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Where:

- $i$  = test interval number.
- $N$  = number of test intervals.
- $WF$  = weighting factor for the test interval as defined in the standard-setting part.
- $\bar{m}$  = mean steady-state mass rate of emissions over the test interval as determined in paragraph (e) of this section.
- $\bar{P}$  is the mean steady-state power over the test interval as described in paragraph (e) of this section.

Example:

- $N = 2$
- $WF_1 = 0.85$
- $WF_2 = 0.15$
- $\bar{m}_1 = 2.25842 \text{ g/hr}$
- $\bar{m}_2 = 0.063443 \text{ g/hr}$
- $\bar{P}_1 = 4.5383 \text{ kW}$
- $\bar{P}_2 = 0.0 \text{ kW}$

$$e_{\text{NO}_x, \text{composite}} = \frac{(0.85 \cdot 2.25842) + (0.15 \cdot 0.063443)}{(0.85 \cdot 4.5383) + (0.15 \cdot 0.0)}$$

$$e_{\text{NO}_x, \text{composite}} = 0.5001 \text{ g/kW} \cdot \text{hr}$$

(h) *Rounding.* Round the final brake-specific emission values to be compared to the applicable standard only after all calculations are complete (including any drift correction, applicable deterioration factors, adjustment factors, and allowances) and the result is in g/(kW · hr) or units equivalent to the units of the standard, such as g/(hp · hr). See the definition of “Round” in §1065.1001.

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**§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,  $\bar{W}$  when you choose to determine brake-specific emissions as described in §1065.650(f).

(2) The amount of water in a raw or diluted exhaust flow,  $x_{\text{H}_2\text{Oexh}}$ , 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.

(3) The calculated dilution air flow when you do not measure dilution air flow to correct for background emissions as described in §1065.667(c) and (d).

(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,  $x_{\text{H}_2\text{Oexh}}$ , fraction of dilution air in diluted exhaust,  $x_{\text{dil/exh}}$ , and the amount of products on a  $C_1$  basis per dry mole of dry measured flow,  $x_{\text{Ccombdry}}$ . You may use time-weighted mean values of combustion air humidity and dilution air humidity in the chemical balance; as long as your combustion air and dilution air humidities remain within tolerances of  $\pm 0.0025$  mol/mol of their respective mean values over the test interval. For each emission concentration,  $x$ , and amount of water,  $x_{\text{H}_2\text{Oexh}}$ , you must determine their completely dry concentrations,  $x_{\text{dry}}$  and  $x_{\text{H}_2\text{Oexhdry}}$ . You must also use your fuel’s atomic hydrogen-to-carbon ratio,  $\alpha$ , oxygen-to-carbon ratio,  $\beta$ , sulfur-to-carbon ratio,  $\gamma$ , and nitrogen-to-carbon ratio,  $\delta$ . You may calculate  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  based on measured fuel composition as described in paragraph (d)(1) or (d)(2) of this section, or you may use default values for a given fuel as described in paragraph

(d)(3) of this section. 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:  $x_{\text{H}_2\text{OxCO}_2\text{meas}}$ ,  $x_{\text{H}_2\text{OxNOmeas}}$ , 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,  $x_{\text{H}_2\text{Oexh}}$ , iteratively solve for that value in the system of equations. If you measure only total  $\text{NO}_x$  and not  $\text{NO}$  and  $\text{NO}_2$  separately, use good engineering judgment to estimate a split in your total  $\text{NO}_x$  concentration between  $\text{NO}$  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  $\text{NO}$ . For a compression-ignition engine, you may assume that your molar concentration of  $\text{NO}_x$ ,  $x_{\text{NOx}}$ , is 75%  $\text{NO}$  and 25%  $\text{NO}_2$ . For  $\text{NO}_2$  storage aftertreatment systems, you may assume  $x_{\text{NOx}}$  is 25%  $\text{NO}$  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  $x_{\text{H}_2\text{Oexh}}$ ,  $x_{\text{Ccombdry}}$ , and  $x_{\text{dil/exh}}$ . Use good engineering judgment to guess initial values for  $x_{\text{H}_2\text{Oexh}}$ ,  $x_{\text{Ccombdry}}$ , and  $x_{\text{dil/exh}}$ . We recommend guessing an initial amount of water that is about twice the amount of water in your intake or dilution air. We recommend guessing an initial value of  $x_{\text{Ccombdry}}$  as the sum of your measured  $\text{CO}_2$ ,  $\text{CO}$ , and  $\text{THC}$  values. We also recommend guessing an initial  $x_{\text{dil/exh}}$  between 0.75 and 0.95, such as 0.8. Iterate values in the system of equations until the most recently updated guesses are all within  $\pm 1\%$  of their respective most recently calculated values.

