measurements. If the true concentration of the gas changes deviates by more than  $\pm 2\%$ , but less than  $\pm 10\%$ , the gas may be relabeled with the new concentration.

### 850 Calculations.

Use the calculations specified in 665 to determine THCE or NMHCE.

## Subpart K—Definitions and Other Reference Information

### §1001 Definitions.

The definitions in this section apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives them. The definitions follow:

300 series stainless steel means any stainless steel alloy with a Unified Numbering System for Metals and Alloys number designated from S30100 to S39000. For all instances in this part where we specify 300 series stainless steel, such parts must also have a smooth inner-wall construction. We recommend an average roughness,  $R_a$ , no greater than 4  $\mu\text{m}$ .

Accuracy means the absolute difference between a reference quantity and the arithmetic mean of ten mean measurements of that quantity. Determine instrument accuracy, repeatability, and noise from the same data set. We specify a procedure for determining accuracy in §305.

Adjustable parameter means any device, system, or element of design that someone can adjust (including those which are difficult to access) and that, if adjusted, may affect emissions or vehicle performance during emission testing or normal in-use operation. This includes, but is not limited to, parameters related to injection timing and fueling rate. In some cases, this may exclude a parameter that is difficult to access if it cannot be adjusted to affect emissions without significantly degrading vehicle performance, or if it will not be adjusted in a way that affects emissions during in-use operation.

Aerodynamic diameter means the diameter of a spherical water droplet that settles at the same constant velocity as the particle being sampled.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the vehicle exhaust before it is exhausted to the environment. Exhaust-gas recirculation (EGR) and turbochargers are not aftertreatment.

Allowed procedures means procedures that we specify.

Applicable standard means an emission standard to which an vehicle is subject.

Aqueous condensation means the precipitation of water-containing constituents from a gas phase to a liquid phase. Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulfuric acid. These parameters vary as a function of vehicle intake-air humidity, dilution-air humidity, vehicle air-to-fuel ratio, and fuel composition—including the amount of hydrogen and sulfur in the fuel.

Atmospheric pressure means the wet, absolute, atmospheric static pressure. Note that if you measure atmospheric pressure in a duct, you must ensure that there are negligible pressure losses between the atmosphere and your measurement location, and you must account for changes in the duct's static pressure resulting from the flow.

Auto-ranging means a gas analyzer function that automatically changes the analyzer digital resolution to a larger range of concentrations as the concentration approaches 100 % of the analyzer's current range. Auto-ranging does not mean changing an analog amplifier gain within an analyzer.

Auxiliary emission-control device means any element of design that senses temperature, motive speed, engine RPM, transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission-control system.

## WLTP-DTP-01-02

C<sub>1</sub> equivalent (or basis) means a convention of expressing HC concentrations based on the total number of carbon atoms present, such that the C<sub>1</sub> equivalent of a molar HC concentration equals the molar concentration multiplied by the mean number of carbon atoms in each HC molecule. For example, the C<sub>1</sub> equivalent of 10 μmol/mol of propane (C<sub>3</sub>H<sub>8</sub>) is 30 μmol/mol. C<sub>1</sub> equivalent molar values may be denoted as “ppmC” in the standard-setting part.

Calibration means the process of setting a measurement system’s response so that its output agrees with a range of reference signals. Contrast with “verification”.

Calibration gas means a purified gas mixture used to calibrate gas analyzers. Calibration gases must meet the specifications of §750. Note that calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analyzers and sample handling components might refer to either calibration gases or span gases.

Certification means relating to the process of obtaining a certificate of conformity for a vehicle that complies with the emission standards and requirements in the standard-setting part.

Compression-ignition means relating to a type of reciprocating, internal-combustion engine that is not a spark-ignition engine.

Confidence interval means the range associated with a probability that a quantity will be considered statistically equivalent to a reference quantity.

Dewpoint means a measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity.

Dewpoint is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured. See §645 to determine water vapor mole fractions from dewpoints using the pressure at which the dewpoint is measured.

Dilution ratio (DR) means the amount of diluted exhaust per amount of undiluted exhaust.

