(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 § 1065.1001 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 ± 1.2 kPa of atmospheric pressure. You may use a booster blower to control this pressure. If you test an engine 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 engine.

(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 § 1065.640.

(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 1065.240 describes measurement instruments for diluted exhaust flow.

(6) *Aqueous condensation.* To ensure that you measure a flow that corresponds to a measured concentration, you may either prevent aqueous condensation between the sample probe location and the flow meter inlet in the dilution tunnel or you may allow aqueous condensation to occur and then measure humidity at the flow meter inlet. You may heat or insulate the dilution tunnel walls, as well as the bulk stream tubing downstream of the tunnel to prevent aqueous condensation. Calculations in § 1065.645 and § 1065.650 account for either method of addressing humidity in the diluted exhaust. Note that preventing aqueous condensation involves more than keeping pure water in a vapor phase (see § 1065.1001).

(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 § 1065.545.

(d) *Partial-flow dilution (PFD).* Except as specified in this paragraph (d), you may dilute a partial flow of raw or previously diluted exhaust before measuring emissions. § 1065.240 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 not use PFD if the standard-setting part prohibits it.

(ii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any transient duty cycle only if we have explicitly approved it according to § 1065.10 as an alternative procedure to the specified procedure for full-flow CVS.

(iii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous gaseous emission sampling.

(iv) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any steady-state duty cycle or its ramped-modal cycle (RMC) equivalent.

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

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

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

(iv) For each mode of a discrete-mode test (such as a locomotive notch setting or a specific setting for speed and torque), use a constant dilution ratio for any PM sampling. You must change the overall PM sampling system dilution ratio between modes so that the dilution ratio on the mode with the highest exhaust flow rate meets § 1065.140(e)(2) and the dilution ratios on all other modes is higher than this (minimum) dilution ratio by the ratio of the maximum exhaust flow rate to the exhaust flow rate of the corresponding other mode. This is the same dilution ratio requirement for RMC or field transient testing. You must account for this change in dilution ratio in your emission calculations.

(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 proportional sampling over intervals as short as 200 ms (i.e., 5 Hz control).

(ii) For control input, you may use any sensor output from one or more measurements; for example, intake-air flow, fuel flow, exhaust flow, engine speed, and intake manifold temperature and pressure.

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

(iv) You may use preprogrammed data if they have been determined for the specific test site, duty cycle, and test engine from which you dilute emissions.

(v) We recommend that you run practice cycles to meet the validation criteria in § 1065.545. Note that you must validate every emission test by meeting the validation criteria with the data from that specific test. Data from previously validated practice cycles or other tests may not be used to validate a different emission test.

(vi) 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. Configure dilution systems as follows:

(1) Set the diluent (i.e., dilution air) temperature to (25 ± 5) °C. Use good engineering judgment to select a location to measure this temperature. We recommend that you 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 engine 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 good engineering judgment (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 ± 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 ± 0.025) mm diameter, or with another suitable instrument that has equivalent performance. The intent of these specifications is to minimize heat transfer to or from the emissions sample prior to the final stage of dilution. This is accomplished by initially cooling the sample through dilution.

■ 60. Section 1065.145 is revised to read as follows:

§ 1065.145 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, as described in § 1065.15(c)(2). Both types of sampling systems have probes, transfer lines, and other sampling system components that are described in this section.

(b) *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 (c) 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. Take into account the mixing of any crankcase emissions that may be routed into the raw exhaust. 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) *Probe installation on multi-stack engines.* We recommend combining multiple exhaust streams from multi-stack engines before emission sampling as described in § 1065.130(c)(6). If this is impractical, you may install symmetrical probes and transfer lines in each stack. In this case, each stack must be installed such that similar exhaust velocities are expected at each probe location. Use identical probe and transfer line diameters, lengths, and bends for each stack. Minimize the individual transfer line lengths, and manifold the individual transfer lines into a single transfer line to route the combined exhaust sample to analyzers and/or batch samplers. For PM sampling the manifold design must merge the individual sample streams with a maximum angle of 12.5° relative to the single sample stream's flow. Note that the manifold must meet the same specifications as the transfer line according to paragraph (c) of this section. If you use this probe configuration and you determine your exhaust flow rates with a chemical balance of exhaust gas concentrations and either intake air flow or fuel flow, then show by prior testing that the concentration of O^2 in each stack remains within 5% of the mean O^2 concentration throughout the entire duty cycle.

(3) *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 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, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW, we recommend heating the probe to minimize hydrocarbon contamination consistent with good engineering

judgment. If you routinely fail the contamination check in the 1065.520 pretest check, we recommend heating the probe section to approximately 190 °C to minimize contamination.

(4) *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 (e)(1) of this section. We recommend sizing the inside diameter of PM probes to approximate isokinetic sampling at the expected mean flow rate.

(c) *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 § 1065.140(e). Minimize the length of all transfer lines by locating analyzers, storage media, and dilution systems as close to probes as practical. We recommend that you minimize the number of bends in transfer lines and that you maximize the radius of any unavoidable bend. Avoid using 90° elbows, tees, and cross-fittings in transfer lines. Where such connections and fittings are necessary, take steps, using good engineering judgment, to ensure that you meet the temperature tolerances in this paragraph (c). 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™, 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 NO_X transfer lines upstream of either an NO_2-to-NO converter that meets the specifications of § 1065.378 or a chiller that meets the specifications of § 1065.376, maintain a sample temperature that prevents aqueous condensation.

(ii) For THC transfer lines for testing compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW, maintain a wall temperature tolerance throughout the entire line of (191 ±11) °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 °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 ±11) °C.

(2) *PM samples.* We recommend heated transfer lines or a heated enclosure to minimize temperature differences between transfer lines and exhaust constituents. Use transfer lines that are inert with respect to PM and are electrically conductive on the inside surfaces. We recommend using PM transfer lines made of 300 series stainless steel. Electrically ground the inside surface of PM transfer lines.

(d) *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 engines comply with all applicable gaseous emission standards.

(1) *NO_2-to-NO converter.* You may use an NO_2-to-NO converter that meets the efficiency-performance check specified in § 1065.378 at any point upstream of a NO_X analyzer, sample bag, or other storage medium.

(2) *Sample dryer.* You may use either type of sample dryer described in this paragraph (d)(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 (c)(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_{dew}, and absolute pressure, p_{total}, downstream of an osmotic-membrane dryer. You may use continuously recorded values of T_{dew} and p_{total} in the amount of water calculations specified in § 1065.645. If you do not continuously record these values, you may use their peak values observed during a test or their alarm setpoints as constant values in the calculations specified in § 1065.645.

You may also use a nominal p_{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_2-to-NO converter or in a sampling system without an NO_2-to-NO converter, the chiller must meet the NO_2 loss-performance check specified in § 1065.376. Monitor the dewpoint, T_{dew}, and absolute pressure, p_{total}, downstream of a thermal chiller. You may use continuously recorded values of T_{dew} and p_{total} in the emission calculations specified in § 1065.650. If you do not continuously record these values, you may use the maximum temperature and minimum pressure values observed during a test or the high alarm temperature setpoint and the low alarm pressure setpoint as constant values in the amount of water calculations specified in § 1065.645. You may also use a nominal p_{total}, which you may estimate as the dryer's lowest absolute pressure expected during testing. If it is valid to assume the degree of saturation in the thermal chiller, you may calculate T_{dew} based on the known chiller performance and continuous monitoring of chiller temperature, $T_{chiller}$. If you do not continuously record values of $T_{chiller}$, you may use its peak value observed during a test, or its alarm setpoint, as a constant value to determine a constant amount of water according to § 1065.645. If it is valid to assume that $T_{chiller}$ is equal to T_{dew}, you may use $T_{chiller}$ in lieu of T_{dew} according to § 1065.645. If it is valid to assume a constant temperature offset between $T_{chiller}$ and T_{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 (d)(2)(ii).

(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_X sample pump upstream of either an NO_2-to-NO converter that meets § 1065.378 or a chiller that meets § 1065.376, it must be heated to prevent aqueous condensation.

(ii) For testing compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW, 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_3, poisoning of the NO_2-to-NO converter, and deposits in the sampling system or analyzers. Follow the ammonia scrubber manufacturer's recommendations or use good engineering judgment in applying ammonia scrubbers.

(e) *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.

(2) *Other components.* You may request to use other PM conditioning components upstream of a PM preclassifier, such as components that condition humidity or remove gaseous-phase hydrocarbons from the diluted exhaust stream. You may use such components only if we approve them under § 1065.10.

■ 61. Section 1065.170 is amended by revising the introductory text and paragraphs (a) and (c)(1) to read as follows:

§ 1065.170 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.* If you extract from a constant-volume flow rate, sample at a constant-volume flow rate as follows:

(1) Validate proportional sampling after an emission test as described in § 1065.545. Use good engineering judgment to 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 offgas emissions to the extent that it affects your ability to demonstrate compliance with the applicable gaseous emission standards. As another example, do not use PM filters that irreversibly absorb or adsorb gases to the extent that it affects your ability to demonstrate compliance with the applicable PM emission standard.

(2) You must follow the requirements in § 1065.140(e)(2) related to PM dilution ratios. For each filter, if you expect the net PM mass on the filter to exceed 400 μg, assuming a 38 mm diameter filter stain area, you may take the following actions in sequence:

(i) First, reduce filter face velocity as needed to target a filter loading of 400 μg, down to 50 cm/s or less.

(ii) Then, for discrete-mode testing only, you may reduce sample time as needed to target a filter loading of 400 μg, but not below the minimum sample time specified in the standard-setting part.

(iii) Then, increase overall dilution ratio above the values specified in § 1065.140(e)(2) to target a filter loading of 400 μg.

* * * * *

(c) * * *

(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%. Collection efficiency must be measured as described in ASTM D2986–95a (incorporated by reference in § 1065.1010), though you may rely on the sample-media manufacturer's measurements reflected in their product ratings to show that you meet this requirement.

(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) We highly recommend that you 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. Note that we will use pure PTFE filter material for compliance testing, and we may require you to use pure PTFE filter material for any compliance testing we require, such as for selective enforcement audits.

(iv) You may request to use other filter materials or sizes under the provisions of § 1065.10.

(v) To minimize turbulent deposition and to deposit PM evenly on a filter, use 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 § 1065.140(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 § 1065.170 and made of any 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_2H_5OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's PM and HC emissions.

(viii) If you store filters in cassettes in an automatic PM sampler, cover or seal individual filter cassettes after sampling to prevent communication of semi-volatile matter from one filter to another.

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■ 62. Section 1065.190 is amended by revising paragraphs (c), (e), (f) and (g) to read as follows:

§ 1065.190 PM-stabilization and weighing environments for gravimetric analysis.

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(c) Verify the cleanliness of the PM-stabilization environment using reference filters, as described in § 1065.390(d).

* * * * *

(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). We recommend that you use an interlock that automatically prevents the balance from reporting values if either of the environments have not been within the applicable tolerances for the past 60 min.

(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 ±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 § 1065.690.

(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}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 ±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.

■ 63. Section 1065.195 is amended by revising paragraphs (a) and (c)(4) to read as follows:

§ 1065.195 PM-stabilization environment for in-situ analyzers.

(a) This section describes the environment required to determine PM in-situ. For in-situ analyzers, such as an inertial balance, this is the environment within a PM sampling system that surrounds the PM sample media (e.g., filters). This is typically a very small volume.

* * * * *

(c) * * *

(4) *Absolute pressure.* Use good engineering judgment to maintain a tolerance of absolute pressure if your PM measurement instrument requires it.

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Subpart C—[Amended]

■ 64. Section 1065.201 is amended by revising paragraphs (a) and (b) and adding paragraph (h) to read as follows:

§ 1065.201 Overview and general provisions.

(a) *Scope.* This subpart specifies measurement instruments and associated system requirements related to emission testing in a laboratory or similar environment and in the field. This includes laboratory instruments and portable emission measurement systems (PEMS) for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations.

(b) *Instrument types.* You may use any of the specified instruments as described in this subpart to perform emission tests. If you want to use one of these instruments in a way that is not specified in this subpart, or if you want to use a different instrument, you must first get us to approve your alternate procedure under § 1065.10. 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.

* * * * *

(h) *Recommended practices.* This subpart identifies a variety of recommended but not required practices for proper measurements. We believe in most cases it is necessary to follow these recommended practices for accurate and repeatable measurements and we intend to follow them as much as possible for our testing. However, we do not specifically require you to follow these recommended practices to perform a valid test, as long as you meet the required calibrations and verifications of measurement systems specified in subpart D of this part.

■ 65. Section 1065.210 is amended by revising paragraph (a) before the figure to read as follows:

§ 1065.210   Work input and output sensors.

(a) *Application.* Use instruments as specified in this section to measure work inputs and outputs during engine operation. We recommend that you use sensors, transducers, and meters that meet the specifications in Table 1 of § 1065.205. Note that your overall systems for measuring work inputs and outputs must meet the linearity verifications in § 1065.307. We recommend that you measure work inputs and outputs where they cross the system boundary as shown in Figure 1 of § 1065.210. The system boundary is different for air-cooled engines than for liquid-cooled engines. If you choose to measure work before or after a work conversion, relative to the system boundary, use good engineering judgment to estimate any work-conversion losses in a way that avoids overestimation of total work. For example, if it is impractical to instrument the shaft of an exhaust turbine generating electrical work, you may decide to measure its converted electrical work. As another example, you may decide to measure the tractive (i.e., electrical output) power of a locomotive, rather than the brake power of the locomotive engine. In these cases, divide the electrical work by accurate values of electrical generator efficiency ($\eta < 1$), or assume an efficiency of 1 ($\eta = 1$), which would over-estimate brake-specific emissions. For the example of using locomotive tractive power with a generator efficiency of 1 ($\eta = 1$), this means using the tractive power as the brake power in emission calculations. Do not underestimate any work conversion efficiencies for any components outside the system boundary that do not return work into the system boundary. And do not overestimate any work conversion efficiencies for components outside the system boundary that do return work into the system boundary. In all cases, ensure that you are able to accurately demonstrate compliance with the applicable standards.

* * * * *

■ 66. Section 1065.215 is amended by revising paragraph (e) to read as follows:

§ 1065.215   Pressure transducers, temperature sensors, and dewpoint sensors.

* * * * *

(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.

■ 67. Section 1065.220 is amended by revising paragraph (d) to read as follows:

§ 1065.220   Fuel flow meter.

* * * * *

(d) *Flow conditioning.* For any type of fuel 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. 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, straightening fins, or pneumatic pulsation dampeners to establish a steady and predictable velocity profile upstream of the meter. Condition the flow as needed to prevent any gas bubbles in the fuel from affecting the fuel meter.

■ 68. Section 1065.265 is amended by revising paragraph (c) to read as follows:

§ 1065.265   Nonmethane cutter.

* * * * *

(c) *Configuration.* Configure the nonmethane cutter with a bypass line if it is needed for the verification described in § 1065.365.

* * * * *

■ 69. Section 1065.270 is amended by revising paragraphs (c) and (d) introductory text to read as follows:

§ 1065.270   Chemiluminescent detector.

* * * * *

(c) *NO_2-to-NO converter.* Place upstream of the CLD an internal or external NO_2-to-NO converter that meets the verification in § 1065.378. 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:

* * * * *

■ 70. Section 1065.280 is revised to read as follows:

§ 1065.280   Paramagnetic and magnetopneumatic O_2 detection analyzers.

(a) *Application.* You may use a paramagnetic detection (PMD) or magnetopneumatic detection (MPD) analyzer to measure O_2 concentration in raw or diluted exhaust for batch or continuous sampling. You may use O_2 measurements with intake air or fuel flow measurements to calculate exhaust flow rate according to § 1065.650.

(b) *Component requirements.* We recommend that you use a PMD or MPD analyzer that meets the specifications in Table 1 of § 1065.205. Note that it must meet the linearity verification in § 1065.307. You may use a PMD or MPD 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.

■ 71. Section 1065.290 is amended by revising paragraph (c)(1) to read as follows:

§ 1065.290   PM gravimetric balance.

* * * * *

(c) * * *

(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.

* * * * *

Subpart D—[Amended]

■ 72. Section 1065.303 is revised to read as follows:

§ 1065.303   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 § 1065.303.—SUMMARY OF REQUIRED CALIBRATION AND VERIFICATIONS

Type of calibration or verification	Minimum frequency [a]
§ 1065.305: 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.

TABLE 1 OF § 1065.303.—SUMMARY OF REQUIRED CALIBRATION AND VERIFICATIONS—Continued

Type of calibration or verification	Minimum frequency [a]
§ 1065.307: Linearity	Speed: Upon initial installation, within 370 days before testing and after major maintenance.
	Torque: Upon initial installation, within 370 days before testing and after major maintenance.
	Electrical power: 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 analyzers: Upon initial installation, within 35 days before testing and after major maintenance.
	PM balance: Upon initial installation, within 370 days before testing and after major maintenance.
	Stand-alone pressure and temperature: Upon initial installation, within 370 days before testing and after major maintenance.
§ 1065.308: Continuous analyzer system response and recording.	Upon initial installation, after system reconfiguration, and after major maintenance.
§ 1065.309: Continuous analyzer uniform response.	Upon initial installation, after system reconfiguration, and after major maintenance.
§ 1065.310: Torque	Upon initial installation and after major maintenance.
§ 1065.315: Pressure, temperature, dewpoint	Upon initial installation and after major maintenance.
§ 1065.320: Fuel flow	Upon initial installation and after major maintenance.
§ 1065.325: Intake flow	Upon initial installation and after major maintenance.
§ 1065.330: Exhaust flow	Upon initial installation and after major maintenance.
§ 1065.340: Diluted exhaust flow (CVS)	Upon initial installation and after major maintenance.
§ 1065.341: CVS and batch sampler verification [b].	Upon initial installation, within 35 days before testing, and after major maintenance.
§ 1065.345: Vacuum leak	Before each laboratory test according to subpart F of this part and before each field test according to subpart J of this part.
§ 1065.350: CO_2 NDIR H_2O interference	Upon initial installation and after major maintenance.
§ 1065.355: CO NDIR CO_2 and H_2O interference.	Upon initial installation and after major maintenance.
§ 1065.360: FID calibration THC FID optimization, and THC FID verification.	Calibrate all FID analyzers: Upon initial installation and after major maintenance.
	Optimize and determine CH_4 response for THC FID analyzers: upon initial installation and after major maintenance.
	Verify CH_4 response for THC FID analyzers: Upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.362: Raw exhaust FID O_2 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 § 1065.360.
§ 1065.365: Nonmethane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.370: CLD CO_2 and H_2O quench	Upon initial installation and after major maintenance.
§ 1065.372: NDUV HC and H_2O interference	Upon initial installation and after major maintenance.
§ 1065.376: Chiller NO^2 penetration	Upon initial installation and after major maintenance.
§ 1065.378: NO^2-to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
§ 1065.390: 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.
§ 1065.395: Inertial PM balance and weighing ..	Independent verification: Upon initial installation, within 370 days before testing, and after major maintenance.
	Other verifications: Upon initial installation and after major maintenance.

[a] Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

[b] The CVS verification described in § 1065.341 is not required for systems that agree within ± 2% based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.

■ 73. Section 1065.305 is amended by revising paragraphs (d)(4), (d)(8), and (d)(9)(iii) to read as follows:

§ 1065.305 Verifications for accuracy, repeatability, and noise.

* * * * *

(d) * * *

(4) Use the instrument to quantify a NIST-traceable reference quantity, y_{ref}. For gas analyzers the reference gas must meet the specifications of § 1065.750.

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 or expected during testing, whichever is greater. For noise verification, use the same zero gas from paragraph (e) of this section as the reference quantity. In all cases, allow time for the instrument to stabilize while it measures the reference quantity. Stabilization time may include

time to purge an instrument and time to account for its response.

* * * * *

(8) Repeat the steps specified in paragraphs (d)(2) through (7) of this section until you have ten arithmetic means ($\bar{y}^1, \bar{y}^2, \bar{y}_i,...\bar{y}_{10}$), ten standard deviations, ($\sigma^1, \sigma^2, \sigma_i,...\sigma_{10}$), and ten errors ($\varepsilon^1, \varepsilon^2, \varepsilon_i,...\varepsilon_{10}$).

(9) * * *

(iii) *Noise.* Noise is two times the root-mean-square of the ten standard

deviations (that is, noise = 2·rmsσ) when the reference signal is a zero-quantity signal. Refer to the example of a root-mean-square calculation in § 1065.602. We recommend that instrument noise be within the specifications in Table 1 of § 1065.205.

*　*　*　*　*

■ 74. Section 1065.307 is amended by revising paragraphs (b), (c)(6), (c)(13), and Table 1 and adding paragraphs (d)(8) and (e) before the newly revised table to read as follows:

§ 1065.307　Linearity verification.

*　*　*　*　*

(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.

(c) * * *

(6) For all measured quantities, use instrument manufacturer recommendations and good engineering judgment to select reference values, y_{refi}, that cover a range of values that you expect would prevent extrapolation beyond these values during emission testing. We recommend selecting a zero reference signal as one of the reference values of the linearity verification. For stand-alone pressure and temperature linearity verifications, we recommend at least three reference values. For all other linearity verifications select at least ten reference values.

*　*　*　*　*

(13) Use the arithmetic means, $\bar{y}_i$, and reference values, $\bar{y}_{refi}$, 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 § 1065.602. Using good engineering judgment, you may weight the results of individual

data pairs (i.e., (y_{refi}, $\bar{y}_i$)), in the linear regression calculations.

(d) * * *

(8) *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^{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.

(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 good engineering judgment.

(2) The expression "min" refers to the minimum reference value used during the linearity verification. Note that this value may be zero or a negative value depending on the signal.

(3) The expression "max" generally refers to the maximum reference value used during the linearity verification. For example for gas dividers, x^{max} is the undivided, undiluted, span gas concentration. 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.

(ii) For linearity verification of torque, T^{max} refers to the manufacturer's specified engine torque peak value of the lowest torque engine to be tested.

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

(5) These linearity verifications are optional for systems that pass the flow-rate verification for diluted exhaust as described in § 1065.341 (the propane check) or for systems that agree within ±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) The following provisions apply for stand-alone temperature measurements:

(i) The following temperature linearity checks are required:

(A) Air intake.

(B) Aftertreatment bed(s), for engines tested with aftertreatment devices subject to cold-start testing.

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

(D) PM sample, if applicable.

(E) Chiller sample, for gaseous sampling systems that use chillers to dry samples.

(ii) The following temperature linearity checks are required only if specified by the engine manufacturer:

(A) Fuel inlet.

(B) Air outlet to the test cell's charge air cooler air outlet, for engines tested with a laboratory heat exchanger that simulates an installed charge air cooler.

(C) Coolant inlet to the test cell's charge air cooler, for engines tested with a laboratory heat exchanger that simulates an installed charge air cooler.

(D) Oil in the sump/pan.

(E) Coolant before the thermostat, for liquid-cooled engines.

(8) The following provisions apply for stand-alone pressure measurements:

(i) The following pressure linearity checks are required:

(A) Air intake restriction.

(B) Exhaust back pressure.

(C) Barometer.

(D) CVS inlet gage pressure.

(E) Chiller sample, for gaseous sampling systems that use chillers to dry samples.

(ii) The following pressure linearity checks are required only if specified by the engine manufacturer:

(A) The test cell's charge air cooler and interconnecting pipe pressure drop, for turbo-charged engines tested with a laboratory heat exchanger that simulates an installed charge air cooler.

(B) Fuel outlet.

