

■ 347. Section 1068.330 is amended by revising the section heading and paragraph (c) and adding paragraph (a)(4) to read as follows:

**§ 1068.330 How do I import engines requiring further assembly?**

\* \* \* \* \*

(a) \* \* \*

(4) You import a complete or partially complete engine for installation in equipment subject to equipment-based standards for which you have either a certificate of conformity or an exemption that allows you to sell the equipment.

\* \* \* \* \*

(c) If we approve a temporary exemption for an engine, you may import it under the conditions in this section. If you are not a certificate holder, we may ask the U.S. Customs Service to require a specific bond amount to make sure you comply with the requirements of this subpart.

\* \* \* \* \*

■ 348. Section 1068.335 is amended by revising paragraph (b) to read as follows:

**§ 1068.335 What are the penalties for violations?**

\* \* \* \* \*

(b) *Temporarily imported engines.* If you do not comply with the provisions of this subpart for a temporary exemption under § 1068.325 or § 1068.330, you may forfeit the total amount of the bond in addition to the sanctions we identify in paragraph (a) of this section. We will consider an engine to be exported if it has been destroyed or delivered to the U.S. Customs Service for export or other disposition under applicable Customs laws and regulations. EPA or the U.S. Customs Service may offer you a grace period to allow you to export a temporarily exempted engine without penalty after the exemption expires.

■ 349. Section 1068.410 is amended by adding paragraph (j) to read as follows:

**§ 1068.410 How must I select and prepare my engines?**

\* \* \* \* \*

(j) *Retesting after reaching a fail decision.* You may retest your engines once a fail decision for the audit has been reached based on the first test on each engine under § 1068.420(c). You may test each engine up to a total of three times, but you must perform the same number of tests on each engine. You may further operate the engine to stabilize emission levels before testing, subject to the provisions of paragraph (f) of this section. We may approve retesting at other times if you send us a request with satisfactory justification.

■ 350. Section 1068.505 is amended by adding paragraph (g) to read as follows:

**§ 1068.505 How does the recall program work?**

\* \* \* \* \*

(g) For purposes of recall, *owner* means someone who owns an engine affected by a remedial plan or someone who owns a piece of equipment that has one of these engines.

■ 351. Section 1068.510 is amended by revising paragraph (a)(10) to read as follows:

**§ 1068.510 How do I prepare and apply my remedial plan?**

(a) \* \* \*

(10) If your employees or authorized warranty agents will not be doing the work, state who will and describe their qualifications.

\* \* \* \* \*

**§ 1068.540 [Removed]**

■ 352. Section 1068.540 is removed.

■ 353. Part 1065 is revised to read as follows:

**PART 1065—ENGINE-TESTING PROCEDURES**

**Subpart A—Applicability and General Provisions**

Sec.

- 1065.1 Applicability.
- 1065.2 Submitting information to EPA under this part.
- 1065.5 Overview of this part 1065 and its relationship to the standard-setting part.
- 1065.10 Other procedures.
- 1065.12 Approval of alternate procedures.
- 1065.15 Overview of procedures for laboratory and field testing.
- 1065.20 Units of measure and overview of calculations.
- 1065.25 Recordkeeping.

**Subpart B—Equipment Specifications**

- 1065.101 Overview.
- 1065.110 Work inputs and outputs, accessory work, and operator demand.
- 1065.120 Fuel properties and fuel temperature and pressure.
- 1065.122 Engine cooling and lubrication.
- 1065.125 Engine intake air.
- 1065.127 Exhaust gas recirculation.
- 1065.130 Engine exhaust.
- 1065.140 Dilution for gaseous and PM constituents.
- 1065.145 Gaseous and PM probes, transfer lines, and sampling system components.
- 1065.150 Continuous sampling.
- 1065.170 Batch sampling for gaseous and PM constituents.
- 1065.190 PM-stabilization and weighing environments for gravimetric analysis.
- 1065.195 PM-stabilization environment for in-situ analyzers.

**Subpart C—Measurement Instruments**

- 1065.201 Overview and general provisions.
- 1065.202 Data updating, recording, and control.

1065.205 Performance specifications for measurement instruments.

Measurement of Engine Parameters and Ambient Conditions

- 1065.210 Work input and output sensors.
- 1065.215 Pressure transducers, temperature sensors, and dewpoint sensors.

Flow-Related Measurements

- 1065.220 Fuel flow meter.
- 1065.225 Intake-air flow meter.
- 1065.230 Raw exhaust flow meter.
- 1065.240 Dilution air and diluted exhaust flow meters.
- 1065.245 Sample flow meter for batch sampling.
- 1065.248 Gas divider.

CO and CO<sub>2</sub> Measurements

- 1065.250 Nondispersive infra-red analyzer.

Hydrocarbon Measurements

- 1065.260 Flame ionization detector.
- 1065.265 Nonmethane cutter.
- 1065.267 Gas chromatograph.

NO<sub>x</sub> Measurements

- 1065.270 Chemiluminescent detector.
- 1065.272 Nondispersive ultraviolet analyzer.

O<sub>2</sub> Measurements

- 1065.280 Paramagnetic and magnetopneumatic O<sub>2</sub> detection analyzers.

Air-to-Fuel Ratio Measurements

- 1065.284 Zirconia (ZrO<sub>2</sub>) analyzer.

PM Measurements

- 1065.290 PM gravimetric balance.
- 1065.295 PM inertial balance for field-testing analysis.

**Subpart D—Calibrations and Verifications**

- 1065.301 Overview and general provisions.
- 1065.303 Summary of required calibration and verifications
- 1065.305 Verifications for accuracy, repeatability, and noise.
- 1065.307 Linearity verification.
- 1065.308 Continuous gas analyzer system-response and updating-recording verification.
- 1065.309 Continuous gas analyzer uniform response verification.

Measurement of Engine Parameters and Ambient Conditions

- 1065.310 Torque calibration.
- 1065.315 Pressure, temperature, and dewpoint calibration.

Flow-Related Measurements

- 1065.320 Fuel-flow calibration.
- 1065.325 Intake-flow calibration.
- 1065.330 Exhaust-flow calibration.
- 1065.340 Diluted exhaust flow (CVS) calibration.
- 1065.341 CVS and batch sampler verification (propane check).
- 1065.345 Vacuum-side leak verification.

CO and CO<sub>2</sub> Measurements

- 1065.350 H<sub>2</sub>O interference verification for CO<sub>2</sub> NDIR analyzers.
- 1065.355 H<sub>2</sub>O and CO<sub>2</sub> interference verification for CO NDIR analyzers.

## Hydrocarbon Measurements

- 1065.360 FID optimization and verification.  
 1065.362 Non-stoichiometric raw exhaust FID O<sub>2</sub> interference verification.  
 1065.365 Nonmethane cutter penetration fractions.

NO<sub>x</sub> Measurements

- 1065.370 CLD CO<sub>2</sub> and H<sub>2</sub>O quench verification.  
 1065.372 NDUV analyzer HC and H<sub>2</sub>O interference verification.  
 1065.376 Chiller NO<sub>2</sub> penetration.  
 1065.378 NO<sub>2</sub>-to-NO converter conversion verification.

## PM Measurements

- 1065.390 PM balance verifications and weighing process verification.  
 1065.395 Inertial PM balance verifications.

**Subpart E—Engine Selection, Preparation, and Maintenance**

- 1065.401 Test engine selection.  
 1065.405 Test engine preparation and maintenance.  
 1065.410 Maintenance limits for stabilized test engines.  
 1065.415 Durability demonstration.

**Subpart F—Performing an Emission Test in the Laboratory**

- 1065.501 Overview.  
 1065.510 Engine mapping.  
 1065.512 Duty cycle generation.  
 1065.514 Cycle-validation criteria.  
 1065.520 Pre-test verification procedures and pre-test data collection.  
 1065.525 Engine starting, restarting, and shutdown.  
 1065.530 Emission test sequence.  
 1065.545 Validation of proportional flow control for batch sampling.  
 1065.550 Gas analyzer range validation, drift validation, and drift correction.  
 1065.590 PM sample preconditioning and tare weighing.  
 1065.595 PM sample post-conditioning and total weighing.

**Subpart G—Calculations and Data Requirements**

- 1065.601 Overview.  
 1065.602 Statistics.  
 1065.610 Duty cycle generation.  
 1065.630 1980 international gravity formula.  
 1065.640 Flow meter calibration calculations.  
 1065.642 SSV, CFV, and PDP molar flow rate calculations.  
 1065.645 Amount of water in an ideal gas.  
 1065.650 Emission calculations.  
 1065.655 Chemical balances of fuel, intake air, and exhaust.  
 1065.659 Removed water correction.  
 1065.660 THC and NMHC determination.  
 1065.665 THCE and NMHCE determination.  
 1065.66 Dilution air background emission correction.  
 1065.670 NO<sub>x</sub> intake-air humidity and temperature corrections.  
 1065.672 Drift correction.  
 1065.675 CLD quench verification calculations.  
 1065.690 Buoyancy correction for PM sample media.

- 1065.695 Data requirements.

**Subpart H—Engine Fluids, Test Fuels, Analytical Gases and Other Calibration Standards**

- 1065.701 General requirements for test fuels.  
 1065.703 Distillate diesel fuel.  
 1065.705 Residual fuel. [Reserved]  
 1065.710 Gasoline.  
 1065.715 Natural gas.  
 1065.720 Liquefied petroleum gas.  
 1065.740 Lubricants.  
 1065.745 Coolants.  
 1065.750 Analytical Gases.  
 1065.790 Mass standards.

**Subpart I—Testing with Oxygenated Fuels**

- 1065.801 Applicability.  
 1065.805 Sampling system.  
 1065.845 Response factor determination.  
 1065.850 Calculations.

**Subpart J—Field Testing and Portable Emission Measurement Systems**

- 1065.901 Applicability.  
 1065.905 General provisions.  
 1065.910 PEMS auxiliary equipment for field testing.  
 1065.915 PEMS instruments.  
 1065.920 PEMS Calibrations and verifications.  
 1065.925 PEMS preparation for field testing.  
 1065.930 Engine starting, restarting, and shutdown.  
 1065.935 Emission test sequence for field testing.  
 1065.940 Emission calculations.

**Subpart K—Definitions and Other Reference Information**

- 1065.1001 Definitions.  
 1065.1005 Symbols, abbreviations, acronyms, and units of measure.  
 1065.1010 Reference materials.

**Authority:** 42 U.S.C. 7401–7671q.

**Subpart A—Applicability and General Provisions****§ 1065.1 Applicability.**

(a) This part describes the procedures that apply to testing we require for the following engines or for vehicles using the following engines:

(1) Model year 2010 and later heavy-duty highway engines we regulate under 40 CFR part 86. For earlier model years, manufacturers may use the test procedures in this part or those specified in 40 CFR part 86, subpart N, according to § 1065.10.  
 (2) Land-based nonroad diesel engines we regulate under 40 CFR part 1039.

(3) Large nonroad spark-ignition engines we regulate under 40 CFR part 1048.

(4) Vehicles we regulate under 40 CFR part 1051 (such as snowmobiles and off-highway motorcycles) based on engine testing. See 40 CFR part 1051, subpart F, for standards and procedures that are based on vehicle testing.

(b) The procedures of this part may apply to other types of engines, as described in this part and in the standard-setting part.

(c) This part is addressed to you as a manufacturer, but it applies equally to anyone who does testing for you.

(d) Paragraph (a) of this section identifies the parts of the CFR that define emission standards and other requirements for particular types of engines. In this part, we refer to each of these other parts generically as the “standard-setting part.” For example, 40 CFR part 1051 is always the standard-setting part for snowmobiles.

(e) Unless we specify otherwise, the terms “procedures” and “test procedures” in this part include all aspects of engine testing, including the equipment specifications, calibrations, calculations, and other protocols and procedural specifications needed to measure emissions.

(f) For vehicles subject to this part and regulated under vehicle-based standards, use good engineering judgment to interpret the term “engine” in this part to include vehicles where appropriate.

(g) For additional information regarding these test procedures, visit our Web site at [www.epa.gov](http://www.epa.gov), and in particular <http://www.epa.gov/otaq/testingregs.htm>.

**§ 1065.2 Submitting information to EPA under this part.**

(a) You are responsible for statements and information in your applications for certification, requests for approved procedures, selective enforcement audits, laboratory audits, production-line test reports, field test reports, or any other statements you make to us related to this part 1065.

(b) In the standard-setting part and in 40 CFR 1068.101, we describe your obligation to report truthful and complete information and the consequences of failing to meet this obligation. See also 18 U.S.C. 1001 and 42 U.S.C. 7413(c)(2).

(c) We may void any certificates associated with a submission of information if we find that you intentionally submitted false, incomplete, or misleading information. For example, if we find that you intentionally submitted incomplete information to mislead EPA when requesting approval to use alternate test procedures, we may void the certificates for all engines families certified based on emission data collected using the alternate procedures.

(d) We may require an authorized representative of your company to approve and sign the submission, and to

certify that all of the information submitted is accurate and complete.

(e) See 40 CFR 1068.10 for provisions related to confidential information. Note however that under 40 CFR 2.301, emission data is generally not eligible for confidential treatment.

**§ 1065.5 Overview of this part 1065 and its relationship to the standard-setting part.**

(a) This part specifies procedures that apply generally to testing various categories of engines. See the standard-setting part for directions in applying specific provisions in this part for a particular type of engine. Before using this part's procedures, read the standard-setting part to answer at least the following questions:

- (1) What duty cycles must I use for laboratory testing?
- (2) Should I warm up the test engine before measuring emissions, or do I need to measure cold-start emissions during a warm-up segment of the duty cycle?
- (3) Which exhaust gases do I need to measure?
- (4) Does testing require full-flow dilute sampling? Is raw sampling prohibited? Is partial-flow sampling prohibited?
- (5) Do any unique specifications apply for test fuels?
- (6) What maintenance steps may I take before or between tests on an emission-data engine?
- (7) Do any unique requirements apply to stabilizing emission levels on a new engine?
- (8) Do any unique requirements apply to test limits, such as ambient temperatures or pressures?
- (9) Is field testing required, and are there different emission standards or procedures that apply to field testing?
- (10) Are there any emission standards specified at particular engine-operating conditions or ambient conditions?
- (11) Do any unique requirements apply for durability testing?

(b) The testing specifications in the standard-setting part may differ from the specifications in this part. In cases where it is not possible to comply with both the standard-setting part and this part, you must comply with the specifications in the standard-setting part. The standard-setting part may also allow you to deviate from the procedures of this part for other reasons.

(c) The following table shows how this part divides testing specifications into subparts:

This subpart . . .	Describes these specifications or procedures . . .
Subpart A .....	Applicability and general provisions.

This subpart . . .	Describes these specifications or procedures . . .
Subpart B .....	Equipment for testing.
Subpart C .....	Measurement instruments for testing.
Subpart D .....	Calibration and performance verifications for measurement systems.
Subpart E .....	How to prepare engines for testing, including service accumulation.
Subpart F .....	How to run an emission test.
Subpart G .....	Test procedure calculations.
Subpart H .....	Fuels, engine fluids, analytical gases, and other calibration standards for testing.
Subpart I .....	Special procedures related to oxygenated fuels.
Subpart J .....	How to test with portable emission measurement systems (PEMS).
Subpart K .....	Definitions, abbreviations, and other reference information.

**§ 1065.10 Other procedures.**

(a) *Your testing.* The procedures in this part apply for all testing you do to show compliance with emission standards, with certain exceptions listed in this section. In some other sections in this part, we allow you to use other procedures (such as less precise or less accurate procedures) if they do not affect your ability to show that your engines comply with the applicable emission standards. This generally requires emission levels to be far enough below the applicable emission standards so that any errors caused by greater imprecision or inaccuracy do not affect your ability to state unconditionally that the engines meet all applicable emission standards.

(b) *Our testing.* These procedures generally apply for testing that we do to determine if your engines comply with applicable emission standards. We may perform other testing as allowed by the Act.

(c) *Exceptions.* We may allow or require you to use procedures other than those specified in this part in the following cases, which may apply to laboratory testing, field testing, or both. We intend to publicly announce when we allow or require such exceptions. All of the test procedures noted here as exceptions to the specified procedures are considered generically as "other procedures." Note that the terms "special procedures" and "alternate procedures" have specific meanings; "special procedures" are those allowed by § 1065.10(c)(2) and "alternate procedures" are those allowed by § 1065.10(c)(7).

(1) The objective of the procedures in this part is to produce emission

measurements equivalent to those that would result from measuring emissions during in-use operation using the same engine configuration as installed in a vehicle. However, in unusual circumstances these procedures may result in measurements that do not represent in-use operation. You must notify us if good engineering judgment indicates that the specified procedures cause unrepresentative emission measurements for your engines. Note that you need not notify us of unrepresentative aspects of the test procedure if measured emissions are equivalent to in-use emissions. This provision does not obligate you to pursue new information regarding the different ways your engine might operate in use, nor does it obligate you to collect any other in-use information to verify whether or not these test procedures are representative of your engine's in-use operation. If you notify us of unrepresentative procedures under this paragraph (c)(1), we will cooperate with you to establish whether and how the procedures should be appropriately changed to result in more representative measurements. While the provisions of this paragraph (c)(1) allow us to be responsive to issues as they arise, we would generally work toward making these testing changes generally applicable through rulemaking. We will allow reasonable lead time for compliance with any resulting change in procedures. We will consider the following factors in determining the importance of pursuing changes to the procedures:

(i) Whether supplemental emission standards or other requirements in the standard-setting part address the type of operation of concern or otherwise prevent inappropriate design strategies.

(ii) Whether the unrepresentative aspect of the procedures affect your ability to show compliance with the applicable emission standards.

(iii) The extent to which the established procedures require the use of emission-control technologies or strategies that are expected to ensure a comparable degree of emission control under the in-use operation that differs from the specified procedures.

(2) You may request to use special procedures if your engine cannot be tested using the specified procedures. We will approve your request if we determine that it would produce emission measurements that represent in-use operation and we determine that it can be used to show compliance with the requirements of the standard-setting part.

The following situations illustrate examples that may require special procedures:

(i) Your engine cannot operate on the specified duty cycle. In this case, tell us in writing why you cannot satisfactorily test your engine using this part's procedures and ask to use a different approach.

(ii) Your electronic control module requires specific input signals that are not available during dynamometer testing. In this case, tell us in writing what signals you will simulate, such as vehicle speed or transmission signals, and explain why these signals are necessary for representative testing.

(3) In a given model year, you may use procedures required for later model year engines without request. If you upgrade your testing facility in stages, you may rely on a combination of procedures for current and later model year engines as long as you can ensure, using good engineering judgment, that the combination you use for testing does not affect your ability to show compliance with the applicable emission standards.

(4) In a given model year, you may ask to use procedures allowed for earlier model year engines. We will approve this only if you show us that using the procedures allowed for earlier model years does not affect your ability to show compliance with the applicable emission standards.

(5) You may ask to use emission data collected using other procedures, such as those of the California Air Resources Board or the International Organization for Standardization. We will approve this only if you show us that using these other procedures does not affect your ability to show compliance with the applicable emission standards.

(6) During the 12 months following the effective date of any change in the provisions of this part 1065, you may ask to use data collected using procedures specified in the previously applicable version of this part 1065. This paragraph (c)(6) does not restrict the use of carryover certification data otherwise allowed by the standard-setting part.

(7) You may request to use alternate procedures that are equivalent to allowed procedures, or more accurate or more precise than allowed procedures. You may request to use a particular device or method for laboratory testing even though it was originally designed for field testing. The following provisions apply to requests for alternate procedures:

(i) *Applications.* Follow the instructions in § 1065.12.

(ii) *Submission.* Submit requests in writing to the Designated Compliance Officer.

(iii) *Notification.* We may approve your request by telling you directly, or we may issue guidance announcing our approval of a specific alternate procedure, which would make additional requests for approval unnecessary.

(d) If we require you to request approval to use other procedures under paragraph (c) of this section, you may not use them until we approve your request.

#### § 1065.12 Approval of alternate procedures.

(a) To get approval for an alternate procedure under § 1065.10(c), send the Designated Compliance Officer an initial written request describing the alternate procedure and why you believe it is equivalent to the specified procedure. We may approve your request based on this information alone, or, as described in this section, we may ask you to submit to us in writing supplemental information showing that your alternate procedure is consistently and reliably at least as accurate and repeatable as the specified procedure.

(b) We may make our approval under this section conditional upon meeting other requirements or specifications. We may limit our approval, for example, to certain time frames, specific duty cycles, or specific emission standards. Based upon any supplemental information we receive after our initial approval, we may amend a previously approved alternate procedure to extend, limit, or discontinue its use. We intend to publicly announce alternate procedures that we approve.

(c) Although we will make every effort to approve only alternate procedures that completely meet our requirements, we may revoke our approval of an alternate procedure if new information shows that it is significantly not equivalent to the specified procedure.

If we do this, we will grant time to switch to testing using an allowed procedure, considering the following factors:

(1) The cost, difficulty, and availability to switch to a procedure that we allow.

(2) The degree to which the alternate procedure affects your ability to show that your engines comply with all applicable emission standards.

(3) Any relevant factors considered in our initial approval.

(d) If we do not approve your proposed alternate procedure based on the information in your initial request,

we may ask you to send the following information to fully evaluate your request:

(1) *Theoretical basis.* Give a brief technical description explaining why you believe the proposed alternate procedure should result in emission measurements equivalent to those using the specified procedure. You may include equations, figures, and references. You should consider the full range of parameters that may affect equivalence. For example, for a request to use a different NO<sub>x</sub> measurement procedure, you should theoretically relate the alternate detection principle to the specified detection principle over the expected concentration ranges for NO, NO<sub>2</sub>, and interference gases. For a request to use a different PM measurement procedure, you should explain the principles by which the alternate procedure quantifies particulate mass similarly to the specified procedures. For any proportioning or integrating procedure, such as a partial-flow dilution system, you should compare the alternate procedure's theoretical response to the expected response of the specified procedures.

(2) *Technical description.* Describe briefly any hardware or software needed to perform the alternate procedure. You may include dimensioned drawings, flowcharts, schematics, and component specifications. Explain any necessary calculations or other data manipulation.

(3) *Procedure execution.* Describe briefly how to perform the alternate procedure and recommend a level of training an operator should have to achieve acceptable results.

Summarize the installation, calibration, operation, and maintenance procedures in a step-by-step format. Describe how any calibration is performed using NIST-traceable standards or other similar standards we approve. Calibration must be specified by using known quantities and must not be specified as a comparison with other allowed procedures.

(4) *Data-collection techniques.* Compare measured emission results using the proposed alternate procedure and the specified procedure, as follows:

(i) Both procedures must be calibrated independently to NIST-traceable standards or to other similar standards we approve.

(ii) Include measured emission results from all applicable duty cycles. Measured emission results should show that the test engine meets all applicable emission standards according to specified procedures.

(iii) Use statistical methods to evaluate the emission measurements,

such as those described in paragraph (e) of this section.

(e) We may give you specific directions regarding methods for statistical analysis, or we may approve other methods that you propose. Absent any other directions from us, use a t-test and an F-test calculated according to § 1065.602 to evaluate whether your proposed alternate procedure is equivalent to the specified procedure. We recommend that you consult a statistician if you are unfamiliar with these statistical tests. Perform the tests as follows:

(1) Repeat measurements for all applicable duty cycles at least seven times for each procedure. You may use laboratory duty cycles to evaluate field-testing procedures.

Be sure to include all available results to evaluate the precision and accuracy of the proposed alternate procedure, as described in § 1065.2.

(2) Demonstrate the accuracy of the proposed alternate procedure by showing that it passes a two-sided t-test. Use an unpaired t-test, unless you show that a paired t-test is appropriate under both of the following provisions:

(i) For paired data, the population of the paired differences from which you sampled paired differences must be independent. That is, the probability of any given value of one paired difference is unchanged by knowledge of the value of another paired difference. For example, your paired data would violate this requirement if your series of paired differences showed a distinct increase or decrease that was dependent on the time at which they were sampled.

(ii) For paired data, the population of paired differences from which you sampled the paired differences must have a normal (i.e., Gaussian) distribution. If the population of paired difference is not normally distributed, consult a statistician for a more appropriate statistical test, which may include transforming the data with a mathematical function or using some kind of non-parametric test.

(3) Show that  $t$  is less than the critical  $t$  value,  $t_{crit}$ , tabulated in § 1065.602, for the following confidence intervals:

(i) 90% for a proposed alternate procedure for laboratory testing.

(ii) 95% for a proposed alternate procedure for field testing.

(4) Demonstrate the precision of the proposed alternate procedure by showing that it passes an F-test. Use a set of at least seven samples from the reference procedure and a set of at least seven samples from the alternate procedure to perform an F-test. The sets must meet the following requirements:

(i) Within each set, the values must be independent. That is, the probability of any given value in a set must be unchanged by knowledge of another value in that set. For example, your data would violate this requirement if a set showed a distinct increase or decrease that was dependent upon the time at which they were sampled.

(ii) For each set, the population of values from which you sampled must have a normal (i.e., Gaussian) distribution. If the population of values is not normally distributed, consult a statistician for a more appropriate statistical test, which may include transforming the data with a mathematical function or using some kind of non-parametric test.

(iii) The two sets must be independent of each other. That is, the probability of any given value in one set must be unchanged by knowledge of another value in the other set. For example, your data would violate this requirement if one value in a set showed a distinct increase or decrease that was dependent upon a value in the other set. Note that a trend of emission changes from an engine would not violate this requirement.

(iv) If you collect paired data for the paired t-test in paragraph (e)(2) in this section, use caution when selecting sets from paired data for the F-test. If you do this, select sets that do not mask the precision of the measurement procedure. We recommend selecting such sets only from data collected using the same engine, measurement instruments, and test cycle.

(5) Show that  $F$  is less than the critical  $F$  value,  $F_{crit}$ , tabulated in § 1065.602. If you have several F-test results from several sets of data, show that the mean F-test value is less than the mean critical  $F$  value for all the sets. Evaluate  $F_{crit}$ , based on the following confidence intervals:

(i) 90% for a proposed alternate procedure for laboratory testing.

(ii) 95% for a proposed alternate procedure for field testing.

#### § 1065.15 Overview of procedures for laboratory and field testing.

This section outlines the procedures to test engines that are subject to emission standards.

(a) In the standard-setting part, we set brake-specific emission standards in g/(kW-hr) (or g/(hp-hr)), for the following constituents:

(1) Total oxides of nitrogen,  $NO_x$ .

(2) Hydrocarbons (HC), which may be expressed in the following ways:

(i) Total hydrocarbons, THC.

(ii) Nonmethane hydrocarbons, NMHC, which results from subtracting methane ( $CH_4$ ) from THC.

(iii) Total hydrocarbon-equivalent, THCE, which results from adjusting THC mathematically to be equivalent on a carbon-mass basis.

(iv) Nonmethane hydrocarbon-equivalent, NMHCE, which results from adjusting NMHC mathematically to be equivalent on a carbon-mass basis.

(3) Particulate mass, PM.

(4) Carbon monoxide, CO.

(b) Note that some engines are not subject to standards for all the emission constituents identified in paragraph (a) of this section.

(c) We set brake-specific emission standards over test intervals, as follows:

(1) *Engine operation.* Engine operation is specified over a test interval. A test interval is the time over which an engine's total mass of emissions and its total work are determined. Refer to the standard-setting part for the specific test intervals that apply to each engine. Testing may involve measuring emissions and work during the following types of engine operation:

(i) *Laboratory testing.* Under this type of testing, you determine brake-specific emissions for duty-cycle testing by using an engine dynamometer in a laboratory. This typically consists of one or more test intervals, each defined by a duty cycle, which is a sequence of speeds and torques that an engine must follow. If the standard-setting part allows it, you may also simulate field testing by running on an engine dynamometer in a laboratory.

(ii) *Field testing.* This type of testing consists of normal in-use engine operation while an engine is installed in a vehicle. The standard-setting part specifies how test intervals are defined for field testing.

(2) *Constituent determination.* Determine the total mass of each constituent over a test interval by selecting from the following methods:

(i) *Continuous sampling.* In continuous sampling, measure the constituent's concentration continuously from raw or dilute exhaust. Multiply this concentration by the continuous (raw or dilute) flow rate at the emission sampling location to determine the constituent's flow rate. Sum the constituent's flow rate continuously over the test interval. This sum is the total mass of the emitted constituent.

(ii) *Batch sampling.* In batch sampling, continuously extract and store a sample of raw or dilute exhaust for later measurement. Extract a sample proportional to the raw or dilute exhaust flow rate. You may extract and store a proportional sample of exhaust in an appropriate container, such as a

bag, and then measure HC, CO, and NO<sub>x</sub> concentrations in the container after the test interval. You may deposit PM from proportionally extracted exhaust onto an appropriate substrate, such as a filter. In this case, divide the PM by the amount of filtered exhaust to calculate the PM concentration. Multiply batch sampled concentrations by the total (raw or dilute) flow from which it was extracted during the test interval. This product is the total mass of the emitted constituent.

(iii) *Combined sampling.* You may use continuous and batch sampling simultaneously during a test interval, as follows:

(A) You may use continuous sampling for some constituents and batch sampling for others.

(B) You may use continuous and batch sampling for a single constituent, with one being a redundant measurement. See § 1065.201 for more information on redundant measurements.

(3) *Work determination.* Determine work over a test interval by one of the following methods:

(i) *Speed and torque.* For laboratory testing, synchronously multiply speed and brake torque to calculate instantaneous values for engine brake power. Sum engine brake power over a test interval to determine total work.

(ii) *Fuel consumed and brake-specific fuel consumption.* Directly measure fuel consumed or calculate it with chemical balances of the fuel, intake air, and exhaust. To calculate fuel consumed by

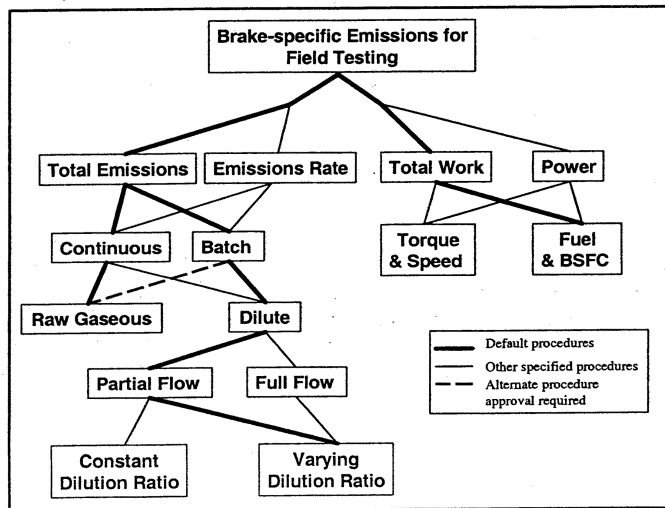
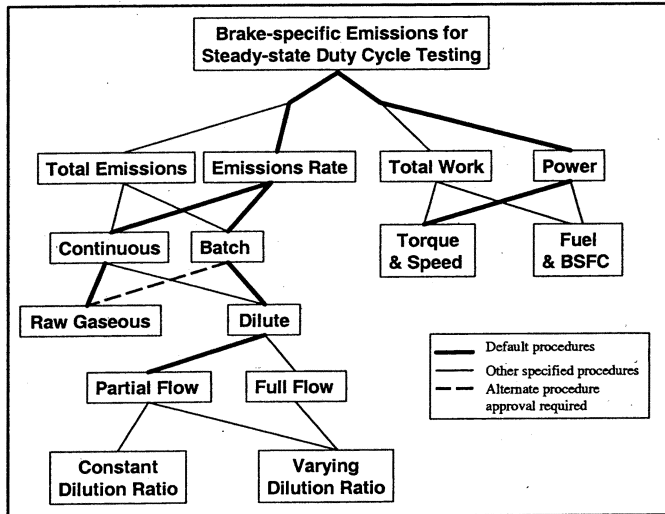
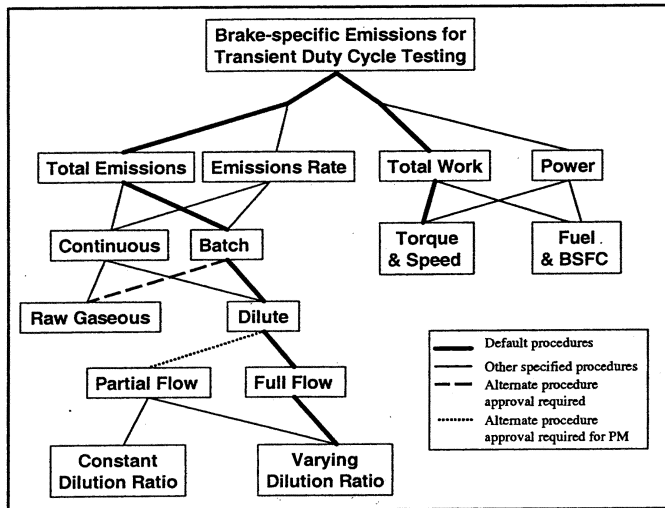
a chemical balance, you must also measure either intake-air flow rate or exhaust flow rate. Divide the fuel consumed during a test interval by the brake-specific fuel consumption to determine work over the test interval. For laboratory testing, calculate the brake-specific fuel consumption using fuel consumed and speed and torque over a test interval. For field testing, refer to the standard-setting part and § 1065.915 for selecting an appropriate value for brake-specific fuel consumption.

(d) Refer to § 1065.650 for calculations to determine brake-specific emissions.

(e) The following figure illustrates the allowed measurement configurations described in this part 1065:

**BILLING CODE 6560-50-P**

Figure 1 of §1065.15—Default test procedures and other specified procedures.



**§ 1065.20 Units of measure and overview of calculations.**

(a) *System of units.* The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, 1995 Edition, "Guide for the Use of the International System of Units (SI)," which we incorporate by reference in § 1065.1010. This document is available on the Internet at <http://physics.nist.gov/Pubs/SP811/contents.html>. Note the following exceptions:

(1) We designate rotational frequency,  $f_n$ , of an engine's crankshaft in revolutions per minute (rev/min), rather than the SI unit of reciprocal seconds (1/s). This is based on the commonplace use of rev/min in many engine dynamometer laboratories. Also, we use the symbol  $f_n$  to identify rotational frequency in rev/min, rather than the SI convention of using  $n$ . This avoids confusion with our usage of the symbol  $n$  for a molar quantity.

(2) We designate brake-specific emissions in grams per kilowatt-hour (g/(kW-hr)), rather than the SI unit of grams per megajoule (g/MJ). This is based on the fact that engines are generally subject to emission standards expressed in g/kW-hr. If we specify engine standards in grams per horsepower-hour (g/(hp-hr)) in the standard-setting part, convert units as specified in paragraph (d) of this section.

(3) We designate temperatures in units of degrees Celsius (°C) unless a calculation requires an absolute temperature. In that case, we designate temperatures in units of Kelvin (K). For conversion purposes throughout this part, 0 °C equals 273.15 K.

(b) *Concentrations.* This part does not rely on amounts expressed in parts per million or similar units. Rather, we express such amounts in the following SI units:

(1) For ideal gases,  $\mu\text{mol/mol}$ , formerly ppm (volume).

(2) For all substances,  $\mu\text{m}^3/\text{m}^3$ , formerly ppm (volume).

(3) For all substances, mg/kg, formerly ppm (mass).

(c) *Absolute pressure.* Measure absolute pressure directly or calculate it as the sum of atmospheric pressure plus a differential pressure that is referenced to atmospheric pressure.

(d) *Units conversion.* Use the following conventions to convert units:

(1) *Testing.* You may record values and perform calculations with other

units. For testing with equipment that involves other units, use the conversion factors from NIST Special Publication 811, as described in paragraph (a) of this section.

(2) *Humidity.* In this part, we identify humidity levels by specifying dewpoint, which is the temperature at which pure water begins to condense out of air. Use humidity conversions as described in § 1065.645.

(3) *Emission standards.* If your standard is in g/(hp-hr) units, convert kW to hp before any rounding by using the conversion factor of 1 hp (550 ft-lbf/s) = 0.7456999 kW. Round the final value for comparison to the applicable standard.

(e) *Rounding.* Unless the standard-setting part specifies otherwise, round only final values, not intermediate values. Round values to the number of significant digits necessary to match the number of decimal places of the applicable standard or specification. For information not related to standards or specifications, use good engineering judgment to record the appropriate number of significant digits.

(f) *Interpretation of ranges.* In this part, we specify ranges such as " $\pm 10\%$  of maximum pressure", "(40 to 50) kPa", or "(30  $\pm$  10) kPa". Interpret a range as a tolerance unless we explicitly identify it as an accuracy, repeatability, linearity, or noise specification. See § 1065.1001 for the definition of Tolerance.

(g) *Scaling of specifications with respect to a standard.* Because this part 1065 is applicable to a wide range of engines and emission standards, some of the specifications in this part are scaled with respect to an engine's emission standard or maximum power. This ensures that the specification will be adequate to determine compliance, but not overly burdensome by requiring unnecessarily high-precision equipment. Many of these specifications are given with respect to a "flow-weighted mean" that is expected at the standard. 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 flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the

same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration. Refer to § 1065.602 for information needed to estimate and calculate flow-weighted means.

**§ 1065.25 Recordkeeping.**

The procedures in this part include various requirements to record data or other information. Refer to the standard-setting part regarding recordkeeping requirements. If the standard-setting part does not specify recordkeeping requirements, store these records in any format and on any media and keep them readily available for one year after you send an associated application for certification, or one year after you generate the data if they do not support an application for certification. You must promptly send us organized, written records in English if we ask for them. We may review them at any time.

**Subpart B—Equipment Specifications****§ 1065.101 Overview.**

(a) This subpart specifies equipment, other than measurement instruments, related to emission testing. The provisions of this subpart apply for all testing in laboratories. See subpart J of this part to determine which of the provisions of this subpart apply for field testing. This includes three broad categories of equipment—dynamometers, engine fluid systems (such as fuel and intake-air systems), and emission-sampling hardware.

(b) Other related subparts in this part identify measurement instruments (subpart C), describe how to evaluate the performance of these instruments (subpart D), and specify engine fluids and analytical gases (subpart H).

(c) Subpart J of this part describes additional equipment that is specific to field testing.

(d) Figures 1 and 2 of this section illustrate some of the possible configurations of laboratory equipment. These figures are schematics only; we do not require exact conformance to them. Figure 1 of this section illustrates the equipment specified in this subpart and gives some references to sections in this subpart. Figure 2 of this section illustrates some of the possible configurations of a full-flow dilution, constant-volume sampling (CVS) system. Not all possible CVS configurations are shown.

BILLING CODE 6560-50-P



Figure 1 of §1065.101—Engine dynamometer laboratory equipment.

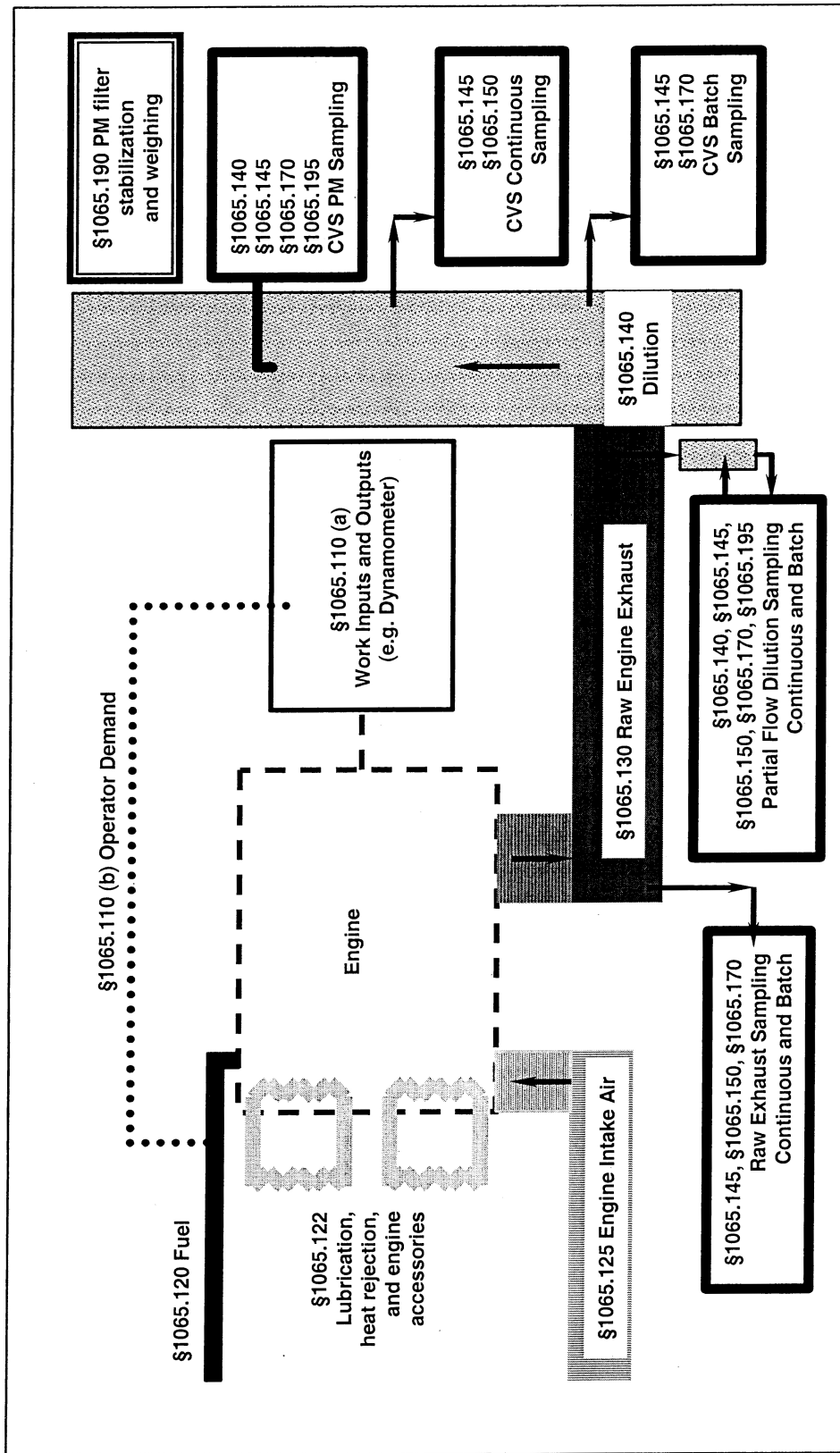
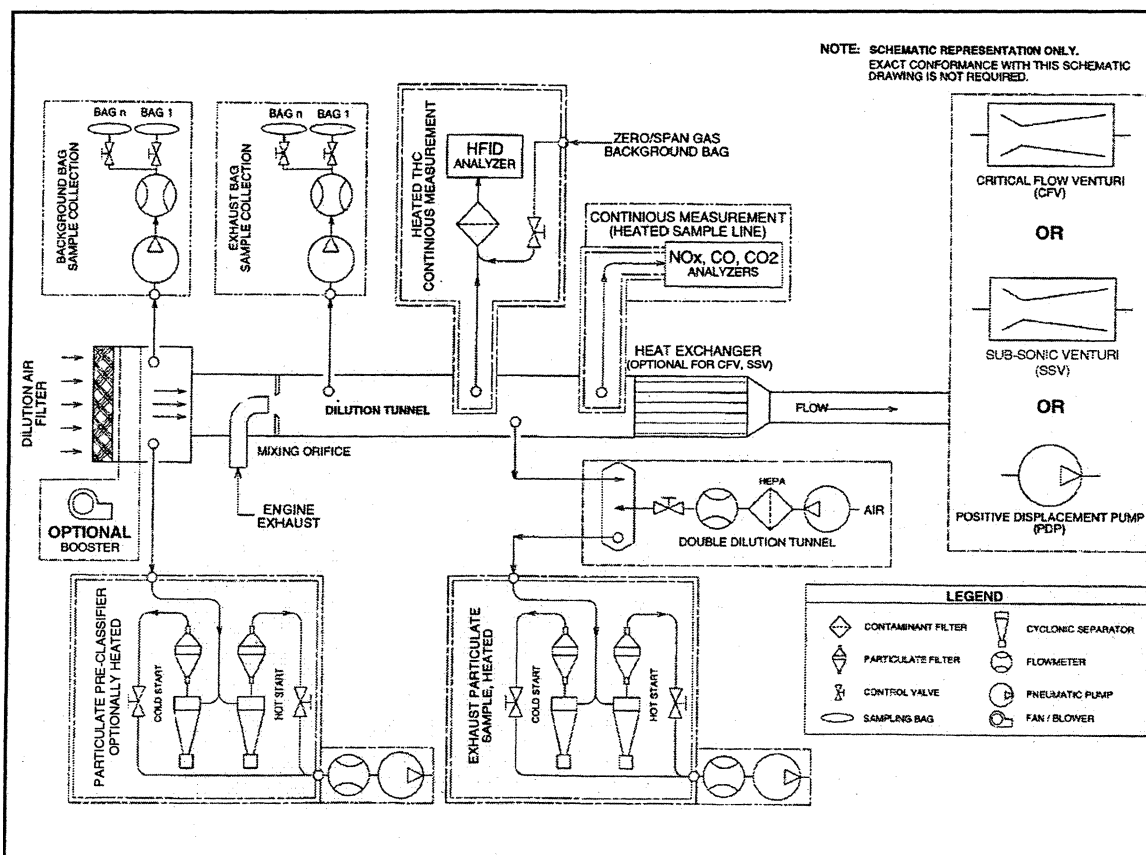


Figure 2 of §1065.101—Examples of some full-flow dilution sampling configurations.



BILLING CODE 6560-50-C

### § 1065.110 Work inputs and outputs, accessory work, and operator demand.

(a) *Work.* Use good engineering judgment to simulate all engine work inputs and outputs as they typically would operate in use. Account for work inputs and outputs during an emission test by measuring them; or, if they are small, you may show by engineering analysis that disregarding them does not affect your ability to determine the net work output by more than  $\pm 0.5\%$  of the net reference work output over the test interval. Use equipment to simulate the specific types of work, as follows:

(1) *Shaft work.* Use an engine dynamometer that is able to meet the cycle-validation criteria in § 1065.514 over each applicable duty cycle.

(i) You may use eddy-current and water-brake dynamometers for any testing that does not involve engine motoring, which is identified by negative torque commands in a reference duty cycle. See the standard setting part for reference duty cycles that are applicable to your engine.