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

$x_{\text{dil/exh}}$  = amount of dilution gas or excess air per mole of exhaust.  
 $x_{\text{H}_2\text{Oexh}}$  = amount of  $\text{H}_2\text{O}$  in exhaust per mole of exhaust.

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

$x_{\text{H}_2\text{dry}}$  = amount of  $\text{H}_2$  in exhaust per amount of dry exhaust.

$x_{\text{H}_2\text{Ogas}}$  = water-gas reaction equilibrium coefficient. You may use 3.5 or calculate your own value using good engineering judgment.

$x_{\text{H}_2\text{Oexhdry}}$  = amount of  $\text{H}_2\text{O}$  in exhaust per dry mole of dry exhaust.

$x_{\text{prod/intdry}}$  = amount of dry stoichiometric products per dry mole of intake air.

$x_{\text{dil/exhdry}}$  = amount of dilution gas and/or excess air per mole of dry exhaust.

$x_{\text{int/exhdry}}$  = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust.

$x_{\text{raw/exhdry}}$  = amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust.

$x_{\text{O}_2\text{int}}$  = amount of intake air  $\text{O}_2$  per mole of intake air.

$x_{\text{CO}_2\text{intdry}}$  = amount of intake air  $\text{CO}_2$  per mole of dry intake air. You may use  $\chi_{\text{CO}_2\text{intdry}} = 375 \mu\text{mol/mol}$ , but we recommend measuring the actual concentration in the intake air.

$x_{\text{H}_2\text{Ointdry}}$  = amount of intake air  $\text{H}_2\text{O}$  per mole of dry intake air.

$x_{\text{CO}_2\text{int}}$  = amount of intake air  $\text{CO}_2$  per mole of intake air.

$x_{\text{CO}_2\text{dil}}$  = amount of dilution gas  $\text{CO}_2$  per mole of dilution gas.

$x_{\text{CO}_2\text{dildry}}$  = amount of dilution gas  $\text{CO}_2$  per mole of dry dilution gas. If you use air as diluent, you may use  $x_{\text{CO}_2\text{dildry}} = 375 \mu\text{mol/mol}$ , but we recommend measuring the actual concentration in the intake air.

$x_{\text{H}_2\text{Odildry}}$  = amount of dilution gas  $\text{H}_2\text{O}$  per mole of dry dilution gas.

$x_{\text{H}_2\text{Odil}}$  = amount of dilution gas  $\text{H}_2\text{O}$  per mole of dilution gas.

$x_{\text{[emission]meas}}$  = amount of measured emission in the sample at the respective gas analyzer.

$x_{\text{[emission]dry}}$  = amount of emission per dry mole of dry sample.

$x_{\text{H}_2\text{O[emission]meas}}$  = amount of  $\text{H}_2\text{O}$  in sample at emission-detection location. Measure or estimate these values according to §1065.145(e)(2).

$x_{\text{H}_2\text{Oint}}$  = amount of  $\text{H}_2\text{O}$  in the intake air, based on a humidity measurement of intake air.