TABLE 1 OF § 1065.307.—MEASUREMENT SYSTEMS THAT REQUIRE LINEARITY VERIFICATIONS

Measurement system	Quantity	Minimum verification frequency	Linearity criteria			
			$\lvert x_{min}(a_1-1)+a_0\rvert$	a_1	SEE	r^2
Engine speed	f_n	Within 370 days before testing	$\le 0.05\% \ f_{nmax}$ ...	0.98–1.02	$\le 2\% \cdot f_{nmax}$	≥ 0.990
Engine torque	T	Within 370 days before testing	$\le 1\% \cdot T_{max}$	0.98–1.02	$\le 2\% \cdot T_{max}$	≥ 0.990
Electrical work	W	Within 370 days before testing	$\le 1\% \cdot T_{max}$	0.98–1.02	$\le 2\% \cdot T_{max}$	≥ 0.990
Fuel flow rate	$\dot{m}$	Within 370 days before testing [d]	$\le 1\% \cdot \dot{m}_{max}$	0.98–1.02	$\le 2\% \cdot \dot{m}_{max}$	≥ 0.990

TABLE 1 OF § 1065.307.—MEASUREMENT SYSTEMS THAT REQUIRE LINEARITY VERIFICATIONS—Continued

Measurement system	Quantity	Minimum verification frequency	Linearity criteria			
			$\lvert x_{min}(a^1-1)+a_0 \rvert$	a^1	SEE	r^2
Intake-air flow rate	$\dot{n}$	Within 370 days before testing	≤1 % · $\dot{n}_{max}$	0.98–1.02	≤2 % · $\dot{n}_{max}$	≥0.990
Dilution air flow rate	$\dot{n}$	Within 370 days before testing	≤1 % · $\dot{n}_{max}$	0.98–1.02	≤2 % · $\dot{n}_{max}$	≥0.990
Diluted exhaust flow rate	$\dot{n}$	Within 370 days before testing	≤1 % · $\dot{n}_{max}$	0.98–1.02	≤2 % · $\dot{n}_{max}$	≥0.990
Raw exhaust flow rate	$\dot{n}$	Within 185 days before testing	≤1 % · $\dot{n}_{max}$	0.98–1.02	≤2 % · $\dot{n}_{max}$	≥0.990
Batch sampler flow rates	$\dot{n}$	Within 370 days before testing	≤1 % · $\dot{n}_{max}$	0.98–1.02	≤2 % · $\dot{n}_{max}$	≥0.990
Gas dividers	x/x_{span}	Within 370 days before testing	≤0.5 % · x_{max}	0.98–1.02	≤2 % · x_{max}	≥0.990
Gas analyzers for laboratory testing.	x	Within 35 days before testing ...	≤0.5 % · x_{max}	0.99–1.01	≤1 % · x_{max}	≥0.998
Gas analyzers for field testing ..	x	Within 35 days before testing ...	≤1 % · x_{max}	0.99–1.01	≤1 % · x_{max}	≥0.998
PM balance	m	Within 370 days before testing	≤1 % · m_{max}	0.99–1.01	≤1 % · m_{max}	≥0.998
Stand-alone pressures	p	Within 370 days before testing	≤1 % · p_{max}	0.99–1.01	≤1 % · p_{max}	≥0.998
Analog-to-digital conversion of stand-alone temperature signals.	T	Within 370 days before testing	≤1 % · T_{max}	0.99–1.01	≤1 % · T_{max}	≥0.998

■ 75. Section 1065.308 is revised to read as follows:

§ 1065.308 Continuous gas analyzer system-response and updating-recording verification—general.

This section describes a general verification procedure for continuous gas analyzer system response and update recording. See § 1065.309 for verification procedures that apply for systems or components involving H_2O correction.

(a) *Scope and frequency.* Perform this verification after installing or replacing a gas analyzer that you use for continuous sampling. Also perform this verification if you reconfigure your system in a way 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 you sample and record gas-analyzer concentrations. You do not have to perform this verification for gas analyzer systems used only for discrete-mode testing.

(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 analyzer 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 continuous gas analyzer systems meet a minimum response time.

(c) *System requirements.* To demonstrate acceptable updating and recording with respect to the system's overall response, use good engineering judgment to select one of the following criteria that your system must meet:

(1) The product of the mean rise time and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time and the frequency at which the system records an updated concentration must be at least 5. This criterion makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing. In any case the mean rise time and the mean fall time must be no more than 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. In any case the mean rise time and the mean fall time must be no more than 10 seconds.

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

(4) You may meet the overall PEMS verification in § 1065.920 instead of the verification in this section for field testing with PEMS.

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

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

(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 analyzers. You may use a gas mixing or blending device to equally blend an NO-CO-CO_2-C_3H_8-CH_4, balance N_2 span gas with a span gas of NO_2, balance purified synthetic air. Standard binary span

gases may also be used, where applicable, in place of blended NO-CO-CO_2-C_3H_8-CH_4, balance N_2 span gas, but separate response tests must then be run for each analyzer. In designing your experimental setup, avoid pressure pulsations due to stopping the flow through the gas-blending device. Note that you may omit any of these gas constituents if they are not relevant to your analyzers for this verification.

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

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

(iii) Start recording data at the frequency used during emission testing. Each recorded value must be a unique updated concentration measured by the analyzer; you may not use interpolation to increase the number of recorded values.

(iv) Switch the flow to allow the blended span gases to flow to the analyzer.

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

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

(vii) Stop recording.

(e) *Performance evaluation.* (1) If you chose 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, $t_{10–90}$, for each of the analyzers. Multiply these times (in seconds) by their respective recording frequencies in Hertz (1/second). The value for each result must be at least 5. If the value is less than 5, increase the 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 digital filters to increase rise and fall times. The mean rise time and mean fall time must be no 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 any case, the mean rise time and mean fall time must be no 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 continuous analyzer system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

■ 76. Section 1065.309 is revised to read as follows:

§ 1065.309 Continuous gas analyzer system-response and updating-recording verification—with humidified-response verification.

This section describes a verification procedure for continuous gas analyzer system response and update recording for systems or components involving H_2O correction. See § 1065.308 for verification procedures that apply for systems not involving humidification.

(a) *Scope and frequency.* Perform this verification to determine a continuous gas analyzer's response, where one analyzer's response is compensated by another's to quantify a gaseous emission. For this check we consider water vapor a gaseous constituent. You do not have to perform this verification for batch gas analyzer systems or for continuous analyzer systems that are only used for discrete-mode testing. Perform this verification after initial installation (i.e. test cell commissioning). The verification in this section is required for initial installation of systems or components involving H_2O correction. For later verifications, you may use the procedures specified in § 1065.308, as long as your system includes no replacement components involving H_2O correction that have never been verified using the procedures in this section.

(b) *Measurement principles.* This procedure verifies the time-alignment and uniform response of continuously combined gas measurements. For this procedure, ensure that all compensation algorithms and humidity corrections are turned on.

(c) *System requirements.* Demonstrate that continuously combined concentration measurements have a uniform rise and fall during a system response to a rapid change in multiple gas concentrations. You must meet one of the following criteria:

(1) The product of the mean rise time and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time and the frequency at which the system records an updated concentration must be at least 5. This criterion makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing. In no case may the mean rise time or the mean fall time be more than 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. In no case may the mean rise time or the mean fall time be more than 10 seconds.

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

(4) You may meet the overall PEMS verification in § 1065.920 instead of the verification in this section for field testing with PEMS.

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

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

(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 analyzers. You may use a gas blending or mixing device to equally blend a span gas of NO-CO-CO_2-C_3H_8-CH_4, balance N_2, with a span gas of NO_2, balance purified synthetic air. Standard binary span gases may be used, where applicable, in place of blended NO-CO-CO_2-C_3H_8-CH_4, balance N_2 span gas, but separate response tests must then be run for each analyzer. In designing your experimental setup, avoid pressure pulsations due to stopping the flow through the gas blending device. Span gases must be humidified before entering the analyzer; however, you may not humidify NO_2 span gas by passing it through a sealed humidification vessel that contains water. We recommend humidifying your NO-CO-CO_2-C_3H_8-CH_4, balance N_2 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_2 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 by flowing the gas mixture through a sealed vessel that humidifies the gas to the highest sample dewpoint that you estimate during emission sampling by bubbling it through distilled water. If your system uses a sample dryer during testing that has passed the sample dryer verification check in § 1065.342, you may introduce the humidified gas mixture downstream of the sample dryer by bubbling it through distilled water in a sealed vessel at (25 ± 10) °C, or a temperature greater than the dewpoint determined in § 1065.145(d)(2). In all cases, maintain the humidified gas temperature downstream of the vessel at least 5 °C above its local dewpoint in the line. We recommend that you heat all gas transfer lines and valves located downstream of the vessel as needed to avoid condensation. Note that you may omit any of these gas constituents if they are not relevant to your analyzers for this verification. If any of your gas constituents are not susceptible to water compensation, you may perform the response check for these analyzers without humidification.

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

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

(iii) Start recording data at the frequency used during emission testing. Each recorded value must be a unique updated concentration measured by the analyzer; you may not use interpolation to increase the number of recorded values.

(iv) Switch the flow to allow the blended span gases to flow to the analyzers.

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

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

(vii) Stop recording.

(e) *Performance evaluations.* (1) If you chose 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_{S90-10}, for each of the analyzers. Multiply these times (in seconds) by their respective recording frequencies in Hz (1/second). The value for each result must be at least 5. If the value is less than 5, increase the 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 digital filters 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 continuous analyzer system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

■ 77. Section 1065.310 is amended by revising paragraph (d) to read as follows:

§ 1065.310   Torque calibration.

*   *   *   *   *

(d) *Strain gage or proving ring calibration.* This technique applies force either by hanging weights on a lever arm (these weights and their lever arm length are not used as part of the reference torque determination) or by operating the dynamometer at different torques. Apply at least six force combinations for each applicable torque-measuring range, spacing the force quantities about equally over the range. Oscillate or rotate the dynamometer during calibration to reduce frictional static hysteresis. In this case, the reference torque is determined by multiplying the force output from the reference meter (such as a strain gage or proving ring) by its effective lever-arm length, which you measure from the point where the force measurement is made to the dynamometer's rotational axis. Make sure you measure this length perpendicular to the reference meter's measurement axis and perpendicular to the dynamometer's rotational axis.

■ 78. Section 1065.315 is amended by revising paragraph (a)(2) to read as follows:

§ 1065.315   Pressure, temperature, and dewpoint calibration.

(a) * * *

(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.

*   *   *   *   *

■ 79. Section 1065.340 is amended by revising paragraphs (f)(5), (f)(6)(ii), (f)(7), (f)(9), (f)(10), (g)(6)(i), and Figure 1 to read as follows:

§ 1065.340   Diluted exhaust flow (CVS) calibration.

*   *   *   *   *

(f) * * *

(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. Note that some blowers have limitations on nonloaded conditions.

(6) * * *

(ii) The mean dewpoint of the calibration air, $\bar{T}_{dew}$. See § 1065.640 for permissible assumptions during emission measurements.

*   *   *   *   *

(7) Incrementally close the restrictor valve or decrease the downstream pressure to decrease the differential pressure across the CFV, $\Delta \bar{P}_{CFV}$.

*   *   *   *   *

(9) Determine C_d and the lowest allowable pressure ratio, r, according to § 1065.640.

(10) Use Cd to determine CFV flow during an emission test. Do not use the CFV below the lowest allowed r, as determined in § 1065.640.
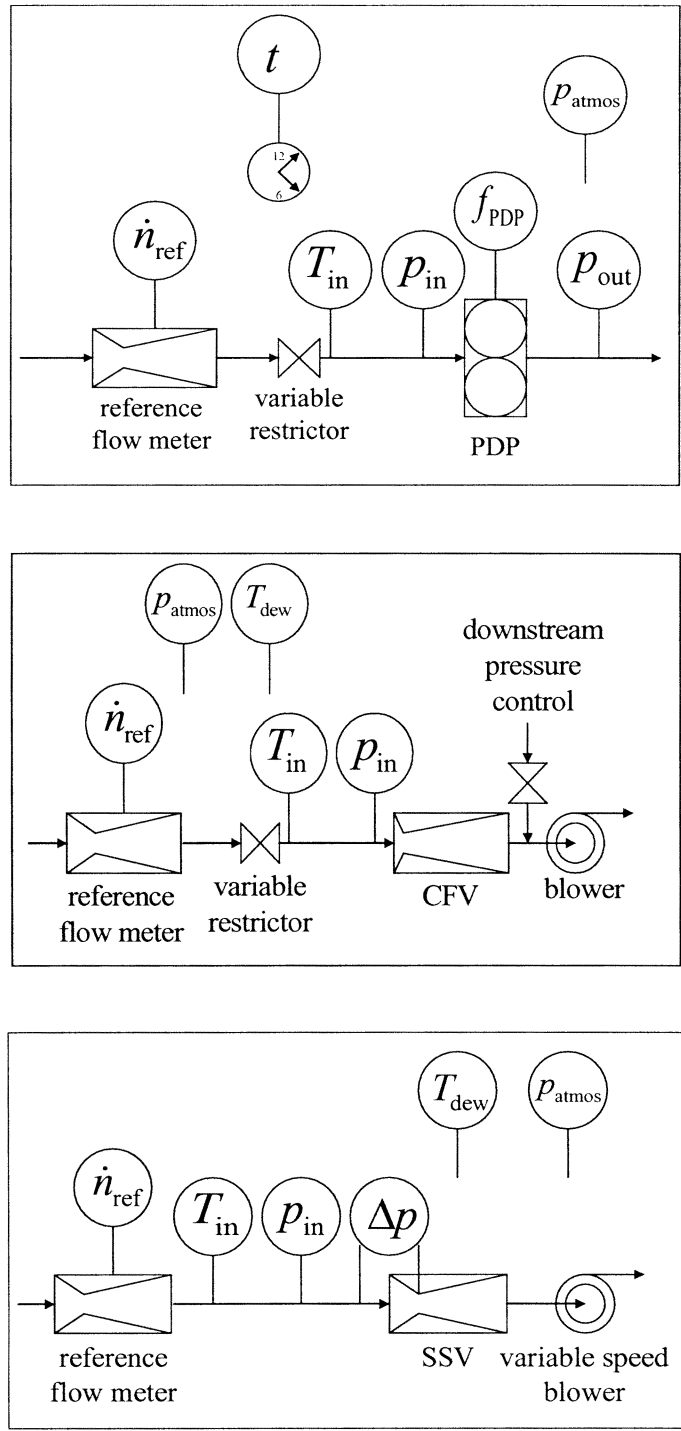
*   *   *   *   *

(g) * * *

(6) * * *

(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 $\bar{n}_{ref}$.

*   *   *   *   *

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Figure 1 of 1065.340 CVS calibration configurations.

■ 80. Section 1065.341 is amended by revising paragraphs (d) introductory text, (d)(7), and (g) introductory text to read as follows:

§ 1065.341 CVS and batch sampler verification (propane check).

*   *   *   *   *

(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 § 1065.520(g) to verify HC contamination. Otherwise, zero, span,

and verify contamination of the HC sampling system, as follows:

*   *   *   *   *

(7) When the overflow HC concentration does not exceed 2 μmol/mol, record this value as $x_{THCinit}$ and use it to correct for HC contamination as described in § 1065.660.

*   *   *   *   *

(g) You may repeat the propane check to verify a batch sampler, such as a PM secondary dilution system.

* * * * *

■ 81. A new § 1065.342 is added to read as follows:

§ 1065.342 Sample dryer verification.

(a) *Scope and frequency.* If you use a sample dryer as allowed in § 1065.145(d)(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 § 1065.145(d)(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, or use good engineering judgment to develop a different protocol:

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

(2) Humidify N^2 or purified air by bubbling it through distilled water in a sealed vessel that humidifies the gas to the highest sample dewpoint that you estimate during emission sampling.

(3) Introduce the humidified gas upstream of the sample dryer.

(4) Downstream of the vessel, maintain the humidified gas temperature at least 5 °C above its dewpoint.

(5) Measure the humidified gas dewpoint, T_{dew}, and pressure, p_{total}, as close as possible to the inlet of the sample dryer to verify the dewpoint is the highest that you estimated during emission sampling.

(6) Measure the humidified gas dewpoint, T_{dew}, and pressure, p_{total}, as close as possible to the outlet of the sample dryer.

(7) The sample dryer meets the verification if the results of paragraph (d)(6) of this section are less than the dew point corresponding to the sample dryer specifications as determined in § 1065.145(d)(2) plus 2 °C or if the mole fraction from (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 § 1065.342(d), but you must make sure that the dryer outlet humidity is below the minimum values used for quench, interference, and compensation checks.

■ 82. Section 1065.345 is revised to read as follows:

§ 1065.345 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 upon initial sampling system installation, after maintenance such as pre-filter changes, and within eight hours before each duty-cycle sequence. 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 § 1065.660. 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.

(3) Route overflow span gas to one of the following locations in the sampling system:

(i) The end of the sample probe.

(ii) Disconnect the transfer line at the probe connection, and overflow the span gas at the open end of the transfer line.

(iii) A three-way valve installed in-line between a probe and its transfer line, such as a system overflow zero and span port.

(4) Verify that the measured overflow span gas concentration is within ± 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 ± 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 in-line between a probe and transfer line.

(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 1065.644, verify that the vacuum-decay leak flow rate is less than 0.5% of the system's normal in-use flow rate.

■ 83. Section 1065.350 is amended by revising paragraphs (c) and (d) to read as follows:

§ 1065.350 H_2O interference verification for CO_2 NDIR analyzers.

*   *   *   *   *

(c) *System requirements.* A CO_2 NDIR analyzer must have an H_2O interference that is within (0.0 ±0.4) mmol/mol, though we strongly recommend a lower interference that is within (0.0 ±0.2) mmol/mol.

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

(1) Start, operate, zero, and span the CO_2 NDIR analyzer as you would before an emission test.

(2) Create a humidified test gas by bubbling zero air that meets the specifications in § 1065.750 through distilled water in a sealed vessel. If the sample is not passed through a dryer, control the vessel temperature to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, control the vessel temperature to generate an H_2O level at least as high as the level determined in § 1065.145(d)(2).

(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) Measure the humidified test gas dewpoint, T_{dew}, and pressure, p_{total}, as close as possible to the inlet of the analyzer.

(5) Downstream of the vessel, maintain the humidified test gas temperature at least 5 °C above its 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 ±0.4) mmol/mol.

*   *   *   *   *

■ 84. Section 1065.355 is amended by revising paragraph (d) to read as follows:

§ 1065.355 H_2O and CO_2 interference verification for CO NDIR analyzers.

*   *   *   *   *

(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.

(2) Create a humidified CO_2 test gas by bubbling a CO_2 span gas through distilled water in a sealed vessel. If the sample is not passed through a dryer, control the vessel temperature to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, control the vessel temperature to generate an H_2O level at least as high as the level determined in § 1065.145(d)(2). Use a CO_2 span gas concentration at least as high as the maximum expected during testing.

(3) Introduce the humidified CO_2 test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(4) Measure the humidified CO_2 test gas dewpoint, T_{dew}, and pressure, p_{total}, as close as possible to the inlet of the analyzer.

(5) Downstream of the vessel, maintain the humidified gas temperature at least 5 °C above its 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_2 and H_2O separately. If the CO_2 and H_2O 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 the separate interference procedures concentrations of H_2O (down to 0.025 mol/mol H_2O content) that are lower than the maximum levels expected during testing, but you must scale up the observed H_2O interference by multiplying the observed interference by the ratio of the maximum expected H_2O 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.

*   *   *   *   *

■ 85. Section 1065.360 is revised to read as follows:

§ 1065.360   FID optimization and verification.

(a) *Scope and frequency.* For all FID analyzers, calibrate the FID upon initial installation. Repeat the calibration as needed using good engineering judgment. 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_4) response factor after initial analyzer installation and after major maintenance as described in paragraph (d) of this section.

(3) Verify the methane (CH_4) response within 185 days before testing as described in paragraph (e) of this section.

(b) *Calibration.* Use good engineering judgment to develop a calibration procedure, such as one based on the FID-analyzer manufacturer's instructions and recommended frequency for calibrating the FID. Alternately, you may remove system components for off-site calibration. For a FID that measures THC, calibrate using C_3H_8 calibration gases that meet the specifications of § 1065.750. For a FID that measures CH_4, calibrate using CH_4 calibration gases that meet the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O_2 expected during testing. If you use a FID to measure methane (CH_4) downstream of a nonmethane cutter, you may calibrate that FID using CH_4 calibration gases with the cutter. Regardless of the calibration gas composition, calibrate on a carbon number basis of one (C_1). For example, if you use a C_3H_8 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_4 span gas with a concentration of 200 µmol/mol, span the FID to respond with a value of 200 µmol/mol.

(c) *THC FID response optimization.* This procedure is only for FID analyzers that measure THC. Use good engineering judgment 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 good engineering judgment 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 (incorporated by reference in § 1065.1010). Determine the optimum flow rates and/or pressures for FID fuel, burner air, and sample and record them for future reference.

(d) *THC FID CH₄ response factor determination.* This procedure is only for FID analyzers that measure THC. Since FID analyzers generally have a different response to CH4 versus C_3H_8, determine each THC FID analyzer's CH_4 response factor, $RF_{CH4[THC–FID]}$, after FID optimization. Use the most recent $RF_{CH4[THC–FID]}$ measured according to this section in the calculations for HC determination described in § 1065.660 to compensate for CH_4 response. Determine $RF_{CH4[THC–FID]}$ as follows, noting that you do not determine $RF_{CH4[THC–FID]}$ for FIDs that are calibrated and spanned using CH_4 with a nonmethane cutter:

(1) Select a C_3H_8 span gas concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of § 1065.750. Record the C_3H_8 concentration of the gas.

(2) Select a CH_4 span gas concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of § 1065.750. Record the CH_4 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 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_3H_8 span gas that you selected under paragraph (d)(1) of this section.

(7) Introduce at the sample port of the FID analyzer, the CH_4 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_4 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_4 calibration gas. The result is the FID analyzer's response factor for CH_4, $RF_{CH4[THC–FID]}$.

(e) *THC FID methane (CH₄) response verification.* This procedure is only for FID analyzers that measure THC. If the value of $RF_{CH4[THC–FID]}$ 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 $RF_{CH4[THC–FID]}$ 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 ±4.8% is less than ±5.0%. Verify $RF_{CH4[THC–FID]}$ as follows:

(1) First verify that the flow rates and/or pressures of FID fuel, burner air, and sample are each within ±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 $RF_{CH4[THC–FID]}$ as described in paragraph (d) of this section and verify that it is within the tolerance specified in this paragraph (e).

(2) If $RF_{CH4[THC–FID]}$ is 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 $RF_{CH4[THC–FID]}$ as described in paragraph (d) of this section. Use this new value of $RF_{CH4[THC–FID]}$ in the calculations for HC determination, as described in § 1065.660.

■ 86. Section 1065.362 is amended by revising paragraph (d) to read as follows:

§ 1065.362 Non-stoichiometric raw exhaust FID O₂ interference verification.

* * * * *

(d) *Procedure.* Determine FID O_2 interference as follows, noting that you may use one or more gas dividers to create the reference gas concentrations that are required to perform this verification:

(1) Select three span reference gases that contain a C_3H_8 concentration that you use to span your analyzers before emission testing. Use only span gases that meet the specifications of § 1065.750. You may use CH_4 span reference gases for FIDs calibrated on CH_4 with a nonmethane cutter. Select

the three balance gas concentrations such that the concentrations of O_2 and N_2 represent the minimum, maximum, and average O_2 concentrations expected during testing. The requirement for using the average O_2 concentration can be removed if you choose to calibrate the FID with span gas balanced with the average expected oxygen concentration.

(2) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(3) Start and operate the FID analyzer as you would before an emission test. Regardless of the FID burner's air source during testing, use zero air as the FID burner's air source for this verification.

(4) Zero the FID analyzer using the zero gas used during emission testing.

(5) Span the FID analyzer using a span gas that you use during emission testing.

(6) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of sampled data is within ±0.5% of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(7) Check the analyzer response using the span gas that has the minimum concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $x_{O2minHC}$.

(8) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of stabilized sample data is within ±0.5% of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(9) Check the analyzer response using the span gas that has the average concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $x_{O2avgHC}$.

(10) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of stabilized sample data is within ±0.5% of the span reference value used in paragraph (d)(5) of this section, proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(11) Check the analyzer response using the span gas that has the maximum concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $x_{O2maxHC}$.

(12) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean

zero response of 30 seconds of stabilized sample data is within ±0.5% of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(13) Calculate the percent difference between $x_{O2maxHC}$ and its reference gas concentration. Calculate the percent difference between $x_{O2avgHC}$ and its reference gas concentration. Calculate the percent difference between $x_{O2minHC}$ and its reference gas concentration. Determine the maximum percent difference of the three. This is the O_2 interference.

(14) If the O_2 interference is within ±2%, the FID passes the O_2 interference verification; otherwise perform one or more of the following to address the deficiency:

(i) Repeat the verification to determine if a mistake was made during the procedure.

(ii) Select zero and span gases for emission testing that contain higher or lower O_2 concentrations and repeat the verification.

(iii) Adjust FID burner air, fuel, and sample flow rates. Note that if you adjust these flow rates on a THC FID to meet the O_2 interference verification, you have reset RF_{CH4} for the next RF_{CH4} verification according to § 1065.360. Repeat the O_2 interference verification after adjustment and determine RF_{CH4}.

(iv) Repair or replace the FID and repeat the O_2 interference verification.

(v) Demonstrate that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable emission standards.