Drift means the difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as you zeroed and spanned the instrument just before the test.

Electronic control module means a vehicle’s electronic device that uses data from vehicle sensors to control vehicle parameters.

Emission-control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from a vehicle.

Exhaust-gas recirculation means a technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust-gas recirculation for the purposes of this part.

Fall time,  $t_{90-10}$ , means the time interval of a measurement instrument's response after any step decrease to the input between the following points:

- (1) The point at which the response has fallen 10% of the total amount it will fall in response to the step change.
- (2) The point at which the response has fallen 90% of the total amount it will fall in response to the step change.

Flow-weighted mean means the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of a vehicle, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration.

Fuel type means a general category of fuels such as gasoline or LPG. There can be multiple grades within a single type of fuel, such as all-season and winter-grade gasoline.

Accepted measurement practices means judgments made consistent with generally accepted scientific and engineering principles and all available relevant information. See 40 CFR 1068.5 for the administrative process we use to evaluate accepted measurement practices.

HEPA filter means high-efficiency particulate air filters that are rated to achieve a minimum initial particle-removal efficiency of 99.97 % using ASTM F1471-93 (incorporated by reference in §1010).

Hydraulic diameter means the diameter of a circle whose area is equal to the area of a noncircular cross section of tubing, including its wall thickness. The wall thickness is included only for the purpose of facilitating a simplified and nonintrusive measurement.

Hydrocarbon (HC) means THC, THCE, NMHC, or NMHCE, as applicable. Hydrocarbon generally means the hydrocarbon group on which the emission standards are based for each type of fuel and vehicle.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular vehicle from other similar vehicles.

Linearity means the degree to which measured values agree with respective reference values. Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing. Perfect linearity would result in an intercept,  $a_0$ , equal to zero, a slope,  $a_1$ , of one, a coefficient of determination,  $r^2$ , of one, and a standard error of the estimate,  $SEE$ , of zero. The term "linearity" is not used in this part to refer to the shape of a measurement instrument's unprocessed response curve, such as a curve relating emission concentration to voltage output. A properly performing instrument with a nonlinear response curve will meet linearity specifications.

NIST-accepted means relating to a value that has been assigned or named by NIST.

NIST-traceable means relating to a standard value that can be related to NIST-stated references through an unbroken chain of comparisons, all having stated uncertainties, as specified in NIST Technical Note 1297 (incorporated by reference in §1010). Allowable uncertainty limits specified for NIST-traceability refer to the propagated uncertainty specified by NIST. You may ask to use other internationally recognized standards that are equivalent to NIST standards.

Noise means the precision of 30 seconds of updated recorded values from a measurement instrument as it quantifies a zero or reference value. Determine instrument noise, repeatability, and accuracy from the same data set. We specify a procedure for determining noise in §305.

Nonmethane hydrocarbons (NMHC) means the sum of all hydrocarbon species except methane. Refer to §660 for NMHC determination.

## WLTP-DTP-01-02

Nonmethane hydrocarbon equivalent (NMHCE) means the sum of the carbon mass contributions of non-oxygenated nonmethane hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust nonmethane hydrocarbon from petroleum-fueled vehicles. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Oxides of nitrogen means NO and NO<sub>2</sub> as measured by the procedures specified in §270. Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO<sub>2</sub>, such that you use an effective molar mass for all oxides of nitrogen equivalent to that of NO<sub>2</sub>.

Oxygenated fuels means fuels composed of oxygen-containing compounds, such as ethanol or methanol. Testing vehicles that use oxygenated fuels generally requires the use of the sampling methods in subpart I of this part. However, you should read the standard-setting part and subpart I of this part to determine appropriate sampling methods.

Partial pressure means the pressure,  $p$ , attributable to a single gas in a gas mixture. For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration,  $x$ .