$\alpha$  = atomic hydrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$\beta$  = atomic oxygen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$\gamma$  = atomic sulfur-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$\delta$  = atomic nitrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

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(4) Use the following equations to iteratively solve for  $x_{\text{dil/exh}}$ ,  $x_{\text{H}_2\text{Oexh}}$ , and  $x_{\text{Ccombdry}}$ :

$$x_{\text{dil/exh}} = 1 - \frac{x_{\text{raw/exhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}} \quad \text{Eq. 1065.655-1}$$

$$x_{\text{H}_2\text{Oexh}} = \frac{x_{\text{H}_2\text{Oexhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}} \quad \text{Eq. 1065.655-2}$$

$$x_{\text{Ccombdry}} = x_{\text{CO}_2\text{dry}} + x_{\text{COdry}} + x_{\text{THCdry}} - x_{\text{CO}_2\text{dil}} \cdot x_{\text{dil/exhdry}} - x_{\text{CO}_2\text{int}} \cdot x_{\text{int/exhdry}} \quad \text{Eq. 1065.655-3}$$

$$x_{\text{H}_2\text{dry}} = \frac{x_{\text{COdry}} \cdot (x_{\text{H}_2\text{Oexhdry}} - x_{\text{H}_2\text{Odil}} \cdot x_{\text{dil/exhdry}})}{K_{\text{H}_2\text{O-gas}} \cdot (x_{\text{CO}_2\text{dry}} - x_{\text{CO}_2\text{dil}} \cdot x_{\text{dil/exhdry}})} \quad \text{Eq. 1065.655-4}$$

$$x_{\text{H}_2\text{Oexhdry}} = \frac{\alpha}{2} (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + x_{\text{H}_2\text{Odil}} \cdot x_{\text{dil/exhdry}} + x_{\text{H}_2\text{Oint}} \cdot x_{\text{int/exhdry}} - x_{\text{H}_2\text{dry}} \quad \text{Eq. 1065.655-5}$$

$$x_{\text{dil/exhdry}} = \frac{x_{\text{dil/exh}}}{1 - x_{\text{H}_2\text{Oexh}}} \quad \text{Eq. 1065.655-6}$$

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O}_2\text{int}}} \left( \left( \frac{\alpha}{2} - \beta + 2 + 2\gamma \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) - (x_{\text{COdry}} - x_{\text{NOdry}} - 2x_{\text{NO}_2\text{dry}} + x_{\text{H}_2\text{dry}}) \right) \quad \text{Eq. 1065.655-7}$$

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left( \left( \frac{\alpha}{2} + \beta + \delta \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + (2x_{\text{THCdry}} + x_{\text{COdry}} - x_{\text{NO}_2\text{dry}} + x_{\text{H}_2\text{dry}}) \right) + x_{\text{int/exhdry}} \quad \text{Eq. 1065.655-8}$$

$$x_{\text{O}_2\text{int}} = \frac{0.209820 - x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}} \quad \text{Eq. 1065.655-9}$$

$$x_{\text{CO}_2\text{int}} = \frac{x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}} \quad \text{Eq. 1065.655-10}$$

$$x_{\text{H}_2\text{Ointdry}} = \frac{x_{\text{H}_2\text{Oint}}}{1 - x_{\text{H}_2\text{Oint}}} \quad \text{Eq. 1065.655-11}$$

$$x_{\text{CO}_2\text{dil}} = \frac{x_{\text{CO}_2\text{dildry}}}{1 + x_{\text{H}_2\text{Odildry}}} \quad \text{Eq. 1065.655-12}$$

$$x_{\text{H}_2\text{Odildry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}} \quad \text{Eq. 1065.655-13}$$

$$x_{\text{COdry}} = \frac{x_{\text{COmeas}}}{1 - x_{\text{H}_2\text{OCmeas}}} \quad \text{Eq. 1065.655-14}$$

$$x_{\text{CO2dry}} = \frac{x_{\text{CO2meas}}}{1 - x_{\text{H2OCO2meas}}} \quad \text{Eq. 1065.655-15}$$

$$x_{\text{NOdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H2ONOmeas}}} \quad \text{Eq. 1065.655-16}$$

$$x_{\text{NO2dry}} = \frac{x_{\text{NO2meas}}}{1 - x_{\text{H2ONO2meas}}} \quad \text{Eq. 1065.655-17}$$

$$x_{\text{THCdry}} = \frac{x_{\text{THCmeas}}}{1 - x_{\text{H2OTHCmeas}}} \quad \text{Eq. 1065.655-18}$$

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

$$x_{\text{dil/exh}} = 1 - \frac{0.184}{1 + \frac{35.37}{1000}} = 0.822 \text{ mol/mol}$$