■ 87. Section 1065.365 is revised to read as follows:

§ 1065.365 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_{CH4}, and ethane, PF_{C2H6}. 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, good engineering judgment 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_{CH4}, of 1.000, and the penetration fraction for all other nonmethane hydrocarbons would be 0.000, as represented by PF_{C2H6}. The emission calculations in § 1065.660 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 $PF_{CH4} > 0.85$ and a $PF_{C2H6} < 0.02$, 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 § 1065.660 and § 1065.665 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, $RFPF_{CH4[NMC–FID]}$, equal to 1.0 for all emission calculations, and determine its combined ethane (C_2H_6) response factor and penetration fraction, $RFPF_{C2H6[NMC–FID]}$ as follows:

(1) Select a CH_4 gas mixture and a C_2H_6 analytical gas mixture and ensure that both mixtures meet the specifications of § 1065.750. Select a CH_4 concentration that you would use for spanning the FID during emission testing and select a C_2H_6 concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to 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 § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID with the cutter and use CH_4 span gas to span the FID with the cutter. Note that you must span the FID on a C1 basis. For example, if your span gas has a CH_4 reference value of 100 μmol/mol, the correct FID response to that span gas is 100 μmol/mol because there is one carbon atom per CH_4 molecule.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the nonmethane cutter.

(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 by the reference value of C_2H_6, converted to a C_1 basis. The result is the C_2H_6 combined response factor and penetration fraction, $RFPF_{C2H6[NMC–FID]}$. Use this combined response factor and penetration fraction and the product of the CH_4 response factor and CH_4 penetration fraction, $RFPF_{CH4[NMC–FID]}$, set to 1.0 in emission calculations according to § 1065.660(b)(2)(i) or § 1065.665, as applicable.

(e) *Procedure for a FID calibrated with propane, bypassing the NMC.* If you use a FID with an NMC that is calibrated with propane, C_3H_8, by bypassing the NMC, determine its penetration fractions, $PF_{C2H6[NMC–FID]}$ and $PF_{CH4[NMC–FID]}$, as follows:

(1) Select CH_4 and C_2H_6 analytical gas mixtures that meet the specifications of § 1065.750 with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyzer 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 § 1065.360.

(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_3H_8 span gas to span the FID. Note that you must span the FID on a C_1 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_3H_8 molecule.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the nonmethane cutter at the same point the zero gas was introduced.

(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_2H_6 analytical gas mixture to the bypass, and repeat the steps in paragraphs (e)(7) through (8) of this section.

(10) Divide the mean C_2H_6 concentration measured through the nonmethane cutter by the mean concentration measured after bypassing the nonmethane cutter. The result is the C_2H_6 penetration fraction, $PF_{C2H6[NMC-FID]}$. Use this penetration fraction according to § 1065.660(b)(2)(ii) or § 1065.665, as applicable.

(11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $PF_{CH4[NMC-FID]}$. Use this penetration fraction according to § 1065.660(b)(2)(ii) or § 1065.665, 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_4, by bypassing the NMC, determine its combined ethane (C_2H_6) response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$, as well as its CH_4 penetration fraction, $PF_{CH4[NMC-FID]}$, as follows:

(1) Select CH_4 and C_2H_6 analytical gas mixtures that meet the specifications of § 1065.750, with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyzer 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 § 1065.360.

(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 with CH_4 span gas by bypassing the cutter. Note that you must span the FID on a C_1 basis. For example, if your span gas has a methane reference value of 100 µmol/mol, the correct FID response to that span gas is 100 µmol/mol because there is one carbon atom per CH_4 molecule.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the nonmethane cutter at the same point the zero gas was introduced.

(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_2H_6 analytical gas mixture to the bypass, and repeat the steps in paragraphs (e)(7) and (8) of this section.

(10) Divide the mean C_2H_6 concentration measured through the nonmethane cutter by the mean concentration measured after bypassing the nonmethane cutter. The result is the C_2H_6 combined response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$. Use this combined response factor and penetration fraction according to § 1065.660(b)(2)(iii) or § 1065.665, as applicable.

(11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $PF_{CH4[NMC-FID]}$. Use this penetration fraction according to § 1065.660(b)(2)(iii) or § 1065.665, as applicable.

■ 88. Section 1065.370 is amended by revising paragraphs (d), (e), and (g)(1) to read as follows:

§ 1065.370 CLD CO_2 and H_2O quench verification.

* * * * *

(d) *CO_2 quench verification procedure.* Use the following method to determine CO_2 quench, or use good engineering judgment to develop a different protocol:

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

(2) Connect a pressure-regulated CO_2 span gas to the port of a gas divider that

meets the specifications in § 1065.248 at the appropriate time. Use a CO_2 span gas that meets the specifications of § 1065.750 and attempt to use a concentration that is approximately twice the maximum CO_2 concentration expected to enter the CLD sample port during testing, if available.

(3) Connect a pressure-regulated purified N_2 gas to the port of a gas divider that meets the specifications in § 1065.248 at the appropriate time. Use a purified N_2 gas that meets the specifications of § 1065.750.

(4) Connect a pressure-regulated NO span gas to the port of the gas divider that meets the specifications in § 1065.248. Use an NO span gas that meets the specifications of § 1065.750. Attempt to use an NO concentration that is approximately twice the maximum NO concentration expected during testing, if available.

(5) Configure the gas divider such that nearly equal amounts of the span gas and balance gas are blended with each other. Apply viscosity corrections as necessary to appropriately ensure correct gas division.

(6) While flowing NO and CO_2 through the gas divider, stabilize the CO_2 concentration downstream of the gas divider and measure the CO_2 concentration with an NDIR analyzer that has been prepared for emission testing. You may alternatively determine the CO_2 concentration from the gas divider cut-point, applying viscosity correction as necessary to ensure accurate gas division. Record this concentration, $x_{CO2meas}$, and use it in the quench verification calculations in § 1065.675.

(7) Measure the NO concentration downstream of the gas divider. If the CLD has an operating mode in which it detects NO-only, as opposed to total NO_X, operate the CLD in the NO-only operating mode. Record this concentration, $x_{NO,CO2}$, and use it in the quench verification calculations in § 1065.675.

(8) Switch the flow of CO_2 off and start the flow of 100% purified N_2 to the inlet port of the gas divider. Monitor the CO_2 at the gas divider's outlet until its concentration stabilizes at zero.

(9) Measure NO concentration at the gas divider's outlet. Record this value, $x_{NO,N2}$, and use it in the quench verification calculations in § 1065.675.

(10) Use the values recorded according to this paragraph (d) of this section and paragraph (e) of this section to calculate quench as described in § 1065.675.

(e) *H_2O quench verification procedure.* Use the following method to determine H_2O quench, or use good

engineering judgment to develop a different protocol:

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

(2) If the CLD has an operating mode in which it detects NO-only, as opposed to total NO_X, operate the CLD in the NO-only operating mode.

(3) Measure an NO calibration span gas that meets the specifications of § 1065.750 and is near the maximum concentration expected during testing. Record this concentration, x_{NOdry}.

(4) Humidify the NO span gas by bubbling it through distilled water in a sealed vessel. If the sample is not passed through a dryer, control the vessel temperature to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, control the vessel temperature to generate an H_2O level at least as high as the level determined in § 1065.145(d)(2). We recommend that you humidify the gas to the highest sample dewpoint that you estimate at the CLD inlet during emission sampling. Regardless of the humidity during this test, the quench verification calculations in § 1065.675 scale the recorded quench to the highest dewpoint expected for flow entering the CLD sample port during emission sampling.

(5) Introduce the humidified NO test gas into the sample system. You may introduce it downstream of any sample dryer, if one is used during testing.

(6) Measure the humidified gas dewpoint, T_{dew}, and pressure, p_{total}, as close as possible to the analyzer inlet.

(7) Downstream of the vessel, maintain the humidified NO test gas temperature at least 5 °C above its dewpoint.

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

(9) While the analyzer measures the sample's concentration, record the analyzer's output for 30 seconds. Calculate the arithmetic mean of these data. This mean is x_{NOmeas}.

(10) Set x_{NOwet} equal to x_{NOmeas} from paragraph (e)(9) of this section.

(11) Use x_{NOwet} to calculate the quench according to § 1065.675.

*   *   *   *   *

(g) * * *

(1) You may omit this verification if you can show by engineering analysis that for your NO_X sampling system and your emission calculations procedures, the combined CO_2 and H_2O interference for your NO_X CLD analyzer always affects your brake-specific NO_X

emission results within no more than ±1.0% of the applicable NO_X standard.

*   *   *   *   *

■ 89. Section 1065.372 is amended by revising paragraphs (d)(7) and (e)(1) to read as follows:

§ 1065.372 NDUV analyzer HC and H₂O interference verification.

*   *   *   *   *

(d) * * *

(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 ±2% of the NO_X concentration expected at the standard.

(e) * * *

(1) You may omit this verification if you can show by engineering analysis that for your NO_X sampling system and your emission calculations procedures, the combined HC and H_2O interference for your NO_X NDUV analyzer always affects your brake-specific NO_X emission results by less than 0.5% of the applicable NO_X standard.

*   *   *   *   *

■ 90. Section 1065.376 is revised to read as follows:

§ 1065.376 Chiller NO₂ penetration.

(a) *Scope and frequency.* If you use a chiller to dry a sample upstream of a NO_X measurement instrument, but you don't use an NO_2-to-NO converter upstream of the chiller, you must perform this verification for chiller NO_2 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_X measurement. However, liquid water remaining in an improperly designed chiller can remove NO_2 from the sample. If a chiller is used without an NO_2-to-NO converter upstream, it could remove NO_2 from the sample prior NO_X measurement.

(c) *System requirements.* A chiller must allow for measuring at least 95% of the total NO_2 at the maximum expected concentration of NO_2.

(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_X gas analyzer(s) as you would before emission testing.

(ii) Select an NO_2 calibration gas, balance gas of dry air, that has an NO_2 concentration within ±5% of the maximum NO_2 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_X response, accounting only for transport delays and instrument response.

(iv) Calculate the mean of 30 seconds of recorded total NO_X data and record this value as $_{NOXref}$.

(v) Stop flowing the NO_2 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_2 calibration gas used to establish x_{NOxref}. Allow for stabilization of the total NO_X response, accounting only for transport delays and instrument response. Calculate the mean of 30 seconds of recorded total NO_X data and record this value as $x_{NOxmeas}$.

(viii) Correct $x_{NOxmeas}$ to x_{NOxdry} based upon the residual water vapor that passed through the chiller at the chiller's outlet temperature and pressure.

(3) *Performance evaluation.* If x_{NOxdry} is less than 95% of x_{NOxref}, 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_X sampling system and your emission calculations procedures, the chiller always affects your brake-specific NO_X emission results by less than 0.5% of the applicable NO_X 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 engines comply with all applicable emission standards.

■ 91. Section 1065.378 is amended by revising paragraphs (d) and (e)(1) to read as follows:

§ 1065.378 NO₂-to-NO converter conversion verification.

*   *   *   *   *

(d) *Procedure.* Use the following procedure to verify the performance of a NO_2-to-NO converter:

(1) *Instrument setup.* Follow the analyzer and NO_2-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_2-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_X concentration expected during testing. The NO_2 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_{NOref}.

(iii) Turn on the ozonator O_2 supply and adjust the O_2 flow rate so the NO indicated by the analyzer is about 10 percent less than x_{NOref}. Record concentration of NO by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as $x_{NO+O2mix}$.

(iv) Switch the ozonator on and adjust the ozone generation rate so the NO measured by the analyzer is 20 percent of x_{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_{NOmeas}.

(v) Switch the NO_X analyzer to NO_X mode and measure total NO_X. Record the concentration of NO_X by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as $x_{NOxmeas}$.

(vi) Switch off the ozonator but maintain gas flow through the system. The NO_X analyzer will indicate the NO_X in the $NO + O_2$ mixture. Record the concentration of NO_X by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as $x_{NOx+O2mix}$.

(vii) Turn off the ozonator O_2 supply. The NO_X analyzer will indicate the NO_X in the original NO-in-N_2 mixture. Record the concentration of NO_X by calculating the mean of 30 seconds of sampled data from the analyzer and record this value as x_{NOxref}. This value should be no more than 5 percent above the x_{NOref} value.

(4) *Performance evaluation.* Calculate the efficiency of the NO_X converter efficiency by substituting the concentrations obtained into the following equation:

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

(5) If the result is less than 95%, repair or replace the NO_2-to-NO converter.

(e) * * *

(1) You may omit this verification if you can show by engineering analysis that for your NO_X sampling system and your emission calculations procedures, the converter always affects your brake-specific NO_X emission results by less than 0.5% of the applicable NO_X standard.

* * * * *

■ 92. Section 1065.390 is revised to read as follows:

§ 1065.390 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 § 1065.790 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 § 1065.790 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 ±10 μg or ±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 good engineering judgment.

(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 § 1065.190(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 good engineering judgment, 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 § 1065.590(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 § 1065.690. 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 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.

Subpart E—[Amended]

■ 93. Section 1065.405 is revised to read as follows:

§ 1065.405   Test engine preparation and maintenance.

This part 1065 describes how to test engines for a variety of purposes, including certification testing, production-line testing, and in-use testing. Depending on which type of testing is being conducted, different preparation and maintenance requirements apply for the test engine.

(a) If you are testing an emission-data engine for certification, make sure it is built to represent production engines. This includes governors that you normally install on production engines. Production engines should also be tested with their installed governors. If you do not install governors on production engines, simulate a governor that is representative of a governor that others will install on your production engines.

(b) Testing generally occurs only after the test engine has undergone a stabilization step (or in-use operation). If the engine has not already been stabilized, run the test engine, with all emission control systems operating, long enough to stabilize emission levels. Note that you must generally use the same stabilization procedures for emission-data engines for which you apply the same deterioration factors so low-hour emission-data engines are consistent with the low-hour engine used to develop the deterioration factor.

(1) Unless otherwise specified in the standard-setting part, you may consider emission levels stable without measurement after 50 h of operation. If the engine needs less operation to stabilize emission levels, record your reasons and the methods for doing this, and give us these records if we ask for them. If the engine will be tested for certification as a low-hour engine, see the standard-setting part for limits on testing engines to establish low-hour emission levels.

(2) You may stabilize emissions from a catalytic exhaust aftertreatment device by operating it on a different engine, consistent with good engineering judgment. Note that good engineering judgment requires that you consider both the purpose of the test and how your stabilization method will affect the development and application of deterioration factors. For example, this method of stabilization is generally not appropriate for production engines. We may also allow you to stabilize emissions from a catalytic exhaust aftertreatment device by operating it on an engine-exhaust simulator.

(c) Record any maintenance, modifications, parts changes, diagnostic or emissions testing and document the need for each event. You must provide this information if we request it.

(d) For accumulating operating hours on your test engines, select engine operation that represents normal in-use operation for the engine family.

(e) If your engine will be used in a vehicle equipped with a canister for storing evaporative hydrocarbons for eventual combustion in the engine and the test sequence involves a cold-start or hot-start duty cycle, attach a canister to the engine before running an emission test. You may omit using an evaporative canister for any hot-stabilized duty cycles. You may request to omit using an evaporative canister during testing if you can show that it would not affect your ability to show compliance with the applicable emission standards. You may operate the engine without an installed canister for service accumulation. Prior to an emission test, use the following steps to attach a canister to your engine:

(1) Use a canister and plumbing arrangement that represents the in-use configuration of the largest capacity canister in all expected applications.

(2) Use a canister that is fully loaded with fuel vapors.

(3) Connect the canister's purge port to the engine.

(4) Plug the canister port that is normally connected to the fuel tank.

■ 94. Section 1065.410 is amended by revising paragraphs (c) and (d) to read as follows:

§ 1065.410   Maintenance limits for stabilized test engines.

* * * * *

(c) Keep a record of the inspection and update your application to document any changes as a result of the inspection. You may use equipment, instruments, or engineering grade tools to identify bad engine components. Any equipment, instruments, or tools used for scheduled maintenance on emission data engines must be representative of what is planned to be available to dealerships and other service outlets.

(d) If we determine that a part failure, system malfunction, or associated repairs have made the engine's emission controls unrepresentative of production engines, you may no longer use it as an emission-data engine. Also, if your test engine has a major mechanical failure that requires you to take it apart, you may no longer use it as an emission-data engine.

* * * * *

■ 95. Section 1065.415 is amended by revising the introductory text and removing paragraph (a)(3) to read as follows:

§ 1065.415 Durability demonstration.

If the standard-setting part requires durability testing, you must accumulate service in a way that represents how you expect the engine to operate in use. You may accumulate service hours using an accelerated schedule, such as through continuous operation or by using duty cycles that are more aggressive than in-use operation, subject to any pre-approval requirements established in the applicable standard-setting part.

* * * * *

■ 96. The heading to subpart F of part 1065 is revised to read as follows:

Subpart F—Performing an Emission Test Over Specified Duty Cycles

97. Section 1065.501 is amended by revising paragraphs (a) introductory text, (a)(1), and (b) to read as follows:

§ 1065.501 Overview.

(a) Use the procedures detailed in this subpart to measure engine emissions over a specified duty cycle. Refer to subpart J of this part for field test procedures that describe how to measure emissions during in-use engine operation. This section describes how to:

(1) Map your engine, if applicable, by recording specified speed and torque data, as measured from the engine's primary output shaft.

* * * * *

(b) An emission test generally consists of measuring emissions and other parameters while an engine follows one or more duty cycles that are specified in the standard-setting part. There are two general types of duty cycles:

(1) *Transient cycles.* Transient duty cycles are typically specified in the standard-setting part as a second-by-second sequence of speed commands and normalized torque (or power) commands. Operate an engine over a transient cycle such that the speed and torque of the engine's primary output shaft follows the target values. Proportionally sample emissions and other parameters and use the calculations in subpart G of this part to calculate emissions. Start a transient test according to the standard-setting part, as follows:

(i) A cold-start transient cycle where you start to measure emissions just before starting an engine that has not been warmed up.

(ii) A hot-start transient cycle where you start to measure emissions just before starting a warmed-up engine.

(iii) A hot running transient cycle where you start to measure emissions

after an engine is started, warmed up, and running.

(2) *Steady-state cycles.* Steady-state duty cycles are typically specified in the standard-setting part as a list of discrete operating points (modes or notches), where each operating point has one value of a normalized speed command and one value of a normalized torque (or power) command. Ramped-modal cycles for steady-state testing also list test times for each mode and transition times between modes where speed and torque are linearly ramped between modes, even for cycles with % power. Start a steady-state cycle as a hot running test, where you start to measure emissions after an engine is started, warmed up and running. You may run a steady-state duty cycle as a discrete-mode cycle or a ramped-modal cycle, as follows:

(i) *Discrete-mode cycles.* Before emission sampling, stabilize an engine at the first discrete mode. Sample emissions and other parameters for that mode and then stop emission sampling. Record mean values for that mode, and then stabilize the engine at the next mode. Continue to sample each mode discretely and calculate weighted emission results according to the standard-setting part.

(ii) *Ramped-modal cycles.* Perform ramped-modal cycles similar to the way you would perform transient cycles, except that ramped-modal cycles involve mostly steady-state engine operation. Generate a ramped-modal duty cycle as a sequence of second-by-second (1 Hz) reference speed and torque points. Run the ramped-modal duty cycle in the same manner as a transient cycle and use the 1 Hz reference speed and torque values to validate the cycle, even for cycles with % power. Proportionally sample emissions and other parameters during the cycle and use the calculations in subpart G of this part to calculate emissions.

* * * * *

■ 98. Section 1065.510 is revised to read as follows:

§ 1065.510 Engine mapping.

(a) *Applicability, scope, and frequency.* An engine map is a data set that consists of a series of paired data points that represent the maximum brake torque versus engine speed, measured at the engine's primary output shaft. Map your engine if the standard-setting part requires engine mapping to generate a duty cycle for your engine configuration. Map your engine while it is connected to a dynamometer or other device that can absorb work output from

the engine's primary output shaft according to § 1065.110. Configure any auxiliary work inputs and outputs such as hybrid, turbo-compounding, or thermoelectric systems to represent their in-use configurations, and use the same configuration for emission testing. See Figure 1 of § 1065.210. This may involve configuring initial states of charge and rates and times of auxiliary-work inputs and outputs. We recommend that you contact the Designated Compliance Officer before testing to determine how you should configure any auxiliary-work inputs and outputs. Use the most recent engine map to transform a normalized duty cycle from the standard-setting part to a reference duty cycle specific to your engine. Normalized duty cycles are specified in the standard-setting part. You may update an engine map at any time by repeating the engine-mapping procedure. You must map or re-map an engine before a test if any of the following apply:

(1) If you have not performed an initial engine map.

(2) If the atmospheric pressure near the engine's air inlet is not within ± 5 kPa of the atmospheric pressure recorded at the time of the last engine map.

(3) If the engine or emission-control system has undergone changes that might affect maximum torque performance. This includes changing the configuration of auxiliary work inputs and outputs.

(4) If you capture an incomplete map on your first attempt or you do not complete a map within the specified time tolerance. You may repeat mapping as often as necessary to capture a complete map within the specified time.

(b) *Mapping variable-speed engines.* Map variable-speed engines as follows:

(1) Record the atmospheric pressure.

(2) Warm up the engine by operating it. We recommend operating the engine at any speed and at approximately 75% of its expected maximum power. Continue the warm-up until the engine coolant, block, or head absolute temperature is within ± 2% of its mean value for at least 2 min or until the engine thermostat controls engine temperature.

(3) Operate the engine at its warm idle speed.

(i) For engines with a low-speed governor, set the operator demand to minimum, use the dynamometer or other loading device to target a torque of zero on the engine's primary output shaft, and allow the engine to govern the speed. Measure this warm idle speed; we recommend recording at least 30

values of speed and using the mean of those values.

(ii) For engines without a low-speed governor, set the dynamometer to target a torque of zero on the engine's primary output shaft, and manipulate the operator demand to control the speed to target the manufacturer-declared value for the lowest engine speed possible with minimum load (also known as manufacturer-declared warm idle speed).

(iii) For all variable-speed engines (with or without a low-speed governor), if a nonzero idle torque is representative of in-use operation, you may target the manufacturer-declared idle torque. If you measure the warm idle speed with the manufacturer-declared torque at this step, you may omit the speed measurement in paragraph (b)(6) of this section.

(4) Set operator demand to maximum and control engine speed at (95 ± 1) % of its warm idle speed determined above for at least 15 seconds. For engines with reference duty cycles whose lowest speed is greater than warm idle speed, you may start the map at (95 ± 1) % of the lowest reference speed.

(5) Perform one of the following:

(i) For any engine subject only to steady-state duty cycles (i.e., discrete-mode or ramped-modal), you may perform an engine map by using discrete speeds. Select at least 20 evenly spaced setpoints between warm idle and the highest speed above maximum mapped power at which (50 to 75)% of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g., for ungoverned engines), use good engineering judgment to map up to the maximum safe speed or the maximum representative speed. At each setpoint, stabilize speed and allow torque to stabilize. Record the mean speed and torque at each setpoint. We recommend that you stabilize an engine for at least 15 seconds at each setpoint and record the mean feedback speed and torque of the last (4 to 6) seconds. Use linear interpolation to determine intermediate speeds and torques. Use this series of speeds and torques to generate the power map as described in paragraph (e) of this section.

(ii) For any variable-speed engine, you may perform an engine map by using a continuous sweep of speed by continuing to record the mean feedback speed and torque at 1 Hz or more frequently and increasing speed at a constant rate such that it takes (4 to 6) min to sweep from 95% of warm idle to the highest speed above maximum power at which (50 to 75)% of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g.,

for ungoverned engines), use good engineering judgment to map up to the maximum safe speed or the maximum representative speed. Stop recording after you complete the sweep. From the series of mean speed and maximum torque values, use linear interpolation to determine intermediate values. Use this series of speeds and torques to generate the power map as described in paragraph (e) of this section.

(6) For engines with a low-speed governor, if a nonzero idle torque is representative of in-use operation, operate the engine at warm idle with the manufacturer-declared idle torque. Set the operator demand to minimum, use the dynamometer to target the declared idle torque, and allow the engine to govern the speed. Measure this speed and use it as the warm idle speed for cycle generation in § 1065.512. We recommend recording at least 30 values of speed and using the mean of those values. You may map the idle governor at multiple load levels and use this map to determine the measured warm idle speed at the declared idle torque.

(c) *Negative torque mapping.* If your engine is subject to a reference duty cycle that specifies negative torque values (i.e., engine motoring), generate a motoring map by any of the following procedures:

(1) Multiply the positive torques from your map by −40%. Use linear interpolation to determine intermediate values.