(ii) You may use alternating-current or direct-current motoring dynamometers for any type of testing.

(iii) You may use one or more dynamometers.

(2) *Electrical work.* Use one or more of the following to simulate electrical work:

(i) Use storage batteries or capacitors that are of the type and capacity installed in use.

(ii) Use motors, generators, and alternators that are of the type and capacity installed in use.

(iii) Use a resistor load bank to simulate electrical loads.

(3) *Pump, compressor, and turbine work.* Use pumps, compressors, and turbines that are of the type and capacity installed in use. Use working fluids that are of the same type and thermodynamic state as normal in-use operation.

(b) *Laboratory work inputs.* You may supply any laboratory inputs of work to the engine. For example, you may supply electrical work to the engine to operate a fuel system, and as another example you may supply compressor work to the engine to actuate pneumatic

valves. We may ask you to show by engineering analysis your accounting of laboratory work inputs to meet the criterion in paragraph (a) of this section.

(c) *Engine accessories.* You must either install or account for the work of engine accessories required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate aftertreatment devices. Operate the engine with these accessories installed or accounted for during all testing operations, including mapping. If these accessories are not powered by the engine during a test, account for the work required to perform these functions from the total work used in brake-specific emission calculations. For air-cooled engines only, subtract externally powered fan work from total work. We may ask you to show by engineering analysis your accounting of engine accessories to meet the criterion in paragraph (a) of this section.

(d) *Engine starter.* You may install a production-type starter.

(e) *Operator demand for shaft work.* Command the operator demand and the dynamometer(s) to follow the prescribed duty cycle with set points for engine

speed and torque at 5 Hz (or more frequently) for transient testing or 1 Hz (or more frequently) for steady-state testing. Use a mechanical or electronic input to control operator demand such that the engine is able to meet the validation criteria in § 1065.514 over each applicable duty cycle. Record feedback values for engine speed and torque at 5 Hz or more frequently for evaluating performance relative to the cycle validation criteria. Using good engineering judgment, you may improve control of operator demand by altering on-engine speed and torque controls. However, if these changes result in unrepresentative testing, you must notify us and recommend other test procedures under § 1065.10(c)(1).

**§ 1065.120 Fuel properties and fuel temperature and pressure.**

(a) Use fuels as specified in subpart H of this part.

(b) If the engine manufacturer specifies fuel temperature and pressure tolerances and the location where they are to be measured, then measure the fuel temperature and pressure at the specified location to show that you are within these tolerances throughout testing.

(c) If the engine manufacturer does not specify fuel temperature and pressure tolerances, use good engineering judgment to set and control fuel temperature and pressure in a way that represents typical in-use fuel temperatures and pressures.

**§ 1065.122 Engine cooling and lubrication.**

(a) *Engine cooling.* Cool the engine during testing so its intake-air, oil, coolant, block, and head temperatures are within their expected ranges for normal operation. You may use laboratory auxiliary coolers and fans.

(1) If you use laboratory auxiliary fans you must account for work input to the fan(s) according to § 1065.110.

(2) See § 1065.125 for more information related to intake-air cooling.

(3) See § 1065.127 for more information related to exhaust gas recirculation cooling.

(4) Measure temperatures at the manufacturer-specified locations. If the manufacturer does not specify temperature measurement locations, then use good engineering judgment to monitor intake-air, oil, coolant, block, and head temperatures to ensure that they are in their expected ranges for normal operation.

(b) *Forced cooldown.* You may install a forced cooldown system for an engine and an exhaust aftertreatment device according to § 1065.530(a)(1).

(c) *Lubricating oil.* Use lubricating oils specified in § 1065.740.

(d) *Coolant.* For liquid-cooled engines, use coolant as specified in § 1065.745.

**§ 1065.125 Engine intake air.**

(a) Use the intake-air system installed on the engine or one that represents a typical in-use configuration. This includes the charge-air cooling and exhaust gas recirculation systems.

(b) Measure temperature, humidity, and atmospheric pressure near the entrance to the engine's air filter, or at the inlet to the air intake system for engines that have no air filter. You may use a shared atmospheric pressure meter as long as your equipment for handling intake air maintains ambient pressure where you test the engine within  $\pm 1$  kPa of the shared atmospheric pressure. You may use a shared humidity measurement for intake air as long as your equipment for handling intake air maintains dewpoint where you test the engine to within  $+0.5$  °C of the shared humidity measurement.

(c) Use an air-intake restriction that represents production engines. Make sure the intake-air restriction is between the manufacturer's specified maximum for a clean filter and the manufacturer's specified maximum allowed. Measure the static differential pressure of the restriction at the location and at the speed and torque set points specified by the manufacturer. If the manufacturer does not specify a location, measure this pressure upstream any turbocharger or exhaust gas recirculation system connection to the intake air system. If the manufacturer does not specify speed and torque points, measure this pressure while the engine outputs maximum power. As the manufacturer, you are liable for emission compliance for all values up to the maximum restriction you specify for a particular engine.

(d) This paragraph (d) includes provisions for simulating charge-air cooling in the laboratory. This approach is described in paragraph (d)(1) of this section. Limits on using this approach are described in paragraphs (d)(2) and (3) of this section.

(1) Use a charge-air cooling system with a total intake-air capacity that represents production engines' in-use installation. Maintain coolant conditions as follows:

(i) Maintain a coolant temperature of at least 20 °C at the inlet to the charge-air cooler throughout testing.

(ii) At maximum engine power, set the coolant flow rate to achieve an air temperature within  $\pm 5$  °C of the value specified by the manufacturer at the charge-air cooler outlet. Measure the air-outlet temperature at the location specified by the manufacturer. Use this

coolant flow rate set point throughout testing.

(2) Using a constant flow rate as described in paragraph (d)(1)(ii) of this section may result in unrepresentative overcooling of the intake air. If this causes any regulated emission to decrease, then you may still use this approach, but only if the effect on emissions is smaller than the degree to which you meet the applicable emission standards. If the effect on emissions is larger than the degree to which you meet the applicable emission standards, you must use a variable flow rate that controls intake-air temperatures to be representative of in-use operation.

(3) This approach does not apply for field testing. You may not correct measured emission levels from field testing to account for any differences caused by the simulated cooling in the laboratory.

**§ 1065.127 Exhaust gas recirculation.**

Use the exhaust gas recirculation (EGR) system installed with the engine or one that represents a typical in-use configuration. This includes any applicable EGR cooling devices.

**§ 1065.130 Engine exhaust.**

(a) *General.* Use the exhaust system installed with the engine or one that represents a typical in-use configuration. This includes any applicable aftertreatment devices.

(b) *Aftertreatment configuration.* If you do not use the exhaust system installed with the engine, configure any aftertreatment devices as follows:

(1) Position any aftertreatment device so its distance from the nearest exhaust manifold flange or turbocharger outlet is within the range specified by the engine manufacturer in the application for certification. If this distance is not specified, position aftertreatment devices to represent typical in-use vehicle configurations.

(2) You may use laboratory exhaust tubing upstream of any aftertreatment device that is of diameter(s) typical of in-use configurations. If you use laboratory exhaust tubing upstream of any aftertreatment device, position each aftertreatment device according to paragraph (b)(1) of this section.

(c) *Sampling system connections.* Connect an engine's exhaust system to any raw sampling location or dilution stage, as follows:

(1) Minimize laboratory exhaust tubing lengths and use a total length of laboratory tubing of no more than 10 m or 50 outside diameters, whichever is greater. If laboratory exhaust tubing consists of several different outside tubing diameters, count the number of

diameters of length of each individual diameter, then sum all the diameters to determine the total length of exhaust tubing in diameters. Use the mean outside diameter of any converging or diverging sections of tubing. Use outside hydraulic diameters of any noncircular sections.

(2) You may install short sections of flexible laboratory exhaust tubing at any location in the engine or laboratory exhaust systems. You may use up to a combined total of 2 m or 10 outside diameters of flexible exhaust tubing.

(3) Insulate any laboratory exhaust tubing downstream of the first 25 outside diameters of length.

(4) Use laboratory exhaust tubing materials that are smooth-walled, electrically conductive, and not reactive with exhaust constituents. Stainless steel is an acceptable material.

(5) We recommend that you use laboratory exhaust tubing that has either a wall thickness of less than 2 mm or is air gap-insulated to minimize temperature differences between the wall and the exhaust.

(d) *In-line instruments.* You may insert instruments into the laboratory exhaust tubing, such as an in-line smoke meter. If you do this, you may leave a length of up to 5 outside diameters of laboratory exhaust tubing uninsulated on each side of each instrument, but you must leave a length of no more than 25 outside diameters of laboratory exhaust tubing uninsulated in total, including any lengths adjacent to in-line instruments.

(e) *Grounding.* Electrically ground the entire exhaust system.

(f) *Forced cooldown.* You may install a forced cooldown system for an exhaust aftertreatment device according to § 1065.530(a)(1)(i).

(g) *Exhaust restriction.* Use an exhaust restriction that represents the performance of production engines. Make sure the exhaust restriction set point is either (80 to 100) % of the maximum exhaust restriction specified by the manufacturer; or if the maximum is 5 kPa or less, make sure the set point is no less than 1.0 kPa from the maximum. For example, if the maximum back pressure is 4.5 kPa, do not use an exhaust restriction set point that is less than 3.5 kPa. Measure and set this pressure at the location and at the speed, torque and aftertreatment set points specified by the manufacturer. As the manufacturer, you are liable for emission compliance for all values up to the maximum restriction you specify for a particular engine.

(h) *Open crankcase emissions.* If the standard-setting part requires measuring open crankcase emissions, you may

either measure open crankcase emissions separately using a method that we approve in advance, or route open crankcase emissions directly into the exhaust system for emission measurement as follows:

(1) Use laboratory tubing materials that are smooth-walled, electrically conductive, and not reactive with crankcase emissions. Stainless steel is an acceptable material.

Minimize tube lengths. We also recommend using heated or thin-walled or air gap-insulated tubing to minimize temperature differences between the wall and the crankcase emission constituents.

(2) Minimize the number of bends in the laboratory crankcase tubing and maximize the radius of any unavoidable bend.

(3) Use laboratory crankcase exhaust tubing that meets the engine manufacturer's specifications for crankcase back pressure.

(4) Connect the crankcase exhaust tubing into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust before sampling. Extend the crankcase exhaust tube into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. You may orient the crankcase exhaust tube's outlet in any direction relative to the raw exhaust flow.

#### **§ 1065.140 Dilution for gaseous and PM constituents.**

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

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

(1) You may measure constituent concentrations in the diluent and compensate for background effects on test results. See § 1065.650 for calculations that compensate for background concentrations.

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

(i) You may disregard any proportional sampling requirements.

(ii) You may use unheated gaseous sampling systems.

(iii) You may use unheated PM sampling systems only if we approve it in advance.

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

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

(3) For removing background PM, we recommend that you filter all dilution air, including primary full-flow dilution air, with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99.97% (see § 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.

(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 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. Note paragraph (c)(6) of this section regarding aqueous condensation.

(5) *Flow measurement.* Section 1065.240 describes measurement instruments for diluted exhaust flow.

(6) *Aqueous condensation.* You may either prevent aqueous condensation throughout the dilution tunnel or you may measure humidity at the flow meter inlet. 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. An example of a varying dilution ratio PFD is a "bag mini-diluter" or BMD.

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

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

(i) Use a control system with sensors and actuators that can maintain 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.

(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, not from practice cycles or other tests.

(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 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. Control sample temperature to a  $(47 \pm 5)^\circ\text{C}$  tolerance, as measured anywhere within 20 cm upstream or downstream of the PM storage media (such as a filter). Measure this temperature with a bare-wire junction thermocouple with wires that are  $(0.500 \pm 0.025)$  mm diameter, or with another suitable instrument that has equivalent performance. Heat or cool the PM sample primarily by dilution.

#### § 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 probes:

(1) *Probe design and construction.* Use sample probes with inside surfaces of 300 series stainless steel or, for raw exhaust sampling, use a 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) *Gaseous sample probes.* Use either single-port or multi-port probes for sampling gaseous emissions. You may orient these probes in any direction relative to the raw or diluted exhaust flow. For some probes, you must control sample temperatures, as follows:

(i) For probes that extract  $\text{NO}_x$  from diluted exhaust, control the probe's wall temperature to prevent aqueous condensation.

(ii) For probes that extract hydrocarbons for NMHC or NMHCE analysis from the diluted exhaust of compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW, maintain a probe wall temperature tolerance of  $(191 \pm 11)^\circ\text{C}$ .

(3) *PM sample probes.* Use PM probes with a single opening at the end. Orient PM probes to face directly upstream. If you shield a PM probe's opening with a PM pre-classifier such as a hat, you may not use the preclassifier we specify in paragraph (d)(4)(i) 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. 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  $90^\circ$  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  $\text{NO}_x$  transfer lines upstream of either an  $\text{NO}_2$ -to- $\text{NO}$  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  $(191 \pm 11)^\circ\text{C}$ . If you sample from raw exhaust, you may connect an unheated, insulated transfer line directly to a probe. Design the length and insulation of the transfer line to cool the highest expected raw exhaust temperature to no lower than  $191^\circ\text{C}$ , as measured at the transfer line's outlet.

(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 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)  *$\text{NO}_2$ -to- $\text{NO}$  converter.* You may use an  $\text{NO}_2$ -to- $\text{NO}$  converter that meets the efficiency-performance check specified in § 1065.378 at any point upstream of a  $\text{NO}_x$  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 used 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  $\text{NO}_2$ -to- $\text{NO}$  converter or in a sampling system without an  $\text{NO}_2$ -to- $\text{NO}$  converter, the chiller must meet the  $\text{NO}_2$  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 their peak values observed during a test or their high alarm setpoints 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 efficiency 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 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<sub>x</sub> sample pump upstream of either an NO<sub>2</sub>-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 compression 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.

(e) *Optional sample-conditioning components for PM sampling.* You may use the following sample-conditioning components to prepare PM samples for analysis, as long 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 50 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.

**§ 1065.150 Continuous sampling.**

You may use continuous sampling techniques for measurements that involve raw or dilute sampling. Make sure continuous sampling systems meet the specifications in § 1065.145. Make sure continuous analyzers meet the specifications in subparts C and D of this part.

**§ 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 and 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 only if we approve it as an alternate procedure under § 1065.10.

(a) *Sampling methods.* For batch sampling, extract the sample at a rate proportional to the exhaust flow. If you extract from a constant-volume flow rate, sample at a constant-volume flow rate. If you extract from a varying flow rate, vary the sample rate in proportion to the varying flow rate. Validate proportional sampling after an emission test as described in § 1065.545. Use storage media that do not change measured emission levels (either up or down). For example, do not use sample bags for storing emissions if the bags are permeable with respect to emissions or if they off-gas emissions. As another example, do not use PM filters that irreversibly absorb or adsorb gases.

(b) *Gaseous sample storage media.* Store gas volumes in sufficiently clean containers that minimally off-gas or allow permeation of gases. Use good engineering judgment to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, you may repeatedly purge and evacuate a container and you may heat it. Use a flexible container (such as a bag) within a temperature-controlled environment, or use a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement. Use containers meeting the specifications in the following table, noting that you may request to use other container materials under § 1065.10:

TABLE 1 OF § 1065.170.—GASEOUS BATCH SAMPLING CONTAINER MATERIALS

Emissions	Engines	
	Compression-ignition, two-stroke spark ignition, 4-stroke spark-ignition <19 kW	All other engines
CO, CO <sub>2</sub> , O <sub>2</sub> , CH <sub>4</sub> , C <sub>2</sub> H <sub>6</sub> , C <sub>3</sub> H <sub>8</sub> , NO, NO <sub>2</sub> <sup>1</sup> .	Tedlar <sup>TM,2</sup> , Kynar <sup>TM,2</sup> , Teflon <sup>TM,3</sup> or 300 series stainless steel <sup>3</sup> .....	Tedlar <sup>TM,2</sup> , Kynar <sup>TM,2</sup> , Teflon <sup>TM,3</sup> or 300 series stainless steel <sup>3</sup>
THC, NMHC .....	Teflon <sup>TM,4</sup> or 300 series stainless steel <sup>4</sup> .....	Tedlar <sup>TM,2</sup> , Kynar <sup>TM,2</sup> , Teflon <sup>TM,3</sup> or 300 series stainless steel <sup>3</sup>

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

<sup>2</sup> Up to 40 °C.

<sup>3</sup> Up to 202 °C.

<sup>4</sup> At (191 ±11) °C.

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

(1) If you use filter-based sampling media to extract and store PM for

measurement, your procedure must meet the following specifications:

(i) If you expect that a filter's total surface concentration of PM will exceed

0.473 mm/mm<sup>2</sup> 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 D 2986-95a (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 applicable requirements.

(ii) The filter must be circular, with an overall diameter of  $46.50 \pm 0.6$  mm and an exposed diameter of at least 38 mm. See the cassette specifications in paragraph (c)(1)(vi) 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  $40 \pm 20$   $\mu$ m. 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)(v) 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 sample velocity at the filter face at or below 100 cm/s, where filter face velocity is the measured volumetric flow rate of the sample at the pressure and temperature upstream of the filter face, divided by the filter's exposed area.

(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<sub>2</sub>H<sub>5</sub>OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's PM and HC emissions.

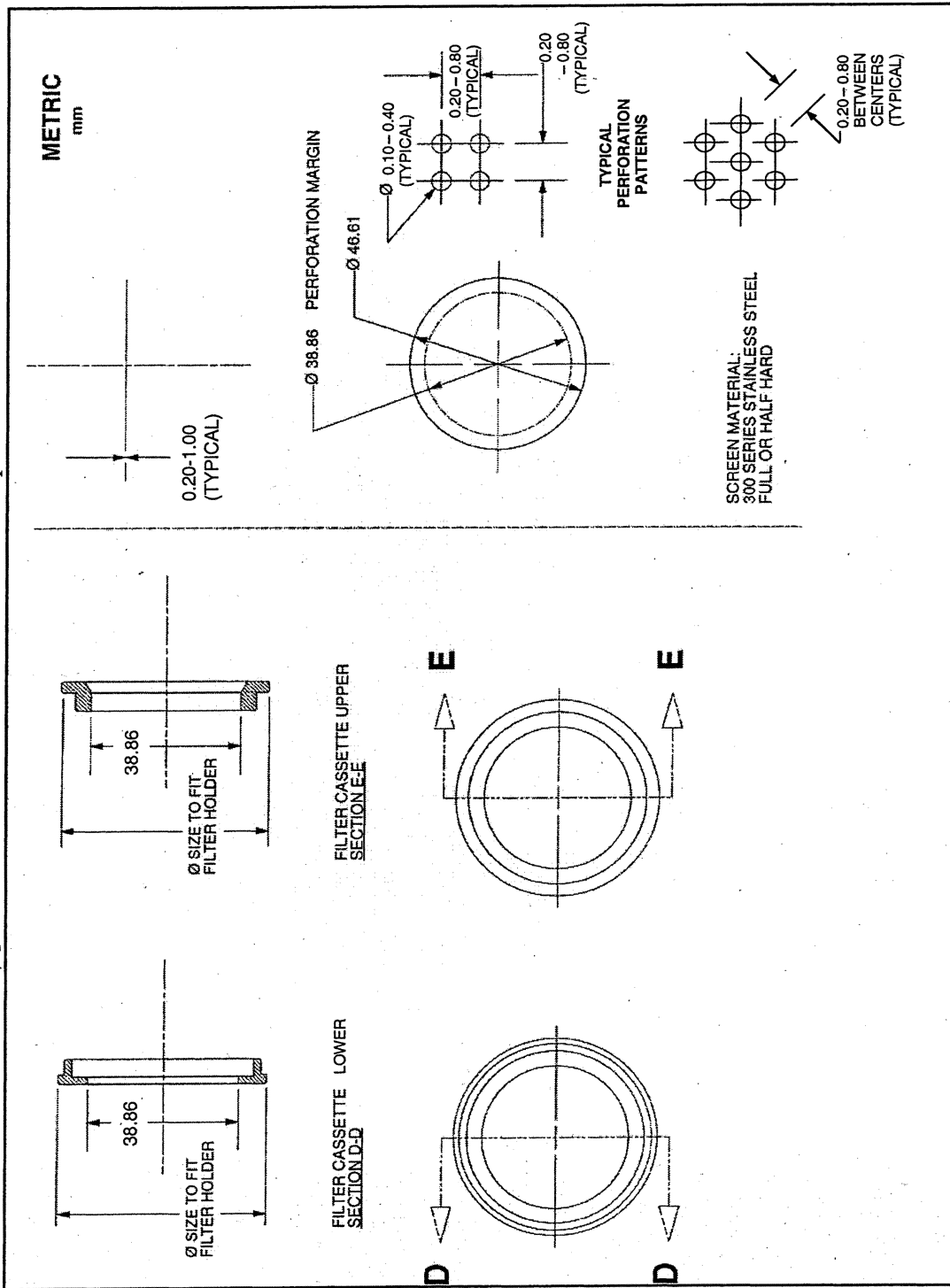
(viii) If you store filters in cassettes in an automatic PM sampler, cover or seal individual filter cassettes after sampling to prevent communication of semi-volatile matter from one filter to another.

(2) You may use other PM sample media that we approve under § 1065.10, including non-filtering techniques. For example, you might deposit PM on an inert substrate that collects PM using electrostatic, thermophoresis, inertia, diffusion, or some other deposition mechanism, as approved.

**BILLING CODE 6560-50-P**



Figure 1 of §1065.170—PM filter cassette specifications.



BILLING CODE 6560-50-C

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

(a) This section describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common

space. These volumes may be one or more rooms, or they may be much smaller, such as a glove box or an automated weighing system consisting of one or more countertop-sized environments.

(b) We recommend that you keep both the stabilization and the weighing environments free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could

contaminate PM samples. We recommend that these environments conform with an "as-built" Class Six clean room specification according to ISO 14644-1 (incorporated by reference in § 1065.1010); however, we also recommend that you deviate from ISO 14644-1 as necessary to minimize air motion that might affect weighing. We recommend maximum air-supply and

air-return velocities of 0.05 m/s in the weighing environment.

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

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

(1) *Ambient temperature and tolerances.* Maintain the weighing environment at a tolerance of  $(22 \pm 1)$  °C. If the two environments share a

common space, maintain both environments at a tolerance of  $(22 \pm 1)$  °C. If they are separate, maintain the stabilization environment at a tolerance of  $(22 \pm 3)$  °C.

(2) *Dewpoint.* Maintain a dewpoint of 9.5 °C in both environments. This dewpoint will control the amount of water associated with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) PM, such that 1.1368 grams of water will be associated with each gram of H<sub>2</sub>SO<sub>4</sub>.

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

TABLE 1 OF § 1065.190.—DEWPOINT TOLERANCE AS A FUNCTION OF % PM CHANGE AND % SULFURIC ACID PM

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

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

(1) Continuously measure dewpoint and ambient temperature. Use these values to determine if the stabilization and weighing environments have remained within the tolerances specified in paragraph (d) of this section for at least the past 60 min. We recommend that you provide 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. You may use a shared atmospheric pressure meter as long as you can show that your equipment for handling the weighing environment air maintains ambient pressure at the balance within  $\pm 100$  Pa of the shared atmospheric pressure. Provide a means to record the most recent atmospheric pressure when you weigh each PM sample. Use this value to calculate the PM 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 samples 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 samples, as follows:

(i) You may use radioactive neutralizers such as a Polonium (<sup>210</sup>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 surfaces.

(6) We recommend that you neutralize PM sample media to within  $\pm 2.0$  V of neutral.

**§ 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. This is typically a very small volume.

(b) Maintain the environment free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples. Filter all air used for stabilization with HEPA filters. Ensure that HEPA filters are installed properly so that background PM does not leak past the HEPA filters.

(c) Maintain the following thermodynamic conditions within the environment before measuring PM:

(1) *Ambient temperature.* Select a nominal ambient temperature,  $T_{amb}$ , between (42 and 52) °C. Maintain the ambient temperature within  $\pm 1.0$  °C of the selected nominal value.

(2) *Dewpoint.* Select a dewpoint,  $T_{dew}$ , that corresponds to  $T_{amb}$  such that  $T_{dew} = (0.95T_{amb} - 11.40)$  °C. The resulting dewpoint will control the amount of water associated with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) PM, such that 1.1368 grams of water will be associated with each gram of H<sub>2</sub>SO<sub>4</sub>. For example, if you select a nominal ambient temperature of 47 °C, set a dewpoint of 33.3 °C.

(3) *Dewpoint tolerance.* If the expected fraction of sulfuric acid in PM is unknown, we recommend controlling dewpoint within  $\pm 1.0$  °C. This would limit any dewpoint-related change in PM to less than  $\pm 2\%$ , even for PM that is 50% sulfuric acid. If you know your expected fraction of sulfuric acid in PM, we recommend that you select an appropriate dewpoint tolerance for showing compliance with emission standards using Table 1 of § 1065.190 as a guide:

(4) *Absolute pressure.* Maintain an absolute pressure of (80.000 to 103.325) kPa. Use good engineering judgment to

maintain a more stringent tolerance of absolute pressure if your PM measurement instrument requires it.

(d) Continuously measure dewpoint, temperature, and pressure using measurement instruments that meet the PM-stabilization environment specifications in subpart C of this part. Use these values to determine if the in-situ stabilization environment is within the tolerances specified in paragraph (c) of this section. Do not use any PM quantities that are recorded when any of these parameters exceed the applicable tolerances.

(e) If you use an inertial PM balance, we recommend that you install it as follows:

(1) Isolate the balance from any external noise and vibration that is within a frequency range that could affect the balance.

(2) Follow the balance manufacturer's specifications.

(f) If static electricity affects an inertial balance, you may use a static neutralizer, as follows:

(1) You may use a radioactive neutralizer such as a Polonium (<sup>210</sup>Po) source or a Krypton (<sup>85</sup>Kr) source. Replace radioactive sources at the intervals recommended by the neutralizer manufacturer.

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

**Subpart C—Measurement Instruments**

**§ 1065.201 Overview and general provisions.**

(a) *Scope.* This subpart specifies measurement instruments and associated system requirements related to emission testing in a laboratory 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 showing that an alternative procedure is equivalent to the specified procedure.

(c) *Measurement systems.* Assemble a system of measurement instruments that allows you to show that your engines comply with the applicable emission standards, using good engineering judgment. When selecting instruments, consider how conditions such as vibration, temperature, pressure, humidity, viscosity, specific heat, and exhaust composition (including trace concentrations) may affect instrument compatibility and performance.

(d) *Redundant systems.* For all measurement instruments described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use good engineering judgment to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements, as described in § 1065.25. This requirements applies whether or not you actually use the measurements in your calculations.

(e) *Range.* You may use an instrument's response above 100% of its operating range if this does not affect your ability to show that your engines comply with the applicable emission standards. Note that we require additional testing and reporting if an analyzer responds above 100% of its range. See § 1065.550. Auto-ranging analyzers do not require additional testing or reporting.

(f) *Related subparts for laboratory testing.* Subpart D of this part describes how to evaluate the performance of the measurement instruments in this subpart. In general, if an instrument is specified in a specific section of this subpart, its calibration and verifications are typically specified in a similarly numbered section in subpart D of this part. For example, § 1065.290 gives instrument specifications for PM balances and § 1065.390 describes the corresponding calibrations and verifications. Note that some instruments also have other requirements in other sections of subpart D of this part. Subpart B of this part identifies specifications for other types of equipment, and subpart H of this part specifies engine fluids and analytical gases.

(g) *Field testing and testing with PEMS.* Subpart J of this part describes how to use these and other measurement instruments for field testing and other PEMS testing.

**§ 1065.202 Data updating, recording, and control.**

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

TABLE OF § 1065.202.—DATA RECORDING AND CONTROL MINIMUM FREQUENCIES

Applicable test protocol section	Measured values	Minimum command and control frequency	Minimum recording frequency
§ 1065.510 .....	Speed and torque during an engine step-map .....	1 Hz .....	1 mean value per step.
§ 1065.510 .....	Speed and torque during an engine sweep-map .....	5 Hz .....	1 Hz means.
§ 1065.514, § 1065.530 .....	Transient duty cycle reference and feedback speeds and torques.	5 Hz .....	1 Hz means.
§ 1065.514, § 1065.530 .....	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques.	1 Hz .....	1 Hz.
§ 1065.520, § 1065.530, § 1065.550 .....	Continuous concentrations of raw or dilute analyzers ..	N/A .....	1 Hz.
§ 1065.520, § 1065.530, § 1065.550 .....	Batch concentrations of raw or dilute analyzers .....	N/A .....	1 mean value per test interval.
§ 1065.530, § 1065.545 .....	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement.	N/A .....	1 Hz.
§ 1065.530, § 1065.545 .....	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement.	5 Hz .....	1 Hz means.

TABLE OF § 1065.202.—DATA RECORDING AND CONTROL MINIMUM FREQUENCIES—Continued

Applicable test protocol section	Measured values	Minimum command and control frequency	Minimum recording frequency
§ 1065.530, § 1065.545 .....	Intake-air or raw-exhaust flow rate .....	N/A .....	1 Hz means.
§ 1065.530, § 1065.545 .....	Dilution air if actively controlled .....	5 Hz .....	1 Hz means.
§ 1065.530 .....	Sample flow from a CVS that has a heat exchanger ...	1 Hz .....	1 Hz.
§ 1065.530, § 1065.545 .....	Sample flow from a CVS does not have a heat exchanger.	5 Hz .....	1 Hz mean.

**§ 1065.205 Performance specifications for measurement instruments.**

Your test system as a whole must meet all the applicable calibrations, verifications, and test-validation criteria specified in subparts D and F of this

part or subpart J of this part for using PEMS and for performing field testing. We recommend that your instruments meet the specifications in Table 1 of this section for all ranges you use for testing. We also recommend that you keep any

documentation you receive from instrument manufacturers showing that your instruments meet the specifications in Table 1 of this section.

Table 1 of §1065.205—Recommended performance specifications for measurement instruments

Measurement Instrument	Measured quantity symbol	Complete System Rise time and Fall time	Recording update frequency	Accuracy <sup>a</sup>	Repeatability <sup>a</sup>	Noise <sup>a</sup>
Engine speed transducer	$f_n$	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max.	1.0 % of pt. or 0.25 % of max.	0.05 % of max.
Engine torque transducer	$T$	1 s	1 Hz means	2.0 % of pt. or 1.0 % of max.	1.0 % of pt. or 0.5 % of max.	0.05 % of max.
Electrical work (active-power meter)	$W$	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max.	1.0 % of pt. or 0.25 % of max.	0.05 % of max.
General pressure transducer (not a part of another instrument)	$p$	5 s	1 Hz	2.0 % of pt. or 1.0 % of max.	1.0 % of pt. or 0.50 % of max.	0.1 % of max.
Atmospheric pressure meter used for PM-stabilization and balance environments	$P_{atmos}$	50 s	5 times per hour	50 Pa	25 Pa	5 Pa
General purpose atmospheric pressure meter	$P_{atmos}$	50 s	5 times per hour	250 Pa	100Pa	50 Pa
Temperature sensor for PM-stabilization and balance environments	$T$	50 s	0.1 Hz	0.25 K	0.1 K	0.1 K
Other temperature sensor (not a part of another instrument)	$T$	10 s	0.5 Hz	0.4 % of pt. K or 0.2 % of max. K	0.2 % of pt. K or 0.1 % of max. K	0.1 % of max.
Dewpoint sensor for PM-stabilization and balance environments	$T_{dew}$	50 s	0.1 Hz	0.25 K	0.1 K	0.02 K
Other dewpoint sensor	$T_{dew}$	50 s	0.1 Hz	1 K	0.5 K	0.1 K
Fuel flow meter (Fuel totalizer in parentheses)	$\dot{m}$	5 s (N/A)	1 Hz (N/A)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	0.5 % of max.
Total diluted exhaust meter (CVS) (With heat exchanger before meter)	$\dot{m}$	1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	1.0 % of max.
Dilution air, inlet air, exhaust, and sample flow meters	$\dot{m}$	1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max.	1.25 % of pt. or 0.75 % of max.	1.0 % of max.
Continuous gas analyzer	$x$	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	1.0 % of max.
Batch gas analyzer	$x$	N/A	N/A	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	1.0 % of max.
Gravimetric PM balance	$m_{PM}$	N/A	N/A	See §1065.790	0.5 µg	N/A
Inertial PM balance	$m_{PM}$	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	0.2 % of max.

<sup>a</sup> Accuracy, repeatability, and noise are all determined with the same collected data, as described in §1065.305, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

**Measurement of Engine Parameters and Ambient Conditions**

**§ 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 this section. 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. In this case, divide the electrical work by an accurate value of electrical generator efficiency ( $\eta < 1$ ), or

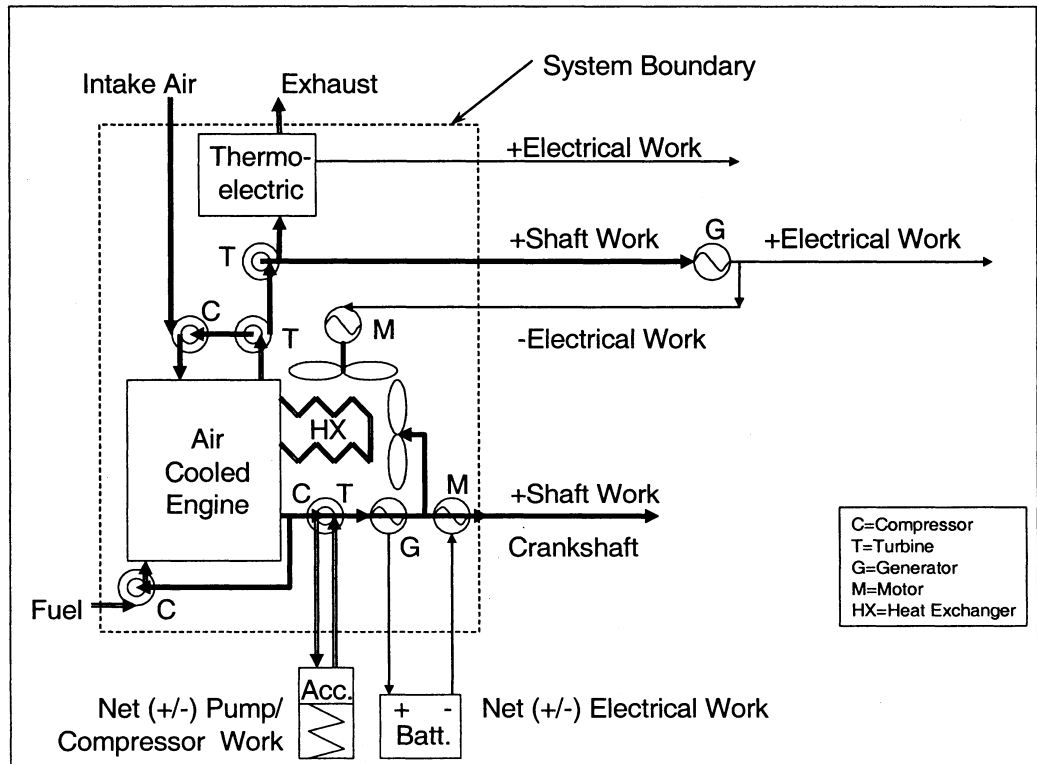
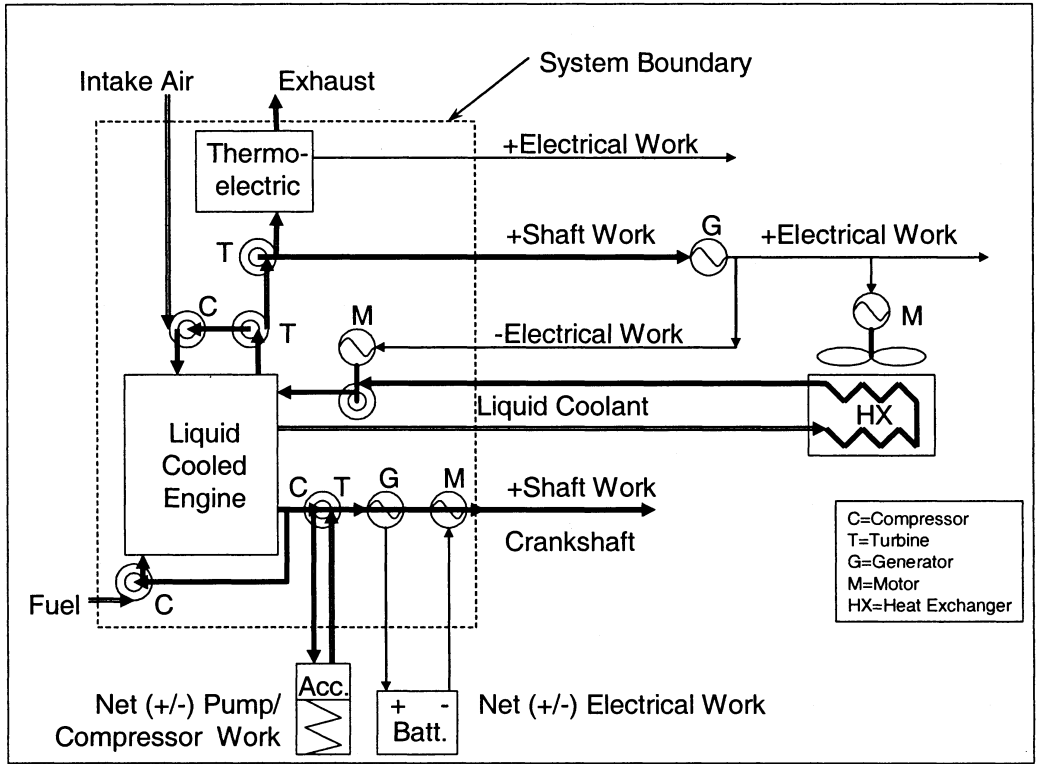
assume an efficiency of 1 ( $\eta=1$ ), which would over-estimate brake-specific emissions. Do not underestimate the generator's efficiency because this

would result in an under-estimation of brake-specific emissions. In all cases, ensure that you are able to accurately

demonstrate compliance with the applicable standards.

**BILLING CODE 6560-50-P**

Figure 1 of §1065.210: Work inputs, outputs, and system boundaries for liquid-cooled and air-cooled engines.



(b) *Shaft work.* Use speed and torque transducer outputs to calculate total work according to § 1065.650.

(1) *Speed.* Use a magnetic or optical shaft-position detector with a resolution of at least 60 counts per revolution, in combination with a frequency counter that rejects common-mode noise.

(2) *Torque.* You may use a variety of methods to determine engine torque. As needed, and based on good engineering judgment, compensate for torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor. Use any of the following methods to determine engine torque:

(i) Measure torque by mounting a strain gage or similar instrument in-line between the engine and dynamometer.

(ii) Measure torque by mounting a strain gage or similar instrument on a lever arm connected to the dynamometer housing.

(iii) Calculate torque from internal dynamometer signals, such as armature current, as long as you calibrate this measurement as described in § 1065.310.

(c) *Electrical work.* Use a watt-hour meter output to calculate total work according to § 1065.650. Use a watt-hour meter that outputs active power (kW). Watt-hour meters typically combine a Wheatstone bridge voltmeter and a Hall-effect clamp-on ammeter into a single microprocessor-based instrument that analyzes and outputs several parameters, such as alternating or direct current voltage (V), current (A), power factor (pf), apparent power (VA), reactive power (VAR), and active power (W).

(d) *Pump, compressor or turbine work.* Use pressure transducer and flow-meter outputs to calculate total work according to § 1065.650. For flow meters, see § 1065.220 through § 1065.248.

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

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

(b) *Component requirements.* We recommend that you use pressure transducers, temperature sensors, and dewpoint sensors that meet the specifications in Table 1 of § 1065.205. Note that your overall systems for measuring pressure, temperature, and dewpoint must meet the calibration and verifications in § 1065.315.

(c) *Temperature.* For PM-balance environments or other precision temperature measurements over a

narrow temperature range, we recommend thermistors. For other applications we recommend thermocouples that are not grounded to the thermocouple sheath. You may use other temperature sensors, such as resistive temperature detectors (RTDs).

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

(e) *Dewpoint.* For PM-stabilization environments, we recommend chilled-surface hygrometers. 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.

#### Flow-Related Measurements

##### § 1065.220 Fuel flow meter.

(a) *Application.* You may use fuel flow in combination with a chemical balance of carbon (or oxygen) between the fuel, inlet air, and raw exhaust to calculate raw exhaust flow as described in § 1065.650, as follows:

(1) Use the actual value of calculated raw exhaust flow rate in the following cases:

(i) For multiplying raw exhaust flow rate with continuously sampled concentrations.

(ii) For multiplying total raw exhaust flow with batch-sampled concentrations.

(2) In the following cases, you may use a fuel flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust molar flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use a fuel flow meter that meets the specifications in

Table 1 of § 1065.205. We recommend a fuel flow meter that measures mass directly, such as one that relies on gravimetric or inertial measurement principles. This may involve using a meter with one or more scales for weighing fuel or using a Coriolis meter. Note that your overall system for measuring fuel flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.320.

(c) *Recirculating fuel.* In any fuel-flow measurement, account for any fuel that bypasses the engine or returns from the engine to the fuel storage tank.

(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.

##### § 1065.225 Intake-air flow meter.

(a) *Application.* You may use an intake-air flow meter in combination with a chemical balance of carbon (or oxygen) between the fuel, inlet air, and raw exhaust to calculate raw exhaust flow as described in § 1065.650, as follows:

(1) Use the actual value of calculated raw exhaust in the following cases:

(i) For multiplying raw exhaust flow rate with continuously sampled concentrations.

(ii) For multiplying total raw exhaust flow with batch-sampled concentrations.

(2) In the following cases, you may use an intake-air flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use an intake-air flow meter that meets the specifications in Table 1 of § 1065.205. This may include a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a thermal-mass meter, an



averaging Pitot tube, or a hot-wire anemometer. Note that your overall system for measuring intake-air flow must meet the linearity verification in § 1065.307 and the calibration in § 1065.325.

(c) *Flow conditioning.* For any type of intake-air 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, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

#### § 1065.230 Raw exhaust flow meter.

(a) *Application.* You may use measured raw exhaust flow, as follows:

(1) Use the actual value of calculated raw exhaust in the following cases:

(i) Multiply raw exhaust flow rate with continuously sampled concentrations.

(ii) Multiply total raw exhaust with batch sampled concentrations.

(2) In the following cases, you may use a raw exhaust flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use a raw-exhaust flow meter that meets the specifications in Table 1 of § 1065.205. This may involve using an ultrasonic flow meter, a subsonic venturi, an averaging Pitot tube, a hot-wire anemometer, or other measurement principle. This would generally not involve a laminar flow element or a thermal-mass meter. Note that your overall system for measuring raw exhaust flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.330. Any raw-exhaust meter must be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states.

(c) *Flow conditioning.* For any type of raw exhaust flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow

pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

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

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

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines, 2-stroke spark-ignition engines, and 4-stroke spark ignition engines below 19 kW.

(3) If cooling causes aqueous condensation, do not sample NO<sub>x</sub> downstream of the cooling unless the cooler meets the performance verification in § 1065.376.

(4) If cooling causes aqueous condensation before the flow reaches a flow meter, measure dewpoint, T<sub>dew</sub> and pressure, p<sub>total</sub> at the flow meter inlet. Use these values in emission calculations according to § 1065.650.

#### § 1065.240 Dilution air and diluted exhaust flow meters.

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

(b) *Component requirements.* We recommend that you use a diluted exhaust flow meter that meets the specifications in Table 1 of § 1065.205. Note that your overall system for measuring diluted exhaust flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.340 and § 1065.341. You may use the following meters:

(1) For constant-volume sampling (CVS) of the total flow of diluted exhaust, you may use a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM). Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller in a CVS system. However, you may also combine any

flow meter with any active flow control system to maintain proportional sampling of exhaust constituents. You may control the total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls to maintain proportional sampling.

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

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

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

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

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines, 2-stroke spark-ignition engines, and 4-stroke spark ignition engines below 19 kW.

(3) If cooling causes aqueous condensation, do not sample NO<sub>x</sub> downstream of the cooling unless the cooler meets the performance verification in § 1065.376.

(4) If cooling causes aqueous condensation before the flow reaches a flow meter, measure dewpoint, T<sub>dew</sub> and pressure, p<sub>total</sub> at the flow meter inlet. Use these values in emission calculations according to § 1065.650.

#### § 1065.245 Sample flow meter for batch sampling.

(a) *Application.* Use a sample flow meter to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. You may use the difference between a diluted exhaust sample flow meter and a dilution air meter to calculate raw exhaust flow rates or total raw exhaust flow over a test interval.

(b) *Component requirements.* We recommend that you use a sample flow meter that meets the specifications in

Table 1 of § 1065.205. This may involve a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. Note that your overall system for measuring sample flow must meet the linearity verification in § 1065.307. For the special case where CFVs are used for both the diluted exhaust and sample-flow measurements and their upstream pressures and temperatures remain similar during testing, you do not have to quantify the flow rate of the sample-flow CFV. In this special case, the sample-flow CFV inherently flow-weights the batch sample relative to the diluted exhaust CFV.

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

#### § 1065.248 Gas divider.

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

(b) *Component requirements.* Use a gas divider that blends gases to the specifications of § 1065.750 and to the flow-weighted concentrations expected during testing. You may use critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers. Note that your overall gas-divider system must meet the linearity verification in § 1065.307.

#### CO and CO<sub>2</sub> Measurements

##### § 1065.250 Nondispersive infra-red analyzer.

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

(b) *Component requirements.* We recommend that you use an NDIR analyzer that meets the specifications in Table 1 of § 1065.205. Note that your NDIR-based system must meet the calibration and verifications in § 1065.350 and § 1065.355 and it must also meet the linearity verification in § 1065.307. You may use an NDIR analyzer that has compensation algorithms that are functions of other

gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

#### Hydrocarbon Measurements

##### § 1065.260 Flame-ionization detector.

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

(b) *Component requirements.* We recommend that you use a FID analyzer that meets the specifications in Table 1 of § 1065.205. Note that your FID-based system for measuring THC, THCE, or CH<sub>4</sub> must meet all of the verifications for hydrocarbon measurement in subpart D of this part, and it must also meet the linearity verification in § 1065.307. You may use a FID 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.