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$$x_{\text{H}_2\text{Oexh}} = \frac{35.37}{1 + \frac{35.37}{1000}} = 34.16 \text{ mmol/mol}$$

$$x_{\text{Ccombdry}} = 0.0252 + \frac{29.3}{1000000} + \frac{47.6}{1000000} - \frac{0.371}{1000} \cdot 0.851 - \frac{0.369}{1000} \cdot 0.172 = 0.0249 \text{ mol/mol}$$

$$x_{\text{H}_2\text{dry}} = \frac{29.3 \cdot (0.034 - 0.012 \cdot 0.851)}{3.5 \cdot \left( \frac{25.2}{1000} - \frac{0.371}{1000} \cdot 0.851 \right)} = 8.5 \text{ } \mu\text{mol/mol}$$

$$x_{\text{H}_2\text{Oexhdry}} = \frac{1.8}{2} \left( 0.0249 - \frac{47.6}{1000000} \right) + 0.012 \cdot 0.851 + 0.017 \cdot 0.172 - \frac{8.5}{1000000} = 0.0353 \text{ mol/mol}$$

$$x_{\text{dil/exhdry}} = \frac{0.822}{1 - 0.034} = 0.851 \text{ mol/mol}$$

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot 0.206} \left( \left( \frac{1.8}{2} - 0.050 + 2 + 2 \cdot 0.0003 \right) \left( 0.0249 - \frac{47.6}{1000000} \right) - \left( \frac{29.3}{1000000} - \frac{50.4}{1000000} - 2 \cdot \frac{12.1}{1000000} + \frac{8.5}{1000000} \right) \right) = 0.172 \text{ mol/mol}$$

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left( \left( \frac{1.8}{2} + 0.050 + 0.0001 \right) \left( 0.0249 - \frac{47.6}{1000000} \right) + \left( 2 \cdot \frac{47.6}{1000000} + \frac{29.3}{1000000} - \frac{12.1}{1000000} + \frac{8.5}{1000000} \right) \right) + 0.172 = 0.184 \text{ mol/mol}$$

$$x_{\text{O}_2\text{int}} = \frac{0.209820 - 0.000375}{1 + \frac{17.22}{1000}} = 0.206 \text{ mol/mol}$$

$$x_{\text{CO}_2\text{int}} = \frac{0.000375 \cdot 1000}{1 + \frac{17.22}{1000}} = 0.369 \text{ mmol/mol}$$

$$x_{\text{H}_2\text{Ointdry}} = \frac{16.93}{1 - \frac{16.93}{1000}} = 17.22 \text{ mmol/mol}$$

$$x_{\text{CO}_2\text{dil}} = \frac{0.375}{1 + \frac{12.01}{1000}} = 0.371 \text{ mmol/mol}$$

$$x_{\text{H}_2\text{Odil dry}} = \frac{11.87}{1 - \frac{11.87}{1000}} = 12.01 \text{ mmol/mol}$$

$$x_{\text{COdry}} = \frac{29.0}{1 - \frac{8.601}{1000}} = 29.3 \text{ mmol/mol}$$

$$x_{\text{CO}_2\text{dry}} = \frac{24.98}{1 - \frac{8.601}{1000}} = 25.2 \text{ mmol/mol}$$

$$x_{\text{NOdry}} = \frac{50.0}{1 - \frac{8.601}{1000}} = 50.4 \text{ mmol/mol}$$

$$x_{\text{NO}_2\text{dry}} = \frac{12.0}{1 - \frac{8.601}{1000}} = 12.1 \text{ mmol/mol}$$

$$x_{\text{THCdry}} = \frac{46}{1 - \frac{34.16}{1000}} = 47.6 \text{ mmol/mol}$$

$$\begin{aligned}\alpha &= 1.8 \\ \beta &= 0.05 \\ \gamma &= 0.0003 \\ \delta &= 0.0001\end{aligned}$$

(d) Carbon mass fraction and fuel composition. Determine carbon mass fraction of fuel,  $w_c$ , and fuel composition

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represented by  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  using one of the following methods:

(1) You may calculate  $w_c$  as described in this paragraph (d)(1) based on measured fuel properties. To do so, you

must determine values for  $\alpha$  and  $\beta$  in all cases, but you may set  $\gamma$  and  $\delta$  to zero if the default value listed in Table 1 of this section is zero. Calculate  $w_c$  using the following equation:

$$w_c = \frac{1 \cdot M_C}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N}$$

Eq. 1065.655-19

Where:

$w_c$  = carbon mass fraction of fuel.