(2) Map the amount of negative torque required to motor the engine by repeating paragraph (b) of this section with minimum operator demand.

(3) Determine the amount of negative torque required to motor the engine at the following two points near the ends of the engine's speed range. Operate the engine at these two points at minimum operator demand. Use linear interpolation to determine intermediate values.

(i) *Low-speed point.* For engines without a low-speed governor, determine the amount of negative torque at warm idle speed. For engines with a low-speed governor, motor the engine above warm idle speed so the governor is inactive and determine the amount of negative torque at that speed.

(ii) *High-speed point.* For engines without a high-speed governor, determine the amount of negative torque at the maximum safe speed or the maximum representative speed. For engines with a high-speed governor, determine the amount of negative torque at a speed at or above n_{hi} per § 1065.610(c)(2).

(d) *Mapping constant-speed engines.* For constant-speed engines, generate a map as follows:

(1) Record the atmospheric pressure.

(2) Warm up the engine by operating it. We recommend operating the engine at approximately 75% of the engine's expected maximum power. Continue the warm-up until the engine coolant, block, or head absolute temperature is within ±2% of its mean value for at least 2 min or until the engine thermostat controls engine temperature.

(3) You may operate the engine with a production constant-speed governor or simulate a constant-speed governor by controlling engine speed with an operator demand control system described in § 1065.110. Use either isochronous or speed-droop governor operation, as appropriate.

(4) With the governor or simulated governor controlling speed using operator demand, operate the engine at no-load governed speed (at high speed, not low idle) for at least 15 seconds.

(5) Record at 1 Hz the mean of feedback speed and torque. Use the dynamometer to increase torque at a constant rate. Unless the standard-setting part specifies otherwise, complete the map such that it takes (2 to 4) min to sweep from no-load governed speed to the lowest speed below maximum mapped power at which the engine develops (85–95)% of maximum mapped power. You may map your engine to lower speeds. Stop recording after you complete the sweep. Use this series of speeds and torques to generate the power map as described in paragraph (e) of this section.

(e) *Power mapping.* For all engines, create a power-versus-speed map by transforming torque and speed values to corresponding power values. Use the mean values from the recorded map data. Do not use any interpolated values. Multiply each torque by its corresponding speed and apply the appropriate conversion factors to arrive at units of power (kW). Interpolate intermediate power values between these power values, which were calculated from the recorded map data.

(f) *Measured and declared test speeds and torques.* You must select test speeds and torques for cycle generation as required in this paragraph (f). "Measured" values are either directly measured during the engine mapping process or they are determined from the engine map. "Declared" values are specified by the manufacturer. When both measured and declared values are available, you may use declared test speeds and torques instead of measured speeds and torques if they meet the criteria in this paragraph (f). Otherwise,

you must use measured speeds and torques derived from the engine map.

(1) *Measured speeds and torques.* Determine the applicable speeds and torques for the duty cycles you will run:

(i) Measured maximum test speed for variable-speed engines according to § 1065.610.

(ii) Measured maximum test torque for constant-speed engines according to § 1065.610.

(iii) Measured "A", "B", and "C" speeds for variable-speed engines according to § 1065.610.

(iv) Measured intermediate speed for variable-speed engines according to § 1065.610.

(v) For variable-speed engines with a low-speed governor, measure warm idle speed according to § 1065.510(b) and use this speed for cycle generation in § 1065.512. For engines with no low-speed governor, instead use the manufacturer-declared warm idle speed.

(2) *Required declared speeds.* You must declare the lowest engine speed possible with minimum load (i.e., manufacturer-declared warm idle speed). This is applicable only to variable-speed engines with no low-speed governor. For engines with no low-speed governor, the declared warm idle speed is used for cycle generation in § 1065.512. Declare this speed in a way that is representative of in-use operation. For example, if your engine is typically connected to an automatic transmission or a hydrostatic transmission, declare this speed at the idle speed at which your engine operates when the transmission is engaged.

(3) *Optional declared speeds.* You may use declared speeds instead of measured speeds as follows:

(i) You may use a declared value for maximum test speed for variable-speed engines if it is within (97.5 to 102.5)% of the corresponding measured value. You may use a higher declared speed if the length of the "vector" at the declared speed is within 2.0% of the length of the "vector" at the measured value. The term vector refers to the square root of the sum of normalized engine speed squared and the normalized full-load power (at that speed) squared, consistent with the calculations in § 1065.610.

(ii) You may use a declared value for intermediate, "A", "B", or "C" speeds for steady-state tests if the declared value is within (97.5 to 102.5)% of the corresponding measured value.

(4) *Required declared torques.* If a nonzero idle or minimum torque is representative of in-use operation, you must declare the appropriate torque as follows:

(i) For variable-speed engines, declare a warm idle torque that is representative of in-use operation. For example, if your engine is typically connected to an automatic transmission or a hydrostatic transmission, declare the torque that occurs at the idle speed at which your engine operates when the transmission is engaged. Use this value for cycle generation. You may use multiple warm idle torques and associated idle speeds in cycle generation for representative testing. For example, for cycles that start the engine and begin with idle, you may start a cycle in idle with the transmission in neutral with zero torque and later switch to a different idle with the transmission in drive with the Curb-Idle Transmission Torque (CITT). For variable-speed engines intended primarily for propulsion of a vehicle with an automatic transmission where that engine is subject to a transient duty cycle with idle operation, you must declare a CITT. You must specify a CITT based on typical applications at the mean of the range of idle speeds you specify at stabilized temperature conditions.

(ii) For constant-speed engines, declare a warm minimum torque that is representative of in-use operation. For example, if your engine is typically connected to a machine that does not operate below a certain minimum torque, declare this torque and use it for cycle generation.

(5) *Optional declared torques.* For constant-speed engines you may declare a maximum test torque. You may use the declared value for cycle generation if it is within (95 to 100)% of the measured value.

(g) *Other mapping procedures.* You may use other mapping procedures if you believe the procedures specified in this section are unsafe or unrepresentative for your engine. Any alternate techniques you use must satisfy the intent of the specified mapping procedures, which is to determine the maximum available torque at all engine speeds that occur during a duty cycle. Identify any deviations from this section's mapping procedures when you submit data to us.

■ 99. Section 1065.512 is revised to read as follows:

§ 1065.512 Duty cycle generation.

(a) Generate duty cycles according to this section if the standard-setting part requires engine mapping to generate a duty cycle for your engine configuration. The standard-setting part generally defines applicable duty cycles in a normalized format. A normalized duty cycle consists of a sequence of paired values for speed and torque or for speed and power.

(b) Transform normalized values of speed, torque, and power using the following conventions:

(1) *Engine speed for variable-speed engines.* For variable-speed engines, normalized speed may be expressed as a percentage between warm idle speed, f_{nidle}, and maximum test speed, f_{ntest}, or speed may be expressed by referring to a defined speed by name, such as "warm idle," "intermediate speed," or "A," "B," or "C" speed. Section 1065.610 describes how to transform these normalized values into a sequence of reference speeds, f_{nref}. Running duty cycles with negative or small normalized speed values near warm idle speed may cause low-speed idle governors to activate and the engine torque to exceed the reference torque even though the operator demand is at a minimum. In such cases, we recommend controlling the dynamometer so it gives priority to follow the reference torque instead of the reference speed and let the engine govern the speed. Note that the cycle-validation criteria in § 1065.514 allow an engine to govern itself. This allowance permits you to test engines with enhanced-idle devices and to simulate the effects of transmissions such as automatic transmissions. For example, an enhanced-idle device might be an idle speed value that is normally commanded only under cold-start conditions to quickly warm up the engine and aftertreatment devices. In this case, negative and very low normalized speeds will generate reference speeds below this higher enhanced idle speed and we recommend controlling the dynamometer so it gives priority to follow the reference torque, controlling the operator demand so it gives priority to follow reference speed and let the engine govern the speed when the operator demand is at minimum.

(2) *Engine torque for variable-speed engines.* For variable-speed engines, normalized torque is expressed as a percentage of the mapped torque at the corresponding reference speed. Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref}. Section 1065.610 also describes special requirements for modifying transient duty cycles for variable-speed engines intended primarily for propulsion of a vehicle with an automatic transmission. Section 1065.610 also describes under what conditions you may command T_{ref} greater than the reference torque you calculated from a normalized duty cycle. This provision permits you to

command T_{ref} values that are limited by a declared minimum torque. For any negative torque commands, command minimum operator demand and use the dynamometer to control engine speed to the reference speed, but if reference speed is so low that the idle governor activates, we recommend using the dynamometer to control torque to zero, CITT, or a declared minimum torque as appropriate. Note that you may omit power and torque points during motoring from the cycle-validation criteria in § 1065.514. Also, use the maximum mapped torque at the minimum mapped speed as the maximum torque for any reference speed at or below the minimum mapped speed.

(3) *Engine torque for constant-speed engines.* For constant-speed engines, normalized torque is expressed as a percentage of maximum test torque, T_{test}. Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref}. Section 1065.610 also describes under what conditions you may command T_{ref} greater than the reference torque you calculated from the normalized duty cycle. This provision permits you to command T_{ref} values that are limited by a declared minimum torque.

(4) *Engine power.* For all engines, normalized power is expressed as a percentage of mapped power at maximum test speed, f_{ntest}, unless otherwise specified by the standard-setting part. Section 1065.610 describes how to transform these normalized values into a sequence of reference powers, P_{ref}. Convert these reference powers to corresponding torques for operator demand and dynamometer control. Use the reference speed associated with each reference power point for this conversion. As with cycles specified with % torque, issue torque commands more frequently and linearly interpolate between these reference torque values generated from cycles with % power.

(5) *Ramped-modal cycles.* For ramped modal cycles, generate reference speed and torque values at 1 Hz and use this sequence of points to run the cycle and validate it in the same manner as with a transient cycle. During the transition between modes, linearly ramp the denormalized reference speed and torque values between modes to generate reference points at 1 Hz. Do not linearly ramp the normalized reference torque values between modes and then denormalize them. Do not linearly ramp normalized or denormalized reference power points. These cases will produce nonlinear torque ramps in the denormalized reference torques. If the speed and torque ramp runs through a point above the engine's torque curve, continue to command the reference torques and allow the operator demand to go to maximum. Note that you may omit power and either torque or speed points from the cycle-validation criteria under these conditions as specified in § 1065.514.

(c) For variable-speed engines, command reference speeds and torques sequentially to perform a duty cycle. Issue speed and torque commands at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles (i.e., discrete-mode and ramped-modal). Linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine more frequently issued reference speeds and torques. During an emission test, record the feedback speeds and torques at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles. For transient cycles, you may record the feedback speeds and torques at lower frequencies (as low as 1 Hz) if you record the average value over the time interval between recorded values. Calculate the average values based on feedback values updated at a frequency of at least 5 Hz. Use these recorded values to calculate cycle-validation statistics and total work.

(d) For constant-speed engines, operate the engine with the same production governor you used to map the engine in § 1065.510 or simulate the in-use operation of a governor the same way you simulated it to map the engine in § 1065.510. Command reference torque values sequentially to perform a duty cycle. Issue torque commands at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles (i.e., discrete-mode, ramped-modal). Linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine more frequently issued reference torque values. During an emission test, record the feedback speeds and torques at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles. For transient cycles, you may record the feedback speeds and torques at lower frequencies (as low as 1 Hz) if you record the average value over the time interval between recorded values. Calculate the average values based on feedback values updated at a frequency of at least 5 Hz. Use these recorded values to calculate cycle-validation statistics and total work.

(e) You may perform practice duty cycles with the test engine to optimize operator demand and dynamometer controls to meet the cycle-validation criteria specified in § 1065.514.

■ 100. Section 1065.514 is revised to read as follows:

§ 1065.514 Cycle-validation criteria for operation over specified duty cycles.

Validate the execution of your duty cycle according to this section unless the standard-setting part specifies otherwise. This section describes how to determine if the engine's operation during the test adequately matched the reference duty cycle. This section applies only to speed, torque, and power from the engine's primary output shaft. Other work inputs and outputs are not subject to cycle-validation criteria. You must compare the original reference duty cycle points generated as described in § 1065.512 to the corresponding feedback values recorded during the test. You may compare reference duty cycle points recorded during the test to the corresponding feedback values recorded during the test as long as the recorded reference values match the original points generated in § 1065.512. The number of points in the validation regression are based on the number of points in the original reference duty cycle generated in § 1065.512. For example if the original cycle has 1199 reference points at 1 Hz, then the regression will have up to 1199 pairs of reference and feedback values at the corresponding moments in the test. The feedback speed and torque signals may be filtered—either in real-time while the test is run or afterward in the analysis program. Any filtering that is used on the feedback signals used for cycle validation must also be used for calculating work. Feedback signals for control loops may use different filtering.

(a) *Testing performed by EPA.* Our tests must meet the specifications of paragraph (f) of this section, unless we determine that failing to meet the specifications is related to engine performance rather than to shortcomings of the dynamometer or other laboratory equipment.

(b) *Testing performed by manufacturers.* Emission tests that meet the specifications of paragraph (f) of this section satisfy the standard-setting part's requirements for duty cycles. You may ask to use a dynamometer or other laboratory equipment that cannot meet those specifications. We will approve your request as long as using the alternate equipment does not adversely affect your ability to show compliance with the applicable emission standards.

(c) *Time-alignment.* Because time lag between feedback values and the reference values may bias cycle-validation results, you may advance or delay the entire sequence of feedback engine speed and torque pairs to

synchronize them with the reference sequence. If you advance or delay feedback signals for cycle validation, you must make the same adjustment for calculating work. You may use linear interpolation between successive recorded feedback signals to time shift an amount that is a fraction of the recording period.

(d) *Omitting additional points.* Besides engine cranking, you may omit additional points from cycle-validation statistics as described in the following table:

TABLE 1 OF § 1065.514.—PERMISSIBLE CRITERIA FOR OMITTING POINTS FROM DUTY-CYCLE REGRESSION STATISTICS

When operator demand is at its . . .	you may omit . . .	if . . .
For reference duty cycles that are specified in terms of speed and torque (f_{nref}, T_{ref}):		
minimum	power and torque	T_{ref} < 0% (motoring).
minimum	power and speed	f_{nref} = 0% (idle speed) and T_{ref} = 0% (idle torque) and $T_{ref} - (2\% \cdot T_{max\ mapped})$ < T < $T_{ref} + (2\% \cdot <T_{max\ mapped})$.
minimum	power and either torque or speed.	f_n > f_{nref} or T < T_{ref} but not if f_n > ($f_{nref} \cdot 102\%$) and T > $T_{ref} + (2\% \cdot <T_{max,\ mapped})$.
maximum	power and either torque or speed.	f_n < f_{nref} or T < T_{ref} but not if f_n < ($f_{nref} \cdot 98\%$) and T < $T_{ref} - (2\% \cdot T_{max\ mapped})$.
For reference duty cycles that are specified in terms of speed and power (f_{nref}, P_{ref}):		
minimum	power and torque	< P_{ref} < 0% (motoring).
minimum	power and speed	f_{nref} = 0% (idle speed) and P_{ref} = 0% (idle power) and $P_{ref} - (2\% \cdot P_{max\ mapped})$ < P < $P_{ref} + (2\% \cdot P_{max\ mapped})$.
minimum	power and either torque or speed.	f_n > f_{nref} or < P > P_{ref} but not if f_n > ($f_{nref} \cdot 102\%$) and P < $P_{ref} + (2\% \cdot P_{max\ mapped})$.
maximum	power and either torque or speed.	f_n < f_{nref} or P < P_{ref} but not if f_n ($f_{nref} \cdot 98\%$) and P < $P_{ref} - (2\% \cdot P_{max\ mapped})$.

(e) *Statistical parameters.* Use the remaining points to calculate regression statistics described in § 1065.602. Round calculated regression statistics to the same number of significant digits as the criteria to which they are compared. Refer to Table 2 of § 1065.514 for the default criteria and refer to the standard-setting part to determine if there are other criteria for your engine. Calculate the following regression statistics:

(1) Slopes for feedback speed, a_{1fn}, feedback torque, a_{1T}, and feedback power a_{1P}.

(2) Intercepts for feedback speed, a_{0fn}, feedback torque, a_{0T}, and feedback power a_{0P}.

(3) Standard estimates of error for feedback speed, SEE_{fn}, feedback torque, SEE_T, and feedback power SEE_P.

(4) Coefficients of determination for feedback speed, r^2_{fn}, feedback torque, r^2_T, and feedback power r^2_P.

(f) *Cycle-validation criteria.* Unless the standard-setting part specifies otherwise, use the following criteria to validate a duty cycle:

(1) For variable-speed engines, apply all the statistical criteria in Table 2 of this section.

(2) For constant-speed engines, apply only the statistical criteria for torque in Table 2 of this section.

(3) For discrete-mode steady-state testing, apply cycle-validation criteria using one of the following approaches:

(i) Treat the sampling periods from the series of test modes as a continuous sampling period, analogous to ramped-modal testing and apply statistical criteria as described in paragraph (f)(1) or (2) of this section.

(ii) Evaluate each mode separately to validate the duty cycle. For variable-speed engines, all speed values measured during the sampling period for each mode would need to stay within a tolerance of 2 percent of the reference value, and all load values would need to stay within a tolerance of 2 percent or ± 0.27 N·m of the reference value, whichever is greater. Also, the mean speed value during the sampling period for each mode would need to be within 1 percent of the reference value, and the mean load value would need to stay within 1 percent or ± 0.12 N·m of the reference value, whichever is greater. The same torque criteria apply for constant-speed engines but the speed criteria do not apply.

TABLE 2 OF § 1065.514.—DEFAULT STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter	Speed	Torque	Power
Slope, a_1	$0.950 \le a_1 \le 1.030$	$0.830 \le a_1 \le 1.030$	$0.830 \le a_1 \le 1.030$.
Absolute value of intercept, $\lvert a_0 \rvert$	≤ 10% of warm idle	≤ 2.0% of maximum mapped torque.	≤ 2.0% of maximum mapped power.
Standard error of estimate, *SEE* ...	≤ 5.0% of maximum test speed ...	≤ 10% of maximum mapped torque.	≤ 10% of maximum mapped power.
Coefficient of determination, r^2	≥ 0.970	≥ 0.850	≥ 0.910.

■ 101. Section 1065.520 is revised to read as follows:

§ 1065.520 Pre-test verification procedures and pre-test data collection.

(a) If your engine must comply with a PM standard, follow the procedures for PM sample preconditioning and tare weighing according to § 1065.590.

(b) Unless the standard-setting part specifies different tolerances, verify that

ambient conditions are within the following tolerances before the test:

(1) Ambient temperature of (20 to 30) °C.

(2) Atmospheric pressure of (80.000 to 103.325) kPa and within ± 5 kPa of the value recorded at the time of the last engine map.

(3) Dilution air conditions as specified in § 1065.140, except in cases where you preheat your CVS before a cold start test.

(c) You may test engines at any intake-air humidity, and we may test engines at any intake-air humidity.

(d) Verify that auxiliary-work inputs and outputs are configured as they were during engine mapping, as described in § 1065.510(a).

(e) You may perform a final calibration of the speed, torque, and proportional-flow control systems, which may include performing practice duty cycles.

(f) You may perform the following recommended procedure to precondition sampling systems:

(1) Start the engine and use good engineering judgment to bring it to one of the following:

(i) 100% torque at any speed above its peak-torque speed.

(ii) 100% operator demand.

(2) Operate any dilution systems at their expected flow rates. Prevent aqueous condensation in the dilution systems.

(3) Operate any PM sampling systems at their expected flow rates.

(4) Sample PM for at least 10 min using any sample media. You may change sample media during preconditioning. You may discard preconditioning samples without weighing them.

(5) You may purge any gaseous sampling systems during preconditioning.

(6) You may conduct calibrations or verifications on any idle equipment or analyzers during preconditioning.

(7) Proceed with the test sequence described in § 1065.530(a)(1).

(g) Verify the amount of nonmethane contamination in the exhaust and background HC sampling systems within eight hours of starting 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_4 sample train for the cases where NMHC is determined by subtracting CH_4 from THC, using an NMC as configured in § 1065.365(d), (e), and (f); and the calculations in § 1065.660(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 § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O_2 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_1). For example, if you use a C_3H_8 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 or into a fitting between the HC probe and its transfer line.

(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.*, filter) 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, $x_{THC[THC-FID]init-}$ and use it to correct measured values as described in § 1065.660.

(7) If any of the $x_{THC[THC-FID]init-}$ 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 µmol/mol.

(8) If corrective action does not resolve the deficiency, you may request to use the contaminated system as an alternate procedure under § 1065.10.

■ 102. Section 1065.525 is revised to read as follows:

§ 1065.525 Engine starting, restarting, shutdown, and optional repeating of void discrete modes.

(a) Start the engine using one of the following methods:

(1) Start the engine as recommended in the owners manual using a production starter motor or air-start system and either an adequately charged battery, a suitable power supply, or a suitable compressed air source.

(2) Use the dynamometer to start the engine. To do this, motor the engine within ±25% of its typical in-use cranking speed. Stop cranking within 1 second of starting the engine.

(b) If the engine does not start after 15 seconds of cranking, stop cranking and determine why the engine failed to start, unless the owners manual or the service-repair manual describes the longer cranking time as normal.

(c) Respond to engine stalling with the following steps:

(1) If the engine stalls during warm-up before emission sampling begins, restart the engine and continue warm-up.

(2) If the engine stalls during preconditioning before emission sampling begins, restart the engine and restart the preconditioning sequence.

(3) If the engine stalls at any time after emission sampling begins for a transient test or ramped-modal cycle test, the test is void.

(4) Except as described in paragraph (d) of this section, void the test if the engine stalls at any time after emission sampling begins.

(d) If emission sampling is interrupted during one of the modes of a discrete-mode test, you may void the results only for that individual mode and perform the following steps to continue the test:

(1) If the engine has stalled, restart the engine.

(2) Use good engineering judgment to restart the test sequence using the appropriate steps in § 1065.530(b).

(3) Precondition the engine by operating at the previous mode for approximately the same amount of time it operated at that mode for the last emission measurement.

(4) Advance to the mode at which the engine stalled and continue with the duty cycle as specified in the standard-setting part.

(5) Complete the remainder of the test according to the requirements in this subpart.

(e) Shut down the engine according to the manufacturer's specifications.

■ 103. Section 1065.530 is revised to read as follows:

§ 1065.530 Emission test sequence.

(a) Time the start of testing as follows:

(1) Perform one of the following if you precondition sampling systems as described in § 1065.520(f):

(i) For cold-start duty cycles, shut down the engine. Unless the standard-setting part specifies that you may only perform a natural engine cooldown, you may perform a forced engine cooldown. Use good engineering judgment to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from coolant through the engine cooling system, and to remove heat from any exhaust aftertreatment systems. In the case of a forced aftertreatment cooldown, good engineering judgment would indicate that you not start flowing cooling air until the aftertreatment system has cooled below its catalytic activation temperature. For platinum-group metal catalysts, this temperature is about 200 °C. Once the aftertreatment system has naturally cooled below its catalytic activation temperature, good engineering judgment would indicate that you use clean air with a temperature of at least 15 °C, and direct the air through the aftertreatment system in the normal direction of exhaust flow. Do not use any cooling procedure that results in unrepresentative emissions (see § 1065.10(c)(1)). You may start a cold-start duty cycle when the temperatures of an engine's lubricant, coolant, and aftertreatment systems are all between (20 and 30) °C.

(ii) For hot-start emission measurements, shut down the engine. Start the hot-start duty cycle as specified in the standard-setting part.

(iii) For testing that involves hot-stabilized emission measurements, such as any steady-state testing, you may continue to operate the engine at maximum test speed and 100% torque if that is the first operating point. Otherwise, operate the engine at warm idle or the first operating point of the duty cycle. In any case, start the emission test within 10 min after you complete the preconditioning procedure.

(2) If you do not precondition sampling systems, perform one of the following:

(i) For cold-start duty cycles, prepare the engine according to paragraph (a)(1)(i) of this section.

(ii) For hot-start emission measurements, first operate the engine at any speed above peak-torque speed and at (65 to 85)% of maximum mapped power until either the engine coolant, block, or head absolute temperature is within ±2% of its mean value for at least 2 min or until the engine thermostat controls engine temperature. Shut down

the engine. Start the duty cycle within 20 min of engine shutdown.

