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§ 90.415 Raw gaseous sampling procedures.

Fit all heated sampling lines with a heated filter to extract solid particles from the flow of gas required for analysis. The sample line for HC measurement must be heated. The sample line for CO, CO₂ and NO_x analysis may be heated or unheated.

§ 90.416 Intake air flow measurement specifications.

(a) If used, the engine intake air flow measurement method used must have a range large enough to accurately measure the air flow over the engine operating range during the test. Overall measurement accuracy must be two percent of full-scale value of the measurement device for all modes except the idle mode. For the idle mode, the measurement accuracy must be ± five percent or less of the full-scale value. The Administrator must be advised of the method used prior to testing.

(b) When an engine system incorporates devices that affect the air flow measurement (such as air bleeds, air injection, pulsed air, and so forth) resulting in understated exhaust emission results, make corrections to the exhaust emission results to account for such effects.

§ 90.417 Fuel flow measurement specifications.

(a) Fuel flow measurement is required only for raw testing. Fuel flow is allowed for dilute testing. If the measured fuel flow is used in the dilute calculations for brake-specific fuel consumption (see § 90.426(e)), the fuel flow instrument must meet the requirements of this section.

(b) The fuel flow measurement instrument must have a minimum accuracy of one percent of full-scale flow rate for each measurement range used. An exception is allowed for the idle mode. For this mode, the minimum accuracy is ± five percent of full-scale flow rate for the measurement range used. The controlling parameters are the elapsed time measurement of the event and the weight or volume measurement.

§ 90.418 Data evaluation for gaseous emissions.

For the evaluation of the gaseous emissions recording, record the last four minutes of each mode and determine the average values for HC, CO, CO₂ and NO_x during each mode from the average concentration readings determined from the corresponding calibration data. Longer averaging times are acceptable, but the sampling period which is reported must be a continuous set of data.

§ 90.419 Raw emission sampling calculations—gasoline fueled engines.

(a) Derive the final weighted brake-specific mass emission rates (g/kW-hr) through the steps described in this section.

(b) *Air and fuel flow method.* If both air and fuel flow mass rates are measured, use the following equations to determine the weighted emission values for the test engine:

$$W_{NO_x} = (G_{AIRD} + G_{FUEL}) \times \frac{M_{NO_2}}{M_{exh}} \times WNO_x \times K_H \times \frac{1}{10^6}$$

$$W_{HC} = (G_{AIRD} + G_{FUEL}) \times \frac{M_{HC_{exh}}}{M_{exh}} \times WHC \times \frac{1}{10^6}$$

$$W_{CO} = (G_{AIRD} + G_{FUEL}) \times \frac{M_{CO}}{M_{exh}} \times WCO \times \frac{1}{10^2}$$

Where:

W_{HC} = Mass rate of HC in exhaust [g/hr],

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G_{AIRD} = Intake air mass flow rate on dry basis [g/hr],
 G_{FUEL} = Fuel mass flow rate [g/hr],
 $M_{HC_{exh}}$ = Molecular weight of hydrocarbons in the exhaust, see the following equation:

$$M_{HC_{exh}} = 12.01 + \alpha 1.008 + \beta 16.00$$

Where:

α = Hydrogen/carbon atomic ratio of the fuel
 β = Oxygen/carbon atomic ratio of the fuel
 M_{exh} = Molecular weight of the total exhaust, see the following equation:

$$M_{exh} = \frac{M_{HC_{exh}} \times WHC}{10^6} + \frac{28.01 \times WCO}{10^2} + \frac{44.01 \times WCO_2}{10^2} + \frac{46.01 \times WNO_x}{10^6} + \frac{32.00 \times WO_2}{10^2} + \frac{2.016 \times WH_2}{10^2} + 18.01 \times (1 - K) + 28.01 \times \left[100 - \frac{WHC}{10^4} - WCO - WCO_2 - \frac{WNO_x}{10^4} - WO_2 - WH_2 - 100 \times (1 - K) \right] \times 10^2$$

Where:

WHC = HC volume concentration in exhaust, ppmC wet
 WCO = CO percent concentration in the exhaust, wet
 DCO = CO percent concentration in the exhaust, dry
 WCO₂ = CO₂ percent concentration in the exhaust, wet
 DCO₂ = CO₂ percent concentration in the exhaust, dry