$M_C$  = molar mass of carbon.

$\alpha$  = atomic hydrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_H$  = molar mass of hydrogen.

$\beta$  = atomic oxygen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_O$  = molar mass of oxygen.

$\gamma$  = atomic sulfur-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_S$  = molar mass of sulfur.

$\delta$  = atomic nitrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

$M_N$  = molar mass of nitrogen.

*Example:*

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

$$M_C = 12.0107$$

$$M_H = 1.00794$$

$$M_O = 15.9994$$

$$M_S = 32.065$$

$$M_N = 14.0067$$

$$w_c = \frac{1 \cdot 12.0107}{1 \cdot 12.0107 + 1.8 \cdot 1.00794 + 0.05 \cdot 15.9994 + 0.0003 \cdot 32.065 + 0.0001 \cdot 14.0067}$$

$$w_c = 0.8206$$

(2) Determine a fuel's elemental mass fractions and values for  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  as follows:

(i) For gaseous fuels, use the default values for  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  in Table 1 of this section or use good engineering judgment to determine those values based on measurement.

(ii) Determine mass fractions of liquid fuels as follows:

(A) You may determine the carbon and hydrogen mass fractions according to ASTM D5291 (incorporated by reference in §1065.1010). When using ASTM D5291 to determine carbon and hydrogen mass fractions of gasoline (with or without blended ethanol), use good engineering judgment to adapt the method as appropriate.

(B) Determine oxygen mass fraction of gasoline (with or without blended ethanol) according to ASTM D5599 (incorporated by reference in §1065.1010). For all other liquid fuels, determine the oxygen mass fraction using good engineering judgment.

(C) Determine the nitrogen mass fraction according to ASTM D4629 or ASTM D5762 (incorporated by reference in §1065.1010) for all liquid fuels. Select the correct method based on the expected nitrogen content.

(D) Determine the sulfur mass fraction according to subpart H of this part.

(iii) For liquid fuels, use the default values for  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  in Table 1 of this section, or you may determine the value for any of these parameters based



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on measurement. Calculate these values using the following equations:

$$\alpha = \frac{w_H \cdot M_C}{w_C \cdot M_H}$$

Eq. 1065.655-20

$$\beta = \frac{w_O \cdot M_C}{w_C \cdot M_O}$$

Eq. 1065.655-21

Where:

$w_C$  = carbon mass fraction of fuel.  
 $w_H$  = hydrogen mass fraction of fuel.

$w_O$  = oxygen mass fraction of fuel.  
 $w_S$  = sulfur mass fraction of fuel.  
 $w_N$  = nitrogen mass fraction of fuel.

$$\gamma = \frac{w_S \cdot M_C}{w_C \cdot M_S}$$

Eq. 1065.655-22

$$\delta = \frac{w_N \cdot M_C}{w_C \cdot M_N}$$

Eq. 1065.655-23

Where:

 $w_C$  = carbon mass fraction of fuel. $w_H$  = hydrogen mass fraction of fuel. $w_O$  = oxygen mass fraction of fuel. $w_S$  = sulfur mass fraction of fuel. $w_N$  = nitrogen mass fraction of fuel.*Example:*

$$w_C = 0.8206$$

$$w_H = 0.1239$$

$$w_O = 0.0547$$

$$w_S = 0.00066$$

$$w_N = 0.000095$$

$$M_C = 12.0107$$

$$M_H = 1.00794$$

$$M_O = 15.9994$$

$$M_S = 32.065$$

$$M_N = 14.0067$$

$$\alpha = \frac{0.1239 \cdot 12.0107}{0.8206 \cdot 1.00794}$$

$$\beta = \frac{0.0547 \cdot 12.0107}{0.8206 \cdot 15.9994}$$

$$\gamma = \frac{0.00066 \cdot 12.0107}{0.8206 \cdot 32.065}$$

$$\delta = \frac{0.000095 \cdot 12.0107}{0.8206 \cdot 14.0067}$$

$$\alpha = 1.8$$

$$\beta = 0.05$$

$$\gamma = 0.0003$$

$$\delta = 0.0001$$

TABLE 1 OF § 1065.655—DEFAULT VALUES OF  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ , AND  $w_c$ , FOR VARIOUS FUELS