(iii) For testing that involves hot-stabilized emission measurements, bring the engine either to warm idle or the first operating point of the duty cycle. Start the test within 10 min of achieving temperature stability. Determine temperature stability either as the point at which the engine coolant, block, or head absolute temperature is within ±2% of its mean value for at least 2 min, or as the point at which the engine thermostat controls engine temperature.

(b) Take the following steps before emission sampling begins:

(1) For batch sampling, connect clean storage media, such as evacuated bags or tare-weighed filters.

(2) Start all measurement instruments according to the instrument manufacturer's instructions and using good engineering judgment.

(3) Start dilution systems, sample pumps, cooling fans, and the data-collection system.

(4) Pre-heat or pre-cool heat exchangers in the sampling system to within their operating temperature tolerances for a test.

(5) Allow heated or cooled components such as sample lines, filters, chillers, and pumps to stabilize at their operating temperatures.

(6) Verify that there are no significant vacuum-side leaks according to § 1065.345.

(7) Adjust the sample flow rates to desired levels, using bypass flow, if desired.

(8) Zero or re-zero any electronic integrating devices, before the start of any test interval.

(9) Select gas analyzer ranges. You may automatically or manually switch gas analyzer ranges during a test only if switching is performed by changing the span over which the digital resolution of the instrument is applied. During a test you may not switch the gains of an analyzer's analog operational amplifier(s).

(10) Zero and span all continuous analyzers using NIST-traceable gases that meet the specifications of § 1065.750. Span FID analyzers on a carbon number basis of one (1), C_1. For example, if you use a C_3H_8 span gas of concentration 200 μmol/mol, span the FID to respond with a value of 600 μmol/mol. Span FID analyzers consistent with the determination of their respective response factors, RF, and penetration fractions, PF, according to § 1065.365.

(11) We recommend that you verify gas analyzer responses after zeroing and spanning by sampling a calibration gas that has a concentration near one-half of

the span gas concentration. Based on the results and good engineering judgment, you may decide whether or not to re-zero, re-span, or re-calibrate a gas analyzer before starting a test.

(12) If you correct for dilution air background concentrations of engine exhaust constituents, start measuring and recording background concentrations.

(13) Drain any condensate from the intake air system and close any intake air condensate drains that are not normally open during in-use operation.

(c) Start testing as follows:

(1) If an engine is already running and warmed up, and starting is not part of the duty cycle, perform the following for the various duty cycles:

(i) Transient and steady-state ramped-modal cycles. Simultaneously start running the duty cycle, sampling exhaust gases, recording data, and integrating measured values.

(ii) Steady-state discrete-mode cycles. Control the engine operation to match the first mode in the test cycle. This will require controlling engine speed and load, engine load, or other operator demand settings, as specified in the standard-setting part. Follow the instructions in the standard-setting part to determine how long to stabilize engine operation at each mode, how long to sample emissions at each mode, and how to transition between modes.

(2) If engine starting is part of the duty cycle, initiate data logging, sampling of exhaust gases, and integrating measured values before attempting to start the engine. Initiate the duty cycle when the engine starts.

(d) At the end of each test interval, continue to operate all sampling and dilution systems to allow the sampling system's response time to elapse. Then stop all sampling and recording, including the recording of background samples. Finally, stop any integrating devices and indicate the end of the duty cycle in the recorded data.

(e) Shut down the engine if you have completed testing or if it is part of the duty cycle.

(f) If testing involves another duty cycle after a soak period with the engine off, start a timer when the engine shuts down, and repeat the steps in paragraphs (b) through (e) of this section as needed.

(g) Take the following steps after emission sampling is complete:

(1) For any proportional batch sample, such as a bag sample or PM sample, verify that proportional sampling was maintained according to § 1065.545. Void any samples that did not maintain proportional sampling according to § 1065.545.

(2) Place any used PM samples into covered or sealed containers and return them to the PM-stabilization environment. Follow the PM sample post-conditioning and total weighing procedures in § 1065.595.

(3) As soon as practical after the duty cycle is complete, or during the soak period if practical, perform the following:

(i) Zero and span all batch gas analyzers no later than 30 minutes after the duty cycle is complete, or during the soak period if practical.

(ii) Analyze any conventional gaseous batch samples no later than 30 minutes after the duty cycle is complete, or during the soak period if practical.

(iii) Analyze background samples no later than 60 minutes after the duty cycle is complete.

(iv) Analyze non-conventional gaseous batch samples, such as ethanol (NMCHE) as soon as practical using good engineering judgment.

(4) After quantifying exhaust gases, verify drift as follows:

(i) For batch and continuous gas analyzers, record the mean analyzer value after stabilizing a zero gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.

(ii) Record the mean analyzer value after stabilizing the span gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.

(iii) Use these data to validate and correct for drift as described in § 1065.550.

(h) Unless the standard-setting part specifies otherwise, determine whether or not the test meets the cycle-validation criteria in § 1065.514.

(1) If the criteria void the test, you may retest using the same denormalized duty cycle, or you may re-map the engine, denormalize the reference duty cycle based on the new map and retest the engine using the new denormalized duty cycle.

(2) If the criteria void the test for a constant-speed engine only during commands of maximum test torque, you may do the following:

(i) Determine the first and last feedback speeds at which maximum test torque was commanded.

(ii) If the last speed is greater than or equal to 90% of the first speed, the test is void. You may retest using the same denormalized duty cycle, or you may re-map the engine, denormalize the reference duty cycle based on the new map and retest the engine using the new denormalized duty cycle.

(iii) If the last speed is less than 90% of the first speed, reduce maximum test torque by 5%, and proceed as follows:

(A) Denormalize the entire duty cycle based on the reduced maximum test torque according to § 1065.512.

(B) Retest the engine using the denormalized test cycle that is based on the reduced maximum test torque.

(C) If your engine still fails the cycle criteria, reduce the maximum test torque by another 5% of the original maximum test torque.

(D) If your engine fails after repeating this procedure four times, such that your engine still fails after you have reduced the maximum test torque by 20% of the original maximum test torque, notify us and we will consider specifying a more appropriate duty cycle for your engine under the provisions of § 1065.10(c).

(i) [Reserved]

(j) Measure and record ambient temperature, pressure, and humidity, as appropriate.

■ 104. Section 1065.545 is revised to read as follows:

§ 1065.545 Validation of proportional flow control for batch sampling and minimum dilution ratio for PM 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 § 1065.602. 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 ±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 ±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 ±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 ±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 ±2% of the mean or target absolute temperature over each test interval.

(c) Using good engineering judgment, 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.

(d) Use measured or calculated flows and/or tracer gas concentrations (e.g., CO_2) to determine the minimum dilution ratio for PM batch sampling over the test interval.

■ 105. Section 1065.550 is revised to read as follows:

§ 1065.550 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. Calculate one set using the data before drift correction and calculate the other set after correcting all the data for drift according to § 1065.672. Use the two sets of brake-specific emission results as follows:

(1) This test is validated for drift if, for each regulated pollutant, the difference between the uncorrected and the corrected brake-specific emission values is within ±4% of the uncorrected results or applicable standard, whichever is greater. If not, the entire test is void.

(2) If the test is validated for drift, you must use only the drift-corrected emission results when reporting emissions, unless you demonstrate to us that using the drift-corrected results adversely affects your ability to demonstrate that your engine complies with the applicable standards.

■ 106. Section 1065.590 is revised to read as follows:

§ 1065.590 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 § 1065.390.

(b) Visually inspect unused sample media (e.g., filters) for defects and discard defective media.

(c) To handle PM sampling media (e.g., filters), use electrically grounded tweezers or a grounding strap, as described in § 1065.190.

(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 § 1065.190.

(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 good engineering judgment 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 § 1065.690. 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 good engineering judgment to exclude outliers from the calculation of mean mass values.

(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. 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_2H_5OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's level of PM and HC emissions.

(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 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 g/cm³. The following steps are an example of substitution weighing:

(1) Use electrically grounded tweezers or a grounding strap, as described in § 1065.190.

(2) Use a static neutralizer as described in § 1065.190 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 § 1065.790. 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.

■ 107. Section 1065.595 is revised to read as follows:

§ 1065.595 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 § 1065.190(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, you may remove them from their cassettes before or after stabilization. We recommend always removing 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.

(c) To handle PM samples, use electrically grounded tweezers or a grounding strap, as described in § 1065.190.

(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 § 1065.190. If you expect that a sample medium's (e.g., filter's) total surface concentration of PM will be less than 400 µg, assuming a 38 mm diameter filter stain area, expose the filter to a PM-stabilization environment meeting the specifications of § 1065.190 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 µg 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 tested according to 40 CFR part 86, subpart N, or 50 mg/mile for light-duty vehicles tested according to 40 CFR part 86, subpart B.

(f) Repeat the procedures in § 1065.590(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_{PM}. Use m_{PM} in emission calculations in § 1065.650.

Subpart G—[Amended]

■ 108. Section 1065.601 is amended by revising paragraph (c)(1) to read as follows:

§ 1065.601   Overview.

*   *   *   *   *

(c) * * *

(1) Mass-based emission calculations prescribed by the International Organization for Standardization (ISO), according to ISO 8178, except the following:

(i) ISO 8178–1   Section 14.4, NO_X Correction for Humidity and Temperature. See § 1065.670 for approved methods for humidity corrections.

(ii) ISO 8178–1   Section 15.1, Particulate Correction Factor for Humidity.

*   *   *   *   *

■ 109. Section 1065.602 is amended by revising paragraphs (f)(3) before the table and (l) introductory text to read as follows:

§ 1065.602   Statistics.

*   *   *   *   *

(f) * * *

(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 § 1065.602 Table 1 and may be used in place of Table 1.

*   *   *   *   *

(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, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust molar flow rate, divided by the sum of the recorded flow rate values. 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. You might already expect a certain flow-weighted mean concentration of an emission at its standard based on previous testing with similar engines 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 examples as a guide for how to estimate the flow-weighted mean concentration expected at the standard. Note that these examples are not exact and that they contain assumptions that are not always valid. Use good engineering judgment to determine if you can use similar assumptions.

*   *   *   *   *

■ 110. Section 1065.610 is revised to read as follows:

§ 1065.610   Duty cycle generation.

This section describes how to generate duty cycles that are specific to your engine, based on the normalized duty cycles in the standard-setting part. During an emission test, use a duty cycle that is specific to your engine to command engine speed, torque, and power, as applicable, using an engine dynamometer and an engine operator demand. Paragraph (a) of this section describes how to "normalize" your engine's map to determine the maximum test speed and torque for your engine. The rest of this section describes how to use these values to "denormalize" the duty cycles in the standard-setting parts, which are all published on a normalized basis. Thus, the term "normalized" in paragraph (a) of this section refers to different values than it does in the rest of the section.

(a) *Maximum test speed,* f_{ntest}. This section generally applies to duty cycles for variable-speed engines. For constant-speed engines subject to duty cycles that specify normalized speed commands, use the no-load governed speed as the measured f_{ntest}. This is the highest engine speed where an engine outputs zero torque. For variable-speed engines, determine the measured f_{ntest} from the power-versus-speed map, generated according to § 1065.510, as follows:

(1) Based on the map, determine maximum power, P^{max}, and the speed at which maximum power occurred, f_{nPmax}. Divide every recorded power by P^{max} and divide every recorded speed by f_{nPmax}. The result is a normalized power-versus-speed map. Your measured f_{ntest} is the speed at which the sum of the squares of normalized speed and power is maximum, as follows:

$$f_{ntest} = f_{ni} \text{ at the maximum of } (f_{nnormi}^2 + P_{normi}^2)$$

Eq. 1065.610–1

Where:

f_{ntest} = maximum test speed.
i = an indexing variable that represents one recorded value of an engine map.
f_{nnormi} = an engine speed normalized by dividing it by f_{nPmax}.
P_{normi} = an engine power normalized by dividing it by P^{max}.

Example:

$(f_{nnorm1} = 1.002, P_{norm1} = 0.978, f_{n1} = 2359.71)$
$(f_{nnorm2} = 1.004, P_{norm2} = 0.977, f_{n2} = 2364.42)$
$(f_{nnorm3} = 1.006, P_{norm3} = 0.974, f_{n3} = 2369.13)$
$(f_{nnorm12} + P_{norm1}^2) = (1.002^2 + 0.978^2) = 1.960$
$(f_{nnorm2}^2 + P_{norm2}^2) = (1.004^2 + 0.977^2) = 1.963$
$(f_{nnorm3}^2 + P_{norm3}^2) = (1.006^2 + 0.974^2) = 1.961$
maximum = 1.963 at i = 2
f_{ntest} = 2364.42 rev/min

(2) For variable-speed engines, transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured maximum test speed determined according to paragraph (a)(1) of this section—or use your declared maximum test speed, as allowed in § 1065.510.

(3) For constant-speed engines, transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured no-load governed speed—or use your declared maximum test speed, as allowed in § 1065.510.

(b) *Maximum test torque,* T_{test}. For constant-speed engines, determine the measured T_{test} from the power-versus-speed map, generated according to § 1065.510, as follows:

(1) Based on the map, determine maximum power, P_{max}, and the speed at which maximum power occurs, f_{nPmax}. Divide every recorded power by P_{max} and divide every recorded speed by f_{nPmax}. The result is a normalized power-

versus-speed map. Your measured T_{test} is the torque at which the sum of the squares of normalized speed and power is maximum, as follows:

$$T_{test} = T_i \text{ at the maximum of } (f_{nnormi}^2 + P_{normi}^2)$$

Eq. 1065.610–2

Where:

T_{test} = maximum test torque.

Example:

(f_{nnorm1} = 1.002, P_{norm1} = 0.978, T^1 = 722.62 N×m)
(f_{nnorm2} = 1.004, P_{norm2} = 0.977, T^2 = 720.44 N×m)
(f_{nnorm3} = 1.006, P_{norm3} = 0.974, T^3 = 716.80 N×m)
($f_{nnorm1}^2 + P_{norm1}^2$) = ($1.002^2 + 0.978^2$) = 1.960
($f_{nnorm1}^2 + P_{norm1}^2$) = ($1.004^2 + 0.977^2$) = 1.963
($f_{nnorm1}^2 + P_{norm1}^2$) = ($1.006^2 + 0.974^2$) = 1.961
maximum = 1.963 at i = 2
T_{test} = 720.44 N×m

(2) Transform normalized torques to reference torques according to paragraph (d) of this section by using the measured maximum test torque determined according to paragraph (b)(1) of this section—or use your declared maximum test torque, as allowed in § 1065.510.

(c) *Generating reference speed values from normalized duty cycle speeds.* Transform normalized speed values to reference values as follows:

(1) *% speed.* If your normalized duty cycle specifies % speed values, use your warm idle speed and your maximum test speed to transform the duty cycle, as follows:

$$f_{nref} = \% \text{ speed} \cdot (f_{ntest} - f_{nidle}) + f_{nidle}$$

Eq. 1065.610–3

Example:

% speed = 85%
f_{ntest} = 2364 rev/min
f_{nidle} = 650 rev/min
f_{nref} = 85% · (2364 − 650) + 650
f_{nref} = 2107 rev/min

(2) *A, B, and C speeds.* If your normalized duty cycle specifies speeds as A, B, or C values, use your power-versus-speed curve to determine the lowest speed below maximum power at which 50% of maximum power occurs. Denote this value as n_{lo}. Take n_{lo} to be warm idle speed if all power points at speeds below the maximum power speed are higher than 50% of maximum power. Also determine the highest speed above maximum power at which 70% of maximum power occurs. Denote this value as n_{hi}. If all power points at speeds above the maximum power speed are higher than 70% of maximum power, take n_{hi} to be the declared maximum safe engine speed or the declared maximum representative engine speed, whichever is lower. Use n_{hi} and n_{lo} to calculate reference values for A, B, or C speeds as follows:

$$f_{nrefA} = 0.25 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

Eq. 1065.610–4

$$f_{nrefB} = 0.50 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

Eq. 1065.610–5

$$f_{nrefC} = 0.75 \cdot (n_{hi} - n_{lo}) + n_{lo}$$

Eq. 1065.610–6

Example:

n_{lo} = 1005 rev/min
n_{hi} = 2385 rev/min
f_{nrefA} = 0.25 · (2385 − 1005) + 1005
f_{nrefB} = 0.50 · (2385 − 1005) + 1005
f_{nrefC} = 0.75 · (2385 − 1005) + 1005
f_{nrefA} = 1350 rev/min
f_{nrefB} = 1695 rev/min
f_{nrefC} = 2040 rev/min

(3) *Intermediate speed.* If your normalized duty cycle specifies a speed as ''intermediate speed,'' use your torque-versus-speed curve to determine the speed at which maximum torque occurs. This is peak torque speed. Identify your reference intermediate speed as one of the following values:

(i) Peak torque speed if it is between (60 and 75)% of maximum test speed.

(ii) 60% of maximum test speed if peak torque speed is less than 60% of maximum test speed.

(iii) 75% of maximum test speed if peak torque speed is greater than 75% of maximum test speed.

(d) *Generating reference torques from normalized duty-cycle torques.* Transform normalized torques to reference torques using your map of maximum torque versus speed.

(1) *Reference torque for variable-speed engines.* For a given speed point, multiply the corresponding % torque by the maximum torque at that speed, according to your map. If your engine is subject to a reference duty cycle that specifies negative torque values (i.e., engine motoring), use negative torque for those motoring points (i.e., the motoring torque). If you map negative torque as allowed under § 1065.510 (c)(2) and the low-speed governor activates, resulting in positive torques, you may replace those positive motoring mapped torques with negative values between zero and the largest negative motoring torque. For both maximum and motoring torque maps, linearly interpolate mapped torque values to determine torque between mapped speeds. If the reference speed is below the minimum mapped speed (i.e., 95% of idle speed or 95% of lowest required speed, whichever is higher), use the mapped torque at the minimum mapped speed as the reference torque. The result is the reference torque for each speed point.

(2) *Reference torque for constant-speed engines.* Multiply a % torque value by your maximum test torque. The result is the reference torque for each point.

(3) *Required deviations.* We require the following deviations for variable-speed engines intended primarily for propulsion of a vehicle with an automatic transmission where that engine is subject to a transient duty cycle with idle operation. These deviations are intended to produce a more representative transient duty cycle for these applications. For steady-state duty cycles or transient duty cycles with no idle operation, these requirements do not apply. Idle points for steady state duty cycles of such engines are to be run at conditions simulating neutral or park on the transmission.

(i) Zero-percent speed is the warm idle speed measured according to § 1065.510(b)(6) with CITT applied, i.e., measured warm idle speed in drive.

(ii) If the cycle begins with a set of contiguous idle points (zero-percent speed, and zero-percent torque), leave the reference torques set to zero for this initial contiguous idle segment. This is to represent free idle operation with the transmission in neutral or park at the start of the transient duty cycle, after the engine is started. If the initial idle segment is longer than 24 s, change the reference torques for the remaining idle points in the initial contiguous idle segment to CITT (i.e., change idle points corresponding to 25 s to the end of the initial idle segment to CITT). This is to represent shifting the transmission to drive.

(iii) For all other idle points, change the reference torque to CITT. This is to represent the transmission operating in drive.

(iv) If the engine is intended primarily for automatic transmissions with a Neutral-When-Stationary feature that automatically shifts the transmission to neutral after the vehicle is stopped for a designated time and automatically shifts back to drive when the operator increases demand (i.e., pushes the accelerator pedal), change the reference torque back to zero for idle points in drive after the designated time.

(v) For all points with normalized speed at or below zero percent and reference torque from zero to CITT, set the reference torque to CITT. This is to provide smoother torque references below idle speed.

(vi) For motoring points, make no changes.

(vii) For consecutive points with reference torques from zero to CITT that immediately follow idle points, change their reference torques to CITT. This is to provide smooth torque transition out of idle operation. This does not apply if the Neutral-When-Stationary feature is used and the transmission has shifted to neutral.

(viii) For consecutive points with reference torque from zero to CITT that immediately precede idle points, change their reference torques to CITT. This is to provide smooth torque transition into idle operation.

(4) *Permissible deviations for any engine.* If your engine does not operate below a certain minimum torque under normal in-use conditions, you may use a declared minimum torque as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is connected to a hydrostatic transmission and it has a minimum torque even when all the driven hydraulic actuators and motors are stationary and the engine is at idle, then you may use this declared minimum torque as a reference torque value instead of any reference torque value generated under paragraph (d)(1) or (2) of this section that is between zero and this declared minimum torque.

(e) *Generating reference power values from normalized duty cycle powers.* Transform normalized power values to reference speed and power values using your map of maximum power versus speed.

(1) First transform normalized speed values into reference speed values. For a given speed point, multiply the corresponding % power by the mapped power at maximum test speed, f_{ntest}, unless specified otherwise by the standard-setting part. The result is the reference power for each speed point, P_{ref}. Convert these reference powers to corresponding torques for operator demand and dynamometer control and for duty cycle validation per 1065.514. Use the reference speed associated with each reference power point for this conversion. As with cycles specified with % torque, linearly interpolate between these reference torque values generated from cycles with % power.

(2) Permissible deviations for any engine. If your engine does not operate below a certain power under normal in-use conditions, you may use a declared minimum power as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is directly connected to a propeller, it may have a minimum power called idle power. In this case, you may use this declared minimum power as a reference power value instead of any reference power value generated per paragraph (e)(1) of this section that is from zero to this declared minimum power.

■ 111. Section 1065.640 is amended by revising paragraphs (a) and (e) and redesignating the second ''Table 3'' as ''Table 4'' to read as follows:

§ 1065.640 Flow meter calibration calculations.

* * * * *

(a) *Reference meter conversions.* The calibration equations in this section use molar flow rate, $\dot{n}_{ref}$, as a reference quantity. If your reference meter outputs a flow rate in a different quantity, such as standard volume rate, $\dot{V}_{stdref}$, actual volume rate, $\dot{V}_{actref}$, or mass rate, $\dot{m}_{ref}$, 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 point during a flow meter calibration:

$$\dot{n}_{ref} = \frac{\dot{V}_{stdref} \cdot P_{std}}{T_{std} \cdot R} = \frac{\dot{V}_{actref} \cdot P_{act}}{T_{act} \cdot R} = \frac{\dot{m}_{ref}}{M_{mix}} \qquad \text{Eq. 1065.640-1}$$

Where:
$\dot{N}_{ref}$ = reference molar flow rate.
$\dot{V}_{stdref}$ = reference volume flow rate, corrected to a standard pressure and a standard temperature.
$\dot{V}_{actref}$ = reference volume flow rate at the actual pressure and temperature of the flow rate.
$\dot{N}_{ref}$ = reference mass flow.
P_{std} = standard pressure.
P_{act} = actual pressure of the flow rate.
T_{std} = standard temperature.
T_{act} = actual temperature of the flow rate.
R = molar gas constant.
M_{mix} = molar mass of the flow rate.
Example 1:
$\dot{V}_{stdref}$ = 1000.00 ft³/min = 0.471948 m³/s
P = 29.9213 in Hg @ 32 °F = 101325 Pa
T = 68.0 °F = 293.15 K
R = 8.314472 J/(mol · K)

$$\dot{n}_{ref} = \frac{0.471948 \cdot 101325}{293.15 \cdot 8.314472}$$

$\dot{N}_{ref}$ = 19.169 mol/s
Example 2:
$\dot{M}_{ref}$ = 17.2683 kg/min = 287.805 g/s
M_{mix} = 28.7805 g/mol

$$\dot{n}_{ref} = \frac{287.05}{28.7805}$$

$\dot{n}_{ref}$ = 10.0000 mol/s

(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. 1065.640–4.

(2) Calculate the mean and standard deviation of all the C_d values according to Eqs. 1065.602–1 and 1065.602–2.

(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. 1065.642–6, and use the CFV only down to the lowest r measured during calibration using the following equation:

$$r = 1 - \frac{\Delta p}{p_{in}} \qquad \text{Eq. 1065.640-13}$$

(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. 1065.642–6, 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.

Example:
$A_t = 0.01824$ m^2
$p_{in} = 99132$ Pa
$Z = 1$
$M_{mix} = 28.7805$ g/mol $= 0.0287805$ kg/mol

$\dot{n}= 58.173$ mol/s

*   *   *   *   *

■ 113. A new § 1065.644 is added to read as follows:

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:
$V_{vac} = 2.0000$ L $= 0.00200$ m^3
$R = 8.314472$ J/(mol·K)
$p_2 = 50.600$ kPa $= 50600$ Pa
$T_2 = 293.15$ K
$p_1 = 25.300$ kPa $= 25300$ Pa
$T_1 = 293.15$ K

■ 112. Section 1065.642 is amended by revising paragraph (b) to read as follows:

§ 1065.642 SSV, CFV, and PDP molar flow rate calculations.