WNO_x = NO volume concentration in exhaust, ppm wet
 WO₂ = O₂ percent concentration in the exhaust, wet
 WH₂ = H₂ percent concentration in exhaust, wet
 K = correction factor to be used when converting dry measurements to a wet basis. Therefore, wet concentration = dry concentration × K, where K is:

$$K = \frac{1}{1 + 0.005 \times (DCO + DCO_2) \times \alpha - 0.01 DH_2}$$

DH₂ = H₂ percent concentration in exhaust, dry, calculated from the following equation:

$$DH_2 = \frac{0.5 \times \alpha \times DCO \times (DCO + DCO_2)}{DCO + (3 \times DCO_2)}$$

W_{co} = Mass rate of CO in exhaust, [g/hr]
 M_{co} = Molecular weight of CO=28.01
 W_{NOx} = Mass rate of NO_x in exhaust, [g/hr]
 M_{NO2} = Molecular weight of NO₂=46.01
 K_H = Factor for correcting the effects of humidity on NO₂ formation for 4-stroke gasoline small engines, see the equation below:

$$K_H = \frac{1}{1 - 0.0329(H - 10.71)}$$

Where:

H = absolute humidity of the intake air in grams of moisture per kilogram of dry air, see §90.426(f) for a method by which H can be calculated.

For two-stroke gasoline engines, K_H should be set to 1.

(c) *Fuel flow method.* The following equations are to be used when fuel flow is selected as the basis for mass emission calculations using the raw gas method.

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$$W_{HC} = \frac{M_{HC_{exh}}}{M_F} \times \frac{G_{FUEL}}{TC} \times \frac{W_{HC}}{10^4}$$

$$W_{CO} = \frac{M_{CO}}{M_F} \times \frac{G_{FUEL}}{TC} \times W_{CO}$$

$$W_{NO_X} = \frac{M_{NO_X}}{M_F} \times \frac{G_{FUEL}}{TC} \times \frac{W_{NO_X}}{10^4} \times K_H$$

Where:

W_{HC} = Mass rate of HC in exhaust, [g/hr]

$M_{HC_{exh}}$ = Molecular weight of hydrocarbons in the exhaust, see following equation:

$$M_{HC_{exh}} = M_C + \alpha M_H + \beta M_O$$

M_C = Molecular weight of carbon=12.01 [g/mole]

M_H = Molecular weight of hydrogen=1.008 [g/mole]

M_O = Molecular weight of oxygen=16.00 [g/mole]

α = Hydrogen to carbon ratio of the test fuel

β = Oxygen to carbon ratio of the test fuel

M_F = Molecular weight of test fuel

G_{FUEL} = Fuel mass flow rate, [g/hr]

TC=Total carbon in exhaust, see following equation:

$$TC = W_{CO} + W_{CO_2} + \frac{W_{HC}}{10^4}$$

WCO = CO percent concentration in the exhaust, wet

WCO₂ = CO₂ percent concentration in the exhaust, wet

DCO = CO percent concentration in the exhaust, dry

DCO₂ = CO₂ percent concentration in the exhaust, dry

W_{HC} = HC volume concentration in exhaust, ppmC wet

WNO_x = NO_x volume concentration in exhaust, ppm wet

K = correction factor to be used when converting dry measurements to a wet basis.

Therefore, wet concentration=dry concentration×K, where K is:

$$K = \frac{1}{1 + 0.005 \times (DCO + DCO_2) \times \alpha - 0.01 DH_2}$$

DH₂ = H₂ percent concentration in exhaust, dry, calculated from the following equation:

$$DH_2 = \frac{0.5 \times \alpha \times DCO \times (DCO + DCO_2)}{DCO + (3 \times DCO_2)}$$

W_{CO} = Mass rate of CO in exhaust, [g/hr]

M_{CO} = Molecular weight of CO = 28.01

WNO_x = Mass rate of NO_x in exhaust, [g/hr]

MNO₂ = Molecular weight of NO₂=46.01

K_H = Factor for correcting the effects of humidity on NO₂ formation for 4-stroke gasoline small engines, see the following equation:

$$K_H = \frac{1}{1 - 0.0329(H - 10.71)}$$

Where:

H = specific humidity of the intake air in grams of moisture per kilogram of dry air.