Fuel	Atomic hydrogen, oxygen, sulfur, and nitrogen-to-carbon ratios $CH_xO_yS_zN_\delta$	Carbon mass fraction, $w_c$ g/g
Gasoline .....	$CH_{1.85}O_0S_0N_0$ .....	0.866
E10 Gasoline .....	$CH_{1.92}O_{0.03}S_0N_0$ .....	0.833
E15 Gasoline .....	$CH_{1.95}O_{0.05}S_0N_0$ .....	0.817
E85 Gasoline .....	$CH_{2.73}O_{0.38}S_0N_0$ .....	0.576
#1 Diesel .....	$CH_{1.93}O_0S_1N_0$ .....	0.861
#2 Diesel .....	$CH_{1.80}O_0S_0N_0$ .....	0.869
Liquefied petroleum gas .....	$CH_{2.64}O_0S_0N_0$ .....	0.819
Natural gas .....	$CH_{3.78}O_{0.016}S_0N_0$ .....	0.747
E100 Ethanol .....	$CH_3O_{0.5}S_0N_0$ .....	0.521
M100 Methanol .....	$CH_4O_1S_0N_0$ .....	0.375
Residual fuel blends .....	Must be determined by measured fuel properties as described in paragraph (d)(1) of this section.	

(e) *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,  $\dot{n}_{\text{int}}$ , or the measured fuel mass flow rate,  $\dot{m}_{\text{fuel}}$ , and the values calculated using the chemical balance in paragraph (c) of this section. The chemical balance must be based on raw exhaust gas concentrations. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record or  $\dot{n}_{\text{int}}$  or  $\dot{m}_{\text{fuel}}$ . For laboratory tests, calculating raw exhaust molar flow rate using measured fuel mass flow rate is valid only for steady-state testing. See §1065.915(d)(5)(iv) for application to field testing.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, you may calculate raw exhaust flow based

on  $\dot{n}_{\text{int}}$  or  $\dot{m}_{\text{fuel}}$  using one of the following:

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

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

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

(2) *Intake air molar flow rate calculation.* Calculate  $\dot{n}_{\text{exh}}$  based on  $\dot{n}_{\text{int}}$  using the following equation:

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

Eq. 1065.655-24

Where:

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

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

*Example:*

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

$x_{\text{int/exhdry}} = 0.69021 \text{ mol/mol}$

$x_{\text{raw/exhdry}} = 1.10764 \text{ mol/mol}$

$x_{\text{H2Oexhdry}} = 107.64 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$

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

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

(3) Fuel mass flow rate calculation. This calculation may be used only for steady-state laboratory testing. See § 1065.915(d)(5)(iv) for application to field testing. Calculate  $\dot{n}_{\text{exh}}$  based on  $\dot{m}_{\text{fuel}}$  using the following equation:

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot w_c \cdot (1 + x_{\text{H}_2\text{Oexhdry}})}{M_c \cdot x_{\text{Ccombdry}}}$$

Eq. 1065.655-25

Where:

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

$\dot{m}_{\text{fuel}}$  = fuel mass flow rate.