Percent (%) means a representation of exactly 0.01 (with infinite precision). Significant digits for the product of % and another value, or the expression of any other value as a percentage, are defined as follows:

(1) Where we specify some percentage of a total value, the calculated value has the same number of significant digits as the total value. The specified percentage by which the total value is multiplied has infinite precision. Note that not all displayed or recorded digits are significant. For example, 2 % of a span value where the span value is 101.3302 is 2.026604. However, where the span value has limited precision such that only one digit to the right of the decimal is significant (i.e., the actual value is 101.3), 2 % of the span value is 2.026.

(2) In other cases, determine the number of significant digits using the same method as you would use for determining the number of significant digits of any calculated value. For example, a calculated value of 0.321, where all three digits are significant, is equivalent to 32.1 %.

Portable emission measurement system (PEMS) means a measurement system consisting of portable equipment that can be used to generate brake-specific emission measurements during field testing or laboratory testing.

Precision means two times the standard deviation of a set of measured values of a single zero or reference quantity.

Procedures means all aspects of vehicle testing, including the equipment specifications, calibrations, calculations and other protocols and specifications needed to measure emissions, unless we specify otherwise.

Proving ring is a device used to measure static force based on the linear relationship between stress and strain in an elastic material. It is typically a steel alloy ring, and you measure the deflection (strain) of its diameter when a static force (stress) is applied across its diameter.

PTFE means polytetrafluoroethylene, commonly known as Teflon™.

Recommend has the meaning given in 201.

Regression statistics means any of the regression statistics specified in §602.

Regulated pollutant means an exhaust constituent for which an emission standard or a reporting requirement applies.

Repeatability means the precision of ten mean measurements of a reference quantity. Determine instrument repeatability, accuracy, and noise from the same data set. We specify a procedure for determining repeatability in 305.

Rise time,  $t_{10-90}$ , means the time interval of a measurement instrument's response after any step increase to the input between the following points:

- (1) The point at which the response has risen 10% of the total amount it will rise in response to the step change.
- (2) The point at which the response has risen 90% of the total amount it will rise in response to the step change.

Roughness (or average roughness,  $R_a$ ) means the size of finely distributed vertical surface deviations from a smooth surface, as determined when traversing a surface. It is an integral of the absolute value of the roughness profile measured over an evaluation length.

Round means to round numbers according to NIST SP 811 (incorporated by reference in §1010), unless otherwise specified.

Scheduled maintenance means adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

Shared atmospheric pressure meter means an atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell.

Shared humidity measurement means a humidity measurement that is used as the humidity for an entire test facility that has more than one dynamometer test cell.

Span means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 % and 100 % of the maximum value in the instrument range or expected range of use.

Span gas means a purified gas mixture used to span gas analyzers. Span gases must meet the specifications of §750. Note that calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analyzers and sample handling components might refer to either calibration gases or span gases.

Spark-ignition means relating to a gasoline-fueled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

Standard deviation has the meaning given in §602. Note this is the standard deviation for a non-biased sample.

Stoichiometric means relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen. For example, stoichiometric combustion in a gasoline-fueled engine typically occurs at an air-to-fuel mass ratio of about 14.7:1.

Storage medium means a particulate filter, sample bag, or any other storage device used for batch sampling.

Tolerance means the interval in which at least 95 % of a set of recorded values of a certain quantity must lie. Use the specified recording frequencies and time intervals to determine

## WLTP-DTP-01-02

if a quantity is within the applicable tolerance. The concept of tolerance is intended to address random variability. You may not take advantage of the tolerance specification to incorporate a bias into a measurement.

Total hydrocarbon (THC) means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with a hydrogen-to-carbon mass ratio of 1.85:1.

Total hydrocarbon equivalent (THCE) means the sum of the carbon mass contributions of non-oxygenated hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Transformation time,  $t_{50}$ , means the overall system response time to any step change in input, generally the average of the time to reach 50% response to a step increase,  $t_{0-50}$ , or to a step decrease,  $t_{100-50}$ .

$t_{0-50}$  means the time interval of a measurement system's response after any step increase to the input between the following points:

- (1) The point at which the step change is initiated at the sample probe.
- (2) The point at which the response has risen 50% of the total amount it will rise in response to the step change.