(b) *SSV molar flow rate.* Based on the C_d versus Re$^\#$ equation you determined

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \qquad \text{Eq. 1065.642-3}$$

$R = 8.314472$ J/(mol·K)
$T_{in} = 298.15$ K
$Re^\# = 7.232 \cdot 10$
$y = 1.399$
$\beta = 0.8$
$\Delta p = 2.312$ kPa

$$\dot{n} = 0.990 \cdot 0.274 \cdot \frac{0.01824 \cdot 99132}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}$$

§ 1065.644 Vacuum-decay leak rate.

This section describes how to calculate the leak rate of a vacuum-decay leak verification, which is

$$\dot{n}_{leak} = \frac{V_{vac}}{R} \cdot \frac{\left(\dfrac{p_2}{T_2} - \dfrac{p_1}{T_1} \right)}{\left(t_2 - t_1 \right)} \qquad \text{Eq. 1065.644-1}$$

$t_2 = 10{:}57{:}35$ AM
$t_1 = 10{:}56{:}25$ AM

$$\dot{n}_{leak} = \frac{0.0002}{8.314472} \cdot \frac{\left(\dfrac{50600}{293.15} - \dfrac{25300}{293.15} \right)}{(10{:}57{:}35 - 10{:}56{:}25)}$$

$$\dot{n}_{leak} = \frac{0.00200}{8.314472} \cdot \frac{86.304}{70}$$

$$\dot{n}_{leak} = 0.00030 \text{ mol/s}$$

■ 114. Section 1065.645 is revised to read as follows:

§ 1065.645 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

according to § 1065.640, calculate SSV molar flow rate, $\dot{n}$ during an emission test as follows:

Using Eq. 1065.640–7,
$r_{ssv} = 0.997$
Using Eq. 1065.640–6,
$C_f = 0.274$
Using Eq. 1065.640–5,
$C_d = 0.990$

described in § 1065.345(e). Use Eq. 1065.644–1 to calculate the leak rate, $\dot{n}_{leak}$, and compare it to the criterion specified in § 1065.345(e).

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_{sat}, as follows, or use good engineering judgment 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:

$$-\log_{10}\left(p_{H2O}\right)=10.79574\cdot\left(\frac{273.16}{T_{sat}}-1\right)+5.02800\cdot\log_{10}\left(\frac{T_{sat}}{273.16}\right)+1.50475\cdot10^{-4}\cdot\left(10^{-8.2969\cdot\left(\frac{T_{sat}}{273.16}-1\right)}-1\right)$$

$$+0.42873\cdot10^{-3}\cdot\left(1-10^{-4.76955\left(1-\frac{273.16}{T_{sat}}\right)}\right)+0.21386 \qquad \text{Eq. 1065.645-1}$$

Where:

P_{H2O} = vapor pressure of water at saturation temperature condition, kPa.

T_{sat} = saturation temperature of water at measured conditions, K.

Example:

T_{sat} = 9.5 °C
T_{dsat}= 9.5 + 273.15 = 282.65 K

$$-\log_{10}\left(p_{H2O}\right)=10.79574\cdot\left(\frac{273.16}{282.65}-1\right)+5.02800\cdot\log_{10}\left(\frac{282.65}{273.16}\right)+1.50475\cdot10^{-4}\cdot\left(10^{-8.2969\cdot\left(\frac{282.65}{273.16}-1\right)}-1\right)$$

$$+0.42873\cdot10^{-3}\cdot\left(1-10^{-4.76955\left(1-\frac{273.16}{282.65}\right)}\right)+0.21386$$

$-\log_{10}(p_{H2O}) = -0.073974$
$p_{H2O} = 10^{0.073974} = 1.18569$ kPa

(2) For humidity measurements over ice at ambient temperatures from (−100 to 0) °C, use the following equation:

$$-\log_{10}\left(P_{sat}\right)=9.09685\cdot\left(\frac{273.16}{T_{sat}}-1\right)+3.56654\cdot\log_{10}\left(\frac{273.16}{T_{sat}}\right)+0.87682\cdot\left(\frac{T_{sat}}{273.16}-1\right)+0.21386 \qquad \text{Eq. 1065.645-2}$$

Example:
T_{ice} = −15.4 °C

T_{ice} = −15.4 + 273.15 = 257.75 K

$$-\log_{10}\left(P_{sat}\right)=9.09685\cdot\left(\frac{273.16}{257.75}-1\right)+$$

$$3.56654\cdot\log_{10}\left(\frac{273.16}{257.75}\right)+$$

$$0.87682\cdot\left(\frac{257.75}{273.16}-1\right)+0.21386$$

$-\log_{10}(p_{H2O}) = -0.79821$
$p_{H2O} = 10^{0.79821} = 0.15914$ kPa

(b) *Dewpoint.* If you measure humidity as a dewpoint, determine the amount of water in an ideal gas, x_{H2O}, as follows:

$$x_{H2O}=\frac{p_{H2O}}{p_{abs}} \qquad \text{Eq. 1065.645-3}$$

Where:

x_{H2O} = amount of water in an ideal gas.
p_{H2O} = water vapor pressure at the measured dewpoint, T_{sat} = T_{dew}.

p_{abs} = wet static absolute pressure at the location of your dewpoint measurement.

Example:
p_{abs} = 99.980 kPa
T_{sat} = T_{dew} = 9.5 °C
Using Eq. 1065.645–2,
p_{H2O} = 1.18489 kPa
x_{H2O} = 1.18489/99.980
x_{H2O} = 0.011851 mol/mol

(c) *Relative humidity.* If you measure humidity as a relative humidity, RH %, determine the amount of water in an ideal gas, x_{H2O}, as follows:

$$x_{H2O}=\frac{RH\%\cdot p_{H2O}}{p_{abs}} \qquad \text{Eq. 1065.645-4}$$

Where:

x_{H2O} = amount of water in an ideal gas.
RH % = relative humidity.
p_{H2O} = water vapor pressure at 100% relative humidity at the location of your relative humidity measurement, T_{sat} = T_{amb}.

p_{abs} = wet static absolute pressure at the location of your relative humidity measurement.

Example:
RH % = 50.77%
p_{abs} = 99.980 kPa

$T_{sat} = T_{amb} = 20\ ^\circ C$
Using Eq. 1065.645–2,
$p_{H2O} = 2.3371$ kPa
$x_{H2O} = (50.77\% \cdot 2.3371)/99.980$
$x_{H2O} = 0.011868$ mol/mol

■ 115. Section 1065.650 is revised to read as follows:

§ 1065.650   Emission calculations.

(a) *General.* Calculate brake-specific emissions over each test interval in a duty cycle. Refer to the standard-setting part for any calculations you might need to determine a composite result, such as a calculation that weights and sums the results of individual test intervals in a duty cycle. For summations of continuous signals, each indexed value (i.e., ''i'') represents (or approximates) the mean value of the parameter for its respective time interval, delta-t.

(b) We specify three alternative ways to calculate brake-specific emissions, as follows:

(1) For any testing, you may calculate the total mass of emissions, as described in paragraph (c) of this section, and divide it by the total work generated over the test interval, as described in paragraph (d) of this section, using the following equation:

$$e = \frac{m}{W} \qquad \text{Eq. 1065.650-1}$$

Example:
$m_{NOx} = 64.975$ g
$W = 25.783$ kW·hr
$e_{NOx} = 64.975/25.783$
$e_{NOx} = 2.520$ g/(kW·hr)

(2) For discrete-mode steady-state testing, you may calculate the ratio of emission mass rate to power, as described in paragraph (e) of this section, using the following equation:

$$e = \frac{\bar{\bar{m}}}{\bar{P}} \qquad \text{Eq. 1065.650-2}$$

(3) For field testing, you may calculate the ratio of total mass to total work, where these individual values are determined as described in paragraph (f) of this section. You may also use this approach for laboratory testing, consistent with good engineering judgment. This is a special case in which you use a signal linearly proportional to raw exhaust molar flow rate to determine a value proportional to total emissions. You then use the same linearly proportional signal to determine total work using a chemical balance of fuel, intake air, and exhaust as described in § 1065.655, plus information about your engine's brake-specific fuel consumption. Under this method, flow meters need not meet accuracy specifications, but they must meet the applicable linearity and

repeatability specifications in subpart D or subpart J of this part. The result is a brake-specific emission value calculated as follows:

$$e = \frac{\tilde{m}}{\tilde{W}} \qquad \text{Eq. 1065.650-3}$$

Example:
$\tilde{m} = 805.5 \sim g$
$\tilde{W} = 52.102 \sim kW\cdot hr$
$e_{CO} = 805.5/52.102$
$e_{CO} = 2.520$ g/(kW·hr)

(c) *Total mass of emissions.* 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_4 concentrations, including continuous readings, sample bags readings, and dilution air background readings, for initial contamination, as described in § 1065.660(a).

(ii) Correct all concentrations measured on a ''dry'' basis to a ''wet'' basis, including dilution air background concentrations, as described in § 1065.659.

(iii) Calculate all THC and NMHC concentrations, including dilution air background concentrations, as described in § 1065.660.

(iv) For emission testing with an oxygenated fuel, calculate any HC concentrations, including dilution air background concentrations, as described in § 1065.665. See subpart I of this part for testing with oxygenated fuels.

(v) Correct all the NO_X concentrations, including dilution air background concentrations, for intake-air humidity as described in § 1065.670.

(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 § 1065.660(b)(1), take the background corrected mass of NMHC to be 0.98 times the background corrected mass of THC.

(vii) Calculate brake-specific emissions before and after correcting for drift, including dilution air background concentrations, according to § 1065.672.

(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 (including discrete-mode steady-state testing), 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 good engineering judgment to time align flow and concentration data to match t_{50} rise or fall times to within ±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 flowmeter 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:

$$m = M \cdot \sum_{i=1}^{N} x_i \cdot \dot{n}_i \cdot \Delta t \qquad \text{Eq. 1065.650-4}$$

Where:

$$\Delta t = 1/f_{record} \qquad \text{Eq. 1065.650-5}$$

Example:
$M_{NMHC} = 13.875389$ g/mol
$N = 1200$
$x_{NMHC1} = 84.5\ \mu mol/mol = 84.5 \cdot 10^{-6}$ mol/mol
$x_{NMHC2} = 86.0\ \mu mol/mol = 86.0 \cdot 10^{-6}$ mol/mol
$\dot{n}_{exh1} = 2.876$ mol/s
$\dot{n}_{exh2} = 2.224$ mol/s
$f_{record} = 1$ Hz
Using Eq. 1065.650–5,
$\Delta t = 1/1 = 1$ s
$m_{NMHC} = 13.875389 \cdot (84.5 \cdot 10^{-6} \cdot 2.876 + 86.0 \cdot 10^{-6} \cdot 2.224 + ... + x_{NMHC1200} \cdot \dot{n}_{exh}) \cdot 1$
$m_{NMHC} = 25.53$ 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 flowmeter 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 flowmeter 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, $\bar{M}_{PM}$, simply multiply it by the total flow. The result is the total mass of PM, m_{PM}. Calculate m for batch sampling with variable flow using the following equation:

$$m = M \cdot \bar{x} \cdot \sum_{i=1}^{N} \dot{n}_i \cdot \Delta t \qquad \text{Eq. 1065.650-6}$$

Example:
$M_{NOx} = 46.0055$ g/mol
$N = 9000$
$\bar{x}_{NOx} = 85.6$ μmol/mol $= 85.6 \cdot 10^{-6}$ mol/mol
$\dot{n}_{dexh1} = 25.534$ mol/s
$\dot{n}_{dexh2} = 26.950$ mol/s
$f_{record} = 5$ Hz
Using Eq. 1065.650–5,
$\Delta t = 1/5 = 0.2$
$m_{NOx} = 46.0055 \cdot 85.6 \cdot 10^{-6} \cdot (25.534 + 26.950 + ... + \dot{n}_{exh9000}) \cdot 0.2$
$m_{NOx} = 4.201$ 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 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, $\bar{M}_{PM}$, simply multiply it by the total flow, and the result is the total mass of PM, m_{PM}. Calculate m for sampling with constant flow using the following equations:

$$m = M \cdot \bar{x} \cdot \bar{\bar{n}} \cdot \Delta t \qquad \text{Eq. 1065.650-7}$$

and for PM or any other analysis of a batch sample that yields a mass per mole of sample,

$$\bar{M} = M \cdot \bar{x} \qquad \text{Eq. 1065.650-8}$$

Example:
$\bar{M}_{PM} = 144.0$ μg/mol $= 144.0 \cdot 10^{-6}$ g/mol
$\bar{n}_{dexh} = 57.692$ mol/s
$\Delta t = 1200$ s
$m_{PM} = 144.0 \cdot 10^{-6} \cdot 57.692 \cdot_{1200}$
$m_{PM} = 9.9692$ 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:

$$m = m_{dil} \cdot (DR) \qquad \text{Eq. 1065.650-9}$$

Example:
$m_{PMdil} = 6.853$ g
$DR = 6{:}1$
$m_{PM} = 6.853 \cdot (6)$
$m_{PM} = 41.118$ 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 § 1065.667.

(d) *Total work.* To calculate total work from the engine's primary output shaft, numerically integrate feedback power over a test interval. Before integrating, adjust the speed and torque data for the time alignment used in § 1065.514(c). Any advance or delay used on the feedback signals for cycle validation must also be used for calculating work. Account for work of accessories according to § 1065.110. Exclude any work during cranking and starting. Exclude work during actual motoring operation (negative feedback torques),

unless the engine was connected to one or more energy storage devices. Examples of such energy storage devices include hybrid powertrain batteries and hydraulic accumulators, like the ones illustrated in Figure 1 of § 1065.210. Exclude any work during reference zero-load idle periods (0% speed or idle speed with 0 N·m reference torque). Note, that there must be two consecutive reference zero load idle points to establish a period where this applies. Include work during idle points with simulated minimum torque such as Curb Idle Transmissions Torque (CITT) for automatic transmissions in ''drive''. The work calculation method described in paragraphs (b)(1) though (7) of this section meets these requirements using rectangular integration. You may use other logic that gives equivalent results. For example, you may use a trapezoidal integration method as described in paragraph (b)(8) of this section.

(1) Time align the recorded feedback speed and torque values by the amount used in § 1065.514(c).

(2) Calculate shaft power at each point during the test interval by multiplying all the recorded feedback engine speeds by their respective feedback torques.

(3) Adjust (reduce) the shaft power values for accessories according to § 1065.110.

(4) Set all power values during any cranking or starting period to zero. See § 1065.525 for more information about engine cranking.

(5) Set all negative power values to zero, unless the engine was connected to one or more energy storage devices. If the engine was tested with an energy storage device, leave negative power values unaltered.

(6) Set all power values to zero during idle periods with a corresponding reference torque of 0 N·m.

(7) Integrate the resulting values for power over the test interval. Calculate total work as follows:

$$W = \sum_{i=1}^{N} P_i \cdot \Delta t \qquad \text{Eq. 1065.650-10}$$

$$P_i = f_{ni} \cdot T_i \qquad \text{Eq. 1065.650-11}$$

Example:
$N = 9000$
$f_{n1} = 1800.2$ rev/min
$f_{n2} = 1805.8$ rev/min
$T_1 = 177.23$ N·m
$T_2 = 175.00$ N·m
$C_{rev} = 2 \cdot \pi$ rad/rev
$C_{t1} = 60$ s/min
$C_p = 1000$ (N·m·rad/s)/kW
$f_{record} = 5$ Hz
$C_{t2} = 3600$ s/hr

$$P_1 = \frac{1800.2 \cdot 177.23 \cdot 2 \cdot 3.14159}{60 \cdot 1000}$$

P_1 = 33.41 kW
P_2 = 33.09 kW
Using Eq. 1065.650–5,
$\Delta t = \frac{1}{5} = 0.2$ s

$$W = \frac{(33.41 + 33.09 + \ldots + P_{9000}) \cdot 0.2}{3600}$$

W = 16.875 kW·hr

(8) You may use a trapezoidal integration method instead of the rectangular integration described in this paragraph (b). To do this, you must integrate the fraction of work between points where the torque is positive. You may assume that speed and torque are linear between data points. You may not set negative values to zero before running the integration.

(e) *Steady-state mass rate divided by power.* To determine steady-state brake-specific emissions for a test interval as described in paragraph (b)(2) of this section, calculate the mean steady-state mass rate of the emission, $\bar{m}$, and the mean steady-state power, $\bar{P}$ as follows:

(1) To calculate $\bar{m}$, multiply its mean concentration, $\bar{x}$, by its corresponding mean molar flow rate, $\bar{n}$. If the result is a molar flow rate, convert this quantity to a mass rate by multiplying it by its molar mass, M. The result is the mean mass rate of the emission, $\bar{m}$. In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of sample, $\bar{M}_{PM}$, simply multiply it by the mean molar flow rate, $\bar{n}$. The result is the mass rate of PM, $\bar{m}_{PM}$. Calculate $\bar{m}$ using the following equation:

$$\bar{m} = M \cdot \bar{x} \cdot \bar{n} \qquad \text{Eq. 1065.650-12}$$

(2) Calculate $\bar{P}$ using the following equation:

$$\bar{P} = \bar{f}_n \cdot \bar{T} \qquad \text{Eq. 1065.650-13}$$

(3) Divide emission mass rate by power to calculate a brake-specific emission result as described in paragraph (b)(2) of this section.

(4) The following example shows how to calculate mass of emissions using mean mass rate and mean power:

M_{CO} = 28.0101 g/mol
$\bar{x}_{CO}$ = 12.00 mmol/mol = 0.01200 mol/mol
$\bar{n}$ = 1.530 mol/s

$\bar{f}_n$ = 3584.5 rev/min = 375.37 rad/s

$\bar{T}$ = 121.50 N·m

$\bar{m}$ = 28.0101·0.01200·1.530

$\bar{m}$ = 0.514 g/s = 1850.4 g/hr

$\bar{P}$ = 121.5·375.37

$\bar{P}$ = 45607

W = 45.607 kW

e_{CO} = 1850.4/45.61

e_{CO} = 40.57 g/(kW·hr)

(f) *Ratio of total mass of emissions to total work.* To determine brake-specific emissions for a test interval as described in paragraph (b)(3) of this section, calculate a value proportional to the total mass of each emission. Divide each proportional value by a value that is similarly proportional to total work.

(1) *Total mass.* To determine a value proportional to the total mass of an emission, determine total mass as described in paragraph (c) of this section, except substitute for the molar flow rate, $\dot{n}$, or the total flow, n, with a signal that is linearly proportional to molar flow rate, $\tilde{n}$, or linearly proportional to total flow, $\tilde{n}$, as follows:

$$\tilde{\dot{m}}_{fueli} = \frac{1}{w_{fuel}} \cdot \frac{M_C \cdot \tilde{\dot{n}}_i \cdot x_{Ccombdryi}}{1 + x_{H2Oexhdryi}} \qquad \text{Eq. 1065.650-14}$$

(2) *Total work.* To calculate a value proportional to total work over a test interval, integrate a value that is proportional to power. Use information about the brake-specific fuel consumption of your engine, e_{fuel}, to convert a signal proportional to fuel flow rate to a signal proportional to power. To determine a signal proportional to fuel flow rate, divide a signal that is proportional to the mass rate of carbon products by the fraction of carbon in your fuel, w_c. For your fuel, you may use a measured w_c or you may use the default values in Table 1 of § 1065.655. Calculate the mass rate of carbon from the amount of carbon and water in the exhaust, which you

determine with a chemical balance of fuel, intake air, and exhaust as described in § 1065.655. In the chemical balance, you must use concentrations from the flow that generated the signal proportional to molar flow rate, n~, in paragraph (e)(1) of this section. Calculate a value proportional to total work as follows:

$$W = \sum_{i=1}^{N} \tilde{P}_i \cdot \Delta t \qquad \text{Eq. 1065.650-15}$$

Where:

$$\tilde{P}_i = \frac{\tilde{\dot{m}}_{fueli}}{e_{fuel}} \qquad \text{Eq. 1065.650-16}$$

(3) *Brake-specific emissions.* Divide the value proportional to total mass by

the value proportional to total work to determine brake-specific emissions, as described in paragraph (b)(3) of this section.

(4) *Example.* The following example shows how to calculate mass of emissions using proportional values:

N = 3000
f_{record} = 5 Hz
e_{fuel} = 285 g/(kW·hr)
w_{fuel} = 0.869 g/g
M_c = 12.0107 g/mol
$\dot{n}_1$ = 3.922 ~mol/s = 14119.2 mol/hr
$x_{Ccombdry1}$ = 91.634 mmol/mol = 0.091634 mol/mol
$x_{H2Oexh1}$ = 27.21 mmol/mol = 0.02721 mol/mol
Using Eq. 1065.650–5,
Δt = 0.2 s

$$\tilde{W} = \frac{12.0107 \left[\dfrac{3.922 \cdot 0.091634}{1 + 0.02721} + \dfrac{\tilde{n}_2 \cdot x_{Ccombdry2}}{1 + x_{H2Oexh2}} + \ldots + \dfrac{\tilde{n}_{3000} \cdot x_{Ccombdry3000}}{1 + x_{H2Oexh3000}} \right] \cdot 0.2}{285 \cdot 0.869}$$

$\tilde{W}$ = 5.09 ~(kW·hr)

(g) *Rounding.* Round emission values only after all calculations are complete and the result is in g/(kW·hr) or units

equivalent to the units of the standard, such as g/(hp·hr). See the definition of "Round" in § 1065.1001.

■ 116. Section 1065.655 is revised to read as follows:

§ 1065.655 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 work, $\tilde{W}$, when you choose to determine brake-specific emissions as described in § 1065.650(e).

(2) The amount of water in a raw or diluted exhaust flow, x_{H2Oexh}, 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 § 1065.659(c)(2).

(3) The flow-weighted mean fraction of dilution air in diluted exhaust, $x_{dil/exh}$, when you do not measure dilution air flow to correct for background emissions as described in § 1065.667(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_{H2Oexh}, fraction of dilution air in diluted exhaust, $x_{dil/exh}$, and the amount of products on a C_1 basis per dry mole of dry measured flow, $x_{Ccombdry}$. 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 ± 0.0025 mol/mol of their respective mean values over the test interval. For each emission concentration, x, and amount of water, x_{H2Oexh}, you must determine their completely dry concentrations, x_{dry} and $x_{H2Oexhdry}$. You must also use your fuel's atomic hydrogen-to-carbon ratio, α, and

oxygen-to-carbon ratio, β. For your fuel, you may measure α and β or you may use the default values in Table 1 of § 1065.650. Use the following steps to complete a chemical balance:

(1) Convert your measured concentrations such as, $x_{CO2meas}$, x_{NOmeas}, and x_{H2Oint}, to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $x_{H2OxCO2meas}$, $x_{H2OxNOmeas}$, and x_{H2Oint}. If the amount of water present during a ''wet'' measurement is the same as the unknown amount of water in the exhaust flow, x_{H2Oexh}, iteratively solve for that value in the system of equations. If you measure only total NO_X and not NO and NO_2 separately, use good engineering judgment to estimate a split in your total NO_X concentration between NO and NO_2 for the chemical balances. For example, if you measure emissions from a stoichiometric spark-ignition engine, you may assume all NO_X is NO. For a compression-ignition engine, you may assume that your molar concentration of NO_X, x_{NOx}, is 75% NO and 25% NO_2. For NO_2 storage aftertreatment systems, you may assume x_{NOx} is 25% NO and 75% NO². Note that for calculating the mass of NO_X emissions, you must use the molar mass of NO_2 for the effective molar mass of all NO_X species, regardless of the actual NO_2 fraction of NO_X.

(2) Enter the equations in paragraph (c)(4) of this section into a computer program to iteratively solve for x_{H2Oexh}, $x_{Ccombdry}$, and $x_{dil/exh}$. Use good engineering judgment to guess initial values for x_{H2Oexh}, $x_{Ccombdry}$, and $x_{dil/exh}$. 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 $x_{Ccombdry}$ as the sum of your measured CO_2, CO, and THC values. We also recommend guessing an initial $x_{dil/exh}$ 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 ± 1% of their respective most recently calculated values.

(3) Use the following symbols and subscripts in the equations for this paragraph (c):

$x_{dil/exh}$ = Amount of dilution gas or excess air per mole of exhaust.

x_{H2Oexh} = Amount of water in exhaust per mole of exhaust.

$x_{Ccombdry}$ = Amount of carbon from fuel in the exhaust per mole of dry exhaust.

$x_{H2Oexhdry}$ = 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_{O2int} = Amount of intake air O_2 per mole of intake air.