(c) *Heated FID analyzers.* For diesel-fueled engines, two-stroke spark-ignition engines, and four-stroke spark-ignition engines below 19 kW, you must use heated FID analyzers that maintain all surfaces that are exposed to emissions at a temperature of  $(191 \pm 11)$  °C.

(d) *FID fuel and burner air.* Use FID fuel and burner air that meet the specifications of § 1065.750. Do not allow the FID fuel and burner air to mix before entering the FID analyzer to ensure that the FID analyzer operates with a diffusion flame and not a premixed flame.

(e) *Methane.* FID analyzers measure total hydrocarbons (THC). To determine nonmethane hydrocarbons (NMHC), quantify methane, CH<sub>4</sub>, either with a nonmethane cutter and a FID analyzer as described in § 1065.265, or with a gas chromatograph as described in § 1065.267. Instead of measuring methane, you may assume that 2% of measured total hydrocarbons is methane, as described in § 1065.660. For a FID analyzer used to determine

NMHC, determine its response factor to CH<sub>4</sub>, RF<sub>CH<sub>4</sub></sub>, as described in § 1065.360. Note that NMHC-related calculations are described in § 1065.660.

##### § 1065.265 Nonmethane cutter.

(a) *Application.* You may use a nonmethane cutter to measure CH<sub>4</sub> with a FID analyzer. A nonmethane cutter oxidizes all nonmethane hydrocarbons to CO<sub>2</sub> and H<sub>2</sub>O. You may use a nonmethane cutter for raw or diluted exhaust for batch or continuous sampling.

(b) *System performance.* Determine nonmethane-cutter performance as described in § 1065.365 and use the results to calculate NMHC emission in § 1065.660.

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

(d) *Optimization.* You may optimize a nonmethane cutter to maximize the penetration of CH<sub>4</sub> and the oxidation of all other hydrocarbons. You may humidify a sample and you may dilute a sample with purified air or oxygen (O<sub>2</sub>) upstream of the nonmethane cutter to optimize its performance. You must account for any sample humidification and dilution in emission calculations.

##### § 1065.267 Gas chromatograph.

(a) *Application.* You may use a gas chromatograph to measure CH<sub>4</sub> concentrations of diluted exhaust for batch sampling. While you may also use a nonmethane cutter to measure CH<sub>4</sub>, as described in § 1065.265, use a reference procedure based on a gas chromatograph for comparison with any proposed alternate measurement procedure under § 1065.10.

(b) *Component requirements.* We recommend that you use a gas chromatograph that meets the specifications in Table 1 of § 1065.205, and it must also meet the linearity verification in § 1065.307.

#### NO<sub>x</sub> Measurements

##### § 1065.270 Chemiluminescent detector.

(a) *Application.* You may use a chemiluminescent detector (CLD) to measure NO<sub>x</sub> concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept a CLD for NO<sub>x</sub> measurement, even though it measures only NO and NO<sub>2</sub>, when coupled with an NO<sub>2</sub>-to-NO converter, since conventional engines and aftertreatment systems do not emit significant amounts of NO<sub>x</sub> species other than NO and NO<sub>2</sub>. Measure other NO<sub>x</sub> species if required by the standard-setting part. While you may also use other instruments to measure NO<sub>x</sub>, as

described in § 1065.272, use a reference procedure based on a chemiluminescent detector for comparison with any proposed alternate measurement procedure under § 1065.10.

(b) *Component requirements.* We recommend that you use a CLD that meets the specifications in Table 1 of § 1065.205. Note that your CLD-based system must meet the quench verification in § 1065.370 and it must also meet the linearity verification in § 1065.307. You may use a heated or unheated CLD, and you may use a CLD that operates at atmospheric pressure or under a vacuum. You may use a CLD that has compensation algorithms that are functions of other gaseous measurements and the 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.

(c) *NO<sub>2</sub>-to-NO converter.* Place upstream of the CLD an internal or external NO<sub>2</sub>-to-NO converter that meets the verification in § 1065.378. Configure the converter with a bypass to facilitate this verification.

(d) *Humidity effects.* You must maintain all CLD temperatures to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, use one of the following configurations:

(1) Connect a CLD downstream of any dryer or chiller that is downstream of an NO<sub>2</sub>-to-NO converter that meets the verification in § 1065.378.

(2) Connect a CLD downstream of any dryer or thermal chiller that meets the verification in § 1065.376.

(e) *Response time.* You may use a heated CLD to improve CLD response time.

#### **§ 1065.272 Nondispersive ultraviolet analyzer.**

(a) *Application.* You may use a nondispersive ultraviolet (NDUV) analyzer to measure NO<sub>x</sub> concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept an NDUV for NO<sub>x</sub> measurement, even though it measures only NO and NO<sub>2</sub>, since conventional engines and aftertreatment systems do not emit significant amounts of other NO<sub>x</sub> species. Measure other NO<sub>x</sub> species if required by the standard-setting part.

(b) *Component requirements.* We recommend that you use an NDUV analyzer that meets the specifications in Table 1 of § 1065.205. Note that your NDUV-based system must meet the verifications in § 1065.372 and it must also meet the linearity verification in § 1065.307. You may use a NDUV

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

(c) *NO<sub>2</sub>-to-NO converter.* If your NDUV analyzer measures only NO, place upstream of the NDUV analyzer an internal or external NO<sub>2</sub>-to-NO converter that meets the verification in § 1065.378. Configure the converter with a bypass to facilitate this verification.

(d) *Humidity effects.* You must maintain NDUV temperature to prevent aqueous condensation, unless you use one of the following configurations:

(1) Connect an NDUV downstream of any dryer or chiller that is downstream of an NO<sub>2</sub>-to-NO converter that meets the verification in § 1065.378.

(2) Connect an NDUV downstream of any dryer or thermal chiller that meets the verification in § 1065.376.

#### **O<sub>2</sub> Measurements**

##### **§ 1065.280 Paramagnetic and magnetopneumatic O<sub>2</sub> detection analyzers.**

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

#### **Air-to-Fuel Ratio Measurements**

##### **§ 1065.284 Zirconia (ZrO<sub>2</sub>) analyzer.**

(a) *Application.* You may use a zirconia (ZrO<sub>2</sub>) analyzer to measure air-to-fuel ratio in raw exhaust for continuous sampling. You may use O<sub>2</sub> 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 ZrO<sub>2</sub> analyzer that meets the specifications in Table 1 of § 1065.205. Note that your ZrO<sub>2</sub>-based system must meet the

linearity verification in § 1065.307. You may use a Zirconia analyzer that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

#### **PM Measurements**

##### **§ 1065.290 PM gravimetric balance.**

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

(b) *Component requirements.* We recommend that you use a balance that meets the specifications in Table 1 of § 1065.205. Note that your balance-based system must meet the linearity verification in § 1065.307. If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights must meet the specifications in § 1065.790. While you may also use an inertial balance to measure PM, as described in § 1065.295, use a reference procedure based on a gravimetric balance for comparison with any proposed alternate measurement procedure under § 1065.10.

(c) *Pan design.* We recommend that you use a balance pan designed to minimize corner loading of the balance, as follows:

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

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

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

##### **§ 1065.295 PM inertial balance for field-testing analysis.**

(a) *Application.* You may use an inertial balance to quantify net PM on a sample medium for field testing.

(b) *Component requirements.* We recommend that you use a balance that meets the specifications in Table 1 of § 1065.205. Note that your balance-based system must meet the linearity verification in § 1065.307. If the balance uses an internal calibration process for routine spanning and linearity verifications, the process must be NIST-traceable. You may use an inertial PM balance 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.

**Subpart D—Calibrations and Verifications**

**§ 1065.301 Overview and general provisions.**

(a) This subpart describes required and recommended calibrations and verifications of measurement systems. See subpart C of this part for specifications that apply to individual instruments.

(b) You must generally use complete measurement systems when performing calibrations or verifications in this

subpart. For example, this would generally involve evaluating instruments based on values recorded with the complete system you use for recording test data, including analog-to-digital converters. For some calibrations and verifications, we may specify that you disconnect part of the measurement system to introduce a simulated signal.

(c) If we do not specify a calibration or verification for a portion of a measurement system, calibrate that portion of your system and verify its performance at a frequency consistent with any recommendations from the measurement-system manufacturer,

consistent with good engineering judgment.

(d) Use NIST-traceable standards to the tolerances we specify for calibrations and verifications. Where we specify the need to use NIST-traceable standards, you may alternatively ask for our approval to use international standards that are not NIST-traceable.

**§ 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 <sup>a</sup>
§ 1065.305: accuracy, repeatability and noise ...	<i>Accuracy:</i> Not required, but recommended for initial installation. <i>Repeatability:</i> Not required, but recommended for initial installation. <i>Noise:</i> Not required, but recommended for initial installation.
§ 1065.307: linearity .....	<i>Speed:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Torque:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Electrical power:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Clean gas and diluted exhaust flows:</i> 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. <i>Raw exhaust flow:</i> 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. <i>Gas analyzers:</i> Upon initial installation, within 35 days before testing and after major maintenance. <i>PM balance:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Stand-alone pressure and temperature:</i> 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	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 <sub>2</sub> NDIRH <sub>2</sub> O interference .....	Upon initial installation and after major maintenance.
§ 1065.355: CO NDIRCO <sub>2</sub> and H <sub>2</sub> O interference	Upon initial installation and after major maintenance.
§ 1065.360: FID optimization, etc. ....	<i>Calibrate, optimize, and determine CH<sub>4</sub> response:</i> upon initial installation and after major maintenance. <i>Verify CH<sub>4</sub> response:</i> upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.362: raw exhaustFID O <sub>2</sub> interference ....	Upon initial installation, after FID optimization according to § 1065.360, and after major maintenance.
§ 1065.365: nonmethane cutter penetration .....	Upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.370: CLD CO <sub>2</sub> and H <sub>2</sub> O quench .....	Upon initial installation and after major maintenance.
§ 1065.372: NDUV HC and H <sub>2</sub> O interference ....	Upon initial installation and after major maintenance.
§ 1065.376: chiller NO <sub>2</sub> penetration .....	Upon initial installation and after major maintenance.
§ 1065.378: NO <sub>2</sub> -to-NO converter conversion ....	Upon initial installation, within 35 days before testing, and after major maintenance.
§ 1065.390: PM balance and weighing .....	<i>Independent verification:</i> upon initial installation, within 370 days before testing, and after major maintenance. <i>Zero, span, and reference sample verifications:</i> 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.

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

Type of calibration or verification	Minimum frequency <sup>a</sup>
	<i>Other verifications:</i> upon initial installation and after major maintenance.

<sup>a</sup> Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

**§ 1065.305 Verifications for accuracy, repeatability, and noise.**

(a) This section describes how to determine the accuracy, repeatability, and noise of an instrument. Table 1 of § 1065.205 specifies recommended values for individual instruments.

(b) We do not require you to verify instrument accuracy, repeatability, or noise.

However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

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

(d) Conduct these verifications as follows:

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

(2) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750.

(3) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of § 1065.750.

(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

a 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.

(5) Sample and record values for 30 seconds, record the arithmetic mean,  $\bar{y}_i$ , and record the standard deviation,  $\sigma_i$ , of the recorded values. Refer to § 1065.602 for an example of calculating arithmetic mean and standard deviation.

(6) Also, if the reference quantity is not absolutely constant, which might be the case with a reference flow, sample and record values of  $y_{ref}$  for 30 seconds and record the arithmetic mean of the values,  $\bar{y}_{ref}$ . Refer to § 1065.602 for an example of calculating arithmetic mean.

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

(8) Repeat the steps specified in paragraphs (d)(2) through (6) of this section until you have ten arithmetic means ( $\bar{y}_1, \bar{y}_2, \bar{y}_i, \dots, \bar{y}_{10}$ ), ten standard deviations, ( $\sigma_1, \sigma_2, \sigma_i, \dots, \sigma_{10}$ ), and ten errors ( $\epsilon_1, \epsilon_2, \epsilon_i, \dots, \epsilon_{10}$ ).

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

(i) *Accuracy.* Instrument accuracy is the absolute difference between the reference quantity,  $y_{ref}$  (or  $\bar{y}_{ref}$ ), and the arithmetic mean of the ten  $\bar{y}_i$  values. Refer to the example of an accuracy calculation in § 1065.602. We recommend that instrument accuracy be within the specifications in Table 1 of § 1065.205.

(ii) *Repeatability.* Repeatability is two times the standard deviation of the ten errors (that is,  $\text{repeatability} = 2 \cdot \sigma_\epsilon$ ). Refer to the example of a standard-deviation calculation in § 1065.602. We recommend that instrument repeatability be within the specifications in Table 1 of § 1065.205.

(iii) *Noise.* Noise is two times the root-mean-square of the ten standard deviations (that is,  $\text{noise} = 2 \cdot \text{rms}_\sigma$ ) when the reference signal is a zero-quantity signal. Refer to the example of a root-mean-square calculation in § 1065.602. We recommend that instrument noise be within the specifications in Table 1 of § 1065.205.

Use this value in the noise correction specified in § 1065.657.

(10) You may use a measurement instrument that does not meet the accuracy, repeatability, or noise specifications in Table 1 of § 1065.205, as long as you meet the following criteria:

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

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

**§ 1065.307 Linearity verification.**

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

(b) *Performance requirements.* If a measurement system does not meet the applicable linearity criteria in Table 1 of this section, correct the deficiency by recalibrating, servicing, or replacing components as needed. 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) *Procedure.* Use the following linearity verification protocol, or use good engineering judgment to develop a different protocol that satisfies the

intent of this section, as described in paragraph (a) of this section:

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

(2) Operate a measurement system at its specified temperatures, pressures, and flows. This may include any specified adjustment or periodic calibration of the measurement system.

(3) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(4) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

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

(6) Use instrument manufacturer recommendations and good engineering judgment to select at least 10 reference values,  $y_{refi}$ , that are within the range from zero to the highest values expected during emission testing. We recommend selecting a zero reference signal as one of the reference values of the linearity verification.

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

(8) Generate reference quantities as described in paragraph (d) of this section. For gas analyzers, use gas concentrations known to be within the specifications of § 1065.750 and introduce them directly at the analyzer port.

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

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

(11) At a recording frequency of at least  $f$  Hz, specified in Table 1 of § 1065.205, measure the reference value for 30 seconds and record the arithmetic mean of the recorded values,  $\bar{y}_i$ . Refer to § 1065.602 for an example of calculating an arithmetic mean.

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

(13) Use the arithmetic means  $y_i$ , and reference values,  $y_{refi}$ , 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.

(d) *Reference signals.* This paragraph (d) describes recommended methods for generating reference values for the linearity-verification protocol in paragraph (c) of this section. Use reference values that simulate actual values, or introduce an actual value and measure it with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems must be NIST-traceable. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty, if not specified otherwise in other sections of this part 1065. Use the following recommended methods to generate reference values or use good engineering judgment to select a different reference:

(1) *Engine speed.* Run the engine or dynamometer at a series of steady-state speeds and use a strobe, a photo tachometer, or a laser tachometer to record reference speeds.

(2) *Engine torque.* Use a series of calibration weights and a calibration lever arm to simulate engine torque. You may instead use the engine or dynamometer itself to generate a nominal torque that is measured by a reference load cell or proving ring in series with the torque-measurement system. In this case use the reference load cell measurement as the reference value. Refer to § 1065.310 for a torque-

calibration procedure similar to the linearity verification in this section.

(3) *Electrical work.* Use a controlled source of current and a watt-hour standard reference meter. Complete calibration systems that contain a current source and a reference watt-hour meter are commonly used in the electrical power distribution industry and are therefore commercially available.

(4) *Fuel rate.* Operate the engine at a series of constant fuel-flow rates or recirculate fuel back to a tank through the fuel flow meter at different flow rates. Use a gravimetric reference measurement (such as a scale, balance, or mass comparator) at the inlet to the fuel-measurement system. Use a stopwatch or timer to measure the time intervals over which reference masses of fuel are introduced to the fuel measurement system. The reference fuel mass divided by the time interval is the reference fuel flow rate.

(5) *Flow rates—inlet air, dilution air, diluted exhaust, raw exhaust, or sample flow.* Use a reference flow meter with a blower or pump to simulate flow rates. Use a restrictor, diverter valve, a variable-speed blower or a variable-speed pump to control the range of flow rates. Use the reference meter's response as the reference values.

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

(ii) *Reference flow values.* Because the reference flow is not absolutely constant, sample and record values of  $\dot{n}_{refi}$  for 30 seconds and use the arithmetic mean of the values,  $\bar{n}_{ref}$ , as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(6) *Gas division.* Use one of the two reference signals: (i) At the outlet of the gas-division system, connect a gas analyzer that meets the linearity

verification described in this section and has not been linearized with the gas divider being verified. For example, verify the linearity of an analyzer using a series of reference analytical gases directly from compressed gas cylinders that meet the specifications of § 1065.750. We recommend using a FID analyzer or a PMD/MPD O<sub>2</sub> analyzer because of their inherent linearity. Operate this analyzer consistent with how you would operate it during an emission test. Connect a span gas to the gas-divider inlet. Use the gas-division

system to divide the span gas with purified air or nitrogen. Select gas divisions that you typically use. Use a selected gas division as the measured value. Use the analyzer response divided by the span gas concentration as the reference gas-division value. Because the instrument response is not absolutely constant, sample and record values of  $x_{\text{refi}}$  for 30 seconds and use the arithmetic mean of the values  $\bar{x}_{\text{refi}}$ , as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(ii) Using good engineering judgment and gas divider manufacturer recommendations, use one or more reference flow meters to verify the measured flow rates of the gas divider.

(7) *Continuous constituent concentration.* For reference values, use a series of gas cylinders of known gas concentration or use a gas-division system that is known to be linear with a span gas. Gas cylinders, gas-division systems, and span gases that you use for reference values must meet the specifications of § 1065.750.

Table 1 of §1065.307—Measurement systems that require linearity verifications

Measurement System	Quantity	Minimum verification frequency <sup>a</sup>	Linearity Criteria			
			$ a_0 $ <sup>b</sup>	$a_1$ <sup>c</sup>	$SEE$ <sup>b</sup>	$r^2$
Engine speed	$f_n$	Within 370 days before testing	$\leq 0.05\% \cdot f_{nmax}$	0.98-1.02	$\leq 2\% \cdot f_{nmax}$	$\geq 0.990$
Engine torque	$T$	Within 370 days before testing	$\leq 1\% \cdot T_{max}$	0.98-1.02	$\leq 2\% \cdot T_{max}$	$\geq 0.990$
Electrical work	$W$	Within 370 days before testing	$\leq 1\% \cdot W_{max}$	0.98-1.02	$\leq 2\% \cdot W_{max}$	$\geq 0.990$
Fuel flow rate	$\dot{m}$	Within 370 days before testing <sup>d</sup>	$\leq 1\% \cdot \dot{m}_{max}$	0.98-1.02 <sup>e</sup>	$\leq 2\% \cdot \dot{m}_{max}$	$\geq 0.990$
Intake-air flow rate	$\dot{n}$	Within 370 days before testing <sup>d</sup>	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02 <sup>e</sup>	$\leq 2\% \cdot \dot{n}_{max}$	$\geq 0.990$
Dilution air flow rate	$\dot{n}$	Within 370 days before testing <sup>d</sup>	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{max}$	$\geq 0.990$
Diluted exhaust flow rate	$\dot{n}$	Within 370 days before testing <sup>d</sup>	$\leq 1\% \cdot \dot{n}_{min}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{max}$	$\geq 0.990$
Raw exhaust flow rate	$\dot{n}$	Within 185 days before testing <sup>d</sup>	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02 <sup>e</sup>	$\leq 2\% \cdot \dot{n}_{max}$	$\geq 0.990$
Batch sampler flow rates	$\dot{n}$	Within 370 days before testing <sup>d</sup>	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{max}$	$\geq 0.990$
Gas dividers	$x$	Within 370 days before testing	$\leq 0.5\% \cdot x_{max}$	0.98-1.02	$\leq 2\% \cdot x_{max}$	$\geq 0.990$
All gas analyzers	$x$	Within 35 days before testing	$\leq 0.5\% \cdot x_{max}$	0.99-1.01	$\leq 1\% \cdot x_{max}$	$\geq 0.998$
PM balance	$m$	Within 370 days before testing	$\leq 1\% \cdot m_{max}$	0.99-1.01	$\leq 1\% \cdot m_{max}$	$\geq 0.998$
Stand-alone pressures	$p$	Within 370 days before testing	$\leq 1\% \cdot p_{max}$	0.99-1.01	$\leq 1\% \cdot p_{max}$	$\geq 0.998$
Stand-alone temperatures	$T$	Within 370 days before testing	$\leq 1\% \cdot T_{max}$	0.99-1.01	$\leq 1\% \cdot T_{max}$	$\geq 0.998$

<sup>a</sup> Perform a linearity verification more frequently if the instrument manufacturer recommends it or based on good engineering judgment.

<sup>b</sup> "max" refers to the maximum value expected during a test—the maximum value used for the linearity verification.

<sup>c</sup> The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for  $a_1$  means  $0.98 \leq a_1 \leq 1.02$ .

<sup>d</sup> These linearity verifications are not required 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  $\pm 2\%$  based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust.

<sup>e</sup>  $a_0$  and  $a_1$  for these quantities are required only if the actual value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.

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

(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 change the frequency at which you sample and record gas-analyzer concentrations.

(b) *Measurement principles.* This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas 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.

(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 criteria makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing.

(2) The frequency at which the system records an updated concentration must be at least 5 Hz. This criteria assumes that the frequency content of significant changes in emission concentrations during emission testing do not exceed 1 Hz.

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

(4) For PEMS, you do not have to meet this criteria if your PEMS meets the overall PEMS check in § 1065.920.

(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.* Using minimal gas transfer line lengths between all connections, connect a zero-air source to one inlet of a fast-acting 3-way valve (2 inlets, 1 outlet). Using a gas divider, equally blend an NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub> (balance N<sub>2</sub>) span gas with a span gas of NO<sub>2</sub>. Connect the gas divider outlet to the other inlet of the 3-way valve. Connect the valve outlet to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified.

(3) *Data collection.* (i) Switch the valve to flow 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 valve to flow the blended span gases.

(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,  $T_{90-10}$ , 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.

(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.

(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.

#### § 1065.309 Continuous gas analyzer uniform response verification.

(a) *Scope and frequency.* If you use more than one continuous gas analyzer to quantify a gaseous constituent, you must perform this verification. For example, if you determine NMHC as the difference between continuous THC and CH<sub>4</sub> measurements, you must perform this verification on your NMHC measurement system. As another example if you determine NO<sub>x</sub> as the sum of separate continuous measurements of NO and NO<sub>2</sub>, you must perform this verification on your NO<sub>x</sub> measurement system. Also, you must perform this verification if you use one continuous analyzer to apply an interference compensation algorithm to another continuous gas analyzer. Perform this verification after initial installation or major maintenance. 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 by adding a filter; or if you change the frequency at which you sample and record gas-analyzer concentrations.

(b) *Measurement principles.* This procedure verifies the time-alignment and uniform response of combined continuous gas measurements.

(c) *System requirements.* Demonstrate that combined continuous concentration measurements have a uniform rise and fall during a simultaneous to a step change in both concentrations. During a system response to a rapid change in multiple gas concentrations, demonstrate that the  $t_{50}$  times of all combined analyzers all occur at the same recorded second of data or

between the same two recorded seconds of data.

(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.* Using minimal gas transfer line lengths between all connections, connect a zero-air source to the inlet of a 100 °C heated line. Connect the heated line outlet to one inlet of a 100 °C heated fast-acting 3-way valve (2 inlets, 1 outlet). Using a gas divider, equally blend an NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub> (balance N<sub>2</sub>) span gas with a span gas of NO<sub>2</sub> (balance N<sub>2</sub>). Connect the gas divider outlet to the inlet of a 50 °C heated line. Connect the heated line outlet to the inlet of a 50 °C gas bubbler filled with distilled water. Connect the bubbler outlet to another heated line at 100 °C. Connect the outlet of the 100 °C line to the other inlet of the 3-way valve. Connect the valve outlet to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified.

(3) *Data collection.* (i) Switch the valve to flow 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.

(iv) Switch the valve to flow span gas.

(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.* Perform the following evaluations:

(1) *Uniform response evaluation.* (i) Calculate the mean rise time,  $t_{10-90}$ , mean fall time,  $t_{90-10}$  for each analyzer.

(ii) Determine the maximum mean rise and fall times for the slowest responding analyzer in each combination of continuous analyzer signals that you use to determine a single emission concentration.

(iii) If the maximum rise time or fall time is greater than one second, verify that all other gas analyzers combined with it have mean rise and fall times of at least 75% of that analyzer's response.

(iv) If any analyzer has shorter rise or fall times, disperse that signal so that it better matches the rise and fall times of the slowest signal with which it is combined. We recommend that you perform dispersion using SAE 2001-01-

3536 (incorporated by reference in § 1065.1010) as a guide.

(v) Repeat this verification after optimizing your systems to ensure that you dispersed signals correctly. If after repeated attempts at dispersing signals your system still fails this verification, you may use the continuous analyzer system if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

(2) *Time alignment evaluation.* (i) After all signals are adjusted to meet the uniform response evaluation, determine the second at which—or the two seconds between which—each analyzer crossed the midpoint of its response,  $t_{50}$ .

(ii) Verify that all combined gas analyzer signals are time-aligned such that all of their  $t_{50}$  times occurred at the same second or between the same two seconds in the recorded data.

(iii) If your system fails to meet this criterion, you may change the time alignment of your system and retest the system completely. If after changing the time alignment of your system, some of the  $t_{50}$  times still are not aligned, take corrective action by dispersing analyzer signals that have the shortest rise and fall times.

(iv) If some  $t_{50}$  times are still not aligned after repeated attempts at dispersion and time alignment, you may use the continuous analyzer system if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

### Measurement of Engine Parameters and Ambient Conditions

#### § 1065.310 Torque calibration.

(a) *Scope and frequency.* Calibrate all torque-measurement systems including dynamometer torque measurement transducers and systems upon initial installation and after major maintenance. Use good engineering judgment to repeat the calibration. Follow the torque transducer manufacturer's instructions for linearizing your torque sensor's output. We recommend that you calibrate the torque-measurement system with a reference force and a lever arm.

(b) *Recommended procedure.* (1) *Reference force quantification.* Use either a set of dead-weights or a reference meter such as strain gage or a proving ring to quantify the reference force, NIST-traceable within  $\pm 0.5\%$  uncertainty.

(2) *Lever-arm length quantification.* Quantify the lever arm length, NIST-traceable within  $\pm 0.5\%$  uncertainty. The lever arm's length must be measured from the centerline of the dynamometer

to the point at which the reference force is measured. The lever arm must be perpendicular to gravity (i.e., horizontal), and it must be perpendicular to the dynamometer's rotational axis. Balance the lever arm's torque or quantify its net hanging torque, NIST-traceable within  $\pm 1\%$  uncertainty, and account for it as part of the reference torque.

(c) *Dead-weight calibration.* This technique applies a known force by hanging known weights at a known distance along a lever arm. Make sure the weights' lever arm is perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis. Apply at least six calibration-weight combinations for each applicable torque-measuring range, spacing the weight quantities about equally over the range. Oscillate or rotate the dynamometer during calibration to reduce frictional static hysteresis. Determine each weight's force by multiplying its NIST-traceable mass by the local acceleration of Earth's gravity (using this equation: force = mass · acceleration). The local acceleration of gravity,  $a_g$ , at your latitude, longitude, and elevation may be determined by entering position and elevation data into the U.S. National Oceanographic and Atmospheric Administration's surface gravity prediction Web site at [http://www.ngs.noaa.gov/cgi-bin/grav\\_pdx.prl](http://www.ngs.noaa.gov/cgi-bin/grav_pdx.prl). If this Web site is unavailable, you may use the equation in § 1065.630, which returns the local acceleration of gravity based on a given latitude. In this case, calculate the reference torque as the weights' reference force multiplied by the lever arm reference length (using this equation: torque = force · lever arm length).

(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) 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 reference meter force output 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 gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis.

#### § 1065.315 Pressure, temperature, and dewpoint calibration.

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

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

(2) *Temperature.* We recommend digital dry-block or stirred-liquid temperature calibrators, with datalogging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

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

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

### Flow-Related Measurements

#### § 1065.320 Fuel-flow calibration.

(a) Calibrate fuel-flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration.

(b) You may also develop a procedure based on a chemical balance of carbon or oxygen in engine exhaust.

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

#### § 1065.325 Intake-flow calibration.

(a) Calibrate intake-air flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration. We recommend using a calibration subsonic venturi, ultrasonic flow meter or laminar flow

element. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

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

(c) If you use a subsonic venturi or ultrasonic flow meter for intake flow measurement, we recommend that you calibrate it as described in § 1065.340.

#### § 1065.330 Exhaust-flow calibration.

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

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

(c) If you use a subsonic venturi or ultrasonic flow meter for raw exhaust flow measurement, we recommend that you calibrate it as described in § 1065.340.

#### § 1065.340 Diluted exhaust flow (CVS) calibration.

(a) *Overview.* This section describes how to calibrate flow meters for diluted exhaust constant-volume sampling (CVS) systems.

(b) *Scope and frequency.* Perform this calibration while the flow meter is installed in its permanent position. Perform this calibration after you change any part of the flow configuration upstream or downstream of the flow meter that may affect the flow-meter calibration. Perform this

calibration upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (*i.e.*, propane check) in § 1065.341.

(c) *Reference flow meter.* Calibrate a CVS flow meter using a reference flow meter such as a subsonic venturi flow meter, a long-radius ASME/NIST flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. Use a reference flow meter that reports quantities that are NIST-traceable within  $\pm 1\%$  uncertainty. Use this reference flow meter's response to flow as the reference value for CVS flow-meter calibration.

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

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

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

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

(3) While the PDP operates, maintain a constant temperature at the PDP inlet within  $\pm 2\%$  of the mean absolute inlet temperature,  $\bar{T}_{in}$ .

(4) Set the PDP speed to the first speed point at which you intend to calibrate.

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

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

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

(ii) The mean temperature at the PDP inlet,  $\bar{T}_{in}$ .

(iii) The mean static absolute pressure at the PDP inlet,  $\bar{P}_{in}$ .

(iv) The mean static absolute pressure at the PDP outlet,  $\bar{P}_{out}$ .

(v) The mean PDP speed,  $\bar{f}_{nPDP}$ .

(7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the PDP,  $\bar{P}_{in}$ .

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

(9) Calibrate the PDP by using the collected data and the equations in § 1065.640.

(10) Repeat the steps in paragraphs (e)(6) through (9) of this section for each speed at which you operate the PDP.

(11) Use the equations in § 1065.642 to determine the PDP flow equation for emission testing.

(12) Verify the calibration by performing a CVS verification (*i.e.*, propane check) as described in § 1065.341.

(13) Do not use the PDP below the lowest inlet pressure tested during calibration.

(f) *CFV calibration.* Calibrate a critical-flow venturi (CFV) to verify its discharge coefficient,  $C_d$ , at the lowest expected static differential pressure between the CFV inlet and outlet.

Calibrate a CFV flow meter as follows:

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

(2) Start the blower downstream of the CFV.

(3) While the CFV operates, maintain a constant temperature at the CFV inlet within  $\pm 2\%$  of the mean absolute inlet temperature,  $\bar{T}_{in}$ .

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

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

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

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

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

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

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

(v) The mean static differential pressure between the CFV inlet and the CFV outlet,  $\Delta\bar{P}_{CFV}$ .

(7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the CFV,  $P_{in}$ .

(8) Repeat the steps in paragraphs (f)(6) and (7) of this section to record mean data at a minimum of ten restrictor positions, such that you test the fullest practical range of  $\Delta\bar{P}_{CFV}$  expected during testing. We do not require that you remove calibration components or CVS components to calibrate at the lowest possible restrictions.

(9) Determine  $C_d$  and the lowest allowable  $\Delta\bar{P}_{CFV}$  as described in § 1065.640.

(10) Use  $C_d$  to determine CFV flow during an emission test. Do not use the CFV below the lowest allowed  $\Delta\bar{P}_{CFV}$ , as determined in § 1065.640.

(11) Verify the calibration by performing a CVS verification (*i.e.*, propane check) as described in § 1065.341.

(12) If your CVS is configured to operate more than one CFV at a time in parallel, calibrate your CVS by one of the following:

(i) Calibrate every combination of CFVs according to this section and § 1065.640. Refer to § 1065.642 for instructions on calculating flow rates for this option.

(ii) Calibrate each CFV according to this section and § 1065.640. Refer to § 1065.642 for instructions on calculating flow rates for this option.

(g) *SSV calibration.* Calibrate a subsonic venturi (SSV) to determine its

calibration coefficient,  $C_d$ , for the expected range of inlet pressures.

Calibrate an SSV flow meter as follows:

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

(2) Start the blower downstream of the SSV.

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

(4) While the SSV operates, maintain a constant temperature at the SSV inlet within  $\pm 2$  % of the mean absolute inlet temperature.

(5) Set the variable restrictor or variable-speed blower to a flow rate greater than the greatest flow rate expected during testing. You may not extrapolate flow rates beyond calibrated values, so we recommend that you make sure the Reynolds number,  $Re\#$ , at the SSV throat at the greatest calibrated flow rate is greater than the maximum  $Re\#$  expected during testing.

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

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

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

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

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

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

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

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

(9) Determine a functional form of  $C_d$  versus  $Re\#$  by using the collected data and the equations in § 1065.640.

(10) Verify the calibration by performing a CVS verification (*i.e.*, propane check) as described in § 1065.341 using the new  $C_d$  versus  $Re\#$  equation.

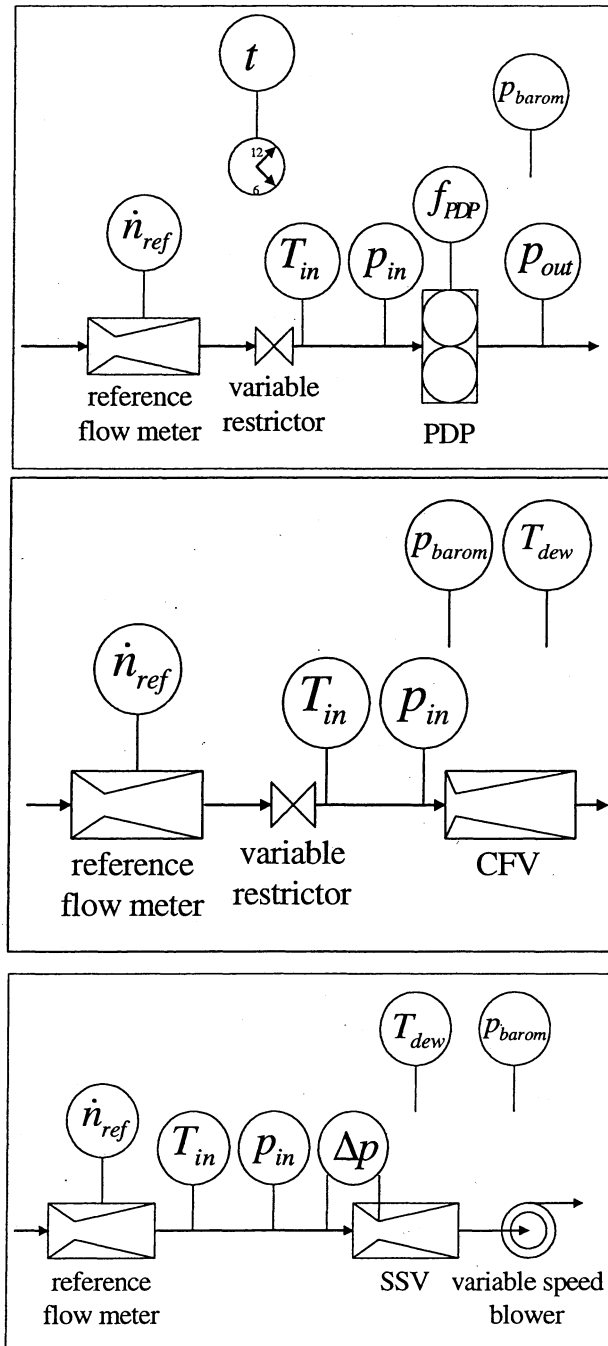
(11) Use the SSV only between the minimum and maximum calibrated flow rates.

(12) Use the equations in § 1065.642 to determine SSV flow during a test.

(h) *Ultrasonic flow meter calibration.* [Reserved]

BILLING CODE 6560-50-P

Figure 1 of §1065.340—Schematic diagrams for diluted exhaust flow (CVS) calibration.



BILLING CODE 6560-50-C

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

(a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in paragraph (g) of this

section. Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as  $\text{CO}_2$  or  $\text{CO}$ . A failed propane check might indicate one or more problems that may require corrective action, as follows:

- (1) *Incorrect analyzer calibration.* Recalibrate, repair, or replace the FID analyzer.
- (2) *Leaks.* Inspect CVS tunnel, connections, fasteners, and HC sampling

system, and repair or replace components.

(3) *Poor mixing.* Perform the verification as described in this section while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyzer response indicates any deviation exceeding  $\pm 2\%$  of the mean measured concentration, consider operating the CVS at a higher flow rate or installing a mixing plate or orifice to improve mixing.

(4) *Hydrocarbon contamination in the sample system.* Perform the hydrocarbon-contamination verification as described in § 1065.520.

(5) *Change in CVS calibration.* Perform an in-situ calibration of the CVS flow meter as described in § 1065.340.

(6) *Other problems with the CVS or sampling verification hardware or software.*

Inspect the CVS system, CVS verification hardware, and software for discrepancies. (b) A propane check uses either a reference mass or a reference flow rate of C<sub>3</sub>H<sub>8</sub> as a tracer gas in a CVS. Note that if you use a reference flow rate, account for any non-ideal gas behavior of C<sub>3</sub>H<sub>8</sub> in the reference flow meter. Refer to § 1065.640 and § 1065.642, which describe how to calibrate and use certain flow meters. Do not use any ideal gas assumptions in § 1065.640 and § 1065.642. The propane check compares the calculated mass of injected C<sub>3</sub>H<sub>8</sub> using HC measurements and CVS flow rate measurements with the reference value.

(c) Prepare for the propane check as follows:

(1) If you use a reference mass of C<sub>3</sub>H<sub>8</sub> instead of a reference flow rate, obtain a cylinder charged with C<sub>3</sub>H<sub>8</sub>. Determine the reference cylinder's mass of C<sub>3</sub>H<sub>8</sub> within ±0.5% of the amount of C<sub>3</sub>H<sub>8</sub> that you expect to use.

(2) Select appropriate flow rates for the CVS and C<sub>3</sub>H<sub>8</sub>.

(3) Select a C<sub>3</sub>H<sub>8</sub> injection port in the CVS. Select the port location to be as close as practical to the location where you introduce engine exhaust into the CVS. Connect the C<sub>3</sub>H<sub>8</sub> cylinder to the injection system.

(4) Operate and stabilize the CVS.

(5) Preheat or precool any heat exchangers in the sampling system.

(6) Allow heated and cooled components such as sample lines, filters, chillers, and pumps to stabilize at operating temperature.

(7) You may purge the HC sampling system during stabilization.

(8) If applicable, perform a vacuum side leak verification of the HC sampling system as described in § 1065.345.

(9) You may also conduct any other calibrations or verifications on equipment or analyzers.

(d) Zero, span, and verify contamination of the HC sampling system, as follows:

(1) Select the lowest HC analyzer range that can measure the C<sub>3</sub>H<sub>8</sub> concentration expected for the CVS and C<sub>3</sub>H<sub>8</sub> flow rates.

(2) Zero the HC analyzer using zero air introduced at the analyzer port.

(3) Span the HC analyzer using C<sub>3</sub>H<sub>8</sub> span gas introduced at the analyzer port.

(4) Overflow zero air at the HC probe or into a fitting between the HC probe and the transfer line.

(5) Measure the stable HC concentration of the HC sampling system as overflow zero air flows. For batch HC measurement, fill the batch container (such as a bag) and measure the HC overflow concentration.

(6) If the overflow HC concentration exceeds 2 µmol/mol, do not proceed until contamination is eliminated. Determine the source of the contamination and take corrective action, such as cleaning the system or replacing contaminated portions.

(7) When the overflow HC concentration does not exceed 2 µmol/mol, record this value as x<sub>HCpre</sub> and use it to correct for HC contamination as described in § 1065.660.

(e) Perform the propane check as follows:

(1) For batch HC sampling, connect clean storage media, such as evacuated bags.

(2) Operate HC measurement instruments according to the instrument manufacturer's instructions.

(3) If you will correct for dilution air background concentrations of HC, measure and record background HC in the dilution air.

(4) Zero any integrating devices.

(5) Begin sampling, and start any flow integrators.

(6) Release the contents of the C<sub>3</sub>H<sub>8</sub> reference cylinder at the rate you selected. If you use a reference flow rate of C<sub>3</sub>H<sub>8</sub>, start integrating this flow rate.

(7) Continue to release the cylinder's contents until at least enough C<sub>3</sub>H<sub>8</sub> has been released to ensure accurate quantification of the reference C<sub>3</sub>H<sub>8</sub> and the measured C<sub>3</sub>H<sub>8</sub>.

(8) Shut off the C<sub>3</sub>H<sub>8</sub> reference cylinder and continue sampling until you have accounted for time delays due to sample transport and analyzer response.

(9) Stop sampling and stop any integrators.

(f) Perform post-test procedure as follows:

(1) If you used batch sampling, analyze batch samples as soon as practical.

(2) After analyzing HC, correct for contamination and background.

(3) Calculate total C<sub>3</sub>H<sub>8</sub> mass based on your CVS and HC data as described in § 1065.650 and § 1065.660, using the molar mass of C<sub>3</sub>H<sub>8</sub>, M<sub>C<sub>3</sub>H<sub>8</sub></sub>, instead of the effective molar mass of HC, M<sub>HC</sub>.

(4) If you use a reference mass, determine the cylinder's propane mass within ±0.5% and determine the C<sub>3</sub>H<sub>8</sub>

reference mass by subtracting the empty cylinder propane mass from the full cylinder propane mass.

(5) Subtract the reference C<sub>3</sub>H<sub>8</sub> mass from the calculated mass. If this difference is within ±2.0 % of the reference mass, the CVS passes this verification. If not, take corrective action as described in paragraph (a) of this section.

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

(1) Configure the HC sampling system to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, you may sample HC from the batch sampler pump's exhaust. Use caution when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flow meter will cause a false failure of the propane check.

(2) Repeat the propane check described in this section, but sample HC from the batch sampler.

(3) Calculate C<sub>3</sub>H<sub>8</sub> mass, taking into account any secondary dilution from the batch sampler.

(4) Subtract the reference C<sub>3</sub>H<sub>8</sub> mass from the calculated mass. If this difference is within ±5% of the reference mass, the batch sampler passes this verification. If not, take corrective action as described in paragraph (a) of this section.

#### § 1065.345 Vacuum-side leak verification.

(a) *Scope and frequency.* Upon initial sampling system installation, after major maintenance, and before each test according to subpart F of this part for laboratory tests and according to subpart J of this part for field tests, verify that there are no significant vacuum-side leaks using one of the leak tests described in this section.

(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 in-line between a probe and transfer line.

(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.* Test any analyzer, other than a FID, for dilution of span gas as follows, noting that this configuration requires an overflow span gas system:

(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 the measurement accuracy and repeatability of the analyzer. 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.

## CO and CO<sub>2</sub> Measurements

### § 1065.350 H<sub>2</sub>O interference verification for CO<sub>2</sub> NDIR analyzers.

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

(b) *Measurement principles.* H<sub>2</sub>O can interfere with an NDIR analyzer's response to CO<sub>2</sub>.

If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* A CO<sub>2</sub> NDIR analyzer must have an H<sub>2</sub>O interference that is within  $\pm 2\%$  of the flow-weighted mean CO<sub>2</sub> concentration expected at the standard, though we strongly recommend a lower interference that is within  $\pm 1\%$ .

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

(1) Start, operate, zero, and span the CO<sub>2</sub> NDIR analyzer as you would before an emission test.

(2) Create a water-saturated test gas by bubbling zero air that meets the specifications in § 1065.750 through distilled water in a sealed vessel at  $(25 \pm 10)$  °C.

(3) Introduce the water-saturated test gas upstream of any sample dryer, if one is used during testing.

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

(5) While 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  $\pm 2\%$  of the flow-weighted mean concentration of CO<sub>2</sub> expected at the standard.

(e) *Exceptions.* The following exceptions apply:

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

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

### § 1065.355 H<sub>2</sub>O and CO<sub>2</sub> interference verification for CO NDIR analyzers.

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

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

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

we strongly recommend a lower interference that is within  $\pm 1\%$ .

(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 water-saturated CO<sub>2</sub> test gas by bubbling a CO<sub>2</sub> span gas through distilled water in a sealed vessel at  $(25 \pm 10)$  °C.

(3) Introduce the water-saturated CO<sub>2</sub> test gas upstream of any sample dryer, if one is used during testing.

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

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

(6) Multiply this mean value by the ratio of expected CO<sub>2</sub> to span gas CO<sub>2</sub> concentration. In other words, estimate the flow-weighted mean dry concentration of CO<sub>2</sub> expected during testing, and then divide this value by the concentration of CO<sub>2</sub> in the span gas used for this verification. Then multiply this ratio by the mean value recorded during this verification.

(7) The analyzer meets the interference verification if the result of paragraph (d)(6) of this section is within  $\pm 2\%$  of the flow-weighted mean concentration of CO expected at the standard.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO sampling system and your emission calculations procedures, the combined CO<sub>2</sub> and H<sub>2</sub>O interference for your CO NDIR analyzer always affects your brake-specific CO emission results within  $\pm 0.5\%$  of the applicable CO standard. (2) You may use a CO NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

## Hydrocarbon Measurements

### § 1065.360 FID optimization and verification.

(a) *Scope and frequency.* For all FID analyzers perform the following steps:

(1) Calibrate a FID upon initial installation. Repeat the calibration as needed using good engineering judgment.

(2) Optimize a FID's response to various hydrocarbons after initial

analyzer installation and after major maintenance.

(3) Determine a FID's methane ( $\text{CH}_4$ ) response factor after initial analyzer installation and after major maintenance.

(4) Verify methane ( $\text{CH}_4$ ) response within 185 days before testing.