$t_{100-50}$  means the time interval of a measurement system's response after any step decrease to the input between the following points:

- (1) The point at which the step change is initiated at the sample probe.
- (2) The point at which the response has fallen 50% of the total amount it will fall in response to the step change.

Uncertainty means uncertainty with respect to NIST-traceability. See the definition of NIST-traceable in this section.

Vehicle means any vehicle, vessel, or type of equipment using engines to which this part applies. For purposes of this part, the term "vehicle" may include nonmotive machines or equipment such as a pump or generator.

Verification means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance. Contrast with "calibration".

Zero means to adjust an instrument so it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air for measuring concentrations of emission constituents.

Zero gas means a gas that yields a zero response in an analyzer. This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen. For field testing, zero gas may include ambient air.

### **§1005 Symbols, abbreviations, acronyms, and units of measure.**

The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, 1995 Edition, "Guide for the Use of the International System, of Units (SI)," which we incorporate by reference in §1010. See §25 for specific provisions related

to these conventions. This section summarizes the way we use symbols, units of measure, and other abbreviations.

(a) Symbols for quantities. This part uses the following symbols and units of measure for various quantities:

Symbol	Quantity	Unit	Unit Symbol	Base SI units
%	percent	0.01	%	$10^{-2}$
$\alpha$	atomic hydrogen to carbon ratio	mole per mole	mol/mol	1
$A$	area	square meter	$m^2$	$m^2$
$A_0$	intercept of least squares regression			
$A_1$	slope of least squares regression			
$\beta$	ratio of diameters	meter per meter	m/m	1
$\beta$	atomic oxygen to carbon ratio	mole per mole	mol/mol	1
$C^\#$	number of carbon atoms in a molecule			
$d$	Diameter	meter	m	m
$DR$	dilution ratio	mole per mol	mol/mol	1
$\varepsilon$	error between a quantity and its reference			
$e$	brake-specific basis	gram per kilowatt hour	g/(kW·h)	$g \cdot 3.6^{-1} \cdot 10^6 \cdot m^{-2} \cdot kg \cdot s^2$
$F$	F-test statistic			
$f$	frequency	hertz	Hz	$s^{-1}$
$f_n$	rotational frequency (shaft)	revolutions per minute	rev/min	$2 \cdot \pi \cdot 60^{-1} \cdot s^{-1}$
$\gamma$	ratio of specific heats	(joule per kilogram kelvin) per (joule per kilogram kelvin)	$(J/(kg \cdot K))/(J/(kg \cdot K))$	1
$K$	correction factor			1
$l$	length	meter	m	m
$\mu$	viscosity, dynamic	pascal second	Pa·s	$m^{-1} \cdot kg \cdot s^{-1}$
$M$	molar mass <sup>1</sup>	gram per mole	g/mol	$10^{-3} \cdot kg \cdot mol^{-1}$
$m$	mass	kilogram	kg	Kg
$\dot{m}$	mass rate	kilogram per second	kg/s	$kg \cdot s^{-1}$
$\nu$	viscosity, kinematic	meter squared per second	$m^2/s$	$m^2 \cdot s^{-1}$
$N$	total number in series			
$n$	amount of substance	mole	mol	mol
$\dot{n}$	amount of substance rate	mole per second	mol/s	$mol \cdot s^{-1}$
$P$	power	kilowatt	kW	$10^3 \cdot m^2 \cdot kg \cdot s^{-3}$
$PF$	penetration fraction			
$p$	pressure	pascal	Pa	$m^{-1} \cdot kg \cdot s^{-2}$
$\rho$	mass density	kilogram per cubic meter	$kg/m^3$	$kg \cdot m^{-3}$
$r$	ratio of pressures	pascal per pascal	Pa/Pa	1
$R^2$	coefficient of determination			
$Ra$	average surface roughness	micrometer	$\mu m$	$m^{-6}$
$Re^\#$	Reynolds number			
$RF$	response factor			
$RH\%$	relative humidity	0.01	%	$10^{-2}$
$\sigma$	non-biased standard deviation			