For two-stroke gasoline engines, K_H should be set to 1.

(d) Calculate the final weighted brake-specific emission rate for each

individual gas component using the following equation:

$$A_{WM} = \frac{\sum_i^n (W_i \times WF_i)}{\sum_i^n (P_i \times WF_i)}$$

Where:

A_{WM} = Final weighted brake-specific mass emission rate (HC, CO, NO_x) [g/kW-hr]

W_i = Mass emission rate during mode i [g/hr]

WF_i = Weighting factors for each mode according to § 90.410(a)

P_i = Gross average power generated during mode i [kW], calculated from the following equation,

$$P_i = \frac{2\pi}{60,000} \times \text{speed} \times \text{torque}$$

Where:

speed = average engine speed measured during mode i [rev./minute]

torque = average engine torque measured during mode i [N-m] (e) Compute the final

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reported brake-specific fuel consumption (BSFC) by use of the following formula:

$$\text{BSFC} = \frac{\sum_i^n (G_{\text{FUEL}_i} \times \text{WF}_i)}{\sum_i^n (P_i \times F_i)}$$

Where:

BSFC = brake-specific fuel consumption in grams of fuel per kilowatt-hour (g/kW-hr).
 G_{FUEL_i} = Fuel mass flow rate of the engine during mode i [g/hr]
 WF_i = Weighting factors for each mode according to §90.410(a)
 P_i = Gross average power generated during mode i [kW].

§ 90.420 CVS concept of exhaust gas sampling system.

(a) A dilute exhaust sampling system is designed to directly measure the true mass of emissions in engine exhaust without the necessity of measuring either fuel flow or intake air flow. This is accomplished by diluting the exhaust produced by a test engine with ambient background air and measuring the total diluted exhaust flow rate and the concentration of emissions within the dilute flow. Total mass flow of an emission is then easily calculated.

(b) A constant volume sampler (CVS) is typically used to control the total amount of dilute flow through the system. As the name implies, a CVS restricts flow to a known value dependent only on the dilute exhaust temperature and pressure.

(c) For the testing described in this subpart, a CVS must consist of: a mixing tunnel into which the engine exhaust and dilutant (background) air are dumped; a dilute exhaust flow metering system; a dilute exhaust sample port; a background sample port; a dilute exhaust sampling system; and a background sampling system.

(1) *Mixing tunnel.* The mixing tunnel must be constructed such that complete mixing of the engine exhaust and background air is assured prior to the sampling probe.

(2) *Exhaust flow metering system.* A dilute exhaust flow metering system must be used to control the total flow rate of the dilute engine exhaust as described in §90.421.

(3) *Exhaust sample port.* A dilute exhaust sample port must be located in or downstream of the mixing tunnel at a point where complete mixing of the engine exhaust and background air is assured.

(4) *Background sample port.* A dilute exhaust sample port must be located in the stream of background air before it is mixed with the engine exhaust. The background probe must draw a representative sample of the background air during each sampling mode.

(5) *Exhaust sampling system.* The dilute exhaust sampling system controls the flow of samples from the mixing tunnel to the analyzer system. This could be either a continuous sampling system or grab (bag) sampling system. If a critical flow venturi (CFV) is used on the dilute exhaust sample probe, this system must assure that the sample CFV is in choke flow during testing. If no CFV is used, this system must assure a constant volumetric flow rate through the dilute exhaust sample probe or must incorporate electronic flow compensation.

(6) *Background sampling system.* The background sampling system controls the flow of samples from the background air supply to the analyzer system. This could be either a continuous sampling system or grab (bag) sampling system. This system must assure a constant volumetric flow rate through the background sample probe.

§ 90.421 Dilute gaseous exhaust sampling and analytical system description.

(a) *General.* The exhaust gas sampling system described in this section is designed to measure the true mass of gaseous emissions in the exhaust of nonroad small spark-ignition engines. This system utilizes the Constant Volume Sampling (CVS) concept (described in §90.420) of measuring mass emissions of HC, NO_x, CO, and CO₂. Grab sampling for individual modes is an acceptable method of dilute testing for all constituents, HC, NO_x, CO, and CO₂. Continuous dilute sampling is not required for any of the exhaust constituents, but is allowable for all. Heated sampling is not required for any of the constituents, but is allowable for