(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. Calibrate using  $\text{C}_3\text{H}_8$  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  $\text{O}_2$  expected during testing. If you use a FID to measure methane ( $\text{CH}_4$ ) downstream of a nonmethane cutter, you may calibrate that FID using  $\text{CH}_4$  calibration gases with the cutter. Regardless of the calibration gas composition, calibrate on a carbon number basis of one ( $\text{C}_1$ ). For example, if you use a  $\text{C}_3\text{H}_8$  span gas of concentration  $200 \mu\text{mol/mol}$ , span the FID to respond with a value of  $600 \mu\text{mol/mol}$ .

(c) *FID response optimization.* 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 for FID fuel, burner air, and sample and record them for future reference.

(d)  *$\text{CH}_4$  response factor determination.* Since FID analyzers generally have a different response to  $\text{CH}_4$  versus  $\text{C}_3\text{H}_8$ , determine each FID analyzer's  $\text{CH}_4$  response factor,  $\text{RF}_{\text{CH}_4}$ , after FID optimization. Use the most recent  $\text{RF}_{\text{CH}_4}$  measured according to this section in the calculations for HC determination described in § 1065.660 to compensate for  $\text{CH}_4$  response. Determine  $\text{RF}_{\text{CH}_4}$  as follows, noting that

you do not determine  $\text{RF}_{\text{CH}_4}$  for FIDs that are calibrated and spanned using  $\text{CH}_4$  with a nonmethane cutter:

(1) Select a  $\text{C}_3\text{H}_8$  span gas that meets the specifications of § 1065.750. Record the  $\text{C}_3\text{H}_8$  concentration of the gas.

(2) Select a  $\text{CH}_4$  span gas that meets the specifications of § 1065.750. Record the  $\text{CH}_4$  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  $\text{C}_3\text{H}_8$ . Calibrate on a carbon number basis of one ( $\text{C}_1$ ). For example, if you use a  $\text{C}_3\text{H}_8$  span gas of concentration  $200 \mu\text{mol/mol}$ , span the FID to respond with a value of  $600 \mu\text{mol/mol}$ .

(5) Zero the FID with a zero gas that you use for emission testing.

(6) Span the FID with the  $\text{C}_3\text{H}_8$  span gas that you selected under paragraph (d)(1) of this section.

(7) Introduce at the sample port of the FID analyzer, the  $\text{CH}_4$  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  $\text{CH}_4$  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  $\text{CH}_4$  calibration gas. The result is the FID analyzer's response factor for  $\text{CH}_4$ ,  $\text{RF}_{\text{CH}_4}$ .

(e) *FID methane ( $\text{CH}_4$ ) response verification.* If the value of  $\text{RF}_{\text{CH}_4}$  from paragraph (d) of this section is within  $\pm 5.0\%$  of its most recent previously determined value, the FID passes the methane response verification. For example, if the most recent previous value for  $\text{RF}_{\text{CH}_4}$  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%.

(1) Verify that the pressures and flow rates of FID fuel, burner air, and sample are each within  $\pm 0.5\%$  of their most recent previously recorded values, as described in paragraph (c) of this section. You may adjust these flow rates as necessary. Determine a new  $\text{RF}_{\text{CH}_4}$  as described in paragraph (d) of this section.

(2) If  $\text{RF}_{\text{CH}_4}$  is still not within  $\pm 5.0\%$  of its most recently determined value after adjusting flow rates, re-optimize the FID response as described in paragraph (c) of this section.

(3) Determine a new  $\text{RF}_{\text{CH}_4}$  as described in paragraph (d) of this

section. Use this new value of  $\text{RF}_{\text{CH}_4}$  in the calculations for HC determination, as described in § 1065.660.

#### § 1065.362 Non-stoichiometric raw exhaust FID $\text{O}_2$ interference verification.

(a) *Scope and frequency.* If you use FID analyzers for raw exhaust measurements from engines that operate in a non-stoichiometric mode of combustion (e.g., compression-ignition, lean-burn), verify the amount of FID  $\text{O}_2$  interference upon initial installation and after major maintenance.

(b) *Measurement principles.* Changes in  $\text{O}_2$  concentration in raw exhaust can affect FID response by changing FID flame temperature. Optimize FID fuel, burner air, and sample flow to meet this verification. Verify FID performance with the compensation algorithms for FID  $\text{O}_2$  interference that you have active during an emission test.

(c) *System requirements.* Any FID analyzer used during testing must meet the FID  $\text{O}_2$  interference verification according to the procedure in this section.

(d) *Procedure.* Determine FID  $\text{O}_2$  interference as follows:

(1) Select two span reference gases that meet the specifications in § 1065.750 and contain  $\text{C}_3\text{H}_8$  near 100% of span for HC. You may use  $\text{CH}_4$  span reference gases for FIDs calibrated on  $\text{CH}_4$  with a nonmethane cutter. Select the two balance gas concentrations such that the concentrations of  $\text{O}_2$  and  $\text{N}_2$  represent the minimum and maximum  $\text{O}_2$  concentrations expected during testing.

(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 the span gas used 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  $\pm 0.5\%$  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  $\text{O}_2$  expected during testing. Record the mean response of 30 seconds of stabilized sample data as  $X_{\text{O}_2\text{minHC}}$ .

(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  $\pm 0.5\%$  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 maximum concentration of  $O_2$  expected during testing. Record the mean response of 30 seconds of stabilized sample data as  $X_{O_2maxHC}$ .

(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  $\pm 0.5\%$  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.

(11) Calculate the percent difference between  $X_{O_2maxHC}$  and its reference gas concentration. Calculate the percent difference between  $X_{O_2minHC}$  and its reference gas concentration. Determine the maximum percent difference of the two. This is the  $O_2$  interference.

(12) If the  $O_2$  interference is within  $\pm 1.5\%$ , then the FID passes the  $O_2$  interference check; otherwise perform one or more of the following to address the deficiency:

(i) Select zero and span gases for emission testing that contain higher or lower  $O_2$  concentrations.

(ii) Adjust FID burner air, fuel, and sample flow rates. Note that if you adjust these flow rates to meet the  $O_2$  interference verification, you must re-verify with the adjusted flow rates that the FID meets the  $CH_4$  response factor verification according to § 1065.360.

(iii) Repair or replace the FID.

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

#### § 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,  $PF_{CH_4}$ , and ethane,  $PF_{C_2H_6}$ . 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 the exhaust stream before the FID analyzer measures the remaining hydrocarbon concentration. An ideal nonmethane cutter would have  $PF_{CH_4}$  of 1.000, and the penetration fraction for all other hydrocarbons would be 0.000, as represented by  $PF_{C_2H_6}$ . The emission calculations in § 1065.660 use this section's measured values of  $PF_{CH_4}$  and  $PF_{C_2H_6}$  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  $PF_{CH_4} > 0.95$  and  $PF_{C_2H_6} < 0.02$  as determined by paragraphs (d) and (e) 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.* 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 cutter using a  $CH_4$  span gas, set that FID's  $CH_4$  penetration fraction,  $PF_{CH_4}$ , equal to 1.0 for all emission calculations, and determine its ethane ( $C_2H_6$ ) penetration fraction,  $PF_{C_2H_6}$ , 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  $C_1$  basis. For example,

if your span gas has a  $CH_4$  reference value of  $100 \mu\text{mol}$ , the correct FID response to that span gas is  $100 \mu\text{mol}$  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  $C_2H_6$  penetration fraction,  $PF_{C_2H_6}$ . Use this penetration fraction and the  $CH_4$  penetration fraction, which is set equal to 1.0, in emission calculations according to § 1065.660 or § 1065.665, as applicable.

(e) *Procedure for a FID calibrated by bypassing the NMC.* If you use a FID with an NMC that is calibrated by bypassing the NMC, determine penetration fractions 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  $100 \mu\text{mol}$ , the correct FID response to that span gas is  $300 \mu\text{mol}$  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.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.

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

(9) Reroute the flow path to bypass the nonmethane cutter, introduce the C<sub>2</sub>H<sub>6</sub> analytical gas mixture to the bypass, and repeat the steps in paragraphs (e)(7) through (8) of this section.

(10) Divide the mean C<sub>2</sub>H<sub>6</sub> concentration measured through the nonmethane cutter by the mean concentration measured after bypassing the nonmethane cutter. The result is the C<sub>2</sub>H<sub>6</sub> penetration fraction, PF<sub>C<sub>2</sub>H<sub>6</sub></sub>. Use this penetration fraction according to § 1065.660 or § 1065.665, as applicable.

(11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH<sub>4</sub> analytical gas mixture instead of C<sub>2</sub>H<sub>6</sub>. The result will be the CH<sub>4</sub> penetration fraction, PF<sub>CH<sub>4</sub></sub>. Use this penetration fraction according to § 1065.660 or § 1065.665, as applicable.

#### NO<sub>x</sub> Measurements

##### § 1065.370 CLD CO<sub>2</sub> and H<sub>2</sub>O quench verification.

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

(b) *Measurement principles.* H<sub>2</sub>O and CO<sub>2</sub> can negatively interfere with a CLD's NO<sub>x</sub> response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO<sub>x</sub>. The calculations in § 1065.672 for H<sub>2</sub>O quench account for the water vapor in humidified NO span gas. The procedure and the calculations scale the quench results to the water vapor and CO<sub>2</sub> concentrations expected during testing. If the CLD analyzer uses quench compensation algorithms that utilize H<sub>2</sub>O and/or CO<sub>2</sub> measurement instruments, use these instruments to measure H<sub>2</sub>O and/or CO<sub>2</sub> and evaluate quench with the compensation algorithms applied.

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

(d) *CO<sub>2</sub> quench verification procedure.* Use the following method to determine CO<sub>2</sub> quench, or use good engineering judgment to develop a different protocol:

(1) Use PTFE tubing to make necessary connections.

(2) Connect a pressure-regulated CO<sub>2</sub> span gas to one of the inlets of a three-way valve made of 300 series stainless steel. Use a CO<sub>2</sub> span gas that meets the specifications of § 1065.750 and attempt to use a concentration that is approximately twice the maximum CO<sub>2</sub> concentration expected to enter the CLD sample port during testing, if available.

(3) Connect a pressure-regulated purified N<sub>2</sub> gas to the valve's other inlet. Use a purified N<sub>2</sub> gas that meets the specifications of § 1065.750.

(4) Connect the valve's single outlet to the balance-gas port of a gas divider that meets the specifications in § 1065.248.

(5) Connect a pressure-regulated NO span gas to the span-port of the gas divider. 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.

(6) 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.

(7) While flowing balance and span gases through the gas divider, stabilize the CO<sub>2</sub> concentration downstream of the gas divider and measure the CO<sub>2</sub> concentration with an NDIR analyzer that has been prepared for emission testing. Record this concentration, X<sub>CO<sub>2</sub>meas</sub>, and use it in the quench verification calculations in § 1065.675.

(8) 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<sub>x</sub>, operate the CLD in the NO-only operating mode. Record this concentration, X<sub>NO,CO<sub>2</sub></sub>, and use it in the quench verification calculations in § 1065.675.

(9) Switch the three-way valve so 100% purified N<sub>2</sub> flows to the gas divider's balance-port inlet. Monitor the CO<sub>2</sub> at the gas divider's outlet until its concentration stabilizes at zero.

(10) Measure NO concentration at the gas divider's outlet. Record this value, X<sub>NO,N<sub>2</sub></sub>, and use it in the quench verification calculations in § 1065.675.

(11) 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<sub>2</sub>O quench verification procedure.* Use the following method to determine H<sub>2</sub>O quench, or use good engineering judgment to develop a different protocol:

(1) Use PTFE tubing to make necessary connections.

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

(4) Humidify the gas by bubbling it through distilled water in a sealed vessel. We recommend that you humidify the gas to the highest sample dewpoint that you estimate 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 that you expect entering the CLD sample port during emission sampling.

(5) If you do not use any sample dryer for NO<sub>x</sub> during emissions testing, record the vessel water temperature as T<sub>dew</sub>, and its pressure as P<sub>total</sub> and use these values according to § 1065.645 to calculate the amount of water entering the CLD sample port, X<sub>H<sub>2</sub>Omeas</sub>. If you do use a sample dryer for NO<sub>x</sub> during emissions testing, measure the humidity of the sample just upstream of the CLD sample port and use the measured humidity according to § 1065.645 to calculate the amount of water entering the CLD sample port, X<sub>H<sub>2</sub>Omeas</sub>.

(6) To prevent subsequent condensation, make sure that any humidified sample will not be exposed to temperatures lower than T<sub>dew</sub> during transport from the sealed vessel's outlet to the CLD. We recommend using heated transfer lines.

(7) Introduce the humidified sample upstream of any sample dryer, if one is used.

(8) Use the CLD to measure the NO concentration of the humidified span gas and record this value, X<sub>NOwet</sub>.

(9) Use the recorded values from this paragraph (e) to calculate the quench as described in § 1065.675.

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

(f) *Corrective action.* If the sum of the H<sub>2</sub>O quench plus the CO<sub>2</sub> quench is not within ±2%, take corrective action by repairing or replacing the analyzer. Before using a CLD for emission testing, demonstrate that the corrective action resulted in a value within ±2% combined quench.

(g) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and

your emission calculations procedures, the the combined CO<sub>2</sub> and H<sub>2</sub>O interference for your NO<sub>x</sub> CLD analyzer always affects your brake-specific NO<sub>x</sub> emission results within no more than  $\pm 1.0\%$  of the applicable NO<sub>x</sub> standard.

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

**§ 1065.372 NDUV analyzer HC and H<sub>2</sub>O interference verification.**

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

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

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

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

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

(2) We recommend that you extract engine exhaust to perform this verification. Use a CLD that meets the specifications of subpart C of this part to quantify NO<sub>x</sub> in the exhaust. Use the CLD response as the reference value. Also measure HC in the exhaust with a FID analyzer that meets the specifications of subpart C of this part. Use the FID response as the reference hydrocarbon value.

(3) Upstream of any sample dryer, if one is used during testing, introduce the engine exhaust to the NDUV analyzer.

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

(5) While all analyzers measure the sample's concentration, record 30 seconds of sampled data, and calculate

the arithmetic means for the three analyzers.

(6) Subtract the CLD mean from the NDUV mean.

(7) Multiply this difference by the ratio of the flow-weighted mean HC concentration expected at the standard to the HC concentration measured during the verification. The analyzer meets the interference verification of this section if this result is within  $\pm 2\%$  of the HC concentration expected at the standard.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculations procedures, the the combined HC and H<sub>2</sub>O interference for your NO<sub>x</sub> NDUV analyzer always affects your brake-specific NO<sub>x</sub> emission results by less than  $0.5\%$  of the applicable NO<sub>x</sub> standard.

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

**§ 1065.376 Chiller NO<sub>2</sub> penetration.**

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

(b) *Measurement principles.* A chiller removes water, which can otherwise interfere with a NO<sub>x</sub> measurement. However, liquid water in an improperly designed chiller can remove NO<sub>2</sub> from the sample. If a chiller is used without an NO<sub>2</sub>-to-NO converter upstream, it could therefore remove NO<sub>2</sub> from the sample prior NO<sub>x</sub> measurement.

(c) *System requirements.* A chiller must allow for measuring at least 95% of the total NO<sub>2</sub> at the maximum expected concentration of NO<sub>2</sub>.

(d) *Procedure.* Use the following procedure to verify chiller performance:

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

(2) *Equipment setup.* 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 of the tee.

Connect a heated line at 100 °C to the last port, and connect a heated three-way tee to the other end of the line. Connect a dewpoint generator, set at a dewpoint of 50 °C, to one end of a heated line at 100 °C. Connect the other end of the line to the heated tee and connect a third 100 °C heated line to the chiller inlet. Provide an overflow vent line at the chiller inlet.

(3) *Adjustments.* For the following adjustment steps, set the analyzer to measure only NO (*i.e.*, NO mode), or only read the NO channel of the analyzer:

(i) With the dewpoint generator and the ozonator off, adjust the NO and zero-gas flows so the NO concentration at the analyzer is at least two times the peak total NO<sub>x</sub> concentration expected during testing at the standard. Verify that gas is flowing out of the overflow vent line.

(ii) Turn on the dewpoint generator and adjust its flow so the NO concentration at the analyzer is at least at the peak total NO<sub>x</sub> concentration expected during testing at the standard. Verify that gas is flowing out of the overflow vent line.

(iii) Turn on the ozonator and adjust the ozonator so the NO concentration measured by the analyzer decreases by the same amount as the maximum concentration of NO<sub>2</sub> expected during testing. This ensures that the ozonator is generating NO<sub>2</sub> at the maximum concentration expected during testing.

(4) *Data collection.* Maintain the ozonator adjustment in paragraph (d)(3) of this section, and keep the NO<sub>x</sub> analyzer in the NO only mode or only read the NO channel of the analyzer.

(i) Allow for stabilization, accounting only for transport delays and instrument response.

(ii) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO<sub>ref</sub>.

(iii) Switch the analyzer to the total NO<sub>x</sub> mode, (that is, sum the NO and NO<sub>2</sub> channels of the analyzer) and allow for stabilization, accounting only for transport delays and instrument response.

(iv) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO<sub>xmeas</sub>.

(v) Turn off the ozonator and allow for stabilization, accounting only for transport delays and instrument response.

(vi) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO<sub>xref</sub>.

(5) *Performance evaluation.* Divide the quantity of (NO<sub>xmeas</sub> - NO<sub>ref</sub>) by the quantity of (NO<sub>xref</sub> - NO<sub>ref</sub>). If the result

is less than 95%, repair or replace the chiller.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculations procedures, the chiller always affects your brake-specific NO<sub>x</sub> emission results by less than 0.5% of the applicable NO<sub>x</sub> standard.

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

#### **§ 1065.378 NO<sub>2</sub>-to-NO converter conversion verification.**

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

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

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

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

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

(2) *Equipment setup.* Connect an ozonator's inlet to a zero-air or oxygen source and connect its outlet to one port of a 4-way cross fitting. Connect an NO span gas to another port. Connect the NO<sub>2</sub>-to-NO converter inlet to another port, and connect an overflow vent line to the last port.

(3) *Adjustments.* Take the following steps to make adjustments:

(i) With the NO<sub>2</sub>-to-NO converter in the bypass mode (*i.e.*, NO mode) and the ozonator off, adjust the NO and zero-gas flows so the NO concentration at the analyzer is at the peak total NO<sub>x</sub> concentration expected during testing.

Verify that gas is flowing out of the overflow vent.

(ii) With the NO<sub>2</sub>-to-NO converter still in the bypass mode, turn on the ozonator and adjust the ozonator so the NO concentration measured by the analyzer decreases by the same amount as maximum concentration of NO<sub>2</sub> expected during testing. This ensures that the ozonator is generating NO<sub>2</sub> at the maximum concentration expected during testing.

(4) *Data collection.* Maintain the ozonator adjustment in paragraph (d)(3) of this section, and keep the NO<sub>x</sub> analyzer in the NO only mode (*i.e.*, bypass the NO<sub>2</sub>-to-NO converter).

(i) Allow for stabilization, accounting only for transport delays and instrument response.

(ii) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO<sub>ref</sub>.

(iii) Switch the analyzer to the total NO<sub>x</sub> mode (that is, sample with the NO<sub>2</sub>-to-NO converter) and allow for stabilization, accounting only for transport delays and instrument response.

(iv) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO<sub>xmeas</sub>.

(v) Turn off the ozonator and allow for stabilization, accounting only for transport delays and instrument response.

(vi) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO<sub>xref</sub>.

(5) *Performance evaluation.* Divide the quantity of (NO<sub>xmeas</sub> - NO<sub>ref</sub>) by the quantity of (NO<sub>xref</sub> - NO<sub>ref</sub>). If the result is less than 95%, repair or replace the NO<sub>2</sub>-to-NO converter.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO<sub>x</sub> sampling system and your emission calculations procedures, the converter always affects your brake-specific NO<sub>x</sub> emission results by less than 0.5% of the applicable NO<sub>x</sub> standard.

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

#### **PM Measurements**

##### **§ 1065.390 PM balance verifications and weighing process verification.**

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

verification requires an independent verification of PM balance performance, and this must be performed within 370 days before emission testing. The second verification requires zeroing and spanning the balance, and this must be performed within 12 h before weighing. The third verification requires comparing a current mass determination of pooled reference samples with the previous mass determination of the pooled reference samples. This verification must be performed within 12 h before weighing.

(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 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.* You must also verify the PM-weighing environment and weighing process by weighing reference PM sample media. Repeated weighing of a reference mass must return the same value within ±10 µg or ±10% of the net PM mass expected at the standard (if known), whichever is higher. Perform this verification as follows:

(1) Keep at least two samples of unused PM sample media 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.

(5) Weigh each of the reference samples 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 PM measurements, use the same process to measure reference 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 of the reference's buoyancy-corrected masses from the most recent previous determinations of their masses.

(9) If the mean of the reference's masses changes by more than that allowed under paragraph (d) of this section, then invalidate all PM results that were determined between the two times that the reference masses were determined.

#### § 1065.395 Inertial PM balance verifications.

This section describes how to verify the performance of an inertial PM balance.

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

(b) *Other verifications.* Perform other verifications using good engineering judgment and instrument manufacturer recommendations.

### Subpart E—Engine Selection, Preparation, and Maintenance

#### § 1065.401 Test engine selection.

While all engine configurations within a certified engine family must comply with the applicable standards in the standard-setting part, you need not test each configuration for certification.

(a) Select an engine configuration within the engine family for testing, as follows:

(1) Test the engine that we specify, whether we issue general guidance or give you specific instructions.

(2) If we do not tell you which engine to test, follow any instructions in the standard-setting part.

(3) If we do not tell you which engine to test and the standard-setting part does not include specifications for selecting test engines, use good engineering judgment to select the engine configuration within the engine family that is most likely to exceed an emission standard.

(b) In the absence of other information, the following characteristics are appropriate to consider when selecting the engine to test:

(1) Maximum fueling rates.

(2) Maximum loads.

(3) Maximum in-use speeds.

(4) Highest sales volume.

(c) For our testing, we may select any engine configuration within the engine family.

#### § 1065.405 Test engine preparation and maintenance.

(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. 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) Run the test engine, with all emission-control systems operating, long enough to stabilize emission levels. Unless otherwise specified in the standard-setting part, you may consider emission levels stable without measurement if you accumulate 12 h of operation for a spark-ignition engine or 125 h for a compression-ignition engine. If the engine needs more or 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. To ensure consistency between low-hour engines and deterioration factors, you must use the same stabilization procedures for all emission-data engines within an engine family.

(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, attach a canister to the engine before running an emission test. 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 do not have to accumulate engine operation before emission testing with an installed canister. 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.

#### § 1065.410 Maintenance limits for stabilized test engines.

(a) After you stabilize the test engine's emission levels, you may do maintenance as allowed by the standard-setting part. However, you may not do any maintenance based on emission measurements from the test engine (*i.e.*, unscheduled maintenance).

(b) For any critical emission-related maintenance—other than what we specifically allow in the standard-setting part—you must completely test an engine for emissions before and after doing any maintenance that might affect emissions, unless we waive this requirement.

(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 tools to identify bad engine components. Any equipment, instruments, or tools used for scheduled maintenance on emission data engines must be available to dealerships and other service outlets.

(d) You may adjust or repair an emission-data engine as long as you document these changes in your application.

(e) 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. 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.

#### § 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.

(a) *Maintenance.* The following limits apply to the maintenance that we allow you to do on an emission-data engine:

(1) You may perform scheduled maintenance that you recommend to operators, but only if it is consistent with the standard-setting part's restrictions.

(2) You may perform additional maintenance only as specified in § 1065.410 or allowed by the standard-setting part.

(3) We may approve additional maintenance to your durability engine if all the following occur:

(i) Something clearly malfunctions—such as persistent misfire, engine stall, overheating, fluid leaks, or loss of oil pressure—and needs maintenance or repair.

(ii) You provide us an opportunity to verify the extent of the malfunction before you do the maintenance.

(b) *Emission measurements.* Perform emission tests following the provisions of the standard setting part and this part, as applicable. Perform emission tests to determine deterioration factors consistent with good engineering judgment. Evenly space any tests between the first and last test points throughout the durability period, unless we approve otherwise.

### Subpart F—Performing an Emission Test in the Laboratory

#### § 1065.501 Overview.

(a) Use the procedures detailed in this subpart to measure engine emissions in a laboratory setting. This section describes how to:

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

(2) Transform normalized duty cycles into reference duty cycles for your engine by using an engine map.

(3) Prepare your engine, equipment, and measurement instruments for an emission test.

(4) Perform pre-test procedures to verify proper operation of certain equipment and analyzers.

(5) Record pre-test data.

(6) Start or restart the engine and sampling systems.

(7) Sample emissions throughout the duty cycle.

(8) Record post-test data.

(9) Perform post-test procedures to verify proper operation of certain equipment and analyzers.

(10) Weigh PM samples.

(b) A laboratory 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 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 a cold engine.

(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), where each operating point has one value of a speed command and one value of a torque (or power) command. Ramped-modal cycles for steady-state testing also list test times for each mode and ramps of speed and torque to follow between modes. 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. Perform a ramped-modal cycle as a sequence of second-by-second speed commands and torque (or power) commands. Proportionally sample emissions and other parameters during the cycle and use the calculations in subpart G of this part to calculate emissions.

(c) Other subparts in this part identify how to select and prepare an engine for testing (subpart E), how to perform the required engine service accumulation (subpart E), and how to calculate emission results (subpart G).

(d) Subpart J of this part describes how to perform field testing.

#### § 1065.510 Engine mapping.

(a) *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 while it is connected to a dynamometer.

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  $\pm 5$  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 either the

engine coolant, block, or head absolute temperature is within  $\pm 2\%$  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.

(4) Set operator demand to maximum and control engine speed at  $(95 \pm 1)\%$  of its warm idle speed 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  $(95 \pm 1)\%$  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.

(c) *Negative torque mapping.* If your engine is subject to a reference duty cycle that specifies negative torque

values, 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: At warm idle and at 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. Operate the engine at these two points at minimum operator demand. Use linear interpolation to determine intermediate values.

(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 either the engine coolant, block, or head absolute temperature is within  $\pm 2\%$  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).

(f) *Measured and declared test speeds and torques.* You may use test speeds and torques that you declare instead of measured speeds and torques if you declare them before engine mapping and they meet the criteria in this paragraph (f). Otherwise, you must use measured speed and torque.

(1) *Measured speeds and torques.*

Determine the applicable measured speeds and torques according to § 1065.610:

(i) Measured maximum test speed for variable-speed engines.

(ii) Measured maximum test torque for constant-speed engines.

(iii) Measured "A", "B", and "C" speeds for steady-state tests.

(iv) Measured intermediate speed for steady-state tests.

(2) *Required declared speeds.* You must declare the following speeds:

(i) Warmed-up, low-idle speed for variable-speed engines. 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.

(ii) Warmed-up, no-load, high-idle speed for constant-speed engines.

(3) *Optional declared speeds.* You may declare an enhanced idle speed according to § 1065.610. You may use a declared value for any of the following as long as the declared value is within  $(97.5$  to  $102.5)\%$  of its corresponding measured value:

(i) Measured maximum test speed for variable-speed engines.

(ii) Measured intermediate speed for steady-state tests.

(iii) Measured "A", "B", and "C" speeds for steady-state tests.

(4) *Declared torques.* You may declare an enhanced idle torque according to § 1065.610. You may declare maximum test torque as long as 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 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. Report any deviations from this section's mapping procedures.

**§ 1065.512 Duty cycle generation.**

(a) The standard-setting part 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 idle speed 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,  $f_{nref}$ . Note that the cycle-validation criteria in § 1065.514 allow an engine to govern itself at its in-use idle speed. This allowance permits you to test engines with enhanced-idle devices and to simulate the effects of transmissions such as automatic transmissions.

(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 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 representing curb-idle transmission torque (CITT).

(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 0 N·m when a normalized duty cycle specifies a 0% torque command.

(4) *Engine power.* For all engines, normalized power is expressed as a percentage of mapped power at maximum test speed,  $f_{ntest}$ . Section 1065.610 describes how to transform these normalized values into a sequence of reference powers,  $P_{ref}$ . You may convert these reference powers to reference speeds and torques for operator demand and dynamometer control.

(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). For transient cycles, linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine the 5 Hz reference speeds and torques. During an emission test, record the 1 Hz mean values of the reference speeds and torques and the feedback speeds and torques. 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 § 1065.525 or simulate the in-use operation of a governor the same way you simulated it to map the engine in § 1065.525. 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). For transient cycles, linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine the 5 Hz reference torque values. During an emission test, record the 1 Hz mean values of the reference torques and the feedback speeds and torques. 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.

**§ 1065.514 Cycle-validation criteria.**

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. For any data required in this section, use the duty cycle reference and feedback values that you recorded during a test interval.

(a) *Testing performed by EPA.* Our tests must meet the specifications of paragraph (g) 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 (g) 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 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.

(d) *Calculating work.* Before calculating work values, omit any points recorded during engine cranking and starting. Cranking and starting includes any time when an engine starter is engaged, any time when the engine is motored with a dynamometer for the sole purpose of starting the engine, and any time during operation before reaching idle speed. See § 1065.525(a) and (b) for more information about engine cranking. After omitting points recorded during engine cranking and starting, but before omitting any points under paragraph (e) of this section, calculate total work,  $W$ , based on the feedback values and reference work,  $W_{ref}$ , based on the reference values, as described in § 1065.650.

(e) *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 demands 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) and $T_{ref} = 0\%$ (idle) 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 $f_n > f_{nref}$ and $T > T_{ref}$ .
maximum .....	power and either torque or speed .....	$f_n < f_{nref}$ or $T < T_{ref}$ but not if $f_n < f_{nref}$ and $T < T_{ref}$ .
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) and $P_{ref} = 0\%$ (idle) 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 $f_n > f_{nref}$ and $P > P_{ref}$ .
maximum .....	power and either torque or speed .....	$f_n < f_{nref}$ or $P < P_{ref}$ but not if $f_n < f_{nref}$ and $P < P_{ref}$ .

(f) *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 criteria. 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,  $SE_{T}$ , and feedback power  $SEE_{P}$ .
- (4) Coefficients of determination for feedback speed,  $r^2_{fn}$ , feedback torque,  $r^2_{T}$ , and feedback power  $r^2_{P}$ .

(g) *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 the Table 2 of this section.

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

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

**§ 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 values, 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  $\pm 5\%$  of the value recorded at the time of the last engine map.
  - (3) Dilution air as specified in § 1065.140(b).
- (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 100% torque at any speed above its peak-torque speed.
  - (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) After the last practice or preconditioning cycle before an emission test, verify the amount of contamination in the HC sampling system 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<sub>2</sub> expected during testing.

(3) Span the HC analyzer using span gas introduced at the analyzer span or sample port. Span on a carbon number basis of one (C<sub>1</sub>). For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.

(4) Overflow zero gas at the HC probe or into a fitting between the HC probe and its transfer line.

(5) Measure the HC concentration in the sampling system, as follows:

(i) For continuous sampling, record the mean HC concentration as overflow zero air flows.

(ii) For batch sampling, fill the sample medium and record its mean HC concentration.

(6) Record this value as the initial HC concentration, X<sub>HCinit</sub>, and use it to correct measured values as described in § 1065.660.

(7) If X<sub>HCinit</sub> exceeds 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 concentration expected at the standard.

(ii) 2% of the flow-weighted mean concentration measured during testing.

(iii) For any compression-ignition engines, any two-stroke spark ignition engines, or 4-stroke spark-ignition engines that are less than 19 kW, 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.

#### § 1065.525 Engine starting, restarting, and shutdown.

(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 and adequately charged battery or a suitable power supply.

(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) If the engine stalls at any time after emission sampling begins for a discrete mode in a discrete-mode duty cycle test, void the test or perform the following steps to continue the test:

(i) Restart the engine.

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

(iii) Precondition the engine at the previous discrete mode for a similar amount of time compared with how long it was initially run.

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

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

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

#### § 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 an exhaust aftertreatment system. 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 a hot-start duty cycle within 20 min of engine shutdown.

(iii) For testing that involves hot-stabilized emission measurements, such as any steady-state testing, you may continue to operate the engine at f<sub>intest</sub> 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) For all other testing, 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-weighted 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 use analyzers that automatically switch 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<sub>1</sub>. For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.

(11) We recommend that you verify gas analyzer response after zeroing and spanning by flowing 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.

(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 speed and torque to the first mode in the test cycle. Follow the instructions in the standard-setting part to determine how long to stabilize engine operation at each mode and how long to sample emissions at each mode.

(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 the 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 but no later than 30 minutes after the duty cycle is complete, perform the following:

(i) Zero and span all batch gas analyzers.

(ii) Analyze any gaseous batch samples, including background samples.

(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) 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).

#### § 1065.545 Validation of proportional flow control for batch sampling.

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

(a) For any pair of flow meters, use the 1 Hz (or more frequently) recorded sample and total flow rates 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 the 1 Hz (or more frequently) recorded sample and total flow rates 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 the 1 Hz (or more frequently) recorded venturi-inlet conditions. Demonstrate that the flow density at the venturi inlet

was constant within  $\pm 2.5\%$  of the mean or target density over each test interval. For a CVS critical-flow venturi, you may demonstrate this by showing that the absolute temperature at the venturi inlet was constant within  $\pm 4\%$  of the mean or target absolute temperature over each test interval.

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

(c) Using 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.

**§ 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 for the entire test.

(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 operates at less than 100% of its range for the entire test.

(b) *Drift validation and drift correction.* Calculate two sets of brake-specific emission results. Calculate one set using the data before drift correction and 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) If the difference between the corrected and uncorrected brake-specific emissions are within  $\pm 4\%$  of the uncorrected results for all regulated emissions, the test is validated for drift. 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 whether or not your engine complies with the applicable standards.

**§ 1065.590 PM sample preconditioning and tare weighing.**

Before an emission test, take the following steps to prepare PM samples 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 (such as filters) for defects.

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

(d) Place unused sample media 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 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 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 weight for buoyancy as described in § 1065.690. These buoyancy-corrected values are the tare masses of the PM samples.

(h) You may repeat measurements to determine mean masses. Use good engineering judgment to exclude outliers and calculate 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 covered or sealed container before taking them to the test cell 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 a PM sample. 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. 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) Place on the balance pan a metal calibration weight that has a similar mass to that of the sample medium and meets the specifications for calibration weights in § 1065.790. If you use filters, the weight's mass should be about (80 to 100) mg for typical 47 mm diameter filters.

(4) Record the stable balance reading, then remove the calibration weight.

(5) Weigh an unused sample, 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) Follow the instructions given in paragraphs (g) through (i) of this section.

**§ 1065.595 PM sample post-conditioning and total weighing.**

(a) Make sure the weighing and PM-stabilization environments have met the periodic verifications in § 1065.390.

(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. 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 PM samples. If PM ever contacts the transport container, cassette assembly, filter-separator tool, tweezers, static neutralizer, balance, or any other surface, void the measurements associated with that sample and clean the surface it contacted.

(e) To stabilize PM samples, place them in one or more containers that are open to the PM-stabilization environment, which is described in § 1065.190. A PM sample is stabilized as long as it has been in the PM-stabilization environment for one of the following durations, during which the stabilization environment has been within the specifications of § 1065.190:

(1) If you expect that a filter's total surface concentration of PM will be greater than about 0.473 mm/mm<sup>2</sup>, expose the filter to the stabilization environment for at least 60 minutes before weighing.

(2) If you expect that a filter's total surface concentration of PM will be less than about 0.473 mm/mm<sup>2</sup>, expose the filter to the stabilization environment for at least 30 minutes before weighing.

(3) If you are unsure of a filter's total surface concentration of PM, expose the filter to the stabilization environment for at least 60 minutes before weighing.

(f) Repeat the procedures in § 1065.590(f) through (i) to weigh used PM samples. Refer to a sample's post-test mass, after correcting for buoyancy, as its total mass.

(g) Subtract each buoyancy-corrected tare mass from its respective buoyancy-corrected total mass. The result is the net PM mass, m<sub>PM</sub>. Use m<sub>PM</sub> in emission calculations in § 1065.650.

**Subpart G—Calculations and Data Requirements**

**§ 1065.601 Overview.**

(a) This subpart describes how to—

(1) Use the signals recorded before, during, and after an emission test to calculate brake-specific emissions of each regulated constituent.

(2) Perform calculations for calibrations and performance checks.

(3) Determine statistical values.

(b) You may use data from multiple systems to calculate test results for a single emission test, consistent with good engineering judgment. You may not use test results from multiple emission tests to report emissions. We allow weighted means where appropriate. You may discard statistical outliers, but you must report all results.

(c) You may use any of the following calculations instead of the calculations specified in this subpart G:

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

(2) Other calculations that you show are equivalent to within ±0.1% of the brake-specific emission results determined using the calculations specified in this subpart G.

**§ 1065.602 Statistics.**

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

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

$$\bar{y} = \frac{\sum_{i=1}^{10} y_i}{N} \quad \text{Eq. 1065.602-1}$$

*Example:*

N = 3  
 y<sub>1</sub> = 10.60  
 y<sub>2</sub> = 11.91  
 y<sub>N</sub> = y<sub>3</sub> = 11.09

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

$\bar{y} \leq 11.20$

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

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N-1)}} \quad \text{Eq. 1065.602-2}$$

*Example:*

N = 3  
 y<sub>1</sub> = 10.60  
 y<sub>2</sub> = 11.91  
 y<sub>N</sub> = y<sub>3</sub> = 11.09  
 $\bar{y} \leq 11.20$

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

$\sigma_y = 0.6619$

(d) *Root mean square.* Calculate a root mean square, rms<sub>y</sub>, as follows:

$$\text{rms}_y = \sqrt{\frac{1}{N} \sum_{i=1}^N y_i^2} \quad \text{Eq. 1065.602-3}$$

*Example:*

N = 3  
 y<sub>1</sub> = 10.60  
 y<sub>2</sub> = 11.91  
 y<sub>N</sub> = y<sub>3</sub> = 11.09

$$\text{rms}_y = \sqrt{\frac{10.60^2 + 11.91^2 + 11.09^2}{3}}$$

rms<sub>y</sub> = 11.21

(e) *Accuracy.* Calculate an accuracy, as follows, noting that the are arithmetic means, each determined by repeatedly measuring one sample of a single reference quantity, y<sub>ref</sub>:

$$\text{accuracy} = |y_{\text{ref}} - \bar{y}| \quad \text{Eq. 1065.602-4}$$

*Example:*

y<sub>ref</sub> = 1800.0  
 N = 10

$$\bar{y} = \frac{\sum_{i=1}^{10} \bar{y}_i}{10} = 1802.5$$

accuracy = |1800.0 - 1802.5|

accuracy = 2.5

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

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

$$t = \frac{|\bar{y}_{\text{ref}} - \bar{y}|}{\sqrt{\frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N}}} \quad \text{Eq. 1065.602-5}$$

$$v = \frac{\left( \frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N} \right)^2}{\frac{(\sigma_{ref}^2/N_{ref})^2}{N_{ref}-1} + \frac{(\sigma_y^2/N)^2}{N-1}} \quad \text{Eq. 1065.602-6}$$

*Example:*  
 $\bar{y}_{ref} = 1205.3$   
 $\bar{y} = 1123.8$   
 $\sigma_{ref} = 9.399$   
 $\sigma_y = 10.583$   
 $N_{ref} = 11$   
 $N = 7$

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

$t = 16.63$   
 $\sigma_{ref} = 9.399$   
 $\sigma_y = 10.583$   
 $N_{ref} = 11$   
 $N = 7$

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

$v = 11.76$

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

$$t = \frac{|\bar{\epsilon}| \cdot \sqrt{N}}{\sigma_\epsilon} \quad \text{Eq. 1065.602-7}$$

*Example:*  
 $\bar{\epsilon} = -0.12580$   
 $N = 16$   
 $\sigma_\epsilon = 0.04837$

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

$t = 10.403$   
 $v = N - 1$

*Example:*  
 $N = 16$   
 $v = 16 - 1$   
 $v = 15$

(3) Use Table 1 of this section to compare t to the  $t_{crit}$  values tabulated versus the number of degrees of freedom. If t is less than  $t_{crit}$ , then t passes the t-test.

TABLE 1 OF § 1065.602.—CRITICAL T VALUES VERSUS NUMBER OF DEGREES OF FREEDOM, v<sup>1</sup>

v	Confidence	
	90%	95%
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365

$$F_y = \frac{\sigma_y^2}{\sigma_{ref}^2} \quad \text{Eq. 1065.602-8}$$

*Example:*

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

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

TABLE 1 OF § 1065.602.—CRITICAL T VALUES VERSUS NUMBER OF DEGREES OF FREEDOM, v<sup>1</sup>—Continued

v	Confidence	
	90%	95%
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
18	1.734	2.101
20	1.725	2.086
22	1.717	2.074
24	1.711	2.064
26	1.706	2.056
28	1.701	2.048
30	1.697	2.042
35	1.690	2.030
40	1.684	2.021
50	1.676	2.009
70	1.667	1.994
100	1.660	1.984
1000+	1.645	1.960

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

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

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

F = 1.268

(1) For a 90% confidence F-test, use Table 2 of this section to compare F to the  $F_{crit90}$  values tabulated versus (N - 1) and  $(N_{ref} - 1)$ . If F is less than  $F_{crit90}$ ,

then F passes the F-test at 90% confidence.

(2) For a 95% confidence F-test, use Table 3 of this section to compare F to the  $F_{crit95}$  values tabulated versus (N - 1)

and  $(N_{ref} - 1)$ . If F is less than  $F_{crit95}$ , then F passes the F-test at 95% confidence.