$x_{CO2intdry}$ = Amount of intake air CO_2 per mole of dry intake air. You may use $x_{CO2intdry}$ = 375 μmol/mol, but we recommend measuring the actual concentration in the intake air.

$x_{H2Ointdry}$ = Amount of intake air H_2O per mole of dry intake air.

x_{CO2int} = Amount of intake air CO_2 per mole of intake air.

x_{CO2dil} = Amount of dilution gas CO_2 per mole of dilution gas.

$x_{CO2dildry}$ = Amount of dilution gas CO_2 per mole of dry dilution gas. If you use air as diluent, you may use $x_{CO2dildry}$ = 375 μmol/mol, but we recommend measuring the actual concentration in the intake air.

$x_{H2Odildry}$ = Amount of dilution gas H_2O per mole of dry dilution gas.

x_{H2Odil} = 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.

$x_{H2O[emission]meas}$ = Amount of water in sample at emission-detection location. Measure or estimate these values according to § 1065.145(d)(2).

x_{H2Oint} = Amount of water in the intake air, based on a humidity measurement of intake air.

α = Atomic hydrogen-to-carbon ratio in fuel.

β = Atomic oxygen-to-carbon ratio in fuel.

(4) Use the following equations to iteratively solve for $x_{dil/exh}$, x_{H2Oexh}, and $x_{Ccombdry}$:

$$x_{dil/exh} = 1 - \frac{x_{raw/exhdry}}{1 + x_{H2Oexhdry}} \qquad \text{Eq. 1065.655-1}$$

$$x_{H2Oexh} = \frac{x_{H2Oexhdry}}{1 + x_{H2Oexhdry}} \qquad \text{Eq. 1065.655-2}$$

$$x_{Ccombdry} = x_{CO2dry} + x_{COdry} + x_{THCdry} - x_{CO2dil} \times x_{dil/exhdry} - x_{CO2int} \times x_{int/exhdry} \qquad \text{Eq. 1065.655-3}$$

$$x_{H2Oexhdry} = \frac{a}{2}\left(x_{Ccombdry} - x_{THCdry}\right) + x_{H2Odil} \times x_{dil/exhdry} + x_{H2Oint} \times x_{int/exhdry} \qquad \text{Eq. 1065.655-4}$$

$$x_{dil/exhdry} = \frac{x_{dil/exh}}{1 - x_{H2Oexh}} \qquad \text{Eq. 1065.655-5}$$

$$x_{int/exhdry} = \frac{1}{2 \cdot x_{O2int}}\left(\left(\frac{a}{2} - b + 2\right)\cdot\left(x_{Ccombdry} - x_{THCdry}\right) - \left(x_{COdry} - x_{NOdry} - 2x_{NO2dry}\right)\right) \qquad \text{Eq. 1065.655-6}$$

$$x_{raw/exhdry} = \frac{1}{2}\left(\left(\frac{a}{2} + b\right)\cdot\left(x_{Ccombdry} - x_{THCdry}\right) + \left(2x_{THCdry} + x_{COdry} - x_{NO2dry}\right)\right) + x_{int/exhdry} \qquad \text{Eq. 1065.655-7}$$

$$x_{O2int} = \frac{0.209820 - x_{CO2intdry}}{1 + x_{H2Ointdry}} \qquad \text{Eq. 1065.655-8}$$

$$x_{CO2int} = \frac{x_{CO2intdry}}{1 + x_{H2Ointdry}} \qquad \text{Eq. 1065.655-9}$$

$$x_{H2Ointdry} = \frac{x_{H2Oint}}{1 - x_{H2Oint}} \quad \text{Eq. 1065.655-10} \qquad x_{H2Odildry} = \frac{x_{H2Odil}}{1 - x_{H2Odil}} \quad \text{Eq. 1065.655-12}$$

$$x_{CO2dil} = \frac{x_{CO2dildry}}{1 + x_{H2Odildry}} \quad \text{Eq. 1065.655-11} \qquad x_{COdry} = \frac{x_{COmeas}}{1 - x_{H2OCOmeas}} \quad \text{Eq. 1065.655-13}$$

$$x_{CO2dry} = \frac{x_{CO2meas}}{1 - x_{H2OCO2meas}} \qquad \text{Eq. 1065.655-14}$$

$$x_{NOdry} = \frac{x_{NOmeas}}{1 - x_{H2ONOmeas}} \qquad \text{Eq. 1065.655-15}$$

$$x_{NO2dry} = \frac{x_{NO2meas}}{1 - x_{H2ONO2meas}} \qquad \text{Eq. 1065.655-16}$$

$$x_{THCdry} = \frac{x_{THCmeas}}{1 - x_{H2OTHCmeas}} \qquad \text{Eq. 1065.655-17}$$

(5) The following example is a solution for $x_{dil/exh}$, x_{H2Oexh}, and $x_{Ccombdry}$ using the equations in paragraph (c)(4) of this section:

$$x_{dil/exh} = 1 - \frac{0.182}{1 + \dfrac{35.18}{1000}} = 0.824 \, \text{mol/mol} \qquad x_{H2Oexh} = \frac{35.18}{1 + \dfrac{35.18}{1000}} = 33.98 \, \text{mmol/mol}$$

$$x_{Ccombdry} = 0.025 + \frac{29.3}{1000000} + \frac{47.6}{1000000} - \frac{0.371}{1000} \times 0.853 - \frac{0.369}{1000} \times 0.171 = 0.0247 \, mol/mol$$

$$x_{H2Oexhdry} = \frac{1.8}{2}\left(0.0247 - \frac{47.6}{1000000}\right) + 0.012 \cdot 0.853 + 0.017 \cdot 0.171 = 0.035 \, mol/mol$$

$$x_{dil/exhdry} = \frac{0.824}{1 - 0.034} = 0.853 \, mol/mol$$

$$x_{int/exhdry} = \frac{1}{2 \cdot 0.206}\left(\begin{array}{c}\left(\frac{1.8}{2} - 0.050 + 2\right) \cdot \left(0.0247 - \frac{47.6}{1000000}\right) - \\ \left(\frac{29.3}{1000000} - \frac{50.4}{1000000} - 2 \cdot \frac{12.1}{1000000}\right)\end{array}\right) = 0.171 \, mol/mol$$

$$x_{raw/exhdry} = \frac{1}{2}\left(\begin{array}{c}\left(\frac{1.8}{2} + 0.050\right) \cdot \left(0.0247 - \frac{47.6}{1000000}\right) + \\ \left(2 \cdot \frac{47.6}{1000000} + \frac{29.3}{1000000} - \frac{12.1}{1000000}\right)\end{array}\right) + 0.171 = 0.182 \, mol/mol$$

$$x_{O2int} = \frac{0.209820 - 0.000375}{1 + \frac{17.22}{1000}} = 0.206 \, mol/mol$$

$$x_{CO2int} = \frac{0.000375 \times 1000}{1 + \frac{17.22}{1000}} = 0.371 \, mmol/mol$$

$$x_{H2Ointdry} = \frac{16.93}{1 - \frac{16.93}{1000}} = 17.22 \, mmol/mol$$

$$x_{CO2dil} = \frac{0.375}{1 + \frac{12.01}{1000}} = 0.37 \, mmol/mol \qquad x_{CO2dry} = \frac{24.98}{1 - \frac{8.601}{1000}} = 25.2 \, mmol/mol \qquad x_{THCdry} = \frac{46}{1 - \frac{33.98}{1000}} = 47.6 \, mmol/mol$$

$$\alpha = 1.8$$
$$\beta = 0.05$$

$$x_{H2Odildry} = \frac{11.87}{1 - \frac{11.87}{1000}} = 12.01 \, mmol/mol \qquad x_{NOdry} = \frac{50.0}{1 - \frac{8.601}{1000}} = 50.4 \, mmol/mol$$

$$x_{COdry} = \frac{29.0}{1 - \frac{8.601}{1000}} = 29.3 \, mmol/mol \qquad x_{NO2dry} = \frac{12.0}{1 - \frac{8.601}{1000}} = 12.1 \, mmol/mol$$

TABLE 1 OF § 1065.655.—DEFAULT VALUES OF ATOMIC HYDROGEN-TO-CARBON RATIO, α, ATOMIC OXYGEN-TO-CARBON RATIO, β, AND CARBON MASS FRACTION OF FUEL, w_C, FOR VARIOUS FUELS

Fuel	Atomic hydrogen and oxygen-to-carbon ratios CHαOβ	Carbon mass concentration, w_C g/g
Gasoline	$CH_{1.85}O_0$	0.866
#2 Diesel	$CH_{1.80}O_0$	0.869
#1 Diesel	$CH_{1.93}O_0$	0.861
Liquified Petroleum Gas	$CH_{2.64}O_0$	0.819
Natural gas	$CH_{3.78}O_{0.016}$	0.747
Ethanol	$CH_3O_{0.5}$	0.521
Methanol	CH_4O_1	0.375

(d) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate or fuel mass flow rate.* You may calculate the raw exhaust molar flow rate from which you sampled emissions, $\dot{n}_{exh}$, based on the measured intake air molar flow rate, $\dot{n}_{int}$, or the measured fuel mass flow rate, $\dot{n}_{fuel}$, and the values calculated using the chemical balance in paragraph (c) of this section. Note that the chemical balance must be based on raw exhaust gas concentrations. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record $\dot{n}_{int}$ or $\dot{n}_{fuel}$.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, you may calculate raw exhaust flow based on $\dot{n}_{int}$ or $\dot{n}_{fuel}$ using one of the following:

(i) You may measure flow rate through the crankcase vent and subtract it from the calculated exhaust flow.

(ii) You may estimate flow rate through the crankcase vent by engineering analysis as long as the uncertainty in your calculation does not adversely affect your ability to show that your engines comply with applicable emission standards.

(iii) You may assume your crankcase vent flow rate is zero.

(2) *Intake air molar flow rate calculation.* Based on $\dot{n}_{int}$, calculate $\dot{n}_{exh}$ as follows:

$$\dot{n}_{exh} = \frac{\dot{n}_{int}}{\left(1 + \frac{\left(x_{int/exhdry} - x_{raw/exhdry}\right)}{\left(1 + x_{H2Oexhdry}\right)}\right)} \qquad \text{Eq. 1065.655-18}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which you measured emissions.

$\dot{n}_{int}$ = intake air molar flow rate including humidity in intake air.

Example:

$\dot{n}_{int}$ = 3.780 mol/s

$x_{int/exhdry}$ = 0.69021 mol/mol
$x_{raw/exhdry}$ = 1.10764 mol/mol
$x_{H2Oexhdry}$ = 107.64 mmol/mol = 0.10764 mol/mol

$$\dot{n}_{exh} = \frac{3.780}{\left(1 + \frac{(0.69021 - 1.10764)}{(1 + 0.10764)}\right)}$$

$\dot{n}_{exh}$ = 6.066 mol/s

(3) *Fuel mass flow rate calculation.* Based on m_{fuel}, calculate $\dot{n}_{exh}$ as follows:

$$\dot{n}_{exh} = \frac{\dot{m}_{fuel} \cdot w_c \cdot \left(1 + x_{H2Oexhdry}\right)}{M_c \cdot x_{Ccombdry}} \qquad \text{Eq. 1065.655-19}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which you measured emissions.

$\dot{m}_{fuel}$ = fuel flow rate including humidity in intake air.

Example:

$\dot{m}_{fuel}$ = 7.559 g/s
w_C = 0.869 g/g
M_C = 12.0107 g/mol

$x_{Ccombdry}$ = 99.87 mmol/mol = 0.09987 mol/mol
$x_{H2Oexhdry}$ = 107.64 mmol/mol = 0.10764 mol/mol

$$\dot{n}_{exh} = \frac{7.559 \cdot 0.869 \cdot (1 + 0.10764)}{12.0107 \cdot 0.09987}$$

$\dot{n}_{exh}$ = 6.066 mol/s

■ 117. Section 1065.659 is revised to read as follows:

§ 1065.659 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, $x_{H2O[emission]meas}$, and at the flow meter, x_{H2Oexh}, 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 § 1065.645.

(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 good engineering judgment 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 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 good engineering judgment.

(4) Set $x_{H2O[emission]meas}$ 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 § 1065.655.

(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 § 1065.655.

(d) Perform a removed water correction to the concentration measurement using the following equation:

$$ x = x_{[emission]meas} \cdot \left[\frac{1 - x_{H2Oexh}}{1 - x_{H2O[emission]meas}} \right] \quad \text{Eq. 1065.659-1} $$

Example:

x_{COmeas} = 29.0 μmol/mol

$x_{H2OCOmeas}$ = 8.601 mmol/mol = 0.008601 mol/mol

x_{H2Oexh} = 34.04 mmol/mol = 0.03404 mol/mol

$$ x_{CO} = 29.0 \cdot \left[\frac{1 - 0.03404}{1 - 0.008601} \right] $$

x_{CO} = 28.3 μmol/mol

■ 118. Section 1065.660 is revised to read as follows:

§ 1065.660 THC and NMHC determination.

(a) *THC determination and THC/CH₄ initial contamination corrections.* (1) If we require you to determine THC emissions, calculate $x_{THC[THC-FID]}$ using the initial THC contamination concentration $x_{THC[THC-FID]init}$ from § 1065.520 as follows:

$$ x_{THC[THC-FID]cor} = x_{THC[THC-FID]uncor} - x_{THC[THC-FID]init} \quad \text{Eq. 1065.660-1} $$

Example:

$x_{THCuncor}$ = 150.3 μmol/mol

$x_{THCinit}$ = 1.1 μmol/mol

x_{THCcor} = 150.3 − 1.1

x_{THCcor} = 149.2 μmol/mol

(2) For the NMHC determination described in paragraph (b) of this section, correct $x_{THC[THC-FID]}$ for initial HC contamination using Eq. 1065.660–1. You may correct for initial

contamination of the CH₄ sample train using Eq. 1065.660–1, substituting in CH₄ concentrations for THC.

(b) *NMHC determination.* Use one of the following to determine NMHC concentration, x_{NMHC}:

(1) If you do not measure CH₄, you may determine NMHC concentrations as described in § 1065.650(c)(1)(vi).

(2) For nonmethane cutters, calculate x_{NMHC} using the nonmethane cutter's

penetration fractions (PF) of CH₄ and C₂H₆ from § 1065.365, and using the HC contamination and wet-to-dry corrected THC concentration $x_{THC[THC-FID]cor}$ as determined in paragraph (a) of this section.

(i) Use the following equation for penetration fractions determined using an NMC configuration as outlined in § 1065.365(d):

$$ x_{NMHC} = \frac{x_{THC[THC-FID]cor} - x_{THC[NMC-FID]} \cdot RF_{CH4[THC-FID]}}{1 - RFPF_{C2H6[NMC-FID]} \cdot RF_{CH4[THC-FID]}} \quad \text{Eq. 1065.660-2} $$

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$x_{THC[NMC-FID]}$ = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$RF_{CH4[THC-FID]}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

$RFPF_{C2H6[NMC-FID]}$ = nonmethane cutter combined ethane response factor and penetration fraction, according to § 1065.365(d).

Example:

$x_{THC[THC-FID]cor}$ = 150.3 µmol/mol
$x_{THC[NMC-FID]}$ = 20.5 µmol/mol
$RFPF_{C2H6[NMC-FID]}$ = 0.019
$RF_{CH4[THC-FID]}$ = 1.05

$$x_{NMHC} = \frac{150.3 - 20.5 \cdot 1.05}{1 - 0.019 \cdot 1.05}$$

x_{NMHC} = 130.4 µmol/mol

(ii) For penetration fractions determined using an NMC configuration as outlined in § 1065.365(e), use the following equation:

$$x_{NMHC} = \frac{x_{THC[THC-FID]cor} \cdot PF_{CH4[NMC-FID]} - x_{THC[NMC-FID]}}{PF_{CH4[N \ C-FID]} - PF_{C2H6[NMC-FID]}}$$

Eq. 1065.660-3

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{CH4[NMC-FID]}$ = nonmethane cutter CH_4 penetration fraction, according to § 1065.365(e).

$x_{THC[NMC-FID]}$ = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$PF_{C2H6[NMC-FID]}$ = nonmethane cutter ethane penetration fraction, according to § 1065.365(e).

Example:

$x_{THC[THC-FID]cor}$ = 150.3 µmol/mol
$PF_{CH4[NMC-FID]}$ = 0.990
$x_{THC[NMC-FID]}$ = 20.5 µmol/mol
$PF_{C2H6[NMC-FID]}$ = 0.020

$$x_{NMHC} = \frac{150.3 \cdot 0.990 - 20.5}{0.990 - 0.020}$$

x_{NMHC} = 132.3 µmol/mol

(iii) For penetration fractions determined using an NMC configuration as outlined in § 1065.365(f), use the following equation:

$$x_{NMHC} = \frac{x_{THC[THC-FID]cor} \cdot PF_{CH4[NMC-FID]} - x_{THC[NMC-FID]} \cdot RF_{CH4[THC-FID]}}{PF_{CH4[NMC-FID]} - RFPF_{C2H6[NMC-FID]} \cdot RF_{CH4[THC-FID]}}$$

Eq. 1065.660-4

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC.

$PF_{CH4[NMC-FID]}$ = nonmethane cutter CH_4 penetration fraction, according to § 1065.365(f).

$x_{THC[NMC-FID]}$ = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the THC FID during sampling through the NMC.

$RFPF_{C2H6[NMC-FID]}$ = nonmethane cutter CH_4 combined ethane response factor and penetration fraction, according to § 1065.365(f).

$RF_{CH4[THC-FID]}$ = response factor of THC FID to CH_4, according to § 1065.360(d).

Example:

$x_{THC[THC-FID]cor}$ = 150.3 µmol/mol
$PF_{CH4[NMC-FID]}$ = 0.990
$x_{THC[NMC-FID]}$ = 20.5 µmol/mol
$RFPF_{C2H6[NMC-FID]}$ = 0.019
$RF_{CH4[THC-FID]}$ = 0.980

$$x_{NMHC} = \frac{150.3 \cdot 0.990 - 20.5 \cdot 0.980}{0.990 - 0.019 \cdot 0.980}$$

x_{NMHC} = 132.5 µmol/mol

(3) For a gas chromatograph, calculate x_{NMHC} using the THC analyzer's response factor (RF) for CH_4, from § 1065.360, and the HC contamination and wet-to-dry corrected initial THC concentration $x_{THC[THC-FID]cor}$ as determined in section (a) above as follows:

$$x_{NMHC} = x_{THC[THC-FID]cor} - RF_{CH4[THC-FID]} \cdot x_{CH4}$$

Eq. 1065.660-5

Where:

x_{NMHC} = concentration of NMHC.

$x_{THC[THC-FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID.

x_{CH4} = concentration of CH_4, HC contamination (optional) and dry-to-wet corrected, as measured by the gas chromatograph FID.

$RF_{CH4[THC-FID]}$ = response factor of THC-FID to CH_4.

Example:

$x_{THC[THC-FID][cor}$ = 145.6 µmol/mol

$RF_{CH4[THC-FID]}$ = 0.970
x_{CH4} = 18.9 µmol/mol
x_{NMHC} = 145.6 − 0.970 · 18.9
x_{NMHC} = 127.3 µmol/mol

■ 119. Section 1065.665 is revised to read as follows:

§ 1065.665 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 1065.665–3 is only required if you need to convert your OHC concentration from mass to moles:

$$x_{THCE} = x_{NOTHC} + \sum_{i=1}^{N}\left(x_{OHCi} - x_{OHCi\text{-}init}\right) \qquad \text{Eq. 1065.665-1}$$

$$x_{NOTHC} = x_{THC[THC\text{-}FID]cor} - \sum_{i=1}^{N}\left(x_{OHCi} \cdot RF_{OHCi[THC\text{-}FID]}\right) \qquad \text{Eq. 1065.665-2}$$

$$x_{OHCi} = \frac{\dfrac{m_{dexhOHCi}}{M_{OHCi}}}{\dfrac{m_{dexh}}{M_{dexh}}} = \frac{n_{dexhOHCi}}{n_{dexh}} \qquad \text{Eq. 1065.665-3}$$

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.

$x_{OHCi\text{-}init}$ = The C_1-equivalent concentration of the initial system contamination

(optional) of oxygenated species i, dry-to-wet corrected.

$x_{THC[THC\text{-}FID]cor}$ = The C_1-equivalent response to NOTHC and all OHC in diluted exhaust, HC contamination and dry-to-wet corrected, as measured by the THC-FID.

$RF_{OHCi[THC\text{-}FID]}$ = The response factor of the FID to species i relative to propane on a C_1-equivalent basis.

$C^{\#}$ = The mean number of carbon atoms in the particular compound.

M_{dexh} = The molar mass of diluted exhaust as determined in § 1065.340.

$m_{dexhOHCi}$ = The mass of oxygenated species i in dilute exhaust.

M_{OHCi} = The C_1-equivalent molecular weight of oxygenated species i.

m_{dexh} = The mass of diluted exhaust.

$n_{dexhOHCi}$ = The number of moles of oxygenated species i in total diluted exhaust flow.

n_{dexh} = The total diluted exhaust flow.

(b) If we require you to determine NMHCE, use the following equation:

$$x_{NMHCE} = x_{THCE} - RF_{CH4[THC\text{-}FID]} \cdot x_{CH4} \qquad \text{Eq. 1065.665-4}$$

Where:

x_{NMHCE} = The C_1-equivalent sum of the concentration of carbon mass contributions of non-oxygenated NMHC, alcohols, and aldehydes.

$RF_{CH4[THC\text{-}FID]}$ = response factor of THC–FID to CH_4.

x_{CH4} = concentration of CH_4, 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_2H_5OH), methanol (CH_3OH), acetaldehyde (C_2H_4O), and formaldehyde (HCHO) as C_1-equivalent molar concentrations:

$x_{THC[THC–FID]cor}$ = 145.6 μmol/mol
x_{CH4} = 18.9 μmol/mol
x_{C2H5OH} = 100.8 μmol/mol
x_{CH3OH} = 1.1 μmol/mol
x_{C2H4O} = 19.1 μmol/mol
x_{HCHO} = 1.3 μmol/mol
$RF_{CH4[THC–FID]}$ = 1.07
$RF_{C2H5OH[THC–FID]}$ = 0.76
$RF_{CH3OH[THC–FID]}$ = 0.74
$RF_{H2H4O[THC–FID]}$ = 0.50
$RF_{HCHO[THC–FID]}$ = 0.0
$x_{NMHCE} = x_{THC[THC–FID]cor} - (x_{C2H5OH} \cdot RF_{C2H5OH[THC–FID]} + x_{CH3OH} \cdot RF_{CH3OH[THC–FID]} + x_{C2H4O} \cdot RF_{C2H4O[THC–FID]} + x_{HCHO} \cdot$
$RF_{HCHO[THC–FID]} + x_{C2H5OH} + x_{CH3OH} + x_{C2H4O} + x_{HCHO} - (RF_{CH4[THC–FID]} \cdot x_{CH4})$
$x_{NMHCE} = 145.6 - (100.8 \cdot 0.76 + 1.1 \cdot 0.74 + 19.1 \cdot 0.50 + 1.3 \cdot 0) + 100.8 + 1.1 + 19.1 + 1.3 - (1.07 \cdot 18.9)$
x_{NMHCE} = 160.71 μmol/mol

■ 120. Section 1065.667 is amended by revising paragraph (b) to read as follows:

§ 1065.667 Dilution air background emission correction.

* * * * *

(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 § 1065.650(b), using the dilution air flow, n_{dil}. Subtract the background mass from the total mass. Use the result in brake-specific emission calculations.

* * * * *

■ 121. Section 1065.670 is amended by revising the introductory text to read as follows:

§ 1065.670 NO$_X$ intake-air humidity and temperature corrections.

See the standard-setting part to determine if you may correct NO$_X$ emissions for the effects of intake-air

humidity or temperature. Use the NO$_X$ intake-air humidity and temperature corrections specified in the standard-setting part instead of the NO$_X$ intake-air humidity correction specified in this part 1065. If the standard-setting part does not prohibit correcting NO$_X$ emissions for intake-air humidity according to this part 1065, first apply any NO$_X$ corrections for background emissions and water removal from the exhaust sample, then correct NO$_X$ 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:

* * * * *

■ 122. Section 1065.675 is revised to read as follows:

§ 1065.675 CLD quench verification calculations.

Perform CLD quench-check calculations as follows:

(a) Calculate the amount of water in the span gas, $x_{H2Ospan}$, assuming

complete saturation at the span-gas temperature.