Example:

$\dot{m}_{\text{fuel}} = 7.559 \text{ g/s}$

$w_c = 0.869 \text{ g/g}$

$M_c = 12.0107 \text{ g/mol}$

$x_{\text{Ccombdry}} = 99.87 \text{ mmol/mol} = 0.09987 \text{ mol/mol}$

$x_{\text{H}_2\text{Oexhdry}} = 107.64 \text{ mmol/mol} = 0.10764 \text{ mol/mol}$

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

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

(f) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate, dilute exhaust molar flow rate, and dilute chemical balance.* You may calculate the raw exhaust molar flow rate,  $\dot{n}_{\text{exh}}$ , based on the measured intake air molar flow rate,  $\dot{n}_{\text{int}}$ , the measured dilute exhaust molar flow rate,  $\dot{n}_{\text{dexh}}$ , and the values calculated using the chemical balance in paragraph (c) of this section. Note that the chemical balance must be based on dilute exhaust gas concentrations. For continuous-flow calculations, solve for the chemical balance in paragraph (c) of this section at the same frequency that you

update and record  $\dot{n}_{\text{int}}$  and  $\dot{n}_{\text{dexh}}$ . This calculated  $\dot{n}_{\text{exh}}$  may be used for the PM dilution ratio verification in §1065.546; the calculation of dilution air molar flow rate in the background correction in §1065.667; and the calculation of mass of emissions in §1065.650(c) for species that are measured in the raw exhaust.

(1) *Crankcase flow rate.* If engines are not subject to crankcase controls under the standard-setting part, calculate raw exhaust flow as described in paragraph (e)(1) of this section.

(2) *Dilute exhaust and intake air molar flow rate calculation.* Calculate  $\dot{n}_{\text{exh}}$  as follows:

$$\dot{n}_{\text{exh}} = \left( x_{\text{raw/exhdry}} - x_{\text{int/exhdry}} \right) \cdot \left( 1 - x_{\text{H}_2\text{Oexh}} \right) \cdot \dot{n}_{\text{dexh}} + \dot{n}_{\text{int}}$$

Eq. 1065.655-26

*Example:*

$$\begin{aligned} \dot{n}_{\text{int}} &= 7.930 \text{ mol/s} \\ x_{\text{raw/exhdry}} &= 0.1544 \text{ mol/mol} \\ x_{\text{int/exhdry}} &= 0.1451 \text{ mol/mol} \\ x_{\text{H}_2\text{O/exh}} &= 32.46 \text{ mmol/mol} = 0.03246 \text{ mol/mol} \\ \dot{n}_{\text{dexh}} &= 49.02 \text{ mol/s} \\ \dot{n}_{\text{exh}} &= (0.1544 - 0.1451) \cdot (1 - 0.03246) \cdot 49.02 + \\ &\quad 7.930 = 0.4411 + 7.930 = 8.371 \text{ mol/s} \end{aligned}$$

[73 FR 37331, June 30, 2008, as amended at 73 FR 59334, Oct. 8, 2008; 75 FR 23051, Apr. 30, 2010; 76 FR 57458, Sept. 15, 2011; 79 FR 23799, Apr. 28, 2014]

**§ 1065.659 Removed water correction.**

(a) If you remove water upstream of a concentration measurement,  $x$ , correct for the removed water. Perform this correction based on the amount of water at the concentration measurement,  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$ , and at the flow meter,  $x_{\text{H}_2\text{Oexh}}$ , whose flow is used to determine the mass emission rate or total mass over a test interval. For continuous analyzers downstream of a sample dryer for transient and ramped-modal cycles, you must apply this correction on a continuous basis over the test interval, even if you use one of the options in §1065.145(e)(2) that results in a constant value for  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$  because  $x_{\text{H}_2\text{Oexh}}$  varies over the test interval. For batch analyzers, determine the flow-weighted average based on the continuous  $x_{\text{H}_2\text{Oexh}}$  values determined as described in paragraph (c) of this section. For batch analyzers, you may determine the flow-weighted average  $x_{\text{H}_2\text{Oexh}}$  based on a single value of  $x_{\text{H}_2\text{Oexh}}$  determined as described in paragraphs (c)(2) and (3) of this section, using flow-weighted average or batch concentration inputs.

(b) Determine the amount of water remaining downstream of a sample

dryer and at the concentration measurement using one of the methods described in §1065.145(e)(2). If you use a sample dryer upstream of an analyzer and if the calculated amount of water remaining downstream of the sample dryer and at the concentration measurement,  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$ , is higher than the amount of water at the flow meter,  $x_{\text{H}_2\text{Oexh}}$ , set  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