**BILLING CODE 6560-50-P**

Table 2 of §1065.602—Critical F values,  $F_{crit(90)}$ , versus  $N-1$  and  $N_{ref}-1$  at 90 % confidence

$N_{ref}-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
1	39.86	49.50	53.59	55.83	57.24	58.20	58.90	59.43	59.85	60.19	60.70	61.22	61.74	62.00	62.26	62.52	62.79	63.06	63.32
2	8.526	9.000	9.162	9.243	9.293	9.326	9.349	9.367	9.381	9.392	9.408	9.425	9.441	9.450	9.458	9.466	9.475	9.483	9.491
3	5.538	5.462	5.391	5.343	5.309	5.285	5.266	5.252	5.240	5.230	5.216	5.200	5.184	5.176	5.168	5.160	5.151	5.143	5.134
4	4.545	4.325	4.191	4.107	4.051	4.010	3.979	3.955	3.936	3.920	3.896	3.870	3.844	3.831	3.817	3.804	3.790	3.775	3.761
5	4.060	3.780	3.619	3.520	3.453	3.405	3.368	3.339	3.316	3.297	3.268	3.238	3.207	3.191	3.174	3.157	3.140	3.123	3.105
6	3.776	3.463	3.289	3.181	3.108	3.055	3.014	2.983	2.958	2.937	2.905	2.871	2.836	2.818	2.800	2.781	2.762	2.742	2.722
7	3.589	3.257	3.074	2.961	2.883	2.827	2.785	2.752	2.725	2.703	2.668	2.632	2.595	2.575	2.555	2.535	2.514	2.493	2.471
8	3.458	3.113	2.924	2.806	2.726	2.668	2.624	2.589	2.561	2.538	2.502	2.464	2.425	2.404	2.383	2.361	2.339	2.316	2.293
9	3.360	3.006	2.813	2.693	2.611	2.551	2.505	2.469	2.440	2.416	2.379	2.340	2.298	2.277	2.255	2.232	2.208	2.184	2.159
10	3.285	2.924	2.728	2.605	2.522	2.461	2.414	2.377	2.347	2.323	2.284	2.244	2.201	2.178	2.155	2.132	2.107	2.082	2.055
11	3.225	2.860	2.660	2.536	2.451	2.389	2.342	2.304	2.274	2.248	2.209	2.167	2.123	2.100	2.076	2.052	2.026	2.000	1.972
12	3.177	2.807	2.606	2.480	2.394	2.331	2.283	2.245	2.214	2.188	2.147	2.105	2.060	2.036	2.011	1.986	1.960	1.932	1.904
13	3.136	2.763	2.560	2.434	2.347	2.283	2.234	2.195	2.164	2.138	2.097	2.053	2.007	1.983	1.958	1.931	1.904	1.876	1.846
14	3.102	2.726	2.522	2.395	2.307	2.243	2.193	2.154	2.122	2.095	2.054	2.010	1.962	1.938	1.912	1.885	1.857	1.828	1.797
15	3.073	2.695	2.490	2.361	2.273	2.208	2.158	2.119	2.086	2.059	2.017	1.972	1.924	1.899	1.873	1.845	1.817	1.787	1.755
16	3.048	2.668	2.462	2.333	2.244	2.178	2.128	2.088	2.055	2.028	1.985	1.940	1.891	1.866	1.839	1.811	1.782	1.751	1.718
17	3.026	2.645	2.437	2.308	2.218	2.152	2.102	2.061	2.028	2.001	1.958	1.912	1.862	1.836	1.809	1.781	1.751	1.719	1.686
18	3.007	2.624	2.416	2.286	2.196	2.130	2.079	2.038	2.005	1.977	1.933	1.887	1.837	1.810	1.783	1.754	1.723	1.691	1.657
19	2.990	2.606	2.397	2.266	2.176	2.109	2.058	2.017	1.984	1.956	1.912	1.865	1.814	1.787	1.759	1.730	1.699	1.666	1.631
20	2.975	2.589	2.380	2.249	2.158	2.091	2.040	1.999	1.965	1.937	1.892	1.845	1.794	1.767	1.738	1.708	1.677	1.643	1.607
21	2.961	2.575	2.365	2.233	2.142	2.075	2.023	1.982	1.948	1.920	1.875	1.827	1.776	1.748	1.719	1.689	1.657	1.623	1.586
20	2.949	2.561	2.351	2.219	2.128	2.061	2.008	1.967	1.933	1.904	1.859	1.811	1.759	1.731	1.702	1.671	1.639	1.604	1.567
23	2.937	2.549	2.339	2.207	2.115	2.047	1.995	1.953	1.919	1.890	1.845	1.796	1.744	1.716	1.686	1.655	1.622	1.587	1.549
24	2.927	2.538	2.327	2.195	2.103	2.035	1.983	1.941	1.906	1.877	1.832	1.783	1.730	1.702	1.672	1.641	1.607	1.571	1.533
25	2.918	2.528	2.317	2.184	2.092	2.024	1.971	1.929	1.895	1.866	1.820	1.771	1.718	1.689	1.659	1.627	1.593	1.557	1.518
26	2.909	2.519	2.307	2.174	2.082	2.014	1.961	1.919	1.884	1.855	1.809	1.760	1.706	1.677	1.647	1.615	1.581	1.544	1.504
27	2.901	2.511	2.299	2.165	2.073	2.005	1.952	1.909	1.874	1.845	1.799	1.749	1.695	1.666	1.636	1.603	1.569	1.531	1.491
28	2.894	2.503	2.291	2.157	2.064	1.996	1.943	1.900	1.865	1.836	1.790	1.740	1.685	1.656	1.625	1.593	1.558	1.520	1.478
29	2.887	2.495	2.283	2.149	2.057	1.988	1.935	1.892	1.857	1.827	1.781	1.731	1.676	1.647	1.616	1.583	1.547	1.509	1.467
30	2.881	2.489	2.276	2.142	2.049	1.980	1.927	1.884	1.849	1.819	1.773	1.722	1.667	1.638	1.606	1.573	1.538	1.499	1.456
40	2.835	2.440	2.226	2.091	1.997	1.927	1.873	1.829	1.793	1.763	1.715	1.662	1.605	1.574	1.541	1.506	1.467	1.425	1.377
60	2.791	2.393	2.177	2.041	1.946	1.875	1.819	1.775	1.738	1.707	1.657	1.603	1.543	1.511	1.476	1.437	1.395	1.348	1.291
120	2.748	2.347	2.130	1.992	1.896	1.824	1.767	1.722	1.684	1.652	1.601	1.545	1.482	1.447	1.409	1.368	1.320	1.265	1.193
1000+	2.706	2.303	2.084	1.945	1.847	1.774	1.717	1.670	1.632	1.599	1.546	1.487	1.421	1.383	1.342	1.295	1.240	1.169	1.000



Table 3 of §1065.602—Critical F values,  $F_{crit(95)}$ , versus  $N-1$  and  $N_{ref}-1$  at 95 % confidence

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
$N_{ref}-1$																			
1	161.4	199.5	215.7	224.5	230.1	233.9	236.7	238.8	240.5	241.8	243.9	245.9	248.0	249.0	250.1	251.1	252.2	253.2	254.3
2	18.51	19.00	19.16	19.24	19.29	19.33	19.35	19.37	19.38	19.39	19.41	19.42	19.44	19.45	19.46	19.47	19.47	19.48	19.49
3	10.12	9.552	9.277	9.117	9.014	8.941	8.887	8.845	8.812	8.786	8.745	8.703	8.660	8.639	8.617	8.594	8.572	8.549	8.526
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094	6.041	5.999	5.964	5.912	5.858	5.803	5.774	5.746	5.717	5.688	5.658	5.628
5	6.608	5.786	5.410	5.192	5.050	4.950	4.876	4.818	4.773	4.735	4.678	4.619	4.558	4.527	4.496	4.464	4.431	4.399	4.365
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207	4.147	4.099	4.060	4.000	3.938	3.874	3.842	3.808	3.774	3.740	3.705	3.669
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787	3.726	3.677	3.637	3.575	3.511	3.445	3.411	3.376	3.340	3.304	3.267	3.230
8	5.318	4.459	4.066	3.838	3.688	3.581	3.501	3.438	3.388	3.347	3.284	3.218	3.150	3.115	3.079	3.043	3.005	2.967	2.928
9	5.117	4.257	3.863	3.633	3.482	3.374	3.293	3.230	3.179	3.137	3.073	3.006	2.937	2.901	2.864	2.826	2.787	2.748	2.707
10	4.965	4.103	3.708	3.478	3.326	3.217	3.136	3.072	3.020	2.978	2.913	2.845	2.774	2.737	2.700	2.661	2.621	2.580	2.538
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012	2.948	2.896	2.854	2.788	2.719	2.646	2.609	2.571	2.531	2.490	2.448	2.405
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913	2.849	2.796	2.753	2.687	2.617	2.544	2.506	2.466	2.426	2.384	2.341	2.296
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832	2.767	2.714	2.671	2.604	2.533	2.459	2.420	2.380	2.339	2.297	2.252	2.206
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764	2.699	2.646	2.602	2.534	2.463	2.388	2.349	2.308	2.266	2.223	2.178	2.131
15	4.543	3.682	3.287	3.056	2.901	2.791	2.707	2.641	2.588	2.544	2.475	2.403	2.328	2.288	2.247	2.204	2.160	2.114	2.066
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657	2.591	2.538	2.494	2.425	2.352	2.276	2.235	2.194	2.151	2.106	2.059	2.010
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614	2.548	2.494	2.450	2.381	2.308	2.230	2.190	2.148	2.104	2.058	2.011	1.960
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577	2.510	2.456	2.412	2.342	2.269	2.191	2.150	2.107	2.063	2.017	1.968	1.917
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544	2.477	2.423	2.378	2.308	2.234	2.156	2.114	2.071	2.026	1.980	1.930	1.878
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514	2.447	2.393	2.348	2.278	2.203	2.124	2.083	2.039	1.994	1.946	1.896	1.843
21	4.325	3.467	3.073	2.840	2.685	2.573	2.488	2.421	2.366	2.321	2.250	2.176	2.096	2.054	2.010	1.965	1.917	1.866	1.812
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464	2.397	2.342	2.297	2.226	2.151	2.071	2.028	1.984	1.938	1.889	1.838	1.783
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442	2.375	2.320	2.275	2.204	2.128	2.048	2.005	1.961	1.914	1.865	1.813	1.757
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423	2.355	2.300	2.255	2.183	2.108	2.027	1.984	1.939	1.892	1.842	1.790	1.733
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405	2.337	2.282	2.237	2.165	2.089	2.008	1.964	1.919	1.872	1.822	1.768	1.711
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388	2.321	2.266	2.220	2.148	2.072	1.990	1.946	1.901	1.853	1.803	1.749	1.691
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373	2.305	2.250	2.204	2.132	2.056	1.974	1.930	1.884	1.836	1.785	1.731	1.672
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359	2.291	2.236	2.190	2.118	2.041	1.959	1.915	1.869	1.820	1.769	1.714	1.654
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346	2.278	2.223	2.177	2.105	2.028	1.945	1.901	1.854	1.806	1.754	1.698	1.638
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334	2.266	2.211	2.165	2.092	2.015	1.932	1.887	1.841	1.792	1.740	1.684	1.622
40	4.085	3.232	2.839	2.606	2.450	2.336	2.249	2.180	2.124	2.077	2.004	1.925	1.839	1.793	1.744	1.693	1.637	1.577	1.509
60	4.001	3.150	2.758	2.525	2.368	2.254	2.167	2.097	2.040	1.993	1.917	1.836	1.748	1.700	1.649	1.594	1.534	1.467	1.389
120	3.920	3.072	2.680	2.447	2.290	2.175	2.087	2.016	1.959	1.911	1.834	1.751	1.659	1.608	1.554	1.495	1.429	1.352	1.254
1000+	3.842	2.996	2.605	2.372	2.214	2.099	2.010	1.938	1.880	1.831	1.752	1.666	1.571	1.517	1.459	1.394	1.318	1.221	1.000

## BILLING CODE 6560-50-C

(h) *Slope*. Calculate a least-squares regression slope,  $a_{1y}$ , as follows:

$$a_{1y} = \frac{\sum_{i=1}^N (y_i - \bar{y}) \cdot (y_{\text{ref}i} - \bar{y}_{\text{ref}})}{\sum_{i=1}^N (y_{\text{ref}i} - \bar{y}_{\text{ref}})^2} \quad \text{Eq. 1065.602-9}$$

*Example:*  
N = 6000

$$y_1 = 2045.8$$

$$\bar{y} = 1051.1$$

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

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

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

$a_{1y} = 1.0110$

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

$$a_{0y} = \bar{y} - (a_{1y} \cdot \bar{y}_{\text{ref}}) \quad \text{Eq. 1065.602-10}$$

*Example:*  
 $\bar{y} = 1050.1$   
 $a_{1y} = 1.0110$

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

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

$$a_{0y} = 16.8083$$

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

$$SEE_y = \frac{\sqrt{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{\text{ref}i})]^2}}{N - 2} \quad \text{Eq. 1065.602-11}$$

*Example:*  
N = 6000

$$y_1 = 2045.8$$

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

$$a_{1y} = 1.0110$$

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

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

$SEE_y = 5.348$

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

$$r_y^2 = 1 - \frac{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{\text{ref}i})]^2}{\sum_{i=1}^N [y_i - \bar{y}]^2} \quad \text{Eq. 1065.602-12}$$

*Example:*  
N = 6000

$$y_1 = 2045.8$$

$$a_{0y} = 16.8083$$

$$a_{1y} = 1.0110$$

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

$$\bar{y} = 1480.5$$

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

$$r_y^2 = 0.9859$$

(1) *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 judgement to determine if you can use similar assumptions.

(1) To estimate the flow-weighted mean raw exhaust NO<sub>x</sub> concentration from a turbocharged heavy-duty compression-ignition engine at a NO<sub>x</sub> standard of 2.5 g/(kW·hr), you may do the following:

(i) Based on your engine design, approximate a map of maximum torque versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a

reference duty cycle as described in § 1065.610. Calculate the total reference work, W<sub>ref</sub>, as described in § 1065.650. Divide the reference work by the duty cycle's time interval, Δt<sub>dutycycle</sub>, to determine mean reference power, P̄<sub>ref</sub>.

(ii) Based on your engine design, estimate maximum power, P<sub>max</sub>, the design speed at maximum power, f<sub>nmax</sub>, the design maximum intake manifold boost pressure, p<sub>inmax</sub>, and temperature, T<sub>inmax</sub>. Also, estimate an mean fraction of power that is lost due to friction and pumping, P̄<sub>frict</sub>. Use this information along with the engine displacement volume, V<sub>disp</sub>, an approximate volumetric efficiency, η<sub>v</sub>, and the number of engine strokes per power stroke (2-stroke or 4-stroke), N<sub>stroke</sub> to estimate the maximum raw exhaust molar flow rate, ṅ<sub>exhmax</sub>.

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

$$\bar{x}_{\text{exp}} = \frac{c_{\text{std}} \cdot W_{\text{ref}}}{M \cdot \dot{n}_{\text{exhmax}} \cdot \Delta t_{\text{duty cycle}} \cdot \left( \frac{\bar{P}_{\text{ref}} + (\bar{P}_{\text{frict}} \cdot P_{\text{max}})}{P_{\text{max}}} \right)} \quad \text{Eq. 1065.602-13}$$

$$\dot{n}_{\text{exhmax}} = \frac{P_{\text{max}} \cdot V_{\text{disp}} \cdot f_{\text{nmax}} \cdot \frac{2}{N_{\text{stroke}}} \cdot \eta_v}{R \cdot T_{\text{max}}} \quad \text{Eq. 1065.602-14}$$

*Example:*

e<sub>NOX</sub> = 2.5 g/(kW · hr)  
 W<sub>ref</sub> = 11.883 kW · hr  
 M<sub>NOX</sub> = 46.0055 g/mol = 46.0055 · 10<sup>-6</sup> g/μmol  
 Δt<sub>dutycycle</sub> = 20 min = 1200 s  
 P̄<sub>ref</sub> = 35.65 kW

P̄<sub>frict</sub> = 15%  
 P<sub>max</sub> = 125 kW  
 p<sub>max</sub> = 300 kPa = 300000 Pa  
 V<sub>disp</sub> = 3.011 = 0.0030 m<sup>3</sup>  
 f<sub>nmax</sub> = 2800 rev/min = 46.67 rev/s  
 N<sub>stroke</sub> = 4 1/rev  
 η<sub>v</sub> = 0.9  
 R = 8.314472 J/(mol·K)

T<sub>max</sub> = 348.15 K

$$\dot{n}_{\text{exhmax}} = \frac{300 \cdot 3.0 \cdot 47.67 \cdot \frac{2}{4} \cdot 0.9}{8.314472 \cdot 348.15}$$

ṅ<sub>exhmax</sub> = 6.53 mol/s

$$\bar{x}_{\text{exp}} = \frac{2.5 \cdot 11.883}{46.0055 \cdot 10^{-6} \cdot 6.53 \cdot 1200 \cdot \left( \frac{35.65 + (0.15 \cdot 125)}{125} \right)}$$

X̄<sub>exp</sub> = 189.4 μmol/mol

(2) To estimate the flow-weighted mean NMHC concentration in a CVS from a naturally aspirated nonroad spark-ignition engine at an NMHC standard of 0.5 g/(kW·hr), you may do the following:

(i) Based on your engine design, approximate a map of maximum torque versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a reference duty cycle as described in § 1065.610. Calculate the total reference work, W<sub>ref</sub>, as described in § 1065.650.

(ii) Multiply your CVS total molar flow rate by the time interval of the duty cycle, Δt<sub>dutycycle</sub>. The result is the total diluted exhaust flow of the n<sub>dexh</sub>.

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

$$\bar{x}_{\text{NMHC}} = \frac{e_{\text{std}} \cdot W_{\text{ref}}}{M \cdot \dot{n}_{\text{dexh}} \cdot \Delta t_{\text{duty cycle}}} \quad \text{Eq. 1065.602-15}$$

**Example:**

$$e_{\text{NMHC}} = 1.5 \text{ g/(kW}\cdot\text{hr)}$$

$$W_{\text{ref}} = 5.389 \text{ kW}\cdot\text{hr}$$

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

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

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

$$\bar{x}_{\text{NMHC}} = \frac{1.5 \cdot 5.389}{13.875389 \cdot 10^{-6} \cdot 6.021 \cdot 1800}$$

$$\bar{x}_{\text{NMHC}} = 53.8 \mu\text{mol/mol}$$

**§ 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,  $f_{\text{ntest}}$ .* 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  $f_{\text{ntest}}$ . This is the highest engine speed where an engine outputs zero torque. For variable-speed engines, determine the measured  $f_{\text{ntest}}$  from the power-versus-speed map, generated according to § 1065.510, as follows:

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

$$f_{\text{ntest}} = f_{\text{ni}} \text{ at the maximum of } \left( f_{\text{nnormi}}^2 + P_{\text{normi}}^2 \right) \quad \text{Eq. 1065.610-1}$$

Where:

$f_{\text{ntest}}$  = maximum test speed.

$i$  = an indexing variable that represents one recorded value of an engine map.

$f_{\text{nnormi}}$  = an engine speed normalized by dividing it by  $f_{\text{nPmax}}$ .

$P_{\text{normi}}$  = an engine power normalized by dividing it by  $P_{\text{max}}$ .

**Example:**

$$(f_{\text{nnorm1}} = 1.002, P_{\text{norm1}} = 0.978, f_{\text{n1}} = 2359.71)$$

$$(f_{\text{nnorm2}} = 1.004, P_{\text{norm2}} = 0.977, f_{\text{n2}} = 2364.42)$$

$$(f_{\text{nnorm3}} = 1.006, P_{\text{norm3}} = 0.974, f_{\text{n3}} = 2369.13)$$

$$(f_{\text{nnorm1}}^2 + P_{\text{norm1}}^2) = (1.002^2 + 0.978^2) = 1.960$$

$$(f_{\text{nnorm1}}^2 + P_{\text{norm1}}^2) = (1.004^2 + 0.977^2) = 1.963$$

$$(f_{\text{nnorm1}}^2 + P_{\text{norm1}}^2) = (1.006^2 + 0.974^2) = 1.961 \text{ maximum} = 1.963 \text{ at } i = 2$$

$$f_{\text{ntest}} = 2364.42 \text{ rev/min}$$

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

(1) Based on the map, determine maximum power,  $P_{\text{max}}$ , and the speed at which maximum power occurs,  $f_{\text{nPmax}}$ . Divide every recorded power by  $P_{\text{max}}$  and divide every recorded speed by  $f_{\text{nPmax}}$ . The result is a normalized power-versus-speed map. Your measured  $T_{\text{test}}$  is the speed at which the sum of the squares of normalized speed and power is maximum, as follows:

$$T_{\text{test}} = T_i \text{ at the maximum of } \left( f_{\text{nnormi}}^2 + P_{\text{normi}}^2 \right) \quad \text{Eq. 1065.610-2}$$

Where:

$T_{\text{test}}$  = maximum test torque.

**Example:**

$$(f_{\text{nnorm1}} = 1.002, P_{\text{norm1}} = 0.978, T_1 = 722.62 \text{ N}\cdot\text{m})$$

$$(f_{\text{nnorm2}} = 1.004, P_{\text{norm2}} = 0.977, T_2 = 720.44 \text{ N}\cdot\text{m})$$

$$(f_{\text{nnorm3}} = 1.006, P_{\text{norm3}} = 0.974, T_3 = 716.80 \text{ N}\cdot\text{m})$$

$$(f_{\text{nnorm1}}^2 + P_{\text{norm1}}^2) = (1.002^2 + 0.978^2) = 1.960$$

$$(f_{\text{nnorm1}}^2 + P_{\text{norm1}}^2) = (1.004^2 + 0.977^2) = 1.963$$

$$(f_{\text{nnorm1}}^2 + P_{\text{norm1}}^2) = (1.006^2 + 0.974^2) = 1.961 \text{ maximum} = 1.963 \text{ at } i = 2$$

$$T_{\text{test}} = 720.44 \text{ N}\cdot\text{m}$$

(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 declared warm idle speed and your maximum test speed to transform the duty cycle, as follows:

$$f_{nref} = \% \text{ speed } (f_{ntest} - f_{nidle}) + f_{nidle} \quad \text{Eq. 1065.610-3}$$

**Example:**

% speed = 85 %  
 $f_{ntest} = 2364 \text{ rev/min}$   
 $f_{nidle} = 650 \text{ rev/min}$   
 $f_{nref} = 85 \% \cdot (2364 - 650) + 650$   
 $f_{nref} = 2107 \text{ rev/min}$

(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  $n_{lo}$ . Also determine the highest speed above maximum power at which 70 % of maximum power occurs. Denote this value as  $n_{hi}$ . Use  $n_{hi}$  and  $n_{lo}$  to calculate reference values for A, B, or C speeds as follows:

$$f_{nrefA} = 0.25 (n_{hi} - n_{lo}) + n_{lo} \quad \text{Eq. 1065.610-4}$$

$$f_{nrefB} = 0.50 (n_{hi} - n_{lo}) + n_{lo} \quad \text{Eq. 1065.610-5}$$

$$f_{nrefC} = 0.75 (n_{hi} - n_{lo}) + n_{lo} \quad \text{Eq. 1065.610-6}$$

**Example:**

$n_{lo} = 1005 \text{ rev/min}$   
 $n_{hi} = 2385 \text{ rev/min}$   
 $f_{nrefA} = 0.25 \cdot (2385 - 1005) + 1005$   
 $f_{nrefB} = 0.50 \cdot (2385 - 1005) + 1005$   
 $f_{nrefC} = 0.75 \cdot (2385 - 1005) + 1005$   
 $f_{nrefA} = 1350 \text{ rev/min}$   
 $f_{nrefB} = 1695 \text{ rev/min}$   
 $f_{nrefC} = 2040 \text{ rev/min}$

(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. Linearly interpolate mapped torque values to determine torque between mapped speeds. 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. Note that if your constant-speed engine is subject to duty cycles that specify normalized speed commands,

use the provisions of paragraph (d)(1) of this section to transform your normalized torque values.

(3) *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 an automatic transmission, it may have a minimum torque called curb idle transmission torque (CITT). In this case, at idle conditions (*i.e.*, 0% speed, 0% torque), you may use CITT as a reference value instead of 0 N·m.

(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 maximum test power defined in the standard-setting part. The result is the reference power for each speed point. You may calculate a corresponding reference torque for each point and command that reference torque instead of a reference power.

(2) 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, at idle conditions (*i.e.*, 0% speed, 0% power), you may use a

corresponding idle power as a reference power instead of 0 kW.

**§ 1065.630 1980 international gravity formula.**

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

$$a_g = 9.7803267715 [1 + s + 5.2790414 \cdot 10^{-3} \sin^2 (\alpha) + 2.32718 \cdot 10^{-5} \sin^4 (\alpha) + 1.262 \cdot 10^{-7} \sin^6 (\alpha) + 7 \cdot 10^{-10} \sin^8 (\alpha)] \quad \text{Eq. 1065.630-1}$$

Where:

$\theta$  = Degrees north or south latitude.

**Example:**

$\theta = 45^\circ$   
 $a_g = 9.7803267715 \cdot (1 + 5.2790414 \cdot 10^{-3} \cdot \sin^2 (45) + 2.32718 \cdot 10^{-5} \cdot \sin^4 (45) + 1.262 \cdot 10^{-7} \cdot \sin^6 (45) + 7 \cdot 10^{-10} \cdot \sin^8 (45))$   
 $a_g = 9.8178291229 \text{ m/s}^2$

**§ 1065.640 Flow meter calibration calculations.**

This section describes the calculations for calibrating various flow meters. After you calibrate a flow meter using these calculations, use the calculations described in § 1065.642 to calculate flow during an emission test. Paragraph (a) of this section first describes how to convert reference flow meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining paragraphs describe the calibration calculations that are specific to certain types of flow meters.

(a) *Reference meter conversions.* The calibration equations in this section use molar flow rate,  $\dot{n}_{ref}$ , 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:

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

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.
- $\dot{m}_{ref}$  = 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:*

$$\dot{V}_{stdref} = 1000.00 \text{ ft}^3/\text{min} = 0.471948 \text{ m}^3/\text{s}$$

- P = 29.9213 in Hg @ 32 °F = 101325 Pa
- T = 68.0 °F = 293.15 K
- R = 8.314472 J/(mol·K)

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

$$\dot{n}_{ref} = 19.169 \text{ mol/s}$$

*Example 2:*

- $\dot{m}_{ref} = 17.2683 \text{ kg/min} = 287.805 \text{ g/s}$
- $M_{mix} = 28.7805 \text{ g/mol}$

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

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

(b) *PDP calibration calculations.* For each restrictor position, calculate the following values from the mean values determined in § 1065.340, as follows:

(1) PDP volume pumped per revolution,  $V_{rev}$  ( $\text{m}^3/\text{rev}$ ):

$$V_{rev} = \frac{\dot{n}_{ref} \cdot R \cdot \bar{T}_{in}}{\bar{P}_{in} \cdot \bar{f}_{nPDP}} \quad \text{Eq. 1065.640-2}$$

*Example:*

- $\dot{n}_{ref} = 25.096 \text{ mol/s}$
- R = 8.314472 J/(mol·K)
- $\bar{T}_{in} = 299.5 \text{ K}$
- $\bar{P}_{in} = 98290 \text{ Pa}$
- $\bar{f}_{nPDP} = 1205.1 \text{ rev/min} = 20.085 \text{ rev/s}$

$$V_{rev} = \frac{25.096 \cdot 8.314472 \cdot 299.5}{98290 \cdot 20.085}$$

$$V_{rev} = 0.03166 \text{ m}^3/\text{rev}$$

(2) PDP slip correction factor,  $K_s$  (s/rev):

$$K_s = \frac{1}{\bar{f}_{rPDP}} \cdot \sqrt{\frac{\bar{P}_{out} - \bar{P}_{in}}{\bar{P}_{out}}} \quad \text{Eq. 1065.640-3}$$

*Example:*

- $\bar{f}_{nPDP} = 1205.1 \text{ rev/min} = 20.085 \text{ rev/s}$
- $\bar{P}_{out} = 100.103 \text{ kPa}$
- $\bar{P}_{in} = 98.290 \text{ kPa}$

$$K_s = \frac{1}{20.085} \cdot \sqrt{\frac{100.103 - 98.290}{100.103}}$$

$$K_s = 0.006700 \text{ s/rev}$$

(3) Perform a least-squares regression of PDP volume pumped per revolution,  $V_{rev}$ , versus PDP slip correction factor,  $K_s$ , by calculating slope,  $a_1$ , and intercept,  $a_0$ , as described in § 1065.602.

(4) Repeat the procedure in paragraphs (b)(1) through (3) of this section for every speed that you run your PDP.

(5) The following example illustrates these calculations:

TABLE 1 OF § 1065.640.—EXAMPLE OF PDP CALIBRATION DATA

$\bar{f}_{nPDP}$	$a_1$	$a_0$
755.0 .....	50.43	0.056
987.6 .....	49.86	-0.013
1254.5 ....	48.54	0.028

TABLE 1 OF § 1065.640.—EXAMPLE OF PDP CALIBRATION DATA—Continued

$\bar{f}_{nPDP}$	$a_1$	$a_0$
1401.3 ....	47.30	-0.061

(6) For each speed at which you operate the PDP, use the corresponding slope,  $a_1$ , and intercept,  $a_0$ , to calculate flow rate during emission testing as described in § 1065.642.

(c) *Venturi governing equations and permissible assumptions.* This section describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio,  $r$  (*i.e.*,  $r_{SSV}$  versus  $r_{CFV}$ ). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In paragraph (c)(4) of this section, we describe other assumptions that you

may make, depending upon how you conduct your emission tests. If we do not allow you to assume that the measured flow is an ideal gas, the governing equations include a first-order correction for the behavior of a real gas; namely, the compressibility factor,  $Z$ . If good engineering judgment dictates using a value other than  $Z=1$ , you may either use an appropriate equation of state to determine values of  $Z$  as a function of measured pressures and temperatures, or you may develop your own calibration equations based on good engineering judgment. Note that the equation for the flow coefficient,  $C_f$ , is based on the ideal gas assumption that the isentropic exponent,  $\gamma$ , is equal to the ratio of specific heats,  $C_p/C_v$ . If good engineering judgment dictates using a real gas isentropic exponent, you may either use an appropriate equation of state to determine values of  $\gamma$  as a function of measured pressures and temperatures, or you may develop your own calibration equations based on good engineering judgment. Calculate molar flow rate,  $\dot{n}$ , as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot P_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{Eq. 1065.640-4}$$

Where:  
 C<sub>d</sub> = Discharge coefficient, as determined in paragraph (c)(1) of this section.  
 C<sub>f</sub> = Flow coefficient, as determined in paragraph (c)(2) of this section.  
 A<sub>t</sub> = Venturi throat cross-sectional area.  
 P<sub>in</sub> = Venturi inlet absolute static pressure.  
 Z = Compressibility factor.  
 M<sub>mix</sub> = Molar mass of gas mixture.  
 R = Molar gas constant.  
 T<sub>in</sub> = Venturi inlet absolute temperature.  
 (1) Using the data collected in § 1065.340, calculate C<sub>d</sub> using the following equation:

$$C_d = \dot{n}_{ref} \cdot \frac{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}{C_f \cdot A_t \cdot P_{in}} \quad \text{Eq. 1065.640-5}$$

Where:  
 n<sub>ref</sub> = A reference molar flow rate.  
 (2) Determine C<sub>f</sub> using one of the following methods:  
 (i) For CFV flow meters only, determine C<sub>fCFV</sub> from the following table based on your values for β and γ, using linear interpolation to find intermediate values:

TABLE 2 OF § 1065.640.—C<sub>fCFV</sub> VERSUS β AND γ FOR CFV FLOW METERS

C <sub>fCFV</sub>		γ <sub>dexh</sub> = γ <sub>air</sub> = 1.399
β	γ <sub>exh</sub> = 1.385	
0.000 .....	0.6822	0.6846

TABLE 2 OF § 1065.640.—C<sub>fCFV</sub> VERSUS β AND γ FOR CFV FLOW METERS—Continued

C <sub>fCFV</sub>		γ <sub>dexh</sub> = γ <sub>air</sub> = 1.399
β	γ <sub>exh</sub> = 1.385	
0.400 .....	0.6857	0.6881
0.500 .....	0.6910	0.6934
0.550 .....	0.6953	0.6977
0.600 .....	0.7011	0.7036
0.625 .....	0.7047	0.7072
0.650 .....	0.7089	0.7114
0.675 .....	0.7137	0.7163
0.700 .....	0.7193	0.7219
0.720 .....	0.7245	0.7271
0.740 .....	0.7303	0.7329
0.760 .....	0.7368	0.7395
0.770 .....	0.7404	0.7431

TABLE 2 OF § 1065.640.—C<sub>fCFV</sub> VERSUS β AND γ FOR CFV FLOW METERS—Continued

C <sub>fCFV</sub>		γ <sub>dexh</sub> = γ <sub>air</sub> = 1.399
β	γ <sub>exh</sub> = 1.385	
0.780 .....	0.7442	0.7470
0.790 .....	0.7483	0.7511
0.800 .....	0.7527	0.7555
0.810 .....	0.7573	0.7602
0.820 .....	0.7624	0.7652
0.830 .....	0.7677	0.7707
0.840 .....	0.7735	0.7765
0.850 .....	0.7798	0.7828

(ii) For any CFV or SSV flow meter, you may use the following equation to calculate C<sub>f</sub>:

$$C_f = \frac{\left[ 2 \cdot \gamma \cdot \left( r^{\frac{\gamma-1}{\gamma}} - 1 \right) \right]^{\frac{1}{2}}}{(\gamma - 1) \cdot \left( \beta^4 - r^{\frac{-2}{\gamma}} \right)} \quad \text{Eq. 1065.640-6}$$

Where:  
 γ = isentropic exponent. For an ideal gas, this is the ratio of specific heats of the gas mixture, C<sub>p</sub>/C<sub>v</sub>.  
 r = Pressure ratio, as determined in paragraph (c)(3) of this section.  
 β = Ratio of venturi throat to inlet diameters.  
 (3) Calculate r as follows:  
 (i) For SSV systems only, calculate r<sub>SSV</sub> using the following equation:  
 (ii) For CFV systems only, calculate r<sub>CFV</sub> iteratively using the following equation:  
 Δ<sub>pSSV</sub> = Differential static pressure; venturi inlet minus venturi throat.

$$r_{SSV} = 1 - \frac{\Delta p}{P_{in}} \quad \text{Eq. 1065.640-7}$$

Where:

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left( \frac{\gamma-1}{2} \right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma+1}{2} \quad \text{Eq. 1065.640-8}$$

(4) You may make any of the following simplifying assumptions of the governing equations, or you may use good engineering judgment to develop more appropriate values for your testing:  
 (i) For emission testing over the full ranges of raw exhaust, diluted exhaust and dilution air, you may assume that the gas mixture behaves as an ideal gas: Z=1.  
 (ii) For the full range of raw exhaust you may assume a constant ratio of specific heats of γ = 1.385.

(iii) For the full range of diluted exhaust and air (e.g., calibration air or dilution air), you may assume a constant ratio of specific heats of  $\gamma = 1.399$ .

(iv) For the full range of diluted exhaust and air, you may assume the molar mass of the mixture is a function only of the amount of water in the

dilution air or calibration air,  $x_{H_2O}$ , determined as described in § 1065.645, as follows:

$$M_{mix} = M_{air} \cdot (1 - x_{H_2O}) + M_{H_2O} \cdot x_{H_2O} \quad \text{Eq. 1065.640-9}$$

**Example:**

$M_{air} = 28.96559 \text{ g/mol}$   
 $x_{H_2O} = 0.0169 \text{ mol/mol}$   
 $M_{H_2O} = 18.01528 \text{ g/mol}$   
 $M_{mix} = 28.96559 \times (1 - 0.0169) + 18.01528 \times 0.0169$   
 $M_{mix} = 28.7805 \text{ g/mol}$

constant molar mass of the mixture,  $M_{mix}$ , for all calibration and all testing as long as your assumed molar mass differs no more than  $\pm 1\%$  from the estimated minimum and maximum molar mass during calibration and testing. You may assume this, using good engineering judgment, if you sufficiently control the amount of water

in calibration air and in dilution air or if you remove sufficient water from both calibration air and dilution air. The following table gives examples of permissible ranges of dilution air dewpoint versus calibration air dewpoint:

(v) For the full range of diluted exhaust and air, you may assume a

TABLE 3 OF § 1065.640.—EXAMPLES OF DILUTION AIR AND CALIBRATION AIR DEWPOINTS AT WHICH YOU MAY ASSUME A CONSTANT  $M_{mix}$ .

If calibration $T_{dew}$ (°C) is...	assume the following constant $M_{mix}$ (g/mol)...	for the following ranges of $T_{dew}$ (°C) during emission tests <sup>a</sup>
dry .....	28.96559	dry to 18.
0 .....	28.89263	dry to 21.
5 .....	28.86148	dry to 22.
10 .....	28.81911	dry to 24.
15 .....	28.76224	dry to 26.
20 .....	28.68685	- 8 to 28.
25 .....	28.58806	12 to 31.
30 .....	28.46005	23 to 34.

<sup>a</sup> Range valid for all calibration and emission testing over the atmospheric pressure range (80.000 to 103.325) kPa.

(5) The following example illustrates the use of the governing equations to calculate the discharge coefficient,  $C_d$  of an SSV flow meter at one reference flow meter value. Note that calculating  $C_d$  for a CFV flow meter would be similar, except that  $C_f$  would be determined from Table 1 of this section or calculated iteratively using values of  $\beta$  and  $\gamma$  as described in paragraph (c)(2) of this section.

**Example:**

$\dot{n}_{ref} = 57.625 \text{ mol/s}$

$Z = 1$   
 $M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$   
 $R = 8.314472 \text{ J/(mol}\cdot\text{K)}$   
 $T_{in} = 298.15 \text{ K}$   
 $A_t = 0.01824 \text{ m}^2$   
 $p_{in} = 99132.0 \text{ Pa}$   
 $\gamma = 1.399$   
 $\beta = 0.8$   
 $\Delta p = 2.312 \text{ kPa}$

$$C_f = \left[ \frac{2 \cdot 1.399 \cdot \left( 0.977^{\frac{1.399-1}{1.399}} - 1 \right)}{(1.399 - 1) \cdot \left( 0.8^4 - 0.977^{\frac{-2}{1.399}} \right)} \right]^{\frac{1}{2}}$$

$C_f = 0.274$

$$r_{SSV} = 1 - \frac{2.312}{99.132} = 0.977$$

$$C_d = 57.625 \cdot \frac{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}{0.274 \cdot 0.01824 \cdot 99132.0}$$

$C_d = 0.981$

(d) *SSV calibration.* Perform the following steps to calibrate an SSV flow meter:

(1) Calculate the Reynolds number,  $Re_{\#}$ , for each reference molar flow rate, using the throat diameter of the venturi,

because the dynamic viscosity,  $\mu$ , is needed to compute  $Re_{\#}$ , you may use your own fluid viscosity model to determine  $\mu$  for your calibration gas (usually air), using good engineering judgment. Alternatively, you may use the Sutherland three-coefficient viscosity model to approximate  $\mu$ , as

shown in the following sample calculation for  $Re_{\#}$ :

$$Re_{\#} = \frac{4 \cdot M_{mix} \cdot \dot{n}_{ref}}{\pi \cdot d_t \cdot \mu} \quad \text{Eq. 1065.640-10}$$

Where, using the Sutherland three-coefficient viscosity model:



$$\mu = \mu_0 \cdot \left( \frac{T_{in}}{T_0} \right)^{\frac{3}{2}} \cdot \left( \frac{T_0 + S}{T_{in} + S} \right) \quad \text{Eq. 1065.640-11}$$

Where:  $T_0$  = Sutherland reference temperature.  
 $\mu$  = Dynamic viscosity of calibration gas.  $S$  = Sutherland constant.  
 $\mu_0$  = Sutherland reference viscosity.

TABLE 3 OF § 1065.640.—SUTHERLAND THREE-COEFFICIENT VISCOSITY MODEL PARAMETERS

Gas <sup>a</sup>	$\mu_0$ kg/(m · s)	$T_0$ K	$S$ K	Temp range within ± 2% error K	Pressure limit kPa
Air .....	$1.716 \cdot 10^{-5}$	273	111	170 to 1900	≤ 1800
CO <sub>2</sub> .....	$1.370 \cdot 10^{-5}$	273	222	190 to 1700	≤ 3600
H <sub>2</sub> O .....	$1.12 \cdot 10^{-5}$	350	1064	360 to 1500	≤ 10000
O <sub>2</sub> .....	$1.919 \cdot 10^{-5}$	273	139	190 to 2000	≤ 2500
N <sub>2</sub> .....	$1.663 \cdot 10^{-5}$	273	107	100 to 1500	≤ 1600

<sup>a</sup>Use tabulated parameters only for the pure gases, as listed. Do not combine parameters in calculations to calculate viscosities of gas mixtures.

Example:  $T_0 = 273.11$  K  
 $\mu_0 = 1.7894 \cdot 10^{-5}$  kg/(m·s)  $S = 110.56$  K

$$\mu = 1.7894 \cdot 10^{-5} \cdot \left( \frac{298.15}{273.11} \right)^{\frac{3}{2}} \cdot \left( \frac{273.11 + 110.56}{298.15 + 110.56} \right)$$

$\mu = 1.916 \cdot 10^{-5}$  kg/(m·s)  
 $M_{mix} = 28.7805$  g/mol  
 $\dot{n}_{ref} = 57.625$  mol/s  
 $d_t = 152.4$  mm  
 $T_{in} = 298.15$  K

$$Re^{\#} = \frac{4 \cdot 28.7805 \cdot 57.625}{3.14159 \cdot 152.4 \cdot 1.916 \cdot 10^{-5}}$$

$Re^{\#} = 7.2317 \cdot 10^5$

(2) Create an equation for  $C_d$  versus  $Re^{\#}$ , using paired values of ( $Re^{\#}$ ,  $C_d$ ). For the equation, you may use any mathematical expression, including a polynomial or a power series. The following equation is an example of a commonly used mathematical expression for relating  $C_d$  and  $Re^{\#}$ :

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}} \quad \text{Eq. 1065.640-12}$$

(3) Perform a least-squares regression analysis to determine the best-fit coefficients to the equation and calculate the equation's regression statistics, SEE and  $r^2$ , according to § 1065.602.

(4) If the equation meets the criteria of  $SEE < 0.5\% \cdot \dot{n}_{refmax}$  and  $r^2 \geq 0.995$ , you may use the equation to determine  $C_d$  for emission tests, as described in § 1065.642.

(5) If the SEE and  $r^2$  criteria are not met, you may use good engineering judgment to omit calibration data points

to meet the regression statistics. You must use at least seven calibration data points to meet the criteria.

(6) If omitting points does not resolve outliers, take corrective action. For example, select another mathematical expression for the  $C_d$  versus  $Re^{\#}$  equation, check for leaks, or repeat the calibration process. If you must repeat the process, we recommend applying tighter tolerances to measurements and allowing more time for flows to stabilize.

(7) Once you have an equation that meets the regression criteria, you may use the equation only to determine flow rates that are within the range of the reference flow rates used to meet the  $C_d$  versus  $Re^{\#}$  equation's regression criteria.

(e) *CFV calibration.* Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flow meters that consist of multiple venturis, either calibrate each venturi independently to determine a separate discharge coefficient,  $C_d$ , for each venturi, or calibrate each combination of venturis as one venturi. In the case where you calibrate a combination of venturis, use the sum of the active venturi throat areas as  $A_t$ , the sum of the active venturi throat diameters as  $d_t$ , and the ratio of venturi throat to inlet diameters as the

ratio of the sum of the active venturi throat diameters to the diameter of the common entrance to all of the venturis. To 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  $C_d$ , then use the mean  $C_d$  in Eq 1065.642-6, and use the CFV only down to the lowest  $\Delta p_{CFV}$  measured during calibration.

(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  $\Delta p_{CFV}$  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  $\Delta p_{CFV}$  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.

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

This section describes the equations for calculating molar flow rates from various flow meters. After you calibrate a flow meter according to § 1065.640, use the calculations described in this section to calculate flow during an emission test.

(a) *PDP molar flow rate.* Based upon the speed at which you operate the PDP for a test interval, select the corresponding slope,  $a_1$ , and intercept,  $a_0$ , as calculated in § 1065.640, to calculate molar flow rate,  $\dot{n}$ , as follows:

$$\dot{n} = f_{nPDP} \cdot \frac{p_{in} \cdot V_{rev}}{R \cdot T_{in}} \quad \text{Eq. 1065.642-1}$$

Where:

$$V_{rev} = \frac{a_1}{f_{nPDP}} \cdot \sqrt{\frac{p_{out} - p_{in}}{p_{in}}} + a_0 \quad \text{Eq. 1065.642-2}$$

*Example:*

$a_1 = 50.43$   
 $f_{nPDP} = 755.0 \text{ rev/min} = 12.58 \text{ rev/s}$   
 $p_{out} = 99950 \text{ Pa}$   
 $p_{in} = 98575 \text{ Pa}$   
 $a_0 = 0.056$   
 $R = 8.314472 \text{ J/(mol}\cdot\text{K)}$   
 $T_{in} = 323.5 \text{ K}$   
 $C_p = 1000 \text{ (J/m}^3\text{)/kPa}$

$C_t = 60 \text{ s/min}$

$$V_{rev} = \frac{50.43}{755} \cdot \sqrt{\frac{99950 - 98575}{98575}} + 0.056$$

$V_{rev} = 0.06389 \text{ m}^3\text{/rev}$

$$\dot{n} = 12.58 \cdot \frac{98575 \cdot 0.06389}{8.314472 \cdot 323.5}$$

$\dot{n} = 29.464 \text{ mol/s}$

(b) *SSV molar flow rate.* Based on the  $C_d$  versus  $Re^\#$  equation you determined according to § 1065.640, calculate SSV molar flow rate,  $\dot{n}^{ssv}$  during an emission test as follows:

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

*Example:*

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

$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$   
 $T_{in} = 298.15 \text{ K}$   
 $Re^\# = 7.232 \cdot 10^5$   
 $\gamma = 1.399$   
 $\beta = 0.8$   
 $\Delta p = 2.312 \text{ kPa}$   
 Using Eq. 1065.640-6,

$r_{ssv} = 0.997$

Using Eq. 1065.640-5,

$C_f = 0.274$

Using Eq. 1065.640-4,

$C_d = 0.990$

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

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

(c) *CFV molar flow rate.* Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. If you use multiple venturis and you calibrated each venturi independently to determine a separate discharge coefficient,  $C_d$ , for each

venturi, calculate the individual molar flow rates through each venturi and sum all their flow rates to determine  $\dot{n}$ . If you use multiple venturis and you calibrated each combination of venturis, calculate using the sum of the active venturi throat areas as  $A_t$ , the sum of the active venturi throat diameters as  $d_t$ , and the ratio of venturi throat to inlet diameters as the ratio of the sum of the active

venturi throat diameters to the diameter of the common entrance to all of the venturis. To calculate the molar flow rate through one venturi or one combination of venturis, use its respective mean  $C_d$  and other constants you determined according to § 1065.640 and calculate its molar flow rate  $\dot{n}$  during an emission test, as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{Eq. 1065.642-6}$$

*Example:*

$C_d = 0.985$   
 $C_f = 0.7219$   
 $A_t = 0.00456 \text{ m}^2$   
 $p_{in} = 98836 \text{ Pa}$

$Z = 1$   
 $M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$   
 $R = 8.314472 \text{ J/(mol}\cdot\text{K)}$   
 $T_{in} = 378.15 \text{ K}$

$\dot{n} = 0.985 \cdot 0.712$

$$\frac{0.00456 \cdot 98836}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 378.15}}$$

$\dot{n} = 33.690 \text{ mol/s}$

**§ 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 vapor pressure of water in paragraph (a) of this section or another appropriate equation and, depending on whether you measure dewpoint or relative humidity, perform one of the calculations in paragraph (b) or (c) of this section.

(a) *Vapor pressure of water.* Calculate the vapor pressure of water for a given saturation temperature condition,  $T_{\text{sat}}$ , as follows, or use 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:

$$\begin{aligned}
 &-\log_{10}(p_{\text{H}_2\text{O}}) = \\
 &10.79574 \cdot \left( \frac{273.16}{T_{\text{sat}}} - 1 \right) + \\
 &5.02800 \cdot \log_{10} \left( \frac{T_{\text{sat}}}{273.16} \right) + \\
 &1.50475 \cdot 10^{-4} \cdot \left( 10^{-8.2969 \cdot \left( \frac{T_{\text{sat}}}{273.16} \right)} - 1 \right) + \\
 &0.42873 \cdot 10^{-3} \cdot \left( 1 - 10^{4.76955 \cdot \left( 1 - \frac{273.16}{T_{\text{sat}}} \right)} \right) + \\
 &0.21386 \quad \text{Eq. 1065.645-1}
 \end{aligned}$$

Where:  
 $p_{\text{H}_2\text{O}}$  = vapor pressure of water at saturation temperature condition, kPa.  
 $T_{\text{sat}}$  = saturation temperature of water at measured conditions, K.

$$\begin{aligned}
 &-\log_{10}(p_{\text{sat}}) = \\
 &9.09685 \cdot \left( \frac{273.16}{T_{\text{sat}}} - 1 \right) + \\
 &3.56654 \cdot \log_{10} \left( \frac{273.16}{T_{\text{sat}}} \right) + \\
 &0.87682 \cdot \left( \frac{257.75}{T_{\text{sat}}} - 1 \right) + \\
 &0.21386 \quad \text{Eq. 1065.645-2}
 \end{aligned}$$

*Example:*

$T_{\text{ice}} = -15.4 \text{ °C}$   
 $T_{\text{ice}} = -15.4 + 273.15 = 257.75 \text{ K}$

$$\begin{aligned}
 &-\log_{10}(p_{\text{sat}}) = \\
 &9.09685 \cdot \left( \frac{273.16}{257.75} - 1 \right) + \\
 &3.56654 \cdot \log_{10} \left( \frac{273.16}{257.75} \right) + \\
 &0.87682 \cdot \left( \frac{257.75}{273.16} - 1 \right) + \\
 &0.21386
 \end{aligned}$$

$-\log_{10}(p_{\text{H}_2\text{O}}) = -0.79821$   
 $p_{\text{H}_2\text{O}} = 10^{0.79821} = 0.15941 \text{ kPa}$

(b) *Dewpoint.* If you measure humidity as a dewpoint, determine the amount of water in an ideal gas,  $x_{\text{H}_2\text{O}}$ , as follows:

$$x_{\text{H}_2\text{O}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad \text{Eq. 1065.645-3}$$

Where:  
 $x_{\text{H}_2\text{O}}$  = amount of water in an ideal gas.  
 $p_{\text{H}_2\text{O}}$  = water vapor pressure at the measured dewpoint,  $T_{\text{sat}} = T_{\text{dew}}$ .  
 $p_{\text{abs}}$  = wet static absolute pressure at the location of your dewpoint measurement.