(b) Estimate the expected amount of water and CO_2 in the exhaust you sample, x_{H2Oexp} and x_{CO2exp},

respectively, by considering the maximum expected amounts of water in combustion air, fuel combustion products, and dilution air concentrations (if applicable).

(c) Set x_{H2Oexp} equal to $x_{H2Omeas}$ if you are using a sample dryer that passes the sample dryer verification check in § 1065.342.

(d) Calculate water quench as follows:

$$\text{quench} = \left(\frac{\dfrac{x_{NOwet}}{1 - x_{H2Omeas}}}{x_{NOdry}} - 1 \right) \cdot \frac{x_{H2Oexp}}{x_{H2Omeas}} + \frac{x_{NO,CO2} - x_{NO,N2}}{x_{NO,N2}} \cdot \frac{x_{CO2exp}}{x_{CO2meas}} \qquad \text{Eq. 1065.675-1}$$

Where:

quench = amount of CLD quench.

x_{NOdry} = measured concentration of NO upstream of a bubbler, according to § 1065.370.

x_{NOwet} = measured concentration of NO downstream of a bubbler, according to § 1065.370.

x_{H2Oexp} = expected maximum amount of water entering the CLD sample port during emission testing.

$x_{H2Omeas}$ = measured amount of water entering the CLD sample port during the quench verification specified in § 1065.370.

$x_{NO,CO2}$ = measured concentration of NO when NO span gas is blended with CO_2 span gas, according to § 1065.370.

$x_{NO,N2}$ = measured concentration of NO when NO span gas is blended with N_2 span gas, according to § 1065.370.

x_{CO2exp} = expected maximum amount of CO_2 entering the CLD sample port during emission testing.

$x_{CO2meas}$ = measured amount of CO_2 entering the CLD sample port during the quench verification specified in § 1065.370.

Example:

x_{NOdry} = 1800.0 µmol/mol
x_{NOwet} = 1760.5 µmol/mol
x_{H2Oexp} = 0.030 mol/mol
$x_{H2Omeas}$ = 0.017 mol/mol
$x_{NO,CO2}$ = 1480.2 µmol/mol
$x_{NO,N2}$ = 1500.8 µmol/mol
x_{CO2exp} = 2.00%
$x_{CO2meas}$ = 3.00%

$$\text{quench} = \left(\frac{\dfrac{1760.5}{1 - 0.017}}{1800.0} - 1 \right) \cdot \frac{0.030}{0.017} + \frac{1480.2 - 1500.8}{1500.8} \cdot \frac{2.00}{3.00}$$

quench = −0.00888 − 0.00915 = −1.80%

■ 123. Section 1065.690 is amended by revising paragraph (e) to read as follows:

§ 1065.690 Buoyancy correction for PM sample media.

* * * * *

(e) *Correction calculation.* Correct the PM sample media for buoyancy using the following equations:

$$m_{cor} = m_{uncor} \cdot \left[\frac{1 - \dfrac{\rho_{air}}{\rho_{weight}}}{1 - \dfrac{\rho_{air}}{\rho_{media}}} \right] \qquad \text{Eq. 1065.690-1}$$

Where:

m_{cor} = PM mass corrected for buoyancy.
m_{uncor} = PM mass uncorrected for buoyancy.
P_{air} = density of air in balance environment.
P_{weight} = density of calibration weight used to span balance.
P_{media} = density of PM sample media, such as a filter.

$$r_{air} = \frac{p_{abs} \cdot M_{mix}}{R \cdot T_{amb}} \qquad \text{Eq.1065.690-2}$$

Where:

p_{abs} = absolute pressure in balance environment.
M_{mix} = molar mass of air in balance environment.
R = molar gas constant.
T_{amb} = absolute ambient temperature of balance environment.

Example:

p_{abs} = 99.980 kPa
$T_{sat} = T_{dew}$ = 9.5 °C
Using Eq. 1065.645–2,
p_{H2O} = 1.1866 kPa
Using Eq. 1065.645–3,
x_{H2O} = 0.011868 mol/mol
Using Eq. 1065.640–9,
M_{mix} = 28.83563 g/mol
R = 8.314472 J/(mol · K)
T_{amb} = 20 °C

$$r_{air} = \frac{99.980 \cdot 28.83563}{8.314472 \cdot 293.15}$$

$P_{air} = 1.18282$ kg/m^3
$m_{uncorr} = 100.0000$ mg
$P_{weight} = 8000$ kg/m^3
$P_{media} = 920$ kg/m^3

$$m_{cor} = 100.0000 \cdot \left[\frac{1 - \dfrac{1.18282}{8000}}{1 - \dfrac{1.18282}{920}} \right]$$

m_{cor} 100.1139 mg

■ 124. Section 1065.695 is amended by revising paragraph (c)(7)(ix) to read as follows:

§ 1065.695   Data requirements.

* * * * *

(c) * * *

(7) * * *

(ix) Warm-idle speed value.

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Subpart H—[Amended]

■ 125. Section 1065.701 is amended by revising paragraphs (b), (c), and (e) to read as follows:

§ 1065.701   General requirements for test fuels.

* * * * *

(b) *Fuels meeting alternate specifications.* We may allow you to use a different test fuel (such as California Phase 2 gasoline) if it does not affect your ability to show that your engines would comply with all applicable emission standards using the fuel specified in this subpart.

(c) *Fuels not specified in this subpart.* If you produce engines that run on a type of fuel (or mixture of fuels) that we do not specify in this subpart, you must get our written approval to establish the appropriate test fuel. See the standard-setting part for provisions related to fuels and fuel mixtures not specified in this subpart.

(1) For engines designed to operate on a single fuel, we will generally allow you to use the fuel if you show us all the following things are true:

(i) Show that your engines will use only the designated fuel in service.

(ii) Show that this type of fuel is commercially available.

(iii) Show that operating the engines on the fuel we specify would be inappropriate, as in the following examples:

(A) The engine will not run on the specified fuel.

(B) The engine or emission controls will not be durable or work properly when operating with the specified fuel.

(C) The measured emission results would otherwise be substantially unrepresentative of in-use emissions.

(2) For engines that are designed to operate on different fuel types, the provisions of paragraphs (c)(1)(ii) and (iii) of this section apply with respect to each fuel type.

(3) For engines that are designed to operate on different fuel types as well as continuous mixtures of those fuels, we may require you to test with either the worst-case fuel mixture or the most representative fuel mixture, unless the standard-setting part specifies otherwise.

* * * * *

(e) *Service accumulation and field testing fuels.* If we do not specify a service-accumulation or field-testing fuel in the standard-setting part, use an appropriate commercially available fuel such as those meeting minimum specifications from the following table:

TABLE 1 OF § 1065.701.—EXAMPLES OF SERVICE-ACCUMULATION AND FIELD-TESTING FUELS

Fuel category	Subcategory	Reference procedure [1]
Diesel	Light distillate and light blends with residual	ASTM D975–07b.
	Middle distillate	ASTM D6751–07b.
	Biodiesel (B100)	ASTM D6985–04a.
Intermediate and residual fuel	All	See § 1065.705.
Gasoline	Motor vehicle gasoline	ASTM D4814–07a.
	Minor oxygenated gasoline blends	ASTM D4814–07a.
Alcohol	Ethanol (Ed75–85)	ASTM D5798–07.
	Methanol (M70–M85)	ASTM D5797–07.
Aviation fuel	Aviation gasoline	ASTM D910–07.
	Gas turbine	ASTM D1655–07e01.
	Jet B wide cut	ASTM D6615–06.
Gas turbine fuel	General	ASTM D2880–03.

[1] ASTM specifications are incorporated by reference in § 1065.1010.

■ 126. Section 1065.703 is amended by revising Table 1 to read as follows:

§ 1065.703   Distillate diesel fuel.

* * * * *

TABLE 1 OF § 1065.703.—TEST FUEL SPECIFICATIONS FOR DISTILLATE DIESEL FUEL

Item	Units	Ultra low sulfur	Low sulfur	High sulfur	Reference procedure [1]
Cetane Number	....	40–50	40–50	40–50	ASTM D613–05.
Distillation range	°C				
Initial boiling point	....	171–204	171–204	171–204	ASTM D86–07a.
10 pct. point	....	204–238	204–238	204–238	
50 pct. point	....	243–282	243–282	243–282	
90 pct. point	....	293–332	293–332	293–332	
Endpoint	....	321–366	321–366	321–366	
Gravity	° API	32–37	32–37	32–37	ASTM D4052–96e01.
Total sulfur	mg/kg	7–15	300–500	2000–4000	ASTM D2622–07.
Aromatics, min. (Remainder shall be paraffins, naphthalenes, and olefins).	g/kg	100	100	100	ASTM D5186–03.
Flashpoint, min.	°C	54	54	54	ASTM D93–07.

TABLE 1 OF §1065.703.—TEST FUEL SPECIFICATIONS FOR DISTILLATE DIESEL FUEL—Continued

Item	Units	Ultra low sulfur	Low sulfur	High sulfur	Reference procedure [1]
Kinematic Viscosity	cSt	2.0–3.2	2.0–3.2	2.0–3.2	ASTM D445–06.

[1] ASTM procedures are incorporated by reference in §1065.1010. See §1065.701(d) for other allowed procedures.

■ 127. A new § 1065.705 is added to read as follows:

§ 1065.705 Residual and intermediate residual fuel.

This section describes the specifications for fuels meeting the definition of residual fuel in 40 CFR 80.2, including fuels marketed as intermediate fuel. Residual fuels for service accumulation and any testing must meet the following specifications:

(a) The fuel must be a commercially available fuel that is representative of the fuel that will be used by the engine in actual use.

(b) The fuel must meet the specifications for one of the categories in the following table:

TABLE 1 OF §1065.705.—SERVICE ACCUMULATION AND TEST FUEL SPECIFICATIONS FOR RESIDUAL FUEL

Characteristic	Unit	Category ISO–F–										Test method reference [1]
		RMA 30	RMB 30	RMD 80	RME 180	RMF 180	RMG 380	RMH 380	RMK 380	RMH 700	RMK 700	
Density at 15 °C, max.	kg/m³	960.0	975.0	980.0	991.0		991.0		1010.0	991.0	1010.0	ISO 3675 or ISO 12185: 1996/Cor 1:2001 (see also ISO 8217:2005(E) 7.1).
Kinematic viscosity at 50 °C, max.	cSt	30.0		80.0	180.0		380.0			700.0		ISO 3104:1994/Cor 1:1997.
Flash point, min	°C	60		60	60		60			60		ISO 2719 (see also ISO 8217:2005(E) 7.2).
Pour point (upper):												
Winter quality, max.	°C	0	24	30	30		30			30		ISO 3016.
Summer quality, max.	....	6	24	30	30		30			30		ISO 3016.
Carbon residue, max.	(kg/kg)%	10		14	15	20	18	22		22		ISO 10370:1993/Cor 1:1996.
Ash, max.	(kg/kg)%	0.10		0.10	0.10	0.15	0.15			0.15		ISO 6245.
Water, max	(m³/m³)%	0.5		0.5	0.5		0.5			0.5		ISO 3733.
Sulfur, max	(kg/kg)%	3.50		4.00	4.50		4.50			4.50		ISO 8754 or ISO 14596: 1998/Cor 1:1999 (see also ISO 8217:2005(E) 7.3).
Vanadium, max	mg/kg	150		350	200	500	300	600		600		ISO 14597 or IP 501 or IP 470 (see also ISO 8217:2005(E) 7.8).
Total sediment potential, max.	(kg/kg)%	0.10		0.10	0.10		0.10			0.10		ISO 10307–2 (see also ISO 8217:2005(E) 7.6).
Aluminium plus silicon, max.	mg/kg 80	80		80	80		80			80		ISO 10478 or IP 501 or IP 470 (see also ISO 8217:2005(E) 7.9).
Used lubricating oil (ULO), max.	....	Fuel shall be free of ULO. We consider a fuel to be free of ULO if one or more of the elements zinc, phosphorus, or calcium is at or below the specified limits. We consider a fuel to contain ULO if all three elements exceed the specified limits.										IP 501 or IP 470 (see ISO 8217:2005(E) 7.7). IP 501 or IP 500 (see ISO 8217:2005(E) 7.7). IP 501 or IP 470 (see ISO 8217:2005(E) 7.7).
	mg/kg	15										
Zinc	....	15										
Phosphorus	....	15										
Calcium	....	30										

[1] ISO procedures are incorporated by reference in §1065.1010. See §1065.701(d) for other allowed procedures.

■ 128. Section 1065.710 is amended by revising Table 1 to read as follows:

§ 1065.710 Gasoline.

* * * * *

TABLE 1 OF § 1065.710.—TEST FUEL SPECIFICATIONS FOR GASOLINE

Item	Units	General testing	Low-temperature testing	Reference procedure [1]
Distillation Range:				
Initial boiling point	°C	24–35 [2]	24–36.	
10% point		49–57	37–48	ASTM D86–07a.
50% point		93–110	82–101.	
90% point		149–163	158–174.	
End point		Maximum, 213	Maximum, 212.	
Hydrocarbon composition:				
Olefins	m^3/m^3	Maximum, 0.10	Maximum, 0.175	ASTM D1319–03.
Aromatics		Maximum, 0.35	Maximum, 0.304.	
Saturates		Remainder	Remainder.	
Lead (organic)	g/liter	Maximum, 0.013	Maximum, 0.013	ASTM D3237–06e01.
Phosphorous	g/liter	Maximum, 0.0013	Maximum, 0.005	ASTM D3231–07.
Total sulfur	mg/kg	Maximum, 80	Maximum, 80	ASTM D2622–07.
Volatility (Reid Vapor Pressure)	kPa	60.0–63.4 [2][3]	77.2–81.4	ASTM D5191–07.

[1] ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.
[2] For testing at altitudes above 1,219 m, the specified volatility range is (52.0 to 55.2) kPa and the specified initial boiling point range is (23.9 to 40.6) °C.
[3] For testing unrelated to evaporative emissions, the specified range is (55.2 to 63.4) kPa.

■ 129. Section 1065.715 is revised to read as follows:

§ 1065.715 Natural gas.

(a) Except as specified in paragraph (b) of this section, natural gas for testing must meet the specifications in the following table:

TABLE 1 OF § 1065.715.—TEST FUEL SPECIFICATIONS FOR NATURAL GAS

Item	Value [1]
Methane, CH_4	Minimum, 0.87 mol/mol.
Ethane, C_2H_6	Maximum, 0.055 mol/mol.
Propane, C_3H_8	Maximum, 0.012 mol/mol.
Butane, C_4H_{10}	Maximum, 0.0035 mol/mol.
Pentane, C_5H_{12}	Maximum, 0.0013 mol/mol.
C_6 and higher	Maximum, 0.001 mol/mol.
Oxygen	Maximum, 0.001 mol/mol.
Inert gases (sum of CO_2 and N_2)	Maximum, 0.051 mol/mol.

[1] All parameters are based on the reference procedures in ASTM D1945–03 (incorporated by reference in § 1065.1010). See § 1065.701(d) for other allowed procedures.

(b) In certain cases you may use test fuel not meeting the specifications in paragraph (a) of this section, as follows:

(1) You may use fuel that your in-use engines normally use, such as pipeline natural gas.

(2) You may use fuel meeting alternate specifications if the standard-setting part allows it.

(3) You may ask for approval to use fuel that does not meet the specifications in paragraph (a) of this section, but only if using the fuel would not adversely affect your ability to demonstrate compliance with the applicable standards.

(c) When we conduct testing using natural gas, we will use fuel that meets the specifications in paragraph (a) of this section.

(d) At ambient conditions, natural gas must have a distinctive odor detectable down to a concentration in air not more than one-fifth the lower flammable limit.

■ 130. Section 1065.720 is revised to read as follows:

§ 1065.720 Liquefied petroleum gas.

(a) Except as specified in paragraph (b) of this section, liquefied petroleum gas for testing must meet the specifications in the following table:

TABLE 1 OF § 1065.720.—TEST FUEL SPECIFICATIONS FOR LIQUEFIED PETROLEUM GAS

Item	Value	Reference procedure [1]
Propane, C_3H_8	Minimum, 0.85 m^3/m^3	ASTM D2163–05.
Vapor pressure at 38 °C	Maximum, 1400 kPa	ASTM D1267–02 or 2598–02[2].
Volatility residue (evaporated temperature, 35 °C)	Maximum, −38 °C	ASTM D1837–02a.
Butanes	Maximum, 0.05 m^3/m^3	ASTM D2163–05.
Butenes	Maximum, 0.02 m^3/m^3	ASTM D2163–05.
Pentenes and heavier	Maximum, 0.005 m^3/m^3	ASTM D2163–05.
Propene	Maximum, 0.1 m^3/m^3	ASTM D2163–05.
Residual matter (residue on evap. of 100 ml oil stain observ.)	Maximum, 0.05 ml pass[3]	ASTM D2158–05.
Corrosion, copper strip	Maximum, No. 1	ASTM D1838–07.
Sulfur	Maximum, 80 mg/kg	ASTM D2784–06.

TABLE 1 OF § 1065.720.—TEST FUEL SPECIFICATIONS FOR LIQUEFIED PETROLEUM GAS—Continued

Item	Value	Reference procedure [1]
Moisture content	pass	ASTM D2713–91.

[1] ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.
[2] If these two test methods yield different results, use the results from ASTM D1267–02.
[3] The test fuel must not yield a persistent oil ring when you add 0.3 ml of solvent residue mixture to a filter paper in 0.1 ml increments and examine it in daylight after two minutes.

(b) In certain cases you may use test fuel not meeting the specifications in paragraph (a) of this section, as follows:

(1) You may use fuel that your in-use engines normally use, such as commercial-quality liquefied petroleum gas.

(2) You may use fuel meeting alternate specifications if the standard-setting part allows it.

(3) You may ask for approval to use fuel that does not meet the specifications in paragraph (a) of this section, but only if using the fuel would not adversely affect your ability to demonstrate compliance with the applicable standards.

(c) When we conduct testing using liquefied petroleum gas, we will use fuel that meets the specifications in paragraph (a) of this section.

(d) At ambient conditions, liquefied petroleum gas must have a distinctive odor detectable down to a concentration in air not more than one-fifth the lower flammable limit.

■ 131. Section 1065.750 is amended by revising paragraph (a) to read as follows:

§ 1065.750 Analytical Gases.

*　　*　　*　　*　　*

(a) Subparts C, D, F, and J of this part 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 μmol/mol, then you would be allowed to use a zero gas with CO contamination less than or equal to 2.000 μmol/mol.

(ii) Contamination as specified in the following table:

TABLE 1 OF § 1065.750.—GENERAL SPECIFICATIONS FOR PURIFIED GASES

Constituent	Purified synthetic air [1]	Purified N_2 [1]
THC (C_1 equivalent)	< 0.05 μmol/mol	< 0.05 μmol/mol.
CO	< 1 μmol/mol	< 1 μmol/mol.
CO_2	< 10 μmol/mol	< 10 μmol/mol.
O_2	0.205 to 0.215 mol/mol	< 2 μmol/mol.
NO_X	< 0.02 μmol/mol	< 0.02 μmol/mol.

[1] We do not require these levels of purity to be NIST-traceable.

(2) Use the following gases with a FID analyzer:

(i) *FID fuel.* Use FID fuel with a stated H^2 concentration of (0.39 to 0.41) mol/mol, balance He, and a stated total hydrocarbon concentration of 0.05 μmol/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_2 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_2 in the exhaust sample during testing.

(iv) *FID propane span gas.* Span and calibrate THC FID with span concentrations of propane, 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 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_2 expected during testing. If the expected O_2 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_4 FID with a nonmethane cutter, then span and calibrate the FID with span concentrations of methane, CH_4. Calibrate on a carbon number basis of one (C_1). For example, if you use a CH_4 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_2 in the exhaust sample during testing. If the expected O_2 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_4, balance purified synthetic air and/or N_2 (as applicable).

(ii) C_2H_6, balance purified synthetic air and/or N_2 (as applicable).

(iii) C_3H_8, balance purified synthetic air and/or N_2 (as applicable).

(iv) CO, balance purified N_2.

(v) CO_2, balance purified N_2.

(vi) NO, balance purified N_2.

(vii) NO_2, balance purified synthetic air.

(viii) O_2, balance purified N_2.

(ix) C_3H_8, CO, CO_2, NO, balance purified N_2.

(x) C_3H_8, CH_4, CO, CO_2, NO, balance purified N_2.

(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_2 or purified synthetic air. If your gas dividers meet the specifications in § 1065.248, 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).

* * * * *

Subpart I—[Amended]

■ 132. Section 1065.805 is amended by revising paragraphs (a), (b), and (c) to read as follows:

§ 1065.805 Sampling system.

(a) Dilute engine 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.

(c) Maintain sample temperatures within the dilution tunnel, 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 good engineering judgment 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 engines.

* * * * *

■ 133. Section 1065.845 is amended by revising the introductory text to read as follows:

§ 1065.845 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.

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Subpart J—[Amended]

■ 134. Section 1065.901 is amended by revising paragraphs (b) introductory text and (b)(2) to read as follows:

§ 1065.901 Applicability.

* * * * *

(b) *Laboratory testing.* You may use PEMS for any testing in a laboratory or similar environment without restriction or prior approval if the PEMS meets all applicable specifications for laboratory testing. You may also use PEMS for any testing in a laboratory or similar environment if we approve it in advance, subject to the following provisions: * * *

(2) Do not apply any PEMS-related field-testing adjustments or measurement allowances to laboratory emission results or standards.

* * * * *

■ 135. Section 1065.905 is amended by revising paragraphs (c)(14) and (e) introductory text to read as follows:

§ 1065.905 General provisions.

* * * * *

(c) * * *

(14) Does any special measurement allowance apply to field-test emission results or standards, based on using PEMS for field-testing versus using laboratory equipment and instruments for laboratory testing?

* * * * *

(e) *Laboratory testing using PEMS.* You may use PEMS for testing in a laboratory as described in § 1065.901(b). Use the following procedures and specifications when using PEMS for laboratory testing:

* * * * *

■ 136. Section 1065.910 is revised to read as follows:

§ 1065.910 PEMS auxiliary equipment for field testing.

For field testing you may use various types of auxiliary equipment to attach PEMS to a vehicle or engine and to power PEMS.

(a) When you use PEMS, you may route engine intake air or exhaust through a flow meter. Route the engine intake air or exhaust as follows:

(1) *Flexible connections.* Use short flexible connectors where necessary.

(i) You may use flexible connectors to enlarge or reduce the pipe diameters to match that of your test equipment.

(ii) We recommend that you use flexible connectors that do not exceed a length of three times their largest inside diameter.

(iii) We recommend that you use four-ply silicone-fiberglass fabric with a temperature rating of at least 315 °C for flexible connectors. You may use connectors with a spring-steel wire helix for support and you may use Nomex™ coverings or linings for durability. You may also use any other nonreactive material with equivalent permeation-resistance and durability, as long as it seals tightly.

(iv) Use stainless-steel hose clamps to seal flexible connectors, or use clamps that seal equivalently.

(v) You may use additional flexible connectors to connect to flow meters.

(2) *Tubing.* Use rigid 300 series stainless steel tubing to connect between flexible connectors. Tubing may be straight or bent to accommodate vehicle geometry. You may use ''T'' or ''Y'' fittings made of 300 series stainless steel tubing to join multiple connections, or you may cap or plug redundant flow paths if the engine manufacturer recommends it.

(3) *Flow restriction.* Use flowmeters, connectors, and tubing that do not increase flow restriction so much that it exceeds the manufacturer's maximum specified value. You may verify this at the maximum exhaust flow rate by measuring pressure at the manufacturer-specified location with your system connected. You may also perform an engineering analysis to verify an acceptable configuration, taking into account the maximum exhaust flow rate expected, the field test system's flexible connectors, and the tubing's characteristics for pressure drops versus flow.

(b) For vehicles or other motive equipment, we recommend installing PEMS in the same location where a passenger might sit. Follow PEMS manufacturer instructions for installing PEMS in cargo spaces, engine spaces, or externally such that PEMS is directly exposed to the outside environment. We recommend locating PEMS where it will be subject to minimal sources of the following parameters:

(1) Ambient temperature changes.

(2) Ambient pressure changes.

(3) Electromagnetic radiation.

(4) Mechanical shock and vibration.

(5) Ambient hydrocarbons—if using a FID analyzer that uses ambient air as FID burner air.

(c) Use mounting hardware as required for securing flexible connectors, ambient sensors, and other equipment. Use structurally sound mounting points such as vehicle frames, trailer hitch receivers, walkspaces, and payload tie-down fittings. We