## WLTP-DTP-01-02

$S$	Sutherland constant	kelvin	K	K
$SEE$	standard estimate of error			
$T$	absolute temperature	kelvin	K	K
$T$	Celsius temperature	degree Celsius	°C	K-273.15
$T$	torque (moment of force)	newton meter	N·m	m <sup>2</sup> ·kg·s <sup>-2</sup>
$t$	time	second	s	s
$\Delta t$	time interval, period, 1/frequency	second	s	s
$V$	volume	cubic meter	m <sup>3</sup>	m <sup>3</sup>
$\dot{V}$	volume rate	cubic meter per second	m <sup>3</sup> /s	m <sup>3</sup> ·s <sup>-1</sup>
$W$	work	kilowatt hour	kW·h	3.6·10 <sup>-6</sup> ·m <sup>2</sup> ·kg·s <sup>-2</sup>
$w_c$	carbon mass fraction	gram per gram	g/g	1
$x$	amount of substance mole fraction <sup>2</sup>	mole per mole	mol/mol	1
$\bar{x}$	flow-weighted mean concentration	mole per mole	mol/mol	1
$y$	generic variable			

<sup>1</sup> See paragraph (f)(2) of this section for the values to use for molar masses. Note that in the cases of NO<sub>x</sub> and HC, the regulations specify effective molar masses based on assumed speciation rather than actual speciation.

<sup>2</sup> Note that mole fractions for THC, THCE, NMHC, NMHCE, and NOTHC are expressed on a C<sub>1</sub> equivalent basis.

(b) Symbols for chemical species. This part uses the following symbols for chemical species and exhaust constituents:

Symbol	Species
Ar	argon
C	carbon
CH <sub>4</sub>	methane
C <sub>2</sub> H <sub>6</sub>	ethane
C <sub>3</sub> H <sub>8</sub>	propane
C <sub>4</sub> H <sub>10</sub>	butane
C <sub>5</sub> H <sub>12</sub>	pentane
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
H	atomic hydrogen
H <sub>2</sub>	molecular hydrogen
H <sub>2</sub> O	water
He	helium
<sup>85</sup> Kr	krypton 85
N <sub>2</sub>	molecular nitrogen
NMHC	nonmethane hydrocarbon
NMHCE	nonmethane hydrocarbon equivalent
NO	nitric oxide
NO <sub>2</sub>	nitrogen dioxide
NO <sub>x</sub>	oxides of nitrogen
N <sub>2</sub> O	nitrous oxide
NOTHC	nonoxygenated hydrocarbon
O <sub>2</sub>	molecular oxygen
OHC	oxygenated hydrocarbon

<sup>210</sup> Po	polonium 210
PM	particulate mass
S	sulfur
THC	total hydrocarbon
ZrO <sub>2</sub>	zirconium dioxide

(c) Prefixes. This part uses the following prefixes to define a quantity:

Symbol	Quantity	Value
μ	micro	10 <sup>-6</sup>
m	milli	10 <sup>-3</sup>
c	centi	10 <sup>-2</sup>
k	kilo	10 <sup>3</sup>
M	mega	10 <sup>6</sup>

(d) Superscripts. This part uses the following superscripts to define a quantity:

Superscript	Quantity
overbar (such as $\bar{y}$ )	arithmetic mean
overdot (such as $\dot{y}$ )	quantity per unit time

(e) Subscripts. This part uses the following subscripts to define a quantity:

Subscript	Quantity
abs	absolute quantity
act	actual condition
air	air, dry
atmos	atmospheric
cal	calibration quantity
CFV	critical flow venturi
cor	corrected quantity
dil	dilution air
dexh	diluted exhaust
exh	raw exhaust
exp	expected quantity
i	an individual of a series
idle	condition at idle
in	quantity in
init	initial quantity, typically before an emission test
j	an individual of a series
max	the maximum (i.e., peak) value expected at the standard over a test interval; not the maximum of an instrument range
meas	measured quantity
out	quantity out
part	partial quantity
PDP	positive-displacement pump
ref	reference quantity
rev	revolution
sat	saturated condition