*Example:*  
 $p_{\text{abs}} = 99.980 \text{ kPa}$   
 $T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ °C}$   
 Using Eq. 1065.645-2,  
 $p_{\text{H}_2\text{O}} = 1.1866 \text{ kPa}$   
 $x_{\text{H}_2\text{O}} = 1.1866/99.980$   
 $x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$

(c) *Relative humidity.* If you measure humidity as a relative humidity, RH%, determine the amount of water in an ideal gas,  $x_{\text{H}_2\text{O}}$ , as follows:

*Example:*

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

$$\begin{aligned}
 &-\log_{10}(p_{\text{H}_2\text{O}}) = \\
 &10.79574 \cdot \left( \frac{273.16}{282.65} - 1 \right) + \\
 &5.02800 \cdot \log_{10} \left( \frac{282.65}{273.16} \right) + \\
 &1.50475 \cdot 10^{-4} \cdot \left( 10^{-8.2969 \cdot \left( \frac{282.65}{273.16} \right)} - 1 \right) + \\
 &0.42873 \cdot 10^{-3} \cdot \left( 1 - 10^{4.76955 \cdot \left( 1 - \frac{273.16}{282.65} \right)} \right) + \\
 &0.21386
 \end{aligned}$$

$-\log_{10}(p_{\text{H}_2\text{O}}) = -0.074297$   
 $p_{\text{H}_2\text{O}} = 10^{0.074297} = 1.1866 \text{ kPa}$

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

$$x_{\text{H}_2\text{O}} = \frac{\text{RH}\% \cdot p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad \text{Eq. 1065.645-4}$$

Where:  
 $x_{\text{H}_2\text{O}}$  = amount of water in an ideal gas.  
 RH% = relative humidity.  
 $p_{\text{H}_2\text{O}}$  = water vapor pressure at 100% relative humidity at the location of your relative humidity measurement,  $T_{\text{sat}} = T_{\text{amb}}$ .  
 $p_{\text{abs}}$  = wet static absolute pressure at the location of your relative humidity measurement.

*Example:*  
 RH% = 50.77%  
 $p_{\text{abs}} = 99.980 \text{ kPa}$   
 $T_{\text{sat}} = T_{\text{amb}} = 20 \text{ °C}$   
 Using Eq. 1065.645-2,  
 $p_{\text{H}_2\text{O}} = 2.3371 \text{ kPa}$   
 $x_{\text{H}_2\text{O}} = (50.77\% \cdot 2.3371)/99.980$   
 $x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$

**§ 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. 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 (b) of this section, and divide it by the total work generated over the test interval, as described in paragraph (c) of this section, using the following equation:

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

*Example:*

$m_{\text{NO}_x} = 64.975 \text{ g}$   
 $W = 25.783 \text{ kW}\cdot\text{hr}$   
 $e_{\text{NO}_x} = 64.975/25.783$   
 $e_{\text{NO}_x} = 2.520 \text{ g}/(\text{kW}\cdot\text{hr})$

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

$$e = \frac{\dot{m}}{P} \quad \text{Eq. 1065.650-2}$$

(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 (e) 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:

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

*Example:*

$\tilde{m} = 805.5 \sim \text{g}$   
 $\tilde{W} = 52.102 \sim \text{kW}\cdot\text{hr}$   
 $e_{\text{CO}} = 805.5/52.102$

$e_{\text{CO}} = 2.520 \text{ g}/(\text{kW}\cdot\text{hr})$

(b) *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 (b)(1) of this section, then use the method in paragraphs (b)(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 concentrations measured on a "dry" basis to a "wet" basis, including dilution air background concentrations, as described in § 1065.659.

(ii) Calculate all HC concentrations, including dilution air background concentrations, as described in § 1065.660.

(iii) 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.

(iv) Correct the total mass of  $\text{NO}_x$  based on intake-air humidity as described in § 1065.670.

(v) 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, synchronously multiply it by the flow rate of the flow from which you extracted it. We consider the following to be examples of changing flows that require a continuous multiplication of concentration times molar flow rate: Raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. Account for dispersion and time alignment as described in § 1065.201. 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:

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

*Example:*

$M_{\text{NMHC}} = 13.875389 \text{ g/mol}$

$N = 1200$

$x_{\text{NMHC1}} = 84.5 \mu\text{mol/mol} = 84.5 \cdot 10^{-6} \text{ mol/mol}$

$x_{\text{NMHC2}} = 86.0 \mu\text{mol/mol} = 86.0 \cdot 10^{-6} \text{ mol/mol}$

$\dot{n}_{\text{exh1}} = 2.876 \text{ mol/s}$

$\dot{n}_{\text{exh2}} = 2.224 \text{ mol/s}$

$f_{\text{record}} = 1 \text{ Hz}$

Using Eq. 1065.650 – 5,

$\Delta t = 1/1 = 1 \text{ s}$

$m_{\text{NMHC}} = 13.875389 \cdot (84.5 \cdot 10^{-6} \cdot 2.876 + 86.0 \cdot 10^{-6} \cdot 2.224 + \dots + x_{\text{NMHC1200}} \cdot \dot{n}_{\text{exh}}) \cdot 1$

$m_{\text{NMHC}} = 25.23 \text{ g}$

(ii) *Constant flow rate.* If you continuously sample from a constant exhaust flow rate, calculate the mean concentration recorded over the test interval and treat the mean as a batch sample, as described in paragraph (b)(3)(ii) of this section. We consider the following to be examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both.

(3) *Batch sampling.* For batch sampling, the concentration is a single value from a proportionally extracted batch sample (such as a bag, filter, impinger, or cartridge). In this case, multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. You may calculate total flow by integrating a changing flow rate or by determining the mean of a constant flow rate, as follows:

(i) *Varying flow rate.* If you collect a batch sample from a changing exhaust flow rate, extract a sample proportional to the changing exhaust flow rate. We consider the following to be examples of changing flows that require proportional sampling: Raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. Integrate the flow rate over a test interval to determine the total flow from which you extracted the proportional sample. Multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass,  $M$ . The result is the mass of the emission,  $m$ . In the case of PM emissions, where

the mean PM concentration is already in units of mass per mole of sample,  $\bar{M}_{PM}$ , 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:

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

*Example:*

$$\bar{M}_{NO_x} = 46.0055 \text{ g/mol}$$

$$N = 9000$$

$$\bar{x}_{NO_x} = 85.6 \text{ } \mu\text{mol/mol} = 85.6 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{dexh1} = 25.534 \text{ mol/s}$$

$$\dot{n}_{dexh2} = 26.950 \text{ mol/s}$$

$$f_{\text{record}} = 5 \text{ Hz}$$

Using Eq. 1065.650-5,

$$\Delta t = 1/5 = 0.2$$

$$m_{NO_x} = 46.0055 \cdot 85.6 \cdot 10^{-6} \cdot (25.534 + 26.950 + \dots + \dot{n}_{\text{exh}9000}) \cdot 0.2$$

$$m_{NO_x} = 4.201 \text{ g}$$

(ii) *Constant flow rate.* If you batch sample from a constant exhaust flow rate, extract a sample at a 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:

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

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

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

*Example:*

$$\bar{M}_{PM} = 144.0 \text{ } \mu\text{g/mol} = 144.0 \cdot 10^{-6} \text{ g/mol}$$

$$\bar{n}_{\text{dexh}} = 57.692 \text{ mol/s}$$

$$\Delta t = 1200 \text{ s}$$

$$m_{PM} = 144.0 \cdot 10^{-6} \cdot 57.692 \cdot 1200$$

$$m_{PM} = 9.9692 \text{ g}$$

(4) *Additional provisions for diluted exhaust sampling; continuous or batch.* The following additional provisions apply for sampling emissions from diluted exhaust:

(i) For sampling with a constant dilution ratio (DR) of air flow versus exhaust flow (e.g., secondary dilution for PM sampling), calculate  $m$  using the following equation:

$$m = m_{\text{dil}} \cdot (\text{DR} + 1) \quad \text{Eq. 1065.650-9}$$

*Example:*

$$m_{\text{PMdil}} = 6.853 \text{ g}$$

$$\text{DR} = 5:1$$

$$m_{\text{PM}} = 6.853 \cdot (5 + 1)$$

$$m_{\text{PM}} = 41.118 \text{ g}$$

(ii) For continuous or batch sampling, you may measure background emissions in the dilution air. You may then subtract the measured background emissions, as described in § 1065.667.

(c) *Total work.* To calculate total work, multiply the feedback engine speed by its respective feedback torque. Integrate the resulting value for power over a test interval. Calculate total work as follows:

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

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

*Example:*

$$N = 9000$$

$$f_{n1} = 1800.2 \text{ rev/min}$$

$$f_{n2} = 1805.8 \text{ rev/min}$$

$$T_1 = 177.23 \text{ N}\cdot\text{m}$$

$$T_2 = 175.00 \text{ N}\cdot\text{m}$$

$$C_{\text{rev}} = 2 \cdot \pi \text{ rad/rev}$$

$$C_{t1} = 60 \text{ s/min}$$

$$C_p = 1000 \text{ (N}\cdot\text{m)/kW}$$

$$f_{\text{record}} = 5 \text{ Hz}$$

$$C_{t2} = 3600 \text{ s/hr}$$

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

$$P_1 = 33.41 \text{ kW}$$

$$P_2 = 33.09 \text{ kW}$$

Using Eq. 1065.650-5,

$$\Delta t = 1/5 = 0.2 \text{ s}$$

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

$$W = 16.875 \text{ kW}\cdot\text{hr}$$

(d) *Steady-state mass rate divided by power.* To determine steady-state brake-specific emissions for a test interval as

described in paragraph (a)(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,  $\bar{m}_{PM}$ . 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:

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

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

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

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

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

$$M_{CO} = 28.0101 \text{ g/mol}$$

$$\bar{x}_{CO} = 12.00 \text{ mmol/mol} = 0.01200 \text{ mol/mol}$$

$$\bar{n} = 1.530 \text{ mol/s}$$

$$\bar{f}$$

$$\bar{T} = 121.50 \text{ N}\cdot\text{m}$$

$$\bar{m} = 28.0101 \cdot 0.01200 \cdot 1.530$$

$$\bar{m} = 0.514 \text{ g/s}$$

$$\bar{P} = 121.5 \cdot 375.37$$

$$\bar{P} = 45607 \text{ W} = 45.607 \text{ kW}$$

$$e_{CO} = 0.514/45.61$$

$$e_{CO} = 0.0113 \text{ g/(kW}\cdot\text{hr)}$$

(e) *Ratio of total mass of emissions to total work.* To determine brake-specific emissions for a test interval as described in paragraph (a)(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 (b) 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,  $\bar{n}$ , or linearly proportional to total flow,  $\bar{n}$ , as follows:

$$\tilde{m}_{\text{fuel}} = \frac{1}{w_{\text{fuel}}} \cdot \frac{M_c \cdot \tilde{n}_i \cdot x_{\text{Cproddry}i}}{1 + x_{\text{H}_2\text{O}i}} \quad \text{Eq. 1065.650-14}$$

(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,  $e_{\text{fuel}}$ , 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,  $\tilde{n}$ , in paragraph (e)(1) of this section. Calculate a value proportional to total work as follows:

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

Where:

$$\tilde{P}_i = \frac{\tilde{m}_{\text{fuel}i}}{e_{\text{fuel}}} \quad \text{Eq. 1065.650-16}$$

(3) Divide the value proportional to total mass by the value proportional to

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

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

$N = 3000$

$f_{\text{record}} = 5 \text{ Hz}$

$e_{\text{fuel}} = 285 \text{ g/(kW}\cdot\text{hr)}$

$w_{\text{fuel}} = 0.869 \text{ g/g}$

$M_c = 12.0107 \text{ g/mol}$

$\tilde{n}_1 = 3.922 \text{ mol/s} = 14119.2 \text{ mol/hr}$

$x_{\text{Cproddry}1} = 91.634 \text{ mmol/mol} = 0.091634 \text{ mol/mol}$

$x_{\text{H}_2\text{O}1} = 27.21 \text{ mmol/mol} = 0.02721 \text{ mol/mol}$

Using 1065.650–5,

$\Delta t = 0.2 \text{ s}$

$$\tilde{W} = \frac{12.0107 \cdot \left[ \frac{3.922 \cdot 0.091634}{1 + 0.02721} + \frac{\tilde{n}_2 \cdot x_{\text{Cproddry}2}}{1 + x_{\text{H}_2\text{O}2}} + \dots + \frac{\tilde{n}_{3000} \cdot x_{\text{Cpdry}3000}}{1 + x_{\text{H}_2\text{O}n3000}} \right] \cdot 0.2}{285 \cdot 0.869}$$

$\tilde{W} = 5.09 \text{ (kW}\cdot\text{hr)}$

(f) *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.

#### § 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,  $x_{\text{H}_2\text{O}}$ , 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  $\tilde{x}_{\text{dil}}$ , 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,  $x_{\text{H}_2\text{O}}$ , fraction of dilution air in diluted exhaust,  $x_{\text{dil}}$ , and the amount of products on a  $C_1$  basis per dry mole of dry measured flow,  $x_{\text{Cproddry}}$ . For each emission concentration,  $x$ , and amount of water  $x_{\text{H}_2\text{O}}$ , you must determine their completely dry concentrations,  $x_{\text{dry}}$  and  $x_{\text{H}_2\text{Odry}}$ . You must also use your fuel’s atomic hydrogen-to-carbon ratio,  $\alpha$ , and oxygen-to-carbon ratio,  $\beta$ . For your fuel, you may measure  $\alpha$  and  $\beta$  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,  $x_{\text{CO}_2\text{meas}}$ ,  $x_{\text{NOmeas}}$ , and  $x_{\text{H}_2\text{Oint}}$ , to dry concentrations by dividing them by one minus the amount of water present

during their respective measurements; for example:  $x_{\text{H}_2\text{O}x\text{CO}_2}$ ,  $x_{\text{H}_2\text{O}x\text{NO}}$ , and  $x_{\text{H}_2\text{Oint}}$ . If the amount of water present during a “wet” measurement is the same as the unknown amount of water in the exhaust flow,  $x_{\text{H}_2\text{O}}$ , iteratively solve for that value in the system of equations. If you measure only total  $\text{NO}_x$  and not NO and  $\text{NO}_2$  separately, use good engineering judgement to estimate a split in your total  $\text{NO}_x$  concentration between NO and  $\text{NO}_2$  for the chemical balances. For example, if you measure emissions from a stoichiometric spark-ignition engine, you may assume all  $\text{NO}_x$  is NO. For a compression-ignition engine, you may assume that your molar concentration of  $\text{NO}_x$ ,  $x_{\text{NO}x}$ , is 75% NO and 25%  $\text{NO}_2$ . For  $\text{NO}_2$  storage aftertreatment systems, you may assume  $x_{\text{NO}x}$  is 25% NO and 75%  $\text{NO}_2$ . Note that for calculating the mass of  $\text{NO}_x$  emissions, you must use the molar mass of  $\text{NO}_2$  for the effective molar mass of all  $\text{NO}_x$  species, regardless of the actual  $\text{NO}_2$  fraction of  $\text{NO}_x$ .

(2) Enter the equations in paragraph (c)(4) of this section into a computer program to iteratively solve for  $x_{\text{H}_2\text{O}}$  and  $x_{\text{Cproddry}}$ . If you measure raw exhaust flow, set  $x_{\text{dil}}$  equal to zero. If you measure diluted exhaust flow, iteratively solve for  $x_{\text{dil}}$ . Use good engineering judgment to guess initial values for  $x_{\text{H}_2\text{O}}$ ,  $x_{\text{Cproddry}}$ , and  $x_{\text{dil}}$ . 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  $x_{C_{proddry}}$  as the sum of your measured  $CO_2$ ,  $CO$ , and  $THC$  values. If you measure diluted exhaust, we also recommend guessing an initial  $x_{dil}$  between 0.75 and 0.95, such as 0.8. Iterate values in the system of equations until the most recently updated guesses are all within  $\pm 1\%$  of their respective most recently calculated values.

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

$x_{H_2O}$  = Amount of water in measured flow.

$x_{H_2Odry}$  = Amount of water per dry mole of measured flow.

$x_{C_{proddry}}$  = Amount of carbon products on a  $C_1$  basis per dry mole of measured flow.

$x_{dil}$  = Fraction of dilution air in measured flow, assuming stoichiometric exhaust; or  $x_{dil}$  = excess air for raw exhaust.

$x_{prod/intdry}$  = Amount of dry stoichiometric products per dry mole of intake air.

$x_{O_2proddry}$  = Amount of oxygen products on an  $O_2$  basis per dry mole of measured flow.

$x_{[emission]dry}$  = Amount of emission per dry mole of measured flow.

$x_{[emission]meas}$  = Amount of emission in measured flow.

$x_{H_2O[emission]meas}$  = Amount of water at emission-detection location. Measure or estimate these values according to § 1065.145(d)(2).

$x_{H_2Oint}$  = Amount of water in the intake air, based on a humidity measurement of intake air.

$x_{H_2Odil}$  = Amount of water in dilution air, based on a humidity measurement of intake air.

$x_{O_2airdry}$  = Amount of oxygen per dry mole of air. Use  $x_{O_2airdry} = 0.209445$  mol/mol.

$x_{CO_2airdry}$  = Amount of carbon dioxide per dry mole of air. Use  $x_{CO_2airdry} = 375$  mol/mol.

$\alpha$  = Atomic hydrogen-to-carbon ratio in fuel.

$\beta$  = Atomic oxygen-to-carbon ratio in fuel.

(4) Use the following equations to iteratively solve for  $x_{H_2O}$  and  $x_{C_{proddry}}$ :

$$x_{H_2O} = \frac{x_{H_2Odry}}{1 + x_{H_2Odry}} \quad \text{Eq. 1065.655-1}$$

$$x_{H_2Odry} = \frac{\alpha}{2} \cdot x_{C_{proddry}} + (1 - x_{dil}) \cdot \frac{x_{H_2Ointdry}}{x_{prod/intdry}} + x_{dil} \cdot x_{H_2Odildry} \quad \text{Eq. 1065.655-2}$$

$$x_{C_{proddry}} = x_{CO_2dry} + x_{COdry} + x_{THCdry} \quad \text{Eq. 1065.655-3}$$

$$x_{dil} = 1 - \frac{x_{O_2proddry} \cdot x_{prod/intdry}}{x_{O_2airdry}} \cdot (1 + x_{H_2Ointdry}) \quad \text{Eq. 1065.655-4}$$

$$x_{prod/intdry} = \frac{1}{1 - \frac{1}{1 - x_{dil}} \cdot \frac{1}{2} \cdot \left( x_{COdry} - \frac{\alpha}{2} \cdot x_{C_{proddry}} - x_{NO_2dry} \right)} \quad \text{Eq. 1065.655-5}$$

$$x_{O_2proddry} = x_{CO_2dry} + \frac{1}{2} \cdot \left( x_{COdry} + \frac{\alpha}{2} \cdot x_{C_{proddry}} + x_{NO_2dry} \right) + x_{NO_2dry} - \beta \cdot x_{C_{proddry}} \quad \text{Eq. 1065.655-6}$$

$$x_{CO_2dry} = \frac{x_{CO_2meas}}{1 - x_{H_2OCO_2meas}} - \frac{x_{CO_2airdry}}{1 - \frac{1}{2} \cdot \left( x_{COdry} - \frac{\alpha}{2} \cdot x_{C_{proddry}} - x_{NO_2dry} \right)} \quad \text{Eq. 1065.655-7}$$

$$x_{COdry} = \frac{x_{COmeas}}{1 - x_{H_2OxCOmeas}} \quad \text{Eq. 1065.655-8}$$

$$x_{THCdry} = \frac{x_{THCmeas}}{1 - x_{H_2OxTHCmeas}} \quad \text{Eq. 1065.655-9}$$

$$x_{H_2Ointdry} = \frac{x_{H_2Oint}}{1 - x_{H_2Oint}} \quad \text{Eq. 1065.655-10}$$

$$x_{\text{H}_2\text{Odil dry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}} \quad \text{Eq. 1065.655-11}$$

$$x_{\text{NO}_2 \text{dry}} = \frac{x_{\text{NO}_2 \text{meas}}}{1 - x_{\text{H}_2\text{O}} x_{\text{NO}_2 \text{meas}}} \quad \text{Eq. 1065.655-12}$$

$$x_{\text{NO dry}} = \frac{x_{\text{NO meas}}}{1 - x_{\text{H}_2\text{O}} x_{\text{NO meas}}} \quad \text{Eq. 1065.655-13}$$

(5) The following example is a solution for  $x_{\text{H}_2\text{O}}$  and  $x_{\text{Cprod dry}}$  using the equations in paragraph (c)(4) of this section:

$$x_{\text{H}_2\text{O}} = \frac{35.24}{1 + \frac{35.24}{1000}} = 34.04 \text{ mmol/mol}$$

$$x_{\text{H}_2\text{O dry}} = \frac{1.8}{2} \cdot 24.69 + (1 - 0.843) \cdot \frac{17.22}{0.9338} + 0.843 \cdot 12.01 = 35.24 \text{ mmol/mol}$$

$$x_{\text{Cprod dry}} = 24.614 + \frac{29.3}{1000} + \frac{47.6}{1000} = 24.69 \text{ mmol/mol}$$

$$x_{\text{dil}} = 1 - \frac{\frac{34.54}{1000} \cdot 0.9338}{0.209445} \cdot \left(1 + \frac{17.22}{1000}\right) = 0.843$$

$$x_{\text{prod/int dry}} = \frac{1}{1 - \frac{1}{1 - 0.843} \cdot \frac{1}{2} \cdot \left(\frac{29.3}{1000000} - \frac{1.8}{2} \cdot \frac{24.69}{1000} - \frac{12.1}{1000000}\right)} = 0.9338 \text{ mol/mol}$$

$$x_{\text{O}_2 \text{prod/int dry}} = 24.614 + \frac{1}{2} \cdot \left(\frac{29.3}{1000} + \frac{1.8}{2} \cdot 24.69 + \frac{50.4}{1000}\right) + \frac{12.1}{1000} - 0.05 \cdot 24.69 = 34.54 \text{ mol/mol}$$

$$x_{\text{CO}_2 \text{dry}} = \frac{24.770}{1 - \frac{8.601}{1000}} - \frac{\frac{375}{1000}}{1 - \frac{1}{2} \cdot \left(\frac{29.3}{1000000} - \frac{1.8}{2} \cdot \frac{24.69}{1000} - \frac{12.1}{1000000}\right)} = 24.614 \text{ mmol/mol}$$



$$x_{COdry} = \frac{29.0}{1 - \frac{8.601}{1000}} = 29.3 \mu\text{mol/mol}$$

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

$$x_{NO2dry} = \frac{12.0}{1 - \frac{8.601}{1000}} = 12.1 \mu\text{mol/mol}$$

$$x_{THCdry} = \frac{46}{1 - \frac{34.04}{1000}} = 47.6 \mu\text{mol/mol}$$

$$x_{H2Odildry} = \frac{11.87}{1 - \frac{11.87}{1000}} = 12.01 \text{ mmol/mol}$$

$$x_{NOdry} = \frac{50.0}{1 - \frac{8.601}{1000}} = 50.4 \mu\text{mol/mol}$$

$X_{O2airdry} = 0.209445 \text{ mol/mol}$   
 $X_{CO2airdry} = 375 \text{ mol/mol}$   
 $\alpha = 1.8$   
 $\beta = 0.05$

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

Fuel	Atomic hydrogen and oxygen-to-carbon ratios CH $\alpha$ O $\beta$	Carbon mass concentration, $w_C$ /g
Gasoline .....	CH <sub>1.85</sub> O <sub>0</sub>	0.866
#2 Diesel .....	CH <sub>1.80</sub> O <sub>0</sub>	0.869
#1 Diesel .....	CH <sub>1.93</sub> O <sub>0</sub>	0.861
Liquified Petroleum Gas .....	CH <sub>2.64</sub> O <sub>0</sub>	0.819
Natural gas .....	CH <sub>3.78</sub> O <sub>0.016</sub>	0.747
Ethanol .....	CH <sub>3</sub> O <sub>0.5</sub>	0.521
Methanol .....	CH <sub>4</sub> O <sub>1</sub>	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,  $\dot{m}_{fuel}$ , and the values calculated using the chemical balance in paragraph (c) of this section. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record  $\dot{n}_{int}$  or  $\dot{m}_{fuel}$ .

(1) *Crankcase flow rate.* You may calculate raw exhaust flow based on  $\dot{n}_{int}$  or  $\dot{m}_{fuel}$  only if at least one of the following is true about your crankcase emission flow rate:

(i) Your test engine has a production emission-control system with a closed crankcase that routes crankcase flow back to the intake air, downstream of your intake air flow meter.

(ii) During emission testing you route open crankcase flow to the exhaust according to § 1065.130(g).

(iii) You measure open crankcase emissions and flow, and you add the masses of crankcase emissions to your brake-specific emission calculations.

(iv) Using emission data or an engineering analysis, you can show that neglecting the flow rate of open crankcase emissions does not adversely affect your ability to demonstrate compliance with the applicable standards.

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

$$\dot{n}_{exh} = \left[ \dot{n}_{int} \cdot (1 - x_{H2Oint}) \cdot x_{prod/intdry} \cdot (1 + x_{H2Odry}) \right] \cdot \left[ 1 + \frac{x_{dil}}{1 - x_{dil}} \right]$$

Eq. 1065.655-14

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:

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

$x_{H2Oint} = 16.930 \text{ mmol/mol} = 0.016930 \text{ mol/mol}$

$x_{prod/intdry} = 0.93382 \text{ mol/mol}$

$x_{H2Odry} = 130.16 \text{ mmol/mol} = 0.13016 \text{ mol/mol}$

$x_{dil} = 0.20278 \text{ mol/mol}$

$$\dot{n}_{exh} = \left[ 3.780 \cdot (1 - 0.016930) \cdot 0.93382 \cdot (1 + 0.13016) \right] \cdot \left[ 1 + \frac{0.20278}{1 - 0.20278} \right]$$

$$\dot{n}_{\text{exh}} = 4.919 \text{ mol/s}$$

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

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot W_c}{M_c \cdot X_{\text{Cproddry}}} \cdot \left(1 + X_{\text{H2Odry}}\right) \cdot \left[1 + \frac{X_{\text{dil}}}{1 - X_{\text{dil}}}\right] \quad \text{Eq. 1065.655-15}$$

Where:

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

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

Example:

$$\dot{m}_{\text{fuel}} = 6.023 \text{ g/s}$$

$$W_c = 0.869 \text{ g/g}$$

$$M_c = 12.0107 \text{ g/mol}$$

$$X_{\text{Cproddry}} = 125.58 \text{ mmol/mol} = 0.12558 \text{ mol/mol}$$

$$X_{\text{H2Odry}} = 130.16 \text{ mmol/mol} = 0.13016 \text{ mol/mol}$$

$$X_{\text{dil}} = 0.20278 \text{ mol/mol}$$

$$\dot{n}_{\text{exh}} = \frac{6.0233 \cdot 0.869}{12.0107 \cdot 0.12558} \cdot (1 + 0.13016) \cdot \left[1 + \frac{0.20278}{1 - 0.20278}\right]$$

$$\dot{n}_{\text{exh}} = 4.919 \text{ mol/s}$$

#### § 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,  $X_{\text{H2O[emission]meas}}$ , and at the flow meter,  $X_{\text{H2O}}$ , whose flow is used to determine the concentration's total mass over a test interval.

(b) 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.

(3) You may also use a nominal value of absolute pressure based on an alarm

setpoint, a pressure regulator setpoint, or good engineering judgment.

(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:

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

Example:

$$X_{\text{COmeas}} = 29.0 \text{ } \mu\text{mol/mol}$$

$$X_{\text{H2O} \times \text{COmeas}} = 8.601 \text{ mmol/mol} = 0.008601 \text{ mol/mol}$$

$$X_{\text{H2O}} = 34.04 \text{ mmol/mol} = 0.03404 \text{ mol/mol}$$

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

$$x_{\text{CO}} = 28.3 \text{ } \mu\text{mol/mol}$$

#### § 1065.660 THC and NMHC determination.

(a) *THC determination.* If we require you to determine THC emissions, calculate  $x_{\text{THC}}$  using the initial THC contamination concentration  $X_{\text{THCinit}}$  from § 1065.520 as follows:

$$X_{\text{THCcor}} = X_{\text{THCuncor}} - X_{\text{THCinit}} \quad \text{Eq. 1065.660-1}$$

Example:

$$X_{\text{THCuncor}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$X_{\text{THCinit}} = 1.1 \text{ } \mu\text{mol/mol}$$

$$X_{\text{THCcor}} = 150.3 - 1.1$$

$$X_{\text{THCcor}} = 149.2 \text{ } \mu\text{mol/mol}$$

(b) *NMHC determination.* Use one of the following to determine NMHC emissions,  $X_{\text{NMHC}}$ .

(1) Report  $X_{\text{NMHC}}$  as  $0.98 \cdot X_{\text{THC}}$  if you did not measure  $\text{CH}_4$ , or if the result of paragraph (b)(2) or (3) of this section is greater than the result using this paragraph (b)(1).

(2) For nonmethane cutters, calculate  $X_{\text{NMHC}}$  using the nonmethane cutter's penetration fractions (PF) of  $\text{CH}_4$  and  $\text{C}_2\text{H}_6$  from § 1065.365, and using the initial NMHC contamination concentration  $X_{\text{NMHCinit}}$  from § 1065.520 as follows:

$$x_{\text{NMHC}} = \frac{\text{PF}_{\text{CH}_4} \cdot x_{\text{THC}} - \text{RF}_{\text{CH}_4} \cdot x_{\text{CH}_4}}{\text{PF}_{\text{CH}_4} - \text{PF}_{\text{C}_2\text{H}_6}} - x_{\text{NMHC}_{\text{init}}} \quad \text{Eq. 1065.660-2}$$

Where:

$x_{\text{NMHC}}$  = concentration of NMHC.  
 $\text{PF}_{\text{CH}_4}$  = nonmethane cutter  $\text{CH}_4$  penetration fraction, according to § 1065.365.  
 $x_{\text{THC}}$  = concentration of THC, as measured by the THC FID.  
 $\text{RF}_{\text{CH}_4}$  = response factor of THC FID to  $\text{CH}_4$ , according to § 1065.360.  
 $x_{\text{CH}_4}$  = concentration of methane, as measured downstream of the nonmethane cutter.

$\text{PF}_{\text{C}_2\text{H}_6}$  = nonmethane cutter  $\text{CH}_4$  penetration fraction, according to § 1065.365.  
 $x_{\text{NMHC}_{\text{init}}}$  = initial NMHC contamination concentration, according to § 1065.520.  
*Example:*  
 $\text{PF}_{\text{CH}_4} = 0.990$   
 $x_{\text{THC}} = 150.3 \mu\text{mol/mol}$   
 $\text{RF}_{\text{CH}_4} = 1.05$   
 $x_{\text{CH}_4} = 20.5 \mu\text{mol/mol}$   
 $\text{PF}_{\text{C}_2\text{H}_6} = 0.020$

$x_{\text{NMHC}_{\text{init}}} = 1.1 \mu\text{mol/mol}$

$$x_{\text{NMHC}} = \frac{0.990 \cdot 150.3 - 1.05 \cdot 20.5}{0.990 - 0.020} - 1.1$$

$x_{\text{NMHC}} = 130.1 \mu\text{mol/mol}$

(3) For a gas chromatograph, calculate  $x_{\text{NMHC}}$  using the THC analyzer's response factor (RF) for  $\text{CH}_4$ , from § 1065.360, and using the initial NMHC contamination concentration  $x_{\text{NMHC}_{\text{init}}}$  from § 1065.520 as follows:

$$x_{\text{NMHC}} = x_{\text{THC}} - \text{RF}_{\text{CH}_4} \cdot x_{\text{CH}_4} - x_{\text{NMHC}_{\text{init}}} \quad \text{Eq. 1065.660-3}$$

*Example:*

$x_{\text{THC}} = 145.6 \mu\text{mol/mol}$   
 $\text{RF}_{\text{CH}_4} = 0.970$   
 $x_{\text{CH}_4} = 18.9 \mu\text{mol/mol}$   
 $x_{\text{NMHC}_{\text{init}}} = 1.1 \mu\text{mol/mol}$   
 $x_{\text{NMHC}} = 145.6 - 0.970 \cdot 18.9 - 1.1$   
 $x_{\text{NMHC}} = 126.2 \mu\text{mol/mol}$

#### § 1065.665 THCE and NMHCE determination.

(a) If you measured an oxygenated hydrocarbon's mass concentration (per mole of exhaust), first calculate its molar concentration by dividing its mass concentration by the effective molar mass of the oxygenated hydrocarbon, then multiply each

oxygenated hydrocarbon's molar concentration by its respective number of carbon atoms per molecule. Add these  $\text{C}_1$ -equivalent molar concentrations to the molar concentration of NOTHC. The result is the molar concentration of THCE. Calculate THCE concentration using the following equations:

$$x_{\text{THCE}} = x_{\text{NOTHC}} + \sum_{i=1}^N x_{\text{OHC}_i} - x_{\text{THCE}_{\text{init}}} \quad \text{Eq. 1065.665-1}$$

$$x_{\text{NOTHC}} = x_{\text{THC}} - \sum_{i=1}^N (x_{\text{OHC}_i} \cdot \text{RF}_{\text{OHC}_i} \cdot \text{C}^{\#}) \quad \text{Eq. 1065.665-2}$$

$$x_{\text{OHC}_i} = \frac{M_{\text{exhOHC}_i} \cdot m_{\text{dexhOHC}}}{M_{\text{OHC}_i} \cdot m_{\text{dexh}}} = \frac{n_{\text{dexhOHC}}}{n_{\text{dexh}}} \quad \text{Eq. 1065.665-3}$$

Where:

$x_{\text{OHC}_i}$  = The  $\text{C}_1$ -equivalent concentration of oxygenated species  $i$  in diluted exhaust.

$x_{\text{THC}}$  = The  $\text{C}_1$ -equivalent FID response to NOTHC and all OHC in diluted exhaust.  
 $\text{RF}_{\text{OHC}_i}$  = The response factor of the FID to species  $i$  relative to propane on a  $\text{C}_1$ -equivalent basis.

$\text{C}^{\#}$  = the mean number of carbon atoms in the particular compound.

(b) If we require you to determine NMHCE, use the following equation:

$$x_{\text{NMHCE}} = x_{\text{THCE}} - x_{\text{CH}_4} \cdot \text{RF}_{\text{CH}_4} \quad \text{Eq. 1065.665-4}$$

(c) The following example shows how to determine NMHCE emissions based on ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) and methanol ( $\text{CH}_3\text{OH}$ ) molar concentrations, and acetaldehyde ( $\text{C}_2\text{H}_4\text{O}$ ) and formaldehyde (HCHO) as mass concentrations:

$x_{\text{NMHC}} = 127.3 \mu\text{mol/mol}$   
 $x_{\text{C}_2\text{H}_5\text{OH}} = 100.8 \mu\text{mol/mol}$   
 $x_{\text{CH}_3\text{OH}} = 25.5 \mu\text{mol/mol}$   
 $M_{\text{exhC}_2\text{H}_4\text{O}} = 0.841 \text{ mg/mol}$

$M_{\text{exhHCHO}} = 39.0 \mu\text{g/mol}$   
 $M_{\text{C}_2\text{H}_4\text{O}} = 44.05256 \text{ g/mol}$   
 $M_{\text{HCHO}} = 30.02598 \text{ g/mol}$   
 $x_{\text{C}_2\text{H}_4\text{O}} = 0.841/44.05256 \cdot 1000$   
 $x_{\text{C}_2\text{H}_4\text{O}} = 19.1 \mu\text{mol/mol}$   
 $x_{\text{HCHO}} = 39/30.02598$   
 $x_{\text{HCHO}} = 1.3 \mu\text{mol/mol}$   
 $x_{\text{NMHCE}} = 127.3 + 2 \cdot 100.8 + 25.5 + 2 \cdot 19.1 + 1.3$   
 $x_{\text{NMHCE}} = 393.9 \mu\text{mol/mol}$

#### § 1065.667 Dilution air background emission correction.

(a) To determine the mass of background emissions to subtract from a diluted exhaust sample, first determine the total flow of dilution air,  $n_{\text{dil}}$ , over the test interval. This may be a measured quantity or a quantity calculated from the diluted exhaust flow and the flow-weighted mean fraction of

dilution air in diluted exhaust,  $\bar{x}_{dii}$ . Multiply the total flow of dilution air by the mean concentration of a background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). The product of  $n_{dii}$  and the mean concentration of a background emission is the total amount of a background emission. If this is a molar quantity, convert it to a mass by multiplying it by its molar mass,  $M$ . The result is the mass of the background emission,  $m$ . In the case of PM, where the mean PM concentration is already in units of mass per mole of sample,  $\bar{M}_{PM}$ , multiply it by the total amount of dilution air, and the result is the total background mass of PM,  $m_{PM}$ . Subtract total background masses from total mass to correct for background emissions.

(b) You may determine the total flow of dilution air by a direct flow measurement. In this case, calculate the total mass of background as described in § 1065.650(b), using the dilution air flow,  $n_{dii}$ . Subtract the background mass

from the total mass. Use the result in brake-specific emission calculations.

(c) You may determine the total flow of dilution air from the total flow of diluted exhaust and a chemical balance of the fuel, intake air, and exhaust as described in § 1065.655. In this case, calculate the total mass of background as described in § 1065.650(b), using the total flow of diluted exhaust,  $n_{dexh}$ , then multiply this result by the flow-weighted mean fraction of dilution air in diluted exhaust,  $\bar{x}_{dii}$ . Calculate  $\bar{x}_{dii}$  using flow-weighted mean concentrations of emissions in the chemical balance, as described in § 1065.655. You may assume that your engine operates stoichiometrically, even if it is a lean-burn engine, such as a compression-ignition engine. Note that for lean-burn engines this assumption could result in an error in emission calculations. This error could occur because the chemical balances in § 1065.655 correct excess air passing through a lean-burn engine as if it was dilution air. If an emission

concentration expected at the standard is about 100 times its dilution air background concentration, this error is negligible. However, if an emission concentration expected at the standard is similar to its background concentration, this error could be significant. If this error might affect your ability to show that your engines comply with applicable standards, we recommend that you remove background emissions from dilution air by HEPA filtration, chemical adsorption, or catalytic scrubbing. You might also consider using a partial-flow dilution technique such as a bag mini-diluter, which uses purified air as the dilution air.

(d) The following is an example of using the flow-weighted mean fraction of dilution air in diluted exhaust,  $\bar{x}_{dii}$ , and the total mass of background emissions calculated using the total flow of diluted exhaust,  $n_{dexh}$ , as described in § 1065.650(b) :

$$m_{bkngnd} = \bar{x}_{dii} \cdot m_{bkngnddexh} \quad \text{Eq. 1065.667-1}$$

$$m_{bkngnddexh} = M \cdot \bar{x}_{bkngnd} \cdot n_{dexh} \quad \text{Eq. 1065.667-2}$$

#### Example:

$$M_{NOx} = 46.0055 \text{ g/mol}$$

$$\bar{x}_{bkngnd} = 0.05 \text{ } \mu\text{mol/mol} = 0.05 \cdot 10^{-6} \text{ mol/mol}$$

$$n_{dexh} = 23280.5 \text{ mol}$$

$$\bar{x}_{dii} = 0.843$$

$$m_{bkngndNOxdexh} = 46.0055 \cdot 0.05 \cdot 10^{-6} \cdot 23280.5$$

$$m_{bkngndNOxdexh} = 0.0536 \text{ g}$$

$$m_{bkngndNOx} = 0.843 \cdot 0.0536$$

$$m_{bkngndNOx} = 0.0452 \text{ g}$$

#### § 1065.670 NO<sub>x</sub> intake-air humidity and temperature corrections.

See the standard-setting part to determine if you may correct NO<sub>x</sub> emissions for the effects of intake-air humidity or temperature. Use the NO<sub>x</sub> intake-air humidity and temperature corrections specified in the standard-setting part instead of the NO<sub>x</sub> intake-air humidity correction specified in this part 1065. If the standard-setting part

allows correcting NO<sub>x</sub> emissions for intake-air humidity according to this part 1065, first apply any NO<sub>x</sub> corrections for background emissions and water removal from the exhaust sample, then correct NO<sub>x</sub> concentrations for intake-air humidity using one of the following approaches:

(a) Correct for intake-air humidity using the following equation:

$$x_{NOxcor} = x_{NOxuncor} \cdot (9.953 \cdot x_{H2O} + 0.832) \quad \text{Eq. 1065.670-1}$$

#### Example:

$$x_{NOxuncor} = 700.5 \text{ } \mu\text{mol/mol}$$

$$x_{H2O} = 0.022 \text{ mol/mol}$$

$$x_{NOxcor} = 700.5 \cdot (9.953 \cdot 0.022 + 0.832)$$

$$x_{NOxcor} = 736.2 \text{ } \mu\text{mol/mol}$$

(b) Develop your own correction, based on good engineering judgment.

#### § 1065.672 Drift correction.

(a) *Scope and frequency.* Perform the calculations in this section to determine if gas analyzer drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, correct that test interval's gas analyzer responses for drift according to this

section. Use the drift-corrected gas analyzer responses in all subsequent emission calculations. Note that the acceptable threshold for gas analyzer drift over a test interval is specified in § 1065.550 for both laboratory testing and field testing.

(b) *Correction principles.* The calculations in this section utilize a gas analyzer's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analyzer's responses that were recorded during a test interval. The correction is based on

an analyzer's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validate and correct for drift as follows:

(c) *Drift validation.* After applying all the other corrections—except drift correction—to all the gas analyzer signals, calculate brake-specific emissions according to § 1065.650. Then correct all gas analyzer signals for drift according to this section. Recalculate brake-specific emissions using all of the drift-corrected gas analyzer signals. Validate and report the brake-specific

emission results before and after drift correction according to § 1065.550.  
 (d) *Drift correction.* Correct all gas analyzer signals as follows:

(1) Correct each recorded concentration,  $x_i$ , for continuous sampling or for batch sampling,  $\bar{x}$ .

(2) Correct for drift using the following equation:

$$x_{\text{idrift corrected}} = x_{\text{refzero}} + \frac{2 \cdot x_{\text{refspan}}}{x_{\text{prespan}} + x_{\text{postspan}}} \cdot \left( x_i - \frac{x_{\text{prezero}} + x_{\text{postzero}}}{2} \right) \quad \text{Eq. 1065.672-1}$$

Where:

$x_{\text{idrift corrected}}$  = concentration corrected for drift.  
 $x_{\text{refzero}}$  = reference concentration of the zero gas, which is usually zero unless known to be otherwise.  
 $x_{\text{refspan}}$  = reference concentration of the span gas.  
 $x_{\text{prespan}}$  = pre-test interval gas analyzer response to the span gas concentration.

$x_{\text{postspan}}$  = post-test interval gas analyzer response to the span gas concentration.  
 $x_i$  or  $\bar{x}$  = concentration recorded during test, before drift correction.  
 $x_{\text{prezero}}$  = pre-test interval gas analyzer response to the zero gas concentration.  
 $x_{\text{postzero}}$  = post-test interval gas analyzer response to the zero gas concentration.

Example:

$x_{\text{refzero}} = 0 \mu\text{mol/mol}$   
 $x_{\text{refspan}} = 1800.0 \mu\text{mol/mol}$   
 $x_{\text{prespan}} = 1800.5 \mu\text{mol/mol}$   
 $x_{\text{postspan}} = 1695.8 \mu\text{mol/mol}$   
 $x_i$  or  $\bar{x} = 435.5 \mu\text{mol/mol}$   
 $x_{\text{prezero}} = 0.6 \mu\text{mol/mol}$   
 $x_{\text{postzero}} = -5.2 \mu\text{mol/mol}$

$$x_{\text{idrift corrected}} = 0 + \frac{2 \cdot 1800.0}{1800.5 + 1695.8} \cdot \left( 435.5 - \frac{0.6 + (-5.2)}{2} \right)$$

$x_{\text{idrift corrected}} = 450.8 \mu\text{mol/mol}$

(3) For any pre-test interval concentrations, use concentrations determined most recently before the test interval. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals.

(4) For any post-test interval concentrations, use concentrations determined most recently after the test interval. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals.

(5) If you do not record any pre-test interval analyzer response to the span gas concentration,  $x_{\text{prespan}}$ , set  $x_{\text{prespan}}$  equal to the reference concentration of the span gas:

$$x_{\text{prespan}} = x_{\text{refspan}}$$

(6) If you do not record any pre-test interval analyzer response to the zero gas concentration,  $x_{\text{prezero}}$ , set  $x_{\text{prezero}}$  equal to the reference concentration of the zero gas:

$$x_{\text{prezero}} = x_{\text{refzero}}$$

(7) Usually the reference concentration of the zero gas,  $x_{\text{refzero}}$ , is zero:  $x_{\text{refzero}} = 0 \mu\text{mol/mol}$ . However, in some cases you might know that  $x_{\text{refzero}}$  has a non-zero concentration. For example, if you zero a CO<sub>2</sub> analyzer using ambient air, you may use the default ambient air concentration of CO<sub>2</sub>, which is 375  $\mu\text{mol/mol}$ . In this case,  $x_{\text{refzero}} = 375 \mu\text{mol/mol}$ . Note that when you zero an analyzer using a non-zero  $x_{\text{refzero}}$ , you must set the analyzer to output the actual  $x_{\text{refzero}}$  concentration. For example, if  $x_{\text{refzero}} = 375 \mu\text{mol/mol}$ ,

set the analyzer to output a value of 375  $\mu\text{mol/mol}$  when the zero gas is flowing to the analyzer.

**§ 1065.675 CLD quench verification calculations.**

Perform CLD quench-check calculations as follows:

(a) Calculate the amount of water in the span gas,  $x_{\text{H}_2\text{Ospan}}$ , assuming complete saturation at the span-gas temperature.

(b) Estimate the expected amount of water and CO<sub>2</sub> in the exhaust you sample,  $x_{\text{H}_2\text{Oexp}}$  and  $x_{\text{CO}_2\text{exp}}$ , respectively, by considering the maximum expected amounts of water in combustion air, fuel combustion products, and dilution air concentrations (if applicable).

(c) Calculate water quench as follows:

$$\text{quench} = \left( \frac{x_{\text{NOwet}} / (1 - x_{\text{H}_2\text{Omeas}})}{x_{\text{NOdry}}} - 1 \right) \cdot \frac{x_{\text{H}_2\text{Oexp}}}{x_{\text{H}_2\text{Omeas}}} + \frac{x_{\text{NO,CO}_2} - x_{\text{NO,N}_2}}{x_{\text{NO,N}_2}} \cdot \frac{x_{\text{CO}_2\text{exp}}}{x_{\text{CO}_2\text{meas}}} \quad \text{Eq. 1065.672-1}$$

Where:

quench = amount of CLD quench.

$x_{\text{NOdry}}$  = measured concentration of NO upstream of a bubbler, according to § 1065.370.

$x_{\text{NOwet}}$  = measured concentration of NO downstream of a bubbler, according to § 1065.370.

$x_{\text{H}_2\text{Oexp}}$  = expected maximum amount of water entering the CLD sample port during emission testing.

$x_{\text{H}_2\text{Omeas}}$  = measured amount of water entering the CLD sample port during the quench verification specified in § 1065.370.

$x_{\text{NO,CO}_2}$  = measured concentration of NO when NO span gas is blended with

CO<sub>2</sub> span gas, according to § 1065.370.  
 x<sub>NO,N2</sub> = measured concentration of NO when NO span gas is blended with N<sub>2</sub> span gas, according to § 1065.370.

x<sub>CO2exp</sub> = expected maximum amount of CO<sub>2</sub> entering the CLD sample port during emission testing.  
 x<sub>CO2meas</sub> = measured amount of CO<sub>2</sub> entering the CLD sample port during the quench verification specified in § 1065.370.

x<sub>NOdry</sub> = 1800.0 μmol/mol  
 x<sub>NOwet</sub> = 1760.5 μmol/mol  
 x<sub>H2Oexp</sub> = 0.030 mol/mol  
 x<sub>H2Omeas</sub> = 0.017 mol/mol  
 x<sub>NO,CO2</sub> = 1480.2 μmol/mol  
 x<sub>NO,N2</sub> = 1500.8 μmol/mol  
 x<sub>CO2exp</sub> = 2.00%  
 x<sub>CO2meas</sub> = 3.00%

Example:

$$\text{quench} = \left( \frac{1760.5 / (1 - 0.017)}{1800.0} - 1 \right) \cdot \frac{0.030}{0.017} + \frac{1480.2 - 1500.8}{1500.8} \cdot \frac{200}{300}$$

quench = -0.00888 - 0.00915 = -1.80%

**§ 1065.690 Buoyancy correction for PM sample media.**

(a) *General.* Correct PM sample media for their buoyancy in air if you weigh them on a balance. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0.01 to 0.10)% of the total weight. A correction to this small fraction of mass would be at the most 0.010%.

(b) *PM sample media density.* Different PM sample media have different densities. Use the known

density of your sample media, or use one of the densities for some common sampling media, as follows:

(1) For PTFE-coated borosilicate glass, use a sample media density of 2300 kg/m<sup>3</sup>.

(2) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95% of the media mass, use a sample media density of 920 kg/m<sup>3</sup>.

(3) For PTFE membrane (film) media with an integral support ring of PTFE, use a sample media density of 2144 kg/m<sup>3</sup>.

(c) *Air density.* Because a PM balance environment must be tightly controlled to an ambient temperature of (22 ± 1) °C and a dewpoint of (9.5 ± 1) °C, air density is primarily function of atmospheric pressure. We therefore

specify a buoyancy correction that is only a function of atmospheric pressure. Using good engineering judgment, you may develop and use your own buoyancy correction that includes the effects of temperature and dewpoint on density in addition to the effect of atmospheric pressure.

(d) *Calibration weight density.* Use the stated density of the material of your metal calibration weight. The example calculation in this section uses a density of 8000 kg/m<sup>3</sup>, but you should know the density of your weight from the calibration weight supplier or the balance manufacturer if it is an internal weight.

(e) *Correction calculation.* Correct the PM sample media for buoyancy using the following equations:

$$m_{\text{cor}} = m_{\text{uncor}} \cdot \left( \frac{1 - \frac{\rho_{\text{air}}}{\rho_{\text{weight}}}}{1 - \frac{\rho_{\text{air}}}{\rho_{\text{media}}}} \right) \quad \text{Eq. 1065.690-1}$$

Where:

m<sub>cor</sub> = PM mass corrected for buoyancy.

m<sub>uncor</sub> = PM mass uncorrected for buoyance.

ρ<sub>air</sub> = density of air in balance environment.

ρ<sub>weight</sub> = density of calibration weight used to span balance.

ρ<sub>media</sub> = density of PM sample media, such as a filter.

$$\rho_{\text{air}} = \frac{\rho_{\text{abs}} \cdot M_{\text{mix}}}{R \cdot T_{\text{amb}}} \quad \text{Eq. 1065.690-2}$$

Where:

ρ<sub>abs</sub> = absolute pressure in balance environment.

M<sub>mix</sub> = molar mass of air in balance environment.

R = molar gas constant.

T<sub>amb</sub> = absolute ambient temperature of balance environment.

Example:

ρ<sub>abs</sub> = 99.980 kPa

T<sub>sat</sub> = T<sub>dew</sub> = 9.5 °C  
 Using Eq. 1065.645 - 2,  
 p<sub>H2O</sub> = 1.1866 kPa  
 Using Eq. 1065.645 - 3,  
 x<sub>H2O</sub> = 0.011868 mol/mol  
 Using Eq. 1065.640 - 8,  
 M<sub>mix</sub> = 28.83563 g/mol  
 R = 8.314472 J/(mol·K)  
 T<sub>amb</sub> = 20 °C

$$\rho_{\text{air}} = \frac{99.980 \cdot 28.83563}{8.314472 \cdot 293.15}$$

ρ<sub>air</sub> = 1.18282 kg/m<sup>3</sup>

m<sub>uncor</sub> = 100.0000 mg

ρ<sub>weight</sub> = 8000 kg/m<sup>3</sup>

ρ<sub>media</sub> = 920 kg/m<sup>3</sup>

$$m_{\text{cor}} = 100.000 \cdot \left[ \frac{1 - \frac{1.18282}{8000}}{1 - \frac{1.18282}{920}} \right]$$

m<sub>cor</sub> = 100.1139 mg

**§ 1065.695 Data requirements.**

(a) To determine the information we require from engine tests, refer to the standard-setting part and request from your Designated Compliance Officer the format used to apply for certification or demonstrate compliance. We may require different information for different purposes, such as for certification applications, approval requests for alternate procedures, selective enforcement audits, laboratory audits, production-line test reports, and field-test reports.

(b) See the standard-setting part and § 1065.25 regarding recordkeeping.

(c) We may ask you the following about your testing, and we may ask you for other information as allowed under the Act:

(1) What approved alternate procedures did you use? For example:

(i) Partial-flow dilution for proportional PM.

(ii) CARB test procedures.

(iii) ISO test procedures.

(2) What laboratory equipment did you use? For example, the make, model, and description of the following:

(i) Engine dynamometer and operator demand.

(ii) Probes, dilution, transfer lines, and sample preconditioning components.

(iii) Batch storage media (such as the bag material or PM filter material).

(3) What measurement instruments did you use? For example, the make, model, and description of the following:

(i) Speed and torque instruments.

(ii) Flow meters.

(iii) Gas analyzers.

(iv) PM balance.

(4) When did you conduct calibrations and performance checks and what were the results? For example, the dates and results of the following:

(i) Linearity checks.

(ii) Interference checks.

(iii) Response checks.

(iv) Leak checks.

(v) Flow meter checks.

(5) What engine did you test? For example, the following:

(i) Manufacturer.

(ii) Family name on engine label.

(iii) Model.

(iv) Model year.

(v) Identification number.

(6) How did you prepare and configure your engine for testing?

Consider the following examples:

(i) Dates, hours, duty cycle and fuel used for service accumulation.

(ii) Dates and description of scheduled and unscheduled maintenance.

(iii) Allowable pressure range of intake restriction.

(iv) Allowable pressure range of exhaust restriction.

(v) Charge air cooler volume.

(vi) Charge air cooler outlet temperature, specified engine conditions and location of temperature measurement.

(vii) Fuel temperature and location of measurement.

(viii) Any aftertreatment system configuration and description.

(ix) Any crankcase ventilation configuration and description (e.g., open, closed, PCV, crankcase scavenged).

(7) How did you test your engine? For example:

(i) Constant speed or variable speed.

(ii) Mapping procedure (step or sweep).

(iii) Continuous or batch sampling for each emission.

(iv) Raw or dilute sampling; any dilution-air background sampling.

(v) Duty cycle and test intervals.

(vi) Cold-start, hot-start, warmed-up running.

(vii) Absolute pressure, temperature, and dewpoint of intake and dilution air.

(viii) Simulated engine loads, curb idle transmission torque value.

(ix) Warm-idle speed value and any enhanced-idle speed value.

(x) Simulated vehicle signals applied during testing.

(xi) Bypassed governor controls during testing.

(xii) Date, time, and location of test (e.g., dynamometer laboratory identification).

(xiii) Cooling medium for engine and charge air.

(xiv) Operating temperatures of coolant, head, and block.

(xv) Natural or forced cool-down and cool-down time.

(xvi) Canister loading.

(8) How did you validate your testing? For example, results from the following:

(i) Duty cycle regression statistics for each test interval.

(ii) Proportional sampling.

(iii) Drift.

(iv) Reference PM sample media in PM-stabilization environment.

(9) How did you calculate results? For example, results from the following:

(i) Drift correction.

(ii) Noise correction.

(iii) "Dry-to-wet" correction.

(iv) NMHC, CH<sub>4</sub>, and contamination correction.

(v) NO<sub>x</sub> humidity correction.

(vi) Brake-specific emission formulation—total mass divided by total work, mass rate divided by power, or ratio of mass to work.

(vii) Rounding emission results.

(10) What were the results of your testing? For example:

(i) Maximum mapped power and speed at maximum power.

(ii) Maximum mapped torque and speed at maximum torque.

(iii) For constant-speed engines: no-load governed speed.

(iv) For constant-speed engines: test torque.

(v) For variable-speed engines: maximum test speed.

(vi) Speed versus torque map.

(vii) Speed versus power map.

(viii) Brake-specific emissions over the duty cycle and each test interval.

(ix) Brake-specific fuel consumption.

(11) What fuel did you use? For example:

(i) Fuel that met specifications of subpart H of this part.

(ii) Alternate fuel.

(iii) Oxygenated fuel.

(12) How did you field test your engine? For example:

(i) Data from paragraphs (c)(1), (3), (4), (5), and (9) of this section.

(ii) Probes, dilution, transfer lines, and sample preconditioning components.

(iii) Batch storage media (such as the bag material or PM filter material).

(iv) Continuous or batch sampling for each emission.

(v) Raw or dilute sampling; any dilution air background sampling.

(vi) Cold-start, hot-start, warmed-up running.

(vii) Intake and dilution air absolute pressure, temperature, dewpoint.

(viii) Curb idle transmission torque value.

(ix) Warm idle speed value, any enhanced idle speed value.

(x) Date, time, and location of test (e.g., identify the testing laboratory).

(xi) Proportional sampling validation.

(xii) Drift validation.

(xiii) Operating temperatures of coolant, head, and block.

(xiv) Vehicle make, model, model year, identification number.

#### **Subpart H—Engine Fluids, Test Fuels, Analytical Gases and Other Calibration Standards**

##### **§ 1065.701 General requirements for test fuels.**

(a) *General.* For all emission measurements, use test fuels that meet the specifications in this subpart, unless the standard-setting part directs otherwise. Section 1065.10(c)(1) does not apply with respect to test fuels. Note that the standard-setting parts generally require that you design your emission controls to function properly when using commercially available fuels, even if they differ from the test fuel.

(b) *Fuels meeting alternate specifications.* We may allow you to use a different test fuel (such as California Phase 2 gasoline) if you show us that using it does not affect your ability to comply with all applicable emission standards using commercially available fuels.

(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. You must show us all the following things before we can specify a different test fuel for your engines:

(1) Show that this type of fuel is commercially available.

(2) Show that your engines will use only the designated fuel in service.

(3) Show that operating the engines on the fuel we specify would unrepresentatively increase emissions or decrease durability.

(d) *Fuel specifications.* The fuel parameters specified in this subpart depend on measurement procedures that are incorporated by reference. For

any of these procedures, you may instead rely upon the procedures identified in 40 CFR part 80 for measuring the same parameter. For example, we may identify different reference procedures for measuring gasoline parameters in 40 CFR 80.46.

(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 ASTM specifications from the following table:

TABLE 1 OF § 1065.701.—SPECIFICATIONS FOR SERVICE-ACCUMULATION AND FIELD-TESTING FUELS

Fuel type	Subcategory	ASTM specification <sup>1</sup>
Diesel	Light distillate and light blends with residual	D975–04c
	Middle distillate	D6751–03a
Gasoline	Biodiesel (B100)	D6985–04a
	Motor vehicle and minor oxygenate blends	D4814–04b
	Ethanol (Ed75–85)	D5798–99
	Methanol (M70–M85)	D5797–96
Aviation fuel	Aviation gasoline	D910–04a
	Gas turbine	D1655–04a
Gas turbine fuel	Jet B wide cut	D6615–04a
	General	D2880–03

<sup>1</sup> All ASTM specifications are incorporated by reference in § 1065.1010.

**§ 1065.703 Distillate diesel fuel.**

(a) Distillate diesel fuels for testing must be clean and bright, with pour and cloud points adequate for proper engine operation.

(b) There are three grades of #2 diesel fuel specified for use as a test fuel. See the standard-setting part to determine which grade to use. If the standard-

setting part does not specify which grade to use, use good engineering judgment to select the grade that represents the fuel on which the engines will operate in use. The three grades are specified in Table 1 of this section.

(c) You may use the following nonmetallic additives with distillate diesel fuels:

- (1) Cetane improver.
- (2) Metal deactivator.
- (3) Antioxidant, dehazer.
- (4) Rust inhibitor.
- (5) Pour depressant.
- (6) Dye.
- (7) Dispersant.
- (8) Biocide.

TABLE 1 OF § 1065.703—TEST FUEL SPECIFICATIONS FOR DISTILLATE DIESEL FUEL

Item	Units	Ultra low sulfur	Low sulfur	High sulfur	Reference procedure <sup>1</sup>
Cetane Number		40–50	40–50	40–50	ASTM D 613–03b
Distillation range:					
Initial boiling point	°C	171–204	171–204	171–204	ASTM D 86–04b
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 D 287–92
Total sulfur	mg/kg	7–15	300–500	2000–4000	ASTM D 2622–03
Aromatics, minimum. (Remainder shall be paraffins, naphthalenes, and olefins).	g/kg	100	100	100	ASTM D 5186–03
Flashpoint, min	°C	54	54	54	ASTM D 93–02a
Viscosity	cSt	2.0–3.2	2.0–3.2	2.0–3.2	ASTM D 445–04

<sup>1</sup> All ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.

**§ 1065.705 Residual fuel [Reserved]**

**§ 1065.710 Gasoline.**

(a) Gasoline for testing must have octane values that represent

commercially available fuels for the appropriate application.

(b) There are two grades of gasoline specified for use as a test fuel. If the standard-setting part requires testing with fuel appropriate for low

temperatures, use the test fuel specified for low-temperature testing. Otherwise, use the test fuel specified for general testing. The two grades are specified in Table 1 of this section.



TABLE 1 OF § 1065.710.—TEST FUEL SPECIFICATIONS FOR GASOLINE

Item	Units	General testing	Low-temperature testing	Reference procedure <sup>1</sup>
Distillation Range:				
Initial boiling point .....	°C .....	24–35 <sup>2</sup> .....	24–36 .....	ASTM D 86–04b
10% point .....	.....do .....	49–57 .....	37–48.	
50% point .....	.....do .....	93–110 .....	82–101.	
90% point .....	.....do .....	149–163 .....	158–174.	
End point .....	.....do .....	Maximum, 213 .....	Maximum, 212.	
Hydrocarbon composition:				
1. Olefins .....	mm <sup>3</sup> /m <sup>3</sup> .....	Maximum, 100,000 .....	Maximum, 175,000 .....	ASTM D 1319–03
2. Aromatics .....	.....do .....	Maximum, 350,000 .....	Maximum, 304,000.	
3. Saturates .....	.....do .....	Remainder .....	Remainder.	
Lead (organic) .....	g/liter .....	Maximum, 0.013 .....	Maximum, 0.013 .....	ASTM D 3237–02
Phosphorous .....	g/liter .....	Maximum, 0.0013 .....	Maximum, 0.005 .....	ASTM D 3231–02
Total sulfur .....	mg/kg .....	Maximum, 80 .....	Maximum, 80 .....	ASTM D 1266–98
Volatility (Reid Vapor Pressure) .....	kPa .....	60.0–63.4 <sup>2,3</sup> .....	77.2–81.4 .....	ASTM D 323–99a

<sup>1</sup> All ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.

<sup>2</sup> For testing at altitudes above 1 219 m, the specified volatility range is (52 to 55) kPa and the specified initial boiling point range is (23.9 to 40.6) °C.

<sup>3</sup> For testing unrelated to evaporative emissions, the specified range is (55 to 63) kPa.

§ 1065.715 Natural gas.

(a) 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 <sup>1</sup>
1. Methane, CH <sub>4</sub> .....	Minimum, 0.87 mol/mol.
2. Ethane, C <sub>2</sub> H <sub>6</sub> .....	Maximum, 0.055 mol/mol.
3. Propane, C <sub>3</sub> H <sub>8</sub> .....	Maximum, 0.012 mol/mol.
4. Butane, C <sub>4</sub> H <sub>10</sub> .....	Maximum, 0.0035 mol/mol.
5. Pentane, C <sub>5</sub> H <sub>12</sub> .....	Maximum, 0.0013 mol/mol.
6. C <sub>6</sub> and higher .....	Maximum, 0.001 mol/mol.
7. Oxygen .....	Maximum, 0.001 mol/mol.
8. Inert gases (sum of CO <sub>2</sub> and N <sub>2</sub> ) .....	Maximum, 0.051 mol/mol.

<sup>1</sup> All parameters are based on the reference procedures in ASTM D 1945–03 (incorporated by reference in § 1065.1010). See § 1065.701(d) for other allowed procedures.

(b) 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.

§ 1065.720 Liquefied petroleum gas.

(a) 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 <sup>1</sup>
1. Propane, C <sub>3</sub> H <sub>8</sub> .....	Minimum, 0.85 m <sup>3</sup> /m <sup>3</sup> .....	ASTM D 2163–91
2. Vapor pressure at 38 °C .....	Maximum, 1400 kPa .....	ASTM D 1267–02 or 2598–02 <sup>2</sup>
3. Volatility residue evaporated temperature, 35 °C) ...	Maximum, –38 °C .....	ASTM D 1837–02a
4. Butanes .....	Maximum, 0.05 m <sup>3</sup> /m <sup>3</sup> .....	ASTM D 2163–91
5. Butenes .....	Maximum, 0.02 m <sup>3</sup> /m <sup>3</sup> .....	ASTM D 2163–91
6. Pentenes and heavier .....	Maximum, 0.005 m <sup>3</sup> /m <sup>3</sup> .....	ASTM D 2163–91
7. Propene .....	Maximum, 0.1 m <sup>3</sup> /m <sup>3</sup> .....	ASTM D 2163–91
8. Residual matter(residue on evap. of 100 ml oil stain observ.) .....	Maximum, 0.05 ml pass <sup>3</sup> .....	ASTM D 2158–04
9. Corrosion, copper strip .....	Maximum, No. 1 .....	ASTM D 1838–03
10. Sulfur .....	Maximum, 80 mg/kg .....	ASTM D 2784–98
11. Moisture content .....	pass .....	ASTM D 2713–91

<sup>1</sup> All ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.

<sup>2</sup> If these two test methods yield different results, use the results from ASTM D 1267–02.

<sup>3</sup> 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) 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.

#### § 1065.740 Lubricants.

(a) Use commercially available lubricating oil that represents the oil that will be used in your engine in use.

(b) You may use lubrication additives, up to the levels that the additive manufacturer recommends.

#### § 1065.745 Coolants.

(a) You may use commercially available antifreeze mixtures or other coolants that will be used in your engine in use.

(b) For laboratory testing of liquid-cooled engines, you may use water with or without rust inhibitors.

(c) For coolants allowed in paragraphs (a) and (b) of this section, you may use rust inhibitors and additives required for lubricity, up to the levels that the additive manufacturer recommends.

#### § 1065.750 Analytical gases.

Analytical gases must meet the accuracy and purity specifications of this section, unless you can show that other specifications would not affect your ability to show that your engines comply with all applicable emission standards.

(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 mmol/mol, then you would be allowed to use a zero gas with CO contamination less than or equal to 2.000 mmol/mol.

(ii) Contamination as specified in the following table:

TABLE 1 OF § 1065.750.—GENERAL SPECIFICATIONS FOR PURIFIED GASES

Constituent	Purified air <sup>1</sup>	Purified N <sub>2</sub> <sup>1</sup>
THC (C <sub>1</sub> equivalent) .....	<0.05 μmol/mol .....	< 0.05 μmol/mol
CO .....	<1 μmol/mol .....	< 1 μmol/mol
CO <sub>2</sub> .....	< 10 μmol/mol .....	< 10 μmol/mol
O <sub>2</sub> .....	0.205 to 0.215 mol/mol .....	< 2 μmol/mol
NO <sub>x</sub> .....	< 0.02 μmol/mol .....	< 0.02 μmol/mol

<sup>1</sup> 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 an H<sub>2</sub> concentration of (0.400 ± 0.004) mol/mol, balance He. Make sure the mixture contains no more than 0.05 μmol/mol THC.

(ii) *FID burner air*. Use FID burner air that meets the specifications of purified air in paragraph (a)(1) of this section. For field testing, you may use ambient air.

(iii) *FID zero gas*. Zero flame-ionization detectors with purified gas that meets the specifications in paragraph (a)(1) of this section, except that the purified gas O<sub>2</sub> concentration may be any value. Note that FID zero balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer zero gases that contain approximately the flow-weighted mean concentration of O<sub>2</sub> expected during testing.

(iv) *FID propane span gas*. Span and calibrate THC FID with span concentrations of propane, C<sub>3</sub>H<sub>8</sub>. Calibrate on a carbon number basis of one (C<sub>1</sub>). For example, if you use a C<sub>3</sub>H<sub>8</sub> span gas of concentration 200 μmol/mol, span a FID to respond with a value of 600 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the flow-weighted mean concentration of O<sub>2</sub> expected during testing.

(v) *FID methane span gas*. If you always span and calibrate a CH<sub>4</sub> FID with a nonmethane cutter, then span and calibrate the FID with span concentrations of methane, CH<sub>4</sub>. Calibrate on a carbon number basis of one (C<sub>1</sub>). For example, if you use a CH<sub>4</sub> span gas of concentration 200 μmol/mol, span a FID to respond with a value of 200 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the flow-weighted mean concentration of O<sub>2</sub> expected during testing.

(3) Use the following gas mixtures, with gases traceable within ± 1.0% of the NIST true value or other gas standards we approve:

(i) CH<sub>4</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable).

(ii) C<sub>2</sub>H<sub>6</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable).

(iii) C<sub>3</sub>H<sub>8</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable).

(iv) CO, balance purified N<sub>2</sub>.

(v) CO<sub>2</sub>, balance purified N<sub>2</sub>.

(vi) NO, balance purified N<sub>2</sub>.

(vii) NO<sub>2</sub>, balance purified N<sub>2</sub>.

(viii) O<sub>2</sub>, balance purified N<sub>2</sub>.

(ix) C<sub>3</sub>H<sub>8</sub>, CO, CO<sub>2</sub>, NO, balance purified N<sub>2</sub>.

(x) C<sub>3</sub>H<sub>8</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>, NO, balance purified N<sub>2</sub>.

(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 ±1.0% of the NIST true value or other similar standards we approve, and meet the stability requirements of paragraph (b) of this section.

(5) You may generate your own calibration gases using a precision blending device, such as a gas divider, to dilute gases with purified N<sub>2</sub> or purified synthetic air. If your gas dividers meet the specifications in § 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).

(b) Record the concentration of any calibration gas standard and its expiration date specified by the gas supplier.

(1) Do not use any calibration gas standard after its expiration date, except as allowed by paragraph (b)(2) of this section.

(2) Calibration gases may be relabeled and used after their expiration date as follows:

(i) Alcohol/carbonyl calibration gases used to determine response factors according to subpart I of this part may be relabeled as specified in subpart I of this part.

(ii) Other gases may be relabeled and used after the expiration date only if we approve it in advance.

(c) Transfer gases from their source to analyzers using components that are dedicated to controlling and transferring only those gases. For example, do not use a regulator, valve, or transfer line for zero gas if those components were previously used to transfer a different gas mixture. We recommend that you label regulators, valves, and transfer lines to prevent contamination. Note that even small traces of a gas mixture in the dead volume of a regulator, valve, or transfer line can diffuse upstream into a high-pressure volume of gas, which would contaminate the entire high-pressure gas source, such as a compressed-gas cylinder.

(d) To maintain stability and purity of gas standards, use good engineering judgment and follow the gas standard supplier's recommendations for storing and handling zero, span, and calibration gases. For example, it may be necessary to store bottles of condensable gases in a heated environment.

#### § 1065.790 Mass standards.

(a) *PM balance calibration weights.* Use PM balance calibration weights that are certified as NIST-traceable within 0.1 % uncertainty. Calibration weights may be certified by any calibration lab that maintains NIST-traceability. Make sure your lowest calibration weight has no greater than ten times the mass of an unused PM-sample medium.

(b) *Dynamometer calibration weights.* [Reserved]

### Subpart I—Testing With Oxygenated Fuels

#### § 1065.801 Applicability.

(a) This subpart applies for testing with oxygenated fuels. Unless the standard-setting part specifies otherwise, the requirements of this subpart do not apply for fuels that contain less than 25 % oxygenated compounds by volume. For example, you generally do not need to follow the requirements of this subpart for tests performed using a fuel containing 10 % ethanol and 90 % gasoline, but you must follow these requirements for tests performed using a fuel containing 85 % ethanol and 15 % gasoline.

(b) Section 1065.805 applies for all other testing that requires measurement of any alcohols or carbonyls.

(c) This subpart specifies sampling procedures and calculations that are different than those used for non-oxygenated fuels. All other test procedures of this part 1065 apply for testing with oxygenated fuels.

#### § 1065.805 Sampling system.

(a) Proportionally dilute engine exhaust, and use batch sampling collect

flow-weighted dilute samples of the applicable alcohols and carbonyls at a constant flow rate. 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 less than 121 °C but high enough to prevent aqueous condensation up to the point where a sample is collected. The maximum temperature limit is intended to prevent chemical reaction of the alcohols and carbonyls. The lower temperature limit is intended to prevent loss of the alcohols and carbonyls by dissolution in condensed water. Use good engineering judgment to minimize the amount of time that the undiluted exhaust is outside this temperature range to the extent practical. We recommend that you minimize the length of exhaust tubing before dilution. Extended lengths of exhaust tubing may require preheating, insulation, and cooling fans to limit excursions outside this temperature range.

(d) You may bubble a sample of the exhaust through water to collect alcohols for later analysis. You may also use a photo-acoustic analyzer to quantify ethanol and methanol in an exhaust sample.

(e) Sample the exhaust through cartridges impregnated with 2,4-dinitrophenylhydrazine to collect carbonyls for later analysis. If the standard-setting part specifies a duty cycle that has multiple test intervals (such as multiple engine starts or an engine-off soak phase), you may proportionally collect a single carbonyl sample for the entire duty cycle. For example, if the standard-setting part specifies a six-to-one weighting of hot-start to cold-start emissions, you may collect a single carbonyl sample for the entire duty cycle by using a hot-start sample flow rate that is six times the cold-start sample flow rate.

(f) You may sample alcohols or carbonyls using "California Non-Methane Organic Gas Test Procedures" (incorporated by reference in § 1065.1010). If you use this method, follow its calculations to determine the mass of the alcohol/carbonyl in the exhaust sample, but follow subpart G of this part for all other calculations.

(g) Use good engineering judgment to sample other oxygenated hydrocarbon compounds in the exhaust.

#### § 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. Formaldehyde response is assumed to be zero and does not need to be determined. Use the most recent alcohol/carbonyl response factors to compensate for alcohol/carbonyl response.

(a) Determine the alcohol/carbonyl response factors as follows:

(1) Select a  $C_3H_8$  span gas that meets the specifications of § 1065.750. 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. Record the  $C_3H_8$  concentration of the gas.

(2) Select or prepare an alcohol/carbonyl calibration gas that meets the specifications of § 1065.750 and has a concentration typical of the peak concentration expected at the hydrocarbon standard. Record the calibration concentration of the gas.

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

(4) Confirm that the FID analyzer has been calibrated using  $C_3H_8$ . Calibrate on a carbon number basis of one ( $C_1$ ). For example, if you use a  $C_3H_8$  span gas of concentration 200  $\mu\text{mol/mol}$ , span the FID to respond with a value of 600  $\mu\text{mol/mol}$ .

(5) Zero the FID. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of  $O_2$  expected during testing.

(6) Span the FID with the  $C_3H_8$  span gas that you selected under paragraph (a)(1) of this section.

(7) Introduce at the inlet of the FID analyzer the alcohol/carbonyl calibration gas that you selected under paragraph (a)(2) of this section.

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

(9) While the analyzer measures the alcohol/carbonyl concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.

(10) Divide the mean measured concentration by the recorded span concentration of the alcohol/carbonyl calibration gas. The result is the FID analyzer's response factor for alcohol/carbonyl,  $RF_{MeOH}$ .

(b) Alcohol/carbonyl calibration gases must remain within  $\pm 2\%$  of the labeled concentration. You must demonstrate the stability based on a quarterly measurement procedure with a precision of  $\pm 2\%$  percent or another method that we approve. Your measurement procedure may incorporate multiple measurements. If the true concentration of the gas changes deviates by more than  $\pm 2\%$ , but less than  $\pm 10\%$ , the gas may be relabeled with the new concentration.

#### § 1065.850 Calculations.

Use the calculations specified in § 1065.665 to determine THCE or NMHCE.

### Subpart J—Field Testing and Portable Emission Measurement Systems

#### § 1065.901 Applicability.

(a) *Field testing.* This subpart specifies procedures for field-testing engines to determine brake-specific emissions using portable emission measurement systems (PEMS). These procedures are designed primarily for in-field measurements of engines that remain installed in vehicles or equipment in the field. Field-test procedures apply to your engines only as specified in the standard-setting part.

(b) *Laboratory testing.* You may optionally use PEMS for any laboratory testing, as long as the standard-setting part does not prohibit it for certain types of laboratory testing, subject to the following provisions:

(1) Follow the laboratory test procedures specified in this part 1065, according to § 1065.905(e).

(2) Do not apply any PEMS-related field-testing adjustments or “measurement allowances” to laboratory emission results or standards.

(3) Do not use PEMS for laboratory measurements if it prevents you from demonstrating compliance with the applicable standards. Some of the PEMS requirements in this part 1065 are less stringent than the corresponding laboratory requirements. Depending on actual PEMS performance, you might therefore need to account for some additional measurement uncertainty when using PEMS for laboratory testing. If we ask, you must show us by engineering analysis that any additional measurement uncertainty due to your use of PEMS for laboratory testing is offset by the extent to which your engine’s emissions are below the applicable standards. For example, you might show that PEMS versus laboratory uncertainty represents 5% of the standard, but your engine’s deteriorated

emissions are at least 20% below the standard for each pollutant.

#### § 1065.905 General provisions.

(a) *General.* Unless the standard-setting part specifies deviations from the provisions of this subpart, field testing and laboratory testing with PEMS must conform to the provisions of this subpart.

(b) *Field-testing scope.* Field testing conducted under this subpart may include any normal in-use operation of an engine.

(c) *Field testing and the standard-setting part.* This subpart J specifies procedures for field-testing various categories of engines. See the standard-setting part for specific provisions for a particular type of engine. Before using this subpart’s procedures for field testing, read the standard-setting part to answer at least the following questions:

(1) How many engines must I test in the field?

(2) How many times must I repeat a field test on an individual engine?

(3) How do I select vehicles for field testing?

(4) What maintenance steps may I take before or between tests?

(5) What data are needed for a single field test on an individual engine?

(6) What are the limits on ambient conditions for field testing? Note that the ambient condition limits in § 1065.520 do not apply for field testing.

(7) Which exhaust constituents do I need to measure?

(8) How do I account for crankcase emissions?

(9) Which engine and ambient parameters do I need to measure?

(10) How do I process the data recorded during field testing to determine if my engine meets field-testing standards? How do I determine individual test intervals? Note that “test interval” is defined in subpart K of this part 1065.

(11) Should I warm up the test engine before measuring emissions, or do I need to measure cold-start emissions during a warm-up segment of in-use operation?

(12) Do any unique specifications apply for test fuels?

(13) Do any special conditions invalidate parts of a field test or all of a field test?

(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?

(15) Do results of initial field testing trigger any requirement for additional field testing or laboratory testing?

(16) How do I report field-testing results?

(d) *Field testing and this part 1065.* Use the following specifications for field testing:

(1) Use the applicability and general provisions of subpart A of this part.

(2) Use equipment specifications in § 1065.101 and in the sections from § 1065.140 to the end of subpart B of this part. Section 1065.910 specifies additional equipment specific to field testing.

(3) Use measurement instruments in subpart C of this part, except as specified in § 1065.915.

(4) Use calibrations and verifications in subpart D of this part, except as specified in § 1065.920. Section 1065.920 also specifies additional calibrations and verifications for field testing.

(5) Use the provisions of the standard-setting part for selecting and maintaining engines in the field instead of the specifications in subpart E of this part.

(6) Use the procedures in §§ 1065.930 and 1065.935 to start and run a field test. If you use a gravimetric balance for PM, weigh PM samples according to §§ 1065.590 and 1065.595.

(7) Use the calculations in subpart G of this part to calculate emissions over each test interval. Note that “test interval” is defined in subpart K of this part 1065, and that the standard setting part indicates how to determine test intervals for your engine.

Section 1065.940 specifies additional calculations for field testing. Use any calculations specified in the standard-setting part to determine if your engines meet the field-testing standards. The standard-setting part may also contain additional calculations that determine when further field testing is required.

(8) Use a typical in-use fuel meeting the specifications of § 1065.701(d).

(9) Use the lubricant and coolant specifications in § 1065.740 and § 1065.745.

(10) Use the analytical gases and other calibration standards in § 1065.750 and § 1065.790.

(11) If you are testing with oxygenated fuels, use the procedures specified for testing with oxygenated fuels in subpart I of this part.

(12) Apply the definitions and reference materials in subpart K of this part.

(e) *Laboratory testing using PEMS.* Use the following specifications when using PEMS for laboratory testing:

(1) Use the applicability and general provisions of subpart A of this part.

(2) Use equipment specifications in subpart B of this part. Section 1065.910

specifies additional equipment specific to testing with PEMS.

(3) Use measurement instruments in subpart C of this part, except as specified in § 1065.915.

(4) Use calibrations and verifications in subpart D of this part, except as specified in § 1065.920. Section 1065.920 also specifies additional calibration and verifications for PEMS.

(5) Use the provisions of § 1065.401 for selecting engines for testing. Use the provisions of subpart E of this part for maintaining engines, except as specified in the standard-setting part.

(6) Use the procedures in subpart F of this part and in the standard-setting part to start and run a laboratory test.

(7) Use the calculations in subpart G of this part to calculate emissions over the applicable duty cycle. Section 1065.940 specifies additional calculations for testing with PEMS.

(8) Use a fuel meeting the specifications of subpart H of this part, as specified in the standard-setting part.

(9) Use the lubricant and coolant specifications in § 1065.740 and § 1065.745.

(10) Use the analytical gases and other calibration standards in § 1065.750 and § 1065.790.

(11) If you are testing with oxygenated fuels, use the procedures specified for testing with oxygenated fuels in subpart I of this part.

(12) Apply the definitions and reference materials in subpart K of this part.

(f) *Summary.* The following table summarizes the requirements of paragraphs (d) and (e) of this section:

TABLE 1 OF § 1065.905.—SUMMARY OF TESTING REQUIREMENTS THAT ARE SPECIFIED OUTSIDE OF THIS SUBPART J<sup>1</sup>

Subpart	Applicability for field testing	Applicability for laboratory testing with PEMS
A: Applicability and general provisions .....	Use all .....	Use all.
B: Equipment for testing .....	Use § 1065.101 and § 1065.140 through the end of subpart B. § 1065.910 specifies equipment specific to field testing.	Use all. § 1065.910 specifies equipment specific to laboratory testing with PEMS.
C: Measurement instruments .....	Use all .....	Use all.
D: Calibrations and verifications .....	§ 1065.915 allows deviations .....	§ 1065.915 allows deviations.
E: Test engine selection, maintenance, and durability.	Use all .....	Use all.
F: Running an emission test in the laboratory ...	§ 1065.920 allows deviations, but also has additional specifications.	§ 1065.920 allows deviations, but also has additional specifications.
G: Calculations and data requirements .....	Do not use .....	Use all.
H: Fuels, engine fluids, analytical gases, and other calibration materials.	Use standard-setting part	Use standard-setting part.
I: Testing with oxygenated fuels .....	Use §§ 1065.590 and 1065.595 for PM .....	Use all.
K: Definitions and reference materials .....	§ 1065.930 and § 1065.935 to start and run a field test.	Use all.
	Use all .....	Use all.
	Use standard-setting part .....	Use standard-setting part.
	§ 1065.940 has additional calculation instructions.	§ 1065.940 has additional calculation instructions.
	Use fuels specified in § 1065.701(d) .....	Use fuels from subpart H of this part as specified in standard-setting part.
	Use lubricant and coolant specifications in § 1065.740 and § 1065.745.	Use lubricant and coolant specifications in subpart H of this part.
	Use analytical gas specifications and other calibration standards in § 1065.750 and § 1065.790.	Use analytical gas specifications and other calibration standards in § 1065.750 and § 1065.790.
	Use all .....	Use all.
	Use all .....	Use all.

<sup>1</sup> Refer to paragraphs (d) and (e) of this section for complete specifications.

**§ 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 will likely route engine exhaust to a raw-exhaust flow meter and sample probes. Route the engine exhaust as follows:

(1) *Flexible connections.* Use short flexible connectors at the end of the engine's exhaust pipe.

(i) You may use flexible connectors to enlarge or reduce the exhaust-pipe diameter to match that of your test equipment.

(ii) Use flexible connectors that do not exceed a length of three times their largest inside diameter.

(iii) 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 material with equivalent permeation-resistance and durability, as long as it seals tightly around tailpipes and does not react with exhaust.

(iv) Use stainless-steel hose clamps to seal flexible connectors to the outside diameter of tailpipes, or use clamps that seal equivalently.

(v) You may use additional flexible connectors to connect to flow meters and sample probe locations.

(2) *Raw exhaust 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 exhaust from multiple tailpipes, or you may cap or plug redundant tailpipes if the engine manufacturer recommends it.

(3) *Exhaust back pressure.* Use connectors and tubing that do not increase back pressure so much that it exceeds the manufacturer's maximum specified exhaust restriction. You may verify this at the maximum exhaust flow rate by measuring back pressure at the manufacturer-specified location with your system connected. You may also perform an engineering analysis to verify proper back pressure, 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 passenger might sit. Follow PEMS manufacturer instructions for installing PEMS in vehicle cargo spaces, vehicle trailers, or externally such that PEMS is directly exposed to the outside environment. Locate 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) *Mounting hardware.* Use mounting hardware as required for securing flexible connectors, exhaust tubing, ambient sensors, and other equipment. Use structurally sound mounting points such as vehicle frames, trailer hitch

receivers, and payload tie-down fittings. We recommend mounting hardware such as clamps, suction cups, and magnets that are specifically designed for vehicle applications. We also recommend considering mounting hardware such as commercially available bicycle racks, trailer hitches, and luggage racks.

(d) *Electrical power.* Field testing may require portable electrical power to run your test equipment. Power your equipment, as follows:

(1) You may use electrical power from the vehicle, up to the highest power level, such that all the following are true:

(i) The vehicle power system is capable of safely supplying your power, such that your demand does not overload the vehicle's power system.

(ii) The engine emissions do not change significantly when you use vehicle power.

(iii) The power you demand does not increase output from the engine by more than 1% of its maximum power.

(2) You may install your own portable power supply. For example, you may use batteries, fuel cells, a portable generator, or any other power supply to supplement or replace your use of vehicle power. However, you must not supply power to the vehicle's power system under any circumstances.

**§ 1065.915 PEMS instruments.**

(a) *Instrument specifications.* We recommend that you use PEMS that meet the specifications of subpart C of this part. For field testing of for laboratory testing with PEMS, the specifications in the following table apply instead of the specifications in Table 1 of § 1065.205.

TABLE 1 OF § 1065.915.—RECOMMENDED MINIMUM PEMS MEASUREMENT INSTRUMENT PERFORMANCE

Measurement	Measured quantity symbol	Rise time and fall time	Recording update frequency	Accuracy <sup>1</sup>	Repeatability <sup>1</sup>	Noise <sup>1</sup>
Engine speed transducer .....	fn .....	1 s .....	1 Hz means	5.0% of pt. or 1.0% of max.	2.0% of pt. or 1.0% of max.	0.5% of max.
Engine torque estimator, BSFC (This is a signal from an engine's ECM).	T or BSFC ...	1 s .....	1 Hz means	8.0% of pt. or 5% of max.	2.0% of pt. or 1.0% of max.	1.0% of max.
General pressure transducer (not a part of another instrument).	p .....	5 s .....	1 Hz .....	5.0% of pt. or 5.0% of max.	2.0% of pt. or 0.5% of max.	1.0% of max.
Atmospheric pressure meter .....	patmos .....	50 s .....	0.1 Hz .....	250 Pa .....	200 Pa .....	100 Pa.
General temperature sensor (not a part of another instrument).	T .....	5 s .....	1 Hz .....	1.0% of pt. K or 5 K.	0.5% of pt. K or 2 K.	0.5% of max 0.5 K.
General dewpoint sensor .....	Tdew .....	50 s .....	0.1 Hz .....	3 K .....	1 K .....	1 K.
Exhaust flow meter .....	ñ .....	1 s .....	1 Hz means	5.0% of pt. or 3.0% of max.	2.0% of pt .....	2.0% of max.
Dilution air, inlet air, exhaust, and sample flow meters.	ñ .....	1 s .....	1 Hz means	2.5% of pt. or 1.5% of max.	1.25% of pt. or 0.75% of max.	1.0% of max.
Continuous gas analyzer .....	X .....	5 s .....	1 Hz .....	4.0% of pt. or 4.0% of meas.	2.0% of pt. or 2.0% of meas.	1.0% of max.
Gravimetric PM balance .....	m <sub>PM</sub> .....	N/A .....	N/A .....	See § 1065.790 ..	0.5 µg .....	N/A
Inertial PM balance .....	m <sub>PM</sub> .....	5 s .....	1 Hz .....	4.0% of pt. or 4.0% of meas.	2.0% of pt. or 2.0% of meas.	1.0% of max.

<sup>1</sup> Accuracy, repeatability, and noise are all determined with the same collected data, as described in § 1065.305, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

(b) *Redundant measurements.* For all PEMS described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use good engineering judgment to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements, as described in § 1065.25. This requirement applies whether or not you actually use the measurements in your calculations.

(c) *Field-testing ambient effects on PEMS.* PEMS must be only minimally

affected by ambient conditions such as temperature, pressure, humidity, physical orientation, mechanical shock and vibration, electromagnetic radiation, and ambient hydrocarbons. Follow the PEMS manufacturer's instructions for proper installation to isolate PEMS from ambient conditions that affect their performance. If a PEMS is inherently affected by ambient conditions that you cannot control, you must monitor those conditions and adjust the PEMS signals to compensate for the ambient effect. The standard-setting part may also specify the use of

one or more field-testing adjustments or "measurement allowances" that you apply to results or standards to account for ambient effects on PEMS.

(d) *ECM signals.* You may use signals from the engine's electronic control module (ECM) in place of values measured by individual instruments within a PEMS, subject to the following provisions:

(1) *Recording ECM signals.* If your ECM updates a broadcast signal more frequently than 1 Hz, take one of the following steps:

(i) Use PEMS to sample and record the signal's value more frequently—up

to 5 Hz maximum. Calculate and record the 1 Hz mean of the more frequently updated data.

(ii) Use PEMS to electronically filter the ECM signals to meet the rise time and fall time specifications in Table 1 of this section. Record the filtered signal at 1 Hz.

(2) *Omitting ECM signals.* Replace any discontinuous or irrational ECM data with linearly interpolated values from adjacent data.

(3) *Aligning ECM signals with other data.* You must perform time-alignment and dispersion of ECM signals, according to PEMS manufacturer instructions and using good engineering judgment.

(4) *ECM signals for determining test intervals.* You may use any combination of ECM signals, with or without other measurements, to determine the start-time and end-time of a test interval.

(5) *ECM signals for determining brake-specific emissions.* You may use any combination of ECM signals, with or without other measurements, to estimate engine speed, torque, and brake-specific fuel consumption (BSFC, in units of mass of fuel per kW-hr) for use in brake-specific emission calculations. We recommend that the overall performance of any speed, torque, or BSFC estimator should meet the performance specifications in Table 1 of this section. We recommend using one of the following methods:

(i) *Speed.* Use the engine speed signal directly from the ECM. This signal is generally accurate and precise. You may develop your own speed algorithm based on other ECM signals.

(ii) *Torque.* Use one of the following:

(A) *ECM torque.* Use the engine-torque signal directly from the ECM, if broadcast. Determine if this signal is proportional to indicated torque or brake torque. If it is proportional to indicated torque, subtract friction torque from indicated torque and record the result as brake torque. Friction torque may be a separate signal broadcast from the ECM or you may have to determine it from laboratory data as a function of engine speed.

(B) *ECM %-load.* Use the %-load signal directly from the ECM, if broadcast. Determine if this signal is proportional to indicated torque or brake torque. If it is proportional to indicated torque, subtract the minimum %-load value from the %-load signal. Multiply this result by the maximum brake torque at the corresponding engine speed. Maximum brake torque versus speed information is commonly published by the engine manufacturer.

(C) *Your algorithms.* You may develop and use your own combination of ECM signals to determine torque.