**WLTP-DTP-01-02**

slip	PDP slip
span	span quantity
SSV	subsonic venturi
std	standard condition
test	test quantity
uncor	uncorrected quantity
zero	zero quantity

(f) Constants. (1) This part uses the following constants for the composition of dry air:

Symbol	Quantity	mol/mol
$x_{Ar_{air}}$	amount of argon in dry air	0.00934
$x_{CO2_{air}}$	amount of carbon dioxide in dry air	0.000375
$x_{N2_{air}}$	amount of nitrogen in dry air	0.78084
$x_{O2_{air}}$	amount of oxygen in dry air	0.209445

(2) This part uses the following molar masses or effective molar masses of chemical species:

Symbol	Quantity	g/mol ( $10^{-3} \cdot \text{kg} \cdot \text{mol}^{-1}$ )
$M_{air}$	molar mass of dry air 1	28.96559
$M_{Ar}$	molar mass of argon	39.948
$M_C$	molar mass of carbon	12.0107
$M_{CO}$	molar mass of carbon monoxide	28.0101
$M_{CO2}$	molar mass of carbon dioxide	44.0095
$M_H$	molar mass of atomic hydrogen	1.00794
$M_{H2}$	molar mass of molecular hydrogen	2.01588
$M_{H2O}$	molar mass of water	18.01528
$M_{He}$	molar mass of helium	4.002602
$M_N$	molar mass of atomic nitrogen	14.0067
$M_{N2}$	molar mass of molecular nitrogen	28.0134
$M_{NMHC}$	effective molar mass of nonmethane hydrocarbon <sup>2</sup>	13.875389
$M_{NMHCE}$	effective molar mass of nonmethane equivalent hydrocarbon <sup>2</sup>	13.875389
$M_{NOx}$	effective molar mass of oxides of nitrogen <sup>3</sup>	46.0055
$M_{N2O}$	effective molar mass of nitrous oxide	44.0128
$M_O$	molar mass of atomic oxygen	15.9994
$M_{O2}$	molar mass of molecular oxygen	31.9988
$M_{C3H8}$	molar mass of propane	44.09562
$M_S$	molar mass of sulfur	32.065
$M_{THC}$	effective molar mass of total hydrocarbon <sup>2</sup>	13.875389
$M_{THCE}$	effective molar mass of total hydrocarbon equivalent <sup>2</sup>	13.875389

<sup>1</sup>See paragraph (f)(1) of this section for the composition of dry air.

<sup>2</sup>The effective molar masses of THC, THCE, NMHC, and NMHCE are defined by an atomic hydrogen-to-carbon ratio,  $\alpha$ , of 1.85.

<sup>3</sup>The effective molar mass of NO<sub>x</sub> is defined by the molar mass of nitrogen dioxide, NO<sub>2</sub>.

(3) This part uses the following molar gas constant for ideal gases:

Symbol	Quantity	J/(mol·K)
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		$(\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-2} \cdot \text{mol}^{-1} \cdot \text{K}^{-1})$
$R$	molar gas constant	8.314472

(4) This part uses the following ratios of specific heats for dilution air and diluted exhaust:

Symbol	Quantity	$[\text{J}/(\text{kg} \cdot \text{K})]/[\text{J}/(\text{kg} \cdot \text{K})]$
$\gamma_{\text{air}}$	ratio of specific heats for intake air or dilution air	1.399
$\gamma_{\text{dil}}$	ratio of specific heats for diluted exhaust	1.399
$\gamma_{\text{exh}}$	ratio of specific heats for raw exhaust	1.385

(g) Other acronyms and abbreviations. This part uses the following additional abbreviations and acronyms:

ASTM	American Society for Testing and Materials
BMD	bag mini-diluter
BSFC	brake-specific fuel consumption
CARB	California Air Resources Board
CFR	Code of Federal Regulations
CFV	critical-flow venturi
CI	compression-ignition
CITT	Curb Idle Transmission Torque
CLD	chemiluminescent detector
CVS	constant-volume sampler
DF	deterioration factor
ECM	electronic control module
EFC	electronic flow control
EGR	exhaust gas recirculation
EPA	Environmental Protection Agency
FEL	Family Emission Limit
FID	flame-ionization detector
GC	gas chromatograph
GC-ECD	gas chromatograph with an electron-capture detector
IBP	initial boiling point
ISO	International Organization for Standardization
LPG	liquefied petroleum gas
NDIR	nondispersive infrared
NDUV	nondispersive ultraviolet
NIST	National Institute for Standards and Technology
PDP	positive-displacement pump
PEMS	portable emission measurement system
PFD	partial-flow dilution
PMP	Polymethylpentene
pt.	a single point at the mean value expected at the standard.
PTFE	polytetrafluoroethylene (commonly known as Teflon™)
RE	rounding error
RMC	ramped-modal cycle

## WLTP-DTP-01-02

RMS	root-mean square
RTD	resistive temperature detector
SSV	subsonic venturi
SI	spark-ignition
UCL	upper confidence limit
UFM	ultrasonic flow meter
U.S.C.	United States Code

### §1010 Reference materials.

Documents listed in this section have been incorporated by reference into this part. The Director of the Federal Register approved the incorporation by reference as prescribed in 5 U.S.C. 552(a) and 1 CFR part 51. Anyone may inspect copies at the U.S. EPA, Air and Radiation Docket and Information Center, 1301 Constitution Ave., NW., Room B102, EPA West Building, Washington, DC 20460 or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202-741-6030, or go to:

[http://www.archives.gov/federal\\_register/code\\_of\\_federal\\_regulations/ibr\\_locations.html](http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html).

(a) ASTM material. Table 1 of this section lists material from the American Society for Testing and Materials that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase copies of these materials from the American Society for Testing and Materials, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428 or [www.astm.com](http://www.astm.com). Table 1 follows:

Table 1 of §1010–ASTM materials

Document number and name	Section reference
ASTM D2986-95a (Reapproved 1999), Standard Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test	170
ASTM F1471-93 (Reapproved 2001), Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air Filter System	1001

(b) ISO material. Table 2 of this section lists material from the International Organization for Standardization that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the section of this part where we reference it. Anyone may purchase copies of these materials from the International Organization for Standardization, Case Postale 56, CH-1211 Geneva 20, Switzerland or [www.iso.org](http://www.iso.org). Table 2 follows:

Table 2 of §1010–ISO materials

Document number and name	Section reference
ISO 14644-1:1999, Cleanrooms and associated controlled environments	190

(c) NIST material. Table 3 of this section lists material from the National Institute of Standards and Technology that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the section of this part where we reference it.

Anyone may purchase copies of these materials from the Government Printing Office, Washington, DC 20402 or download them free from the Internet at [www.nist.gov](http://www.nist.gov). Table 3 follows:

Table 3 of §1010–NIST materials

Document number and name	Section reference
NIST Special Publication 811, 1995 Edition, Guide for the Use of the International System of Units (SI), Barry N. Taylor, Physics Laboratory	20, 1001, 1005
NIST Technical Note 1297, 1994 Edition, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, Barry N. Taylor and Chris E. Kuyatt	1001

(d) SAE material. Table 4 of this section lists material from the Society of Automotive Engineering that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase copies of these materials from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 or [www.sae.org](http://www.sae.org). Table 4 follows:

Table 4 of §1010–SAE materials

Document number and name	Section reference
“Optimization of Flame Ionization Detector for Determination of Hydrocarbon in Diluted Automotive Exhausts,” Reschke Glen D., SAE 770141	360
“Road Load Measurement Using Onboard Anemometry and Coastdown Techniques,” SAE J2263	505
“Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques, Recommended Practice,” SAE J2264	505

(e) California Air Resources Board material. Table 5 of this section lists material from the California Air Resources Board that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may get copies of these materials from the California Air Resources Board 9528 Telstar Ave., El Monte, California 91731. Table 5 follows:

Table 5 of §1010–California Air Resources Board materials

Document number and name	Section reference
“California Non-Methane Organic Gas Test Procedures,” Amended July 30, 2002, Mobile Source Division, California Air Resources Board	805