(iii) *BSFC.* Use one of the following:

(A) Use ECM engine speed and ECM fuel flow signals to interpolate brake-specific fuel consumption data, which might be available from an engine laboratory as a function of ECM engine speed and ECM fuel signals.

(B) Use a single BSFC value that approximates the BSFC value over a test interval (as defined in subpart K of this part). This value may be a nominal BSFC value for all engine operation determined over one or more laboratory duty cycles, or it may be any other BSFC that we approve. If you use a nominal BSFC, we recommend that you select a value based on the BSFC measured over laboratory duty cycles that best represent the range of engine operation that defines a test interval for field-testing.

(C) You may develop and use your own combination of ECM signals to determine BSFC.

(iv) *Other ECM signals.* You may ask to use other ECM signals for determining brake-specific emissions, such as ECM fuel flow or ECM air flow. We must approve the use of such signals in advance.

(6) *Permissible deviations.* ECM signals may deviate from the specifications of this part 1065, but the expected deviation must not prevent you from demonstrating that you meet the applicable standards. For example, your emission results may be sufficiently below an applicable standard, such that the deviation would not significantly change the result. As another example, a very low engine-coolant temperature may define a logical statement that determines when a test interval may start. In this case, even if the ECM's sensor for detecting coolant temperature was not very accurate or repeatable, its output would never deviate so far as to significantly affect when a test interval may start.

#### **§ 1065.920 PEMS Calibrations and verifications.**

(a) *Subsystem calibrations and verifications.* Use all the applicable calibrations and verifications in subpart D of this part, including the linearity verifications in § 1065.307, to calibrate and verify PEMS. Note that a PEMS does not have to meet the system-response specifications of § 1065.308 if it meets the overall verification described in paragraph (b) of this section.

(b) *Overall verification.* We require only that you maintain a record showing that the particular make, model, and

configuration of your PEMS meets this verification. We recommend that you generate your own record to show that your specific PEMS meets this verification, but you may also rely on data and other information from the PEMS manufacturer. If you upgrade or change the configuration of your PEMS, your record must show that your new configuration meets this verification. The verification consists of operating an engine over a duty cycle in the laboratory and statistically comparing data generated and recorded by the PEMS with data simultaneously generated and recorded by laboratory equipment as follows:

(1) Mount an engine on a dynamometer for laboratory testing. Prepare the laboratory and PEMS for emission testing, as described in this part, to get simultaneous measurements. We recommend selecting an engine with emission levels close to the applicable duty-cycle standards, if possible.

(2) Select or create a duty cycle that has all the following characteristics:

(i) Engine operation that represents normal in-use speeds, loads, and degree of transient activity. Consider using data from previous field tests to generate a cycle.

(ii) A duration of (20 to 40) min.

(iii) At least 50% of engine operating time must include at least 10 valid test intervals for calculating emission levels for field testing. For example, for highway compression-ignition engines, select a duty cycle in which at least 50% of the engine operating time can be used to calculate valid NTE events.

(3) Starting with a warmed-up engine, run a valid emission test with the duty cycle from paragraph (b)(2) of this section. The laboratory and PEMS must both meet applicable validation requirements, such as drift validation, hydrocarbon contamination validation, and proportional validation.

(4) Determine the brake-specific emissions for each test interval for both laboratory and the PEMS measurements, as follows:

(i) For both laboratory and PEMS measurements, use identical values to determine the beginning and end of each test interval.

(ii) For both laboratory and PEMS measurements, use identical values to determine total work over each test interval.

(iii) Apply any "measurement allowance" to the PEMS data. If the measurement allowance is normally added to the standard, subtract the measurement allowance from the PEMS brake-specific emission result.

(iv) Round results to the same number of significant digits as the standard.

(5) Repeat the engine duty cycle and calculations until you have at least 100 valid test intervals.

(6) For each test interval and emission, subtract the lab result from the PEMS result.

(7) If for each constituent, the PEMS passes this verification if any one of the following are true:

(i) 91% or more of the differences are zero or less than zero.

(ii) The entire set of test-interval results passes the 95% confidence alternate-procedure statistics for field testing (t-test and F-test) specified in subpart A of this part.

#### **§ 1065.925 PEMS preparation for field testing.**

Take the following steps to prepare PEMS for field testing:

(a) Verify that ambient conditions at the start of the test are within the limits specified in the standard-setting part. Continue to monitor these values to determine if ambient conditions exceed the limits during the test.

(b) Install a PEMS and any accessories needed to conduct a field test.

(c) Power the PEMS and allow pressures, temperatures, and flows to stabilize to their operating set points.

(d) Bypass or purge any gaseous sampling PEMS instruments with ambient air until sampling begins to prevent system contamination from excessive cold-start emissions.

(e) Conduct calibrations and verifications.

(f) Operate any PEMS dilution systems at their expected flow rates using a bypass.

(g) If you use a gravimetric balance to determine whether an engine meets an applicable PM standard, follow the procedures for PM sample preconditioning and tare weighing as described in § 1065.590. Operate the PM-sampling system at its expected flow rates using a bypass.

(h) Verify the amount of contamination in the PEMS HC sampling system as follows:

(1) Select the HC analyzers' ranges for measuring the maximum concentration expected at the HC standard.

(2) Zero the HC analyzers using a zero gas introduced at the analyzer port. When zeroing the FIDs, use the FIDs' burner air that would be used for in-use measurements (generally either ambient air or a portable source of burner air).

(3) Span the HC analyzers using span gas introduced at the analyzer port. When spanning the FIDs, use the FIDs' burner air that would be used in-use (for example, use ambient air or a portable source of burner air).

(4) Overflow zero air at the HC probe or into a fitting between the HC probe and the transfer line.

(5) Measure the HC concentration in the sampling system:

(i) For continuous sampling, record the mean HC concentration as overflow zero air flows.

(ii) For batch sampling, fill the sample medium and record its mean concentration.

(6) Record this value as the initial HC concentration,  $x_{HC,init}$ , and use it to correct measured values as described in § 1065.660.

(7) If the initial HC concentration exceeds the greater of the following values, determine the source of the contamination and take corrective action, such as purging the system or replacing contaminated portions:

(i) 2% of the flow-weighted mean concentration expected at the standard or measured during testing.

(ii) 2  $\mu\text{mol/mol}$ .

(8) If corrective action does not resolve the deficiency, you use a contaminated HC system if it does not prevent you from demonstrating compliance with the applicable emission standards.

#### **§ 1065.930 Engine starting, restarting, and shutdown.**

Unless the standard-setting part specifies otherwise, start, restart, and shut down the test engine for field testing as follows:

(a) Start or restart the engine as described in the owners manual.

(b) If the engine does not start after 15 seconds of cranking, stop cranking and determine the reason it failed to start. However, you may crank the engine longer than 15 seconds, as long as 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 a required warm-up before emission sampling begins, restart the engine and continue warm-up.

(2) If the engine stalls at any other time after emission sampling begins, restart the engine and continue testing.

(d) Shut down and restart the engine according to the manufacturer's specifications, as needed during normal operation in-use, but continue emission sampling until the field test is complete.

#### **§ 1065.935 Emission test sequence for field testing.**

(a) Time the start of field testing as follows:

(1) If the standard-setting part requires only hot-stabilized emission

measurements, operate the engine in-use until the engine coolant, block, or head absolute temperature is within  $\pm 10\%$  of its mean value for the previous 2 min or until an engine thermostat controls engine temperature with coolant or air flow.

(2) If the standard-setting part requires hot-start emission measurements, shut down the engine after at least 2 min at the temperature tolerance specified in paragraph (a)(1) of this section. Start the field test within 20 min of engine shutdown.

(3) If the standard-setting part requires cold-start emission measurements, proceed to the steps specified in paragraph (b) of this section.

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

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

(2) Operate the PEMS according to the instrument manufacturer's instructions and using good engineering judgment.

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

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

(5) Allow all other PEMS components such as sample lines, filters, and pumps to stabilize at operating temperature.

(6) Verify that no significant vacuum-side leak exists in the PEMS, as described in § 1065.345.

(7) Adjust PEMS flow rates to desired levels, using bypass flow if applicable.

(8) Zero and span all PEMS gas analyzers using NIST-traceable gases that meet the specifications of § 1065.750.

(c) Start testing as follows:

(1) Before the start of the first test interval, zero or re-zero any PEMS electronic integrating devices, as needed.

(2) If the engine is already running and warmed up and starting is not part of field testing, start the field test by simultaneously starting to sample exhaust, record engine and ambient data, and integrate measured values using a PEMS.

(3) If engine starting is part of field testing, start field testing by simultaneously starting to sample from the exhaust system, record engine and ambient data, and integrate measured values using a PEMS. Then start the engine.

(d) Continue the test as follows:

(1) Continue to sample exhaust, record data and integrate measured values throughout normal in-use operation of the engine.



(2) Between each test interval, zero or re-zero any electronic integrating devices, and reset batch storage media, as needed.

(3) The engine may be stopped and started, but continue to sample emissions throughout the entire field test.

(4) Conduct periodic verifications such as zero and span verifications on PEMS gas analyzers, as recommended by the PEMS manufacturer or as indicated by good engineering judgment. Results from these verifications will be used to calculate and correct for drift according to paragraph (g) of this section. Do not include data recorded during verifications in emission calculations.

(5) You may periodically condition and analyze batch samples in-situ, including PM samples; for example you may condition an inertial PM balance substrate if you use an inertial balance to measure PM.

(6) You may have personnel monitoring and adjusting the PEMS during a test, or you may operate the PEMS unattended.

(e) Stop testing as follows

(1) Continue sampling as needed to get an appropriate amount of emission measurement, according to the standard setting part. If the standard-setting part does not describe when to stop sampling, develop a written protocol before you start testing to establish how you will stop sampling. You may not determine when to stop testing based on measured values.

(2) At the end of the field test, allow the sampling systems' response times to elapse and then stop sampling. Stop any integrators and indicate the end of the test cycle on the data-collection medium.

(3) You may shut down the engine before or after you stop sampling.

(f) For any proportional batch sample, such as a bag sample or PM sample, verify for each test interval whether or not proportional sampling was maintained according to § 1065.545. Void the sample for any test interval that did not maintain proportional sampling according to § 1065.545.

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

(1) As soon as practical after the emission sampling, analyze any gaseous batch samples.

(2) If you used dilution air, either analyze background samples or assume that background emissions were zero. Refer to § 1065.140 for dilution-air specifications.

(3) After quantifying all exhaust gases, record mean analyzer values after stabilizing a zero gas to each analyzer,

then record mean analyzer values after stabilizing the span gas to the analyzer. Stabilization may include time to purge an analyzer of any sample gas, plus any additional time to account for analyzer response. Use these recorded values to correct for drift as described in § 1065.550.

(4) Invalidate any test intervals that do not meet the range criteria in § 1065.550. Note that it is acceptable that analyzers exceed 100% of their ranges when measuring emissions between test intervals, but not during test intervals. You do not have to retest an engine in the field if the range criteria are not met.

(5) Invalidate any test intervals that do not meet the drift criterion in § 1065.550. For test intervals that do meet the drift criterion, correct those test intervals for drift according to § 1065.672 and use the drift corrected results in emissions calculations.

(6) Unless you weighed PM in-situ, such as by using an inertial PM balance, place any used PM samples into covered or sealed containers and return them to the PM-stabilization environment and weigh them as described in § 1065.595.

#### § 1065.940 Emission calculations.

Perform emission calculations as described in § 1065.650 to calculate brake-specific emissions for each test interval using any applicable information and instructions in the standard-setting part.

#### Subpart K—Definitions and Other Reference Information

##### § 1065.1001 Definitions.

The definitions in this section apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives them. The definitions follow:

**300 series stainless steel** means any stainless steel alloy with a Unified Numbering System for Metals and Alloys number designated from S30100 to S39000. For all instances in this part where we specify 300 series stainless steel, such parts must also have a smooth inner-wall construction. We recommend an average roughness,  $R_a$ , no greater than 4  $\mu\text{m}$ .

**Accuracy** means the absolute difference between a reference quantity and the arithmetic mean of ten mean measurements of that quantity. Determine instrument accuracy, repeatability, and noise from the same data set. We specify a procedure for determining accuracy in § 1065.305.

**Act** means the Clean Air Act, as amended, 42 U.S.C. 7401–7671q.

**Adjustable parameter** means any device, system, or element of design that

someone can adjust (including those which are difficult to access) and that, if adjusted, may affect emissions or engine performance during emission testing or normal in-use operation. This includes, but is not limited to, parameters related to injection timing and fueling rate. In some cases, this may exclude a parameter that is difficult to access if it cannot be adjusted to affect emissions without significantly degrading engine performance, or if it will not be adjusted in a way that affects emissions during in-use operation.

**Aerodynamic diameter** means the diameter of a spherical water droplet that settles at the same constant velocity as the particle being sampled.

**Aftertreatment** means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the engine exhaust before it is exhausted to the environment. Exhaust-gas recirculation (EGR) and turbochargers are not aftertreatment.

**Allowed procedures** means procedures that we either specify in this part 1065 or in the standard-setting part or approve under § 1065.10.

**Alternate procedures** means procedures allowed under § 1065.10(c)(7).

**Applicable standard** means an emission standard to which an engine is subject; or a family emission limit to which an engine is certified under an emission credit program in the standard-setting part.

**Aqueous condensation** means the precipitation of water-containing constituents from a gas phase to a liquid phase. Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulfuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition—including the amount of hydrogen and sulfur in the fuel.

**Atmospheric pressure** means the wet, absolute, atmospheric static pressure. Note that if you measure atmospheric pressure in a duct, you must ensure that there are negligible pressure losses between the atmosphere and your measurement location, and you must account for changes in the duct's static pressure resulting from the flow.

**Auto-ranging** means a gas analyzer function that automatically changes the analyzer digital resolution to a larger range of concentrations as the concentration approaches 100% of the analyzer's current range. Auto-ranging

does not mean changing an analog amplifier gain within an analyzer.

*Auxiliary emission-control device* means any element of design that senses temperature, motive speed, engine RPM, transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission-control system.

*Brake power* has the meaning given in the standard-setting part. If it is not defined in the standard-setting part, brake power means the usable power output of the engine, not including power required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate aftertreatment devices. If the engine does not power these accessories during a test, subtract the work required to perform these functions from the total work used in brake-specific emission calculations. Subtract engine fan work from total work only for air-cooled engines.

*C<sub>1</sub> equivalent (or basis)* means a convention of expressing HC concentrations based on the total number of carbon atoms present, such that the C<sub>1</sub> equivalent of a molar HC concentration equals the molar concentration multiplied by the mean number of carbon atoms in each HC molecule. For example, the C<sub>1</sub> equivalent of 10 μmol/mol of propane (C<sub>3</sub>H<sub>8</sub>) is 30 μmol/mol. C<sub>1</sub> equivalent molar values may be denoted as "ppmC" in the standard-setting part.

*Calibration* means the process of setting a measurement system's response so that its output agrees with a range of reference signals. Contrast with "verification".

*Certification* means relating to the process of obtaining a certificate of conformity for an engine family that complies with the emission standards and requirements in the standard-setting part.

*Compression-ignition* means relating to a type of reciprocating, internal-combustion engine that is not a spark-ignition engine.

*Confidence interval* means the range associated with a probability that a quantity will be considered statistically equivalent to a reference quantity.

*Constant-speed engine* means an engine whose certification is limited to constant-speed operation. Engines whose constant-speed governor function is removed or disabled are no longer constant-speed engines.

*Constant-speed operation* means engine operation with a governor that automatically controls the operator demand to maintain engine speed, even under changing load. Governors do not always maintain speed exactly constant.

Typically speed can decrease (0.1 to 10)% below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power.

*Coriolis meter* means a flow-measurement instrument that determines the mass flow of a fluid by sensing the vibration and twist of specially designed flow tubes as the flow passes through them. The twisting characteristic is called the Coriolis effect. According to Newton's Second Law of Motion, the amount of sensor tube twist is directly proportional to the mass flow rate of the fluid flowing through the tube. See § 1065.220.

*Designated Compliance Officer* means the Manager, Engine Programs Group (6405-J), U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., NW., Washington, DC 20460.

*Dewpoint* means a measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity. Dewpoint is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured. See § 1065.645 to determine water vapor mole fractions from dewpoints using the pressure at which the dewpoint is measured.

*Discrete-mode* means relating to a discrete-mode type of steady-state test, as described in the standard-setting part.

*Dispersion* means either:

(1) The broadening and lowering of a signal due to any fluid capacitance, fluid mixing, or electronic filtering in a sampling system. (Note: To adjust a signal so its dispersion matches that of another signal, you may adjust the system's fluid capacitance, fluid mixing, or electronic filtering.)

(2) The mixing of a fluid, especially as a result of fluid mechanical forces or chemical diffusion.

*Drift* means the difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as you zeroed and spanned the instrument just before the test.

*Duty cycle* means a series of speed and torque values (or power values) that an engine must follow during a laboratory test. Duty cycles are specified in the standard-setting part. A single duty cycle may consist of one or more test intervals. For example, a duty cycle may be a ramped-modal cycle, which has one test interval; a cold-start plus hot-start transient cycle, which has two test intervals; or a discrete-mode cycle, which has one test interval for each mode.

*Electronic control module* means an engine's electronic device that uses data from engine sensors to control engine parameters.

*Emission-control system* means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine.

*Emission-data engine* means an engine that is tested for certification. This includes engines tested to establish deterioration factors.

*Emission-related maintenance* means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

*Engine* means an engine to which this part applies.

*Engine family* means a group of engines with similar emission characteristics throughout the useful life, as specified in the standard-setting part.

*Engine governed speed* means the engine operating speed when it is controlled by the installed governor.

*Exhaust-gas recirculation* means a technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust-gas recirculation for the purposes of this part.

*Fall time, t<sub>90-10</sub>*, means the time interval of a measurement instrument's response after any step decrease to the input between the following points:

(1) The point at which the response has fallen 10% of the total amount it will fall in response to the step change.

(2) The point at which the response has fallen 90% of the total amount it will fall in response to the step change.

*Flow-weighted mean* means the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration.

*Fuel type* means a general category of fuels such as gasoline or LPG. There can be multiple grades within a single type

of fuel, such as all-season and winter-grade gasoline.

*Good engineering judgment* means judgments made consistent with generally accepted scientific and engineering principles and all available relevant information. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

*HEPA filter* means high-efficiency particulate air filters that are rated to achieve a minimum initial particle-removal efficiency of 99.97% using ASTM F 1471-93 (incorporated by reference in § 1065.1010).

*Hydraulic diameter* means the diameter of a circle whose area is equal to the area of a noncircular cross section of tubing, including its wall thickness. The wall thickness is included only for the purpose of facilitating a simplified and nonintrusive measurement.

*Hydrocarbon (HC)* means THC, THCE, NMHC, or NMHCE, as applicable. Hydrocarbon generally means the hydrocarbon group on which the emission standards are based for each type of fuel and engine.

*Identification number* means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular engine from other similar engines.

*Idle speed* means the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. Note that warm idle speed is the idle speed of a warmed-up engine.

*Intermediate test speed* has the meaning given in § 1065.610.

*Linearity* means the degree to which measured values agree with respective reference values. Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing. Perfect linearity would result in an intercept,  $a_0$ , equal to zero, a slope,  $a_1$ , of one, a coefficient of determination,  $r^2$ , of one, and a standard error of the estimate, SEE, of zero. The term "linearity" is not used in this part to refer to the shape of a measurement instrument's unprocessed response curve, such as a curve relating emission concentration to voltage output. A properly performing instrument with a nonlinear response curve will meet linearity specifications.

*Manufacturer* has the meaning given in section 216(1) of the Act. In general, this term includes any person who

manufactures an engine or vehicle for sale in the United States or otherwise introduces a new nonroad engine into commerce in the United States. This includes importers who import engines or vehicles for resale.

*Maximum test speed* has the meaning given in § 1065.610.

*Maximum test torque* has the meaning given in § 1065.610.

*NIST-traceable* means relating to a standard value that can be related to NIST-stated references through an unbroken chain of comparisons, all having stated uncertainties, as specified in NIST Technical Note 1297 (incorporated by reference in § 1065.1010). Allowable uncertainty limits specified for NIST-traceability refer to the propagated uncertainty specified by NIST. You may ask to use other internationally recognized standards that are equivalent to NIST standards.

*Noise* means the precision of 30 seconds of updated recorded values from a measurement instrument as it quantifies a zero or reference value. Determine instrument noise, repeatability, and accuracy from the same data set. We specify a procedure for determining noise in § 1065.305.

*Nonmethane hydrocarbons (NMHC)* means the sum of all hydrocarbon species except methane. Refer to § 1065.660 for NMHC determination.

*Nonmethane hydrocarbon equivalent (NMHCE)* means the sum of the carbon mass contributions of non-oxygenated nonmethane hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust nonmethane hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

*Nonroad* means relating to nonroad engines.

*Nonroad engine* has the meaning we give in 40 CFR 1068.30. In general this means all internal-combustion engines except motor vehicle engines, stationary engines, engines used solely for competition, or engines used in aircraft.

*Open crankcase emissions* means any flow from an engine's crankcase that is emitted directly into the environment. Crankcase emissions are not "open crankcase emissions" if the engine is designed to always route all crankcase emissions back into the engine (for example, through the intake system or an aftertreatment system) such that all the crankcase emissions, or their products, are emitted into the environment only through the engine exhaust system.

*Operator demand* means an engine operator's input to control engine output. The "operator" may be a person (*i.e.*, manual), or a governor (*i.e.*, automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal. Output means engine power, P, which is the product of engine speed,  $f_n$ , and engine torque, T.

*Oxides of nitrogen* means compounds containing only nitrogen and oxygen as measured by the procedures specified in this part, except as specified in the standard-setting part. Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO<sub>2</sub>, such that you use an effective molar mass for all oxides of nitrogen equivalent to that of NO<sub>2</sub>.

*Oxygenated fuels* means fuels composed of oxygen-containing compounds, such as ethanol or methanol. Testing engines that use oxygenated fuels generally requires the use of the sampling methods in subpart I of this part. However, you should read the standard-setting part and subpart I of this part to determine appropriate sampling methods.

*Partial pressure* means the pressure, p, attributable to a single gas in a gas mixture. For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration, x.

*Percent (%)* means a representation of exactly 0.01. Significant digits for the product of % and another value are defined as follows:

(1) Where we specify some percentage of a total value, the calculated value has the same number of significant digits as the total value. For example, 2% is exactly 0.02 and 2% of 101.3302 equals 2.026604.

(2) In other cases, determine the number of significant digits using the same method as you would use for determining the number of significant digits of a fractional value.

*Portable emission measurement system (PEMS)* means a measurement system consisting of portable equipment that can be used to generate brake-specific emission measurements during field testing or laboratory testing.

*Precision* means two times the standard deviation of a set of measured values of a single zero or reference quantity.

*Procedures* means all aspects of engine testing, including the equipment specifications, calibrations, calculations and other protocols and specifications

needed to measure emissions, unless we specify otherwise.

*Proving ring* is a device used to measure static force based on the linear relationship between stress and strain in an elastic material. It is typically a steel alloy ring, and you measure the deflection (strain) of its diameter when a static force (stress) is applied across its diameter.

*PTFE* means polytetrafluoroethylene, commonly known as Teflon™.

*Ramped-modal* means relating to a ramped-modal type of steady-state test, as described in the standard-setting part.

*Regression statistics* means any of the set of statistics specified in § 1065.602(i) through (l).

*Repeatability* means the precision of ten mean measurements of a reference quantity. Determine instrument repeatability, accuracy, and noise from the same data set. We specify a procedure for determining repeatability in § 1065.305.

*Revoke* has the meaning given in 40 CFR 1068.30.

*Rise time*,  $t_{10-90}$ , means the time interval of a measurement instrument's response after any step increase to the input between the following points:

(1) The point at which the response has risen 10% of the total amount it will rise in response to the step change.

(2) The point at which the response has risen 90% of the total amount it will rise in response to the step change.

*Roughness (or average roughness,  $R_a$ )* means the size of finely distributed vertical surface deviations from a smooth surface, as determined when traversing a surface. It is an integral of the absolute value of the roughness profile measured over an evaluation length.

*Round* means to round numbers according to NIST SP 811 (incorporated by reference in § 1065.1010), unless otherwise specified.

*Scheduled maintenance* means adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

*Shared atmospheric pressure meter* means an atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell.

*Shared humidity measurement* means a humidity measurement that is used as the humidity for an entire test facility

that has more than one dynamometer test cell.

*Span* means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75% and 100% of the maximum value in the instrument range or expected range of use.

*Spark-ignition* means relating to a gasoline-fueled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

*Special procedures* means procedures allowed under § 1065.10(c)(2).

*Specified procedures* means procedures we specify in this part 1065 or the standard-setting part. Other procedures allowed or required by § 1065.10(c) are not specified procedures.

*Standard deviation* has the meaning given in § 1065.602. Note this is the standard deviation for a non-biased sample.

*Standard-setting part* means the part in the Code of Federal Regulations that defines emission standards for a particular engine. See § 1065.1(a).

*Steady-state* means relating to emission tests in which engine speed and load are held at a finite set of nominally constant values. Steady-state tests are either discrete-mode tests or ramped-modal tests.

*Stoichiometric* means relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen. For example, stoichiometric combustion in a gasoline-fueled engine typically occurs at an air-to-fuel mass ratio of about 14.7:1.

*Storage medium* means a particulate filter, sample bag, or any other storage device used for batch sampling.

*Test engine* means an engine in a test sample.

*Test interval* means a duration of time over which you determine brake-specific emissions. For example, the standard-setting part may specify a complete laboratory duty cycle as a cold-start test interval, plus a hot-start test interval. As another example, a standard-setting part may specify a field-test interval, such as a "not-to-exceed" (NTE) event, as a duration of time over which an engine operates within a certain range of speed and torque. In cases where multiple test intervals occur over a duty cycle, the standard-setting part may specify additional calculations that weight and combine results to arrive at composite

values for comparison against the applicable standards.

*Test sample* means the collection of engines selected from the population of an engine family for emission testing.

*Tolerance* means the interval in which 95% of a set of recorded values of a certain quantity must lie, with the remaining 5% of the recorded values deviating from the tolerance interval only due to measurement variability. Use the specified recording frequencies and time intervals to determine if a quantity is within the applicable tolerance. For parameters not subject to measurement variability, tolerance means an absolute allowable range.

*Total hydrocarbon (THC)* means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with a hydrogen-to-carbon mass ratio of 1.85:1.

*Total hydrocarbon equivalent (THCE)* means the sum of the carbon mass contributions of non-oxygenated hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

*United States* means the States, the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, Guam, American Samoa, and the U.S. Virgin Islands.

*Useful life* means the period during which a new engine is required to comply with all applicable emission standards. The standard-setting part defines the specific useful-life periods for individual engines.

*Variable-speed engine* means an engine that is not a constant-speed engine.

*Vehicle* means any vehicle, vessel, or type of equipment using engines to which this part applies. For purposes of this part, the term "vehicle" may include nonmotive machines or equipment such as a pump or generator.

*Verification* means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance. Contrast with "calibration".

*We (us, our)* means the Administrator of the Environmental Protection Agency and any authorized representatives.

*Zero* means to adjust an instrument so it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air for measuring concentrations of emission constituents.

Zero gas means a gas that yields a zero response in an analyzer. This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen. For field testing, zero gas may include ambient air.

**§ 1065.1005 Symbols, abbreviations, acronyms, and units of measure.**

The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, 1995 Edition, "Guide for the Use of the International System, of Units (SI)," which we incorporate by

reference in § 1065.1010. See § 1065.25 for specific provisions related to these conventions. This section summarizes the way we use symbols, units of measure, and other abbreviations.

(a) *Symbols for quantities.* This part uses the following symbols and units of measure for various quantities:

Symbol	Quantity	Unit	Unit symbol	Base SI units
%	percent	0.01	%	10 <sup>-2</sup>
α	atomic hydrogen to carbon ratio	mole per mole	mol/mol	1
A	area	square meter	m <sup>2</sup>	m <sup>2</sup>
a <sub>0</sub>	intercept of least squares regression.			
a <sub>1</sub>	slope of least squares regression.			
β	ratio of diameters	meter per meter	m/m	1
β	atomic oxygen to carbon ratio	mole per mole	mol/mol	1
C <sup>#</sup>	number of carbon atoms in a molecule.			
D	diameter	meter	m	m
DF	dilution air fraction	mole per mol	mol/mol	1
ε	error between a quantity and its reference.			
e	brake-specific basis	gram per kilowatt hour	g/(kW-h)	g·3.6 <sup>-1</sup> ·10 <sup>6</sup> ·m <sup>-2</sup> ·kg·s <sup>-2</sup>
F	F-test statistic.			
f	frequency	hertz	Hz	s <sup>-1</sup>
f <sub>n</sub>	rotational frequency (shaft)	revolutions per minute	rev/min	2·pi·60 <sup>-1</sup> ·s <sup>-1</sup>
γ	ratio of specific heats	(joule per kilogram kelvin) per (joule per kilogram kelvin).	(J/(kg·K))/(J/(kg·K))	1
K	correction factor			1
l	length	meter	m	m
μ	viscosity, dynamic	pascal second	Pa·s	m <sup>-1</sup> ·kg·s <sup>-1</sup>
M	molar mass <sup>1</sup>	gram per mole	g/mol	10 <sup>-3</sup> ·kg·mol <sup>-1</sup>
m	mass	kilogram	kg	kg
ṁ	mass rate	kilogram per second	kg/s	kg·s <sup>-1</sup>
ν	viscosity, kinematic	meter squared per second	m <sup>2</sup> /s	m <sup>2</sup> ·s <sup>-1</sup>
N	total number in series.			
n	amount of substance	mole	mol	mol
ṅ	amount of substance rate	mole per second	mol/s	mol·s <sup>-1</sup>
P	power	kilowatt	kW	10 <sup>3</sup> ·m <sup>2</sup> ·kg·s <sup>-3</sup>
PF	penetration fraction.			
p	pressure	pascal	Pa	m <sup>-1</sup> ·kg·s <sup>-2</sup>
ρ	mass density	kilogram per cubic meter	kg/m <sup>3</sup>	kg·m <sup>-3</sup>
r	ratio of pressures	pascal per pascal	Pa/Pa	1
r <sup>2</sup>	coefficient of determination.			
R <sub>a</sub>	average surface roughness	micrometer	μm	m <sup>-6</sup>
Re <sup>#</sup>	Reynolds number.			
RF	response factor.			
σ	non-biased standard deviation.			
SEE	standard estimate of error.			
T	absolute temperature	kelvin	K	K
T	Celsius temperature	degree Celsius	°C	K - 273.15
T	torque (moment of force)	newton meter	N·m	m <sup>2</sup> ·kg·s <sup>-2</sup>
t	time	second	s	s
Δt	time interval, period, 1/frequency	second	s	s
V	volume	cubic meter	m <sup>3</sup>	m <sup>3</sup>
V̇	volume rate	cubic meter per second	m <sup>3</sup> /s	m <sup>3</sup> ·s <sup>-1</sup>
W	work	kilowatt hour	kW·h	3.6·10 <sup>-6</sup> ·m <sup>2</sup> ·kg·s <sup>-2</sup>
x	amount of substance mole fraction <sup>2</sup>	mole per mole	mol/mol	1
X̄	flow-weighted mean concentration	mole per mole	mol/mol	1
y	generic variable.			

<sup>1</sup> See paragraph (f)(2) of this section for the values to use for molar masses. Note that in the cases of NO<sub>x</sub> and HC, the regulations specify effective molar masses based on assumed speciation rather than actual speciation.

<sup>2</sup> Note that mole fractions for THC, THCE, NMHC, NMHCE, and NOTHC are expressed on a C<sub>1</sub> equivalent basis.

(b) *Symbols for chemical species.* This part uses the following symbols for chemical species and exhaust constituents:

Symbol	Species	Symbol	Species
Ar	argon.	CO	carbon monoxide.
C	carbon.	CO <sub>2</sub>	carbon dioxide.
CH <sub>4</sub>	methane.	H	atomic hydrogen
C <sub>2</sub> H <sub>6</sub>	ethane.	H <sub>2</sub>	molecular hydrogen.
C <sub>3</sub> H <sub>8</sub>	propane.	H <sub>2</sub> O	water.
C <sub>4</sub> H <sub>10</sub>	butane	He	helium.
C <sub>5</sub> H <sub>12</sub>	pentane.		

Symbol	Species	Subscript	Quantity	Symbol	Quantity	g/mol (10 <sup>-3</sup> .kg.mol <sup>-1</sup> )
<sup>85</sup> Kr .....	krypton 85.					
N <sub>2</sub> .....	molecular nitrogen.	idle .....	condition at idle.	M <sub>H</sub> .....	molar mass of atomic hydrogen.	1.00794
NMHC ..	nonmethane hydrocarbon.	in .....	quantity in.			
NMHCe	nonmethane hydrocarbon equivalent.	init .....	initial quantity, typically before an emission test.	M <sub>H2</sub> .....	molar mass of molecular hydrogen.	2.01588
NO .....	nitric oxide.	j .....	an individual of a series.			
NO <sub>2</sub> .....	nitrogen dioxide.	max .....	the maximum (i.e., peak) value expected at the standard over a test interval; not the maximum of an instrument range.	M <sub>H2O</sub> .....	molar mass of water.	18.01528
NO <sub>x</sub> .....	oxides of nitrogen.			M <sub>He</sub> .....	molar mass of helium.	4.002602
NOTHC	nonoxygenated hydrocarbon.	meas ....	measured quantity.	M <sub>N</sub> .....	molar mass of atomic nitrogen.	14.0067
O <sub>2</sub> .....	molecular oxygen.	out .....	quantity out.			
OHC .....	oxygenated hydrocarbon.	part .....	partial quantity.	M <sub>N2</sub> .....	molar mass of molecular nitrogen.	28.0134
<sup>210</sup> Po .....	polonium 210.	PDP .....	positive-displacement pump.			
PM .....	particulate mass.	ref .....	reference quantity.			
S .....	sulfur.	rev .....	revolution.			
THC .....	total hydrocarbon.	sat .....	saturated condition.			
ZrO <sub>2</sub> .....	zirconium dioxide.	slip .....	PDP slip.	M <sub>NMHC</sub> ..	effective molar mass of nonmethane hydrocarbon <sup>2</sup> .	13.875389

(c) *Prefixes.* This part uses the following prefixes to define a quantity:

Symbol	Quantity	Value
μ .....	micro .....	10 <sup>-6</sup>
m .....	milli .....	10 <sup>-3</sup>
c .....	centi .....	10 <sup>-2</sup>
k .....	kilo .....	10 <sup>3</sup>
M .....	mega .....	10 <sup>6</sup>

(d) *Superscripts.* This part uses the following superscripts to define a quantity:

Superscript	Quantity
overbar (such as $\bar{y}$ ).	arithmetic mean.
overdot (such as $\dot{y}$ ).	quantity per unit time.

(e) *Subscripts.* This part uses the following subscripts to define a quantity:

Subscript	Quantity
abs .....	absolute quantity.
act .....	actual condition.
air .....	air, dry
atmos ...	atmospheric.
cal .....	calibration quantity.
CFV .....	critical flow venturi.
cor .....	corrected quantity.
dil .....	dilution air.
dexh .....	diluted exhaust.
exh .....	raw exhaust.
exp .....	expected quantity.
i .....	an individual of a series.

(f) *Constants.* (1) This part uses the following constants for the composition of dry air:

Symbol	Quantity	Mol/mol
x <sub>Air</sub> .....	amount of argon in dry air.	0.00934
x <sub>CO2air</sub> ...	amount of carbon dioxide in dry air.	0.000375
x <sub>N2air</sub> .....	amount of nitrogen in dry air.	0.78084
x <sub>O2air</sub> .....	amount of oxygen in dry air.	0.209445

(2) This part uses the following molar masses or effective molar masses of chemical species:

Symbol	Quantity	g/mol (10 <sup>-3</sup> .kg.mol <sup>-1</sup> )
M <sub>air</sub> .....	molar mass of dry air <sup>1</sup> .	28.96559
M <sub>Ar</sub> .....	molar mass of argon.	39.948
M <sub>C</sub> .....	molar mass of carbon.	12.0107
M <sub>CO</sub> .....	molar mass of carbon monoxide.	28.0101
M <sub>CO2</sub> .....	molar mass of carbon dioxide.	44.0095

<sup>1</sup> See paragraph (f)(1) of this section for the composition of dry air.

<sup>2</sup> The effective molar masses of THC, THCE, NMHC, and NMHCe are defined by an atomic hydrogen-to-carbon ratio, α, of 1.85.

<sup>3</sup> The effective molar mass of NO<sub>x</sub> is defined by the molar mass of nitrogen dioxide, NO<sub>2</sub>.

(3) This part uses the following molar gas constant for ideal gases:

Symbol	Quantity	J/(mol) · K (10 <sup>-3</sup> (m <sup>2</sup> .kg.S <sup>-2</sup> mol <sup>-1</sup> . K <sup>-1</sup> ))
R .....	molar gas constant .....	8.314472

(4) This part uses the following ratios of specific heats for dilution air and diluted exhaust:

Symbol	Quantity	[J/(kg.K)]/[J/(kg.K)]	Symbol	Quantity	[J/(kg.K)]/[J/(kg.K)]
γ <sub>air</sub> .....	ratio of specific heats for intake air or dilution air.	1.399	γ <sub>dil</sub> .....	ratio of specific heats for diluted exhaust.	1.399

Symbol	Quantity	[J/(kg·K)]/[J/(kg·K)]		
$\gamma_{exh}$ .....	ratio of specific heats for raw exhaust.	1.385	LPG ....	liquefied petroleum gas.
			NDIR ..	nondispersive infrared.
			NDUV ..	nondispersive ultraviolet.
			NIST ...	National Institute for Standards and Technology.
(g) <i>Other acronyms and abbreviations.</i>			PDP ....	positive-displacement pump.
This part uses the following additional abbreviations and acronyms:			PEMS	portable emission measurement system.
			PFD ....	partial-flow dilution.
			PMP ...	Polymethylpentene.
			pt. ....	a single point at the mean value expected at the standard.
			PTFE ..	polytetrafluoroethylene (commonly known as Teflon™).
			RE .....	rounding error.
			RMC ...	ramped-modal cycle.
			RMS ...	root-mean square.
			RTD ...	resistive temperature detector.
			SSV ....	subsonic venturi.
			SI .....	spark-ignition.
			UCL ...	upper confidence limit.
			UFM ...	ultrasonic flow meter.
			U.S.C.	United States Code.
ASTM	American Society for Testing and Materials.			
BMD ...	bag mini-diluter.			
BSFC ..	brake-specific fuel consumption.			
CARB	California Air Resources Board.			
CFR ...	Code of Federal Regulations.			
CFV ...	critical-flow venturi.			
CI .....	compression-ignition.			
CLD ...	chemiluminescent detector.			
CVS ...	constant-volume sampler.			
DF .....	deterioration factor.			
ECM ...	electronic control module.			
EFC ...	electronic flow control.			
EGR ...	exhaust gas recirculation.			
EPA ...	Environmental Protection Agency.			
FID .....	flame-ionization detector.			
IBP .....	initial boiling point.			
ISO .....	International Organization for Standardization.			

reference as prescribed in 5 U.S.C. 552(a) and 1 CFR part 51. Anyone may inspect copies at the U.S. EPA, Air and Radiation Docket and Information Center, 1301 Constitution Ave., NW., Room B102, EPA West Building, Washington, DC 20460 or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202-741-6030, or go to: [http://www.archives.gov/federal\\_register/code\\_of\\_federal\\_regulations/ibr\\_locations.html](http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html).

(a) *ASTM material.* Table 1 of this section lists material from the American Society for Testing and Materials that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase copies of these materials from the American Society for Testing and Materials, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428 or [www.astm.com](http://www.astm.com). Table 1 follows:

**§ 1065.1010 Reference materials.**

Documents listed in this section have been incorporated by reference into this part. The Director of the Federal Register approved the incorporation by

TABLE 1 OF § 1065.1010.—ASTM MATERIALS

Document number and name	Part 1065 reference
ASTM D 86–04b, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure .....	1065.703, 1065.710
ASTM D 93–02a, Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester .....	1065.703
ASTM D 287 92 (Reapproved 2000), Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method) .....	1065.703
ASTM D 323–99a, Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method) .....	1065.710
ASTM D 445–04, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity) .....	1065.703
ASTM D 613–03b, Standard Test Method for Cetane Number of Diesel Fuel Oil .....	1065.703
ASTM D 910–04a, Standard Specification for Aviation Gasolines .....	1065.701
ASTM D 975–04c, Standard Specification for Diesel Fuel Oils .....	1065.701
ASTM D 1266–98 (Reapproved 2003), Standard Test Method for Sulfur in Petroleum Products (Lamp Method) .....	1065.710
ASTM D 1267–02, Standard Test Method for Gage Vapor Pressure of Liquefied Petroleum (LP) Gases (LP-Gas Method) .....	1065.720
ASTM D 1319–03, Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption .....	1065.710
ASTM D 1655–04a, Standard Specification for Aviation Turbine Fuels .....	1065.701
ASTM D 1837–02a, Standard Test Method for Volatility of Liquefied Petroleum (LP) Gases .....	1065.720
ASTM D 1838–03, Standard Test Method for Copper Strip Corrosion by Liquefied Petroleum (LP) Gases .....	1065.720
ASTM D 1945–03, Standard Test Method for Analysis of Natural Gas by Gas Chromatography .....	1065.715
ASTM D 2158–04, Standard Test Method for Residues in Liquefied Petroleum (LP) Gases .....	1065.720
ASTM D 2163–91 (Reapproved 1996), Standard Test Method for Analysis of Liquefied Petroleum (LP) Gases and Propene Concentrates by Gas Chromatography .....	1065.720
ASTM D 2598–02, Standard Practice for Calculation of Certain Physical Properties of Liquefied Petroleum (LP) Gases from Compositional Analysis .....	1065.720
ASTM D 2622–03, Standard Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry .....	1065.703
ASTM D 2713–91 (Reapproved 2001), Standard Test Method for Dryness of Propane (Valve Freeze Method) .....	1065.720
ASTM D 2784–98 (Reapproved 2003), Standard Test Method for Sulfur in Liquefied Petroleum Gases (Oxy-Hydrogen Burner or Lamp) .....	1065.720
ASTM D 2880–03, Standard Specification for Gas Turbine Fuel Oils .....	1065.701
ASTM D 2986–95a (Reapproved 1999), Standard Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Diethyl Phthalate) Smoke Test .....	1065.170
ASTM D 3231–02, Standard Test Method for Phosphorus in Gasoline .....	1065.710
ASTM D 3237–02, Standard Test Method for Lead in Gasoline By Atomic Absorption Spectroscopy .....	1065.710
ASTM D 4814–04b, Standard Specification for Automotive Spark-Ignition Engine Fuel .....	1065.701
ASTM D 5186–03, Standard Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography .....	1065.703
ASTM D 5797–96 (Reapproved 2001), Standard Specification for Fuel Methanol (M70–M85) for Automotive Spark-Ignition Engines .....	1065.701

TABLE 1 OF § 1065.1010.—ASTM MATERIALS—Continued

Document number and name	Part 1065 reference
ASTM D 5798–99 (Reapproved 2004), Standard Specification for Fuel Ethanol (Ed75–Ed85) for Automotive Spark-Ignition Engines .....	1065.701
ASTM D 6615–04a, Standard Specification for Jet B Wide-Cut Aviation Turbine Fuel .....	1065.701
ASTM D 6751–03a, Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels .....	1065.701
ASTM D 6985–04a, Standard Specification for Middle Distillate Fuel Oil Military Marine Applications .....	1065.701
ASTM F 1471–93 (Reapproved 2001), Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air Filter System .....	1065.1001

(b) *ISO material.* Table 2 of this section lists material from the International Organization for Standardization that we have incorporated by reference. The first

column lists the number and name of the material. The second column lists the section of this part where we reference it. Anyone may purchase copies of these materials from the

International Organization for Standardization, Case Postale 56, CH–1211 Geneva 20, Switzerland or [www.iso.org](http://www.iso.org). Table 2 follows:

TABLE 2 OF § 1065.1010.—ISO MATERIALS

Document number and name	Part 1065 reference
ISO 14644–1, Cleanrooms and associated controlled environments .....	1065.190

(c) *NIST material.* Table 3 of this section lists material from the National Institute of Standards and Technology that we have incorporated by reference. The first column lists the number and

name of the material. The second column lists the section of this part where we reference it. Anyone may purchase copies of these materials from the Government Printing Office,

Washington, DC 20402 or download them free from the Internet at [www.nist.gov](http://www.nist.gov). Table 3 follows:

TABLE 3 OF § 1065.1010. NIST MATERIALS

Document number and name	Part 1065 reference
NIST Special Publication 811, 1995 Edition, Guide for the Use of the International System of Units (SI), Barry N. Taylor, Physics Laboratory .....	1065.20, 1065.1001, 1065.1005
NIST Technical Note 1297, 1994 Edition, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, Barry N. Taylor and Chris E. Kuyatt .....	1065.1001

(d) *SAE material.* Table 4 of this section lists material from the Society of Automotive Engineers that we have incorporated by reference. The first

column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase

copies of these materials from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 or [www.sae.org](http://www.sae.org). Table 4 follows:

TABLE 4 OF § 1065.1010. SAE MATERIALS

Document number and name	Part 1065 reference
“Optimization of Flame Ionization Detector for Determination of Hydrocarbon in Diluted Automotive Exhausts,” Reschke Glen D., SAE 770141 .....	1065.360
“Relationships Between Instantaneous and Measured Emissions in Heavy Duty Applications,” Ganesan B. and Clark N. N., West Virginia University, SAE 2001–01–3536 .....	1065.309

(e) *California Air Resources Board material.* Table 5 of this section lists material from the California Air Resources Board that we have incorporated by reference. The first

column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may get copies of these materials from the California Air

Resources Board 9528 Telstar Ave., El Monte, California 91731. Table 5 follows:



TABLE 5 OF § 1065.1010. CALIFORNIA AIR RESOURCES BOARD MATERIALS

Document number and name	Part 1065 reference
"California Non-Methane Organic Gas Test Procedures," Amended July 30, 2002, Mobile Source Division, California Air Resources Board .....	1065.805

[FR Doc. 05-11534 Filed 7-12-05; 8:45 am]

BILLING CODE 6560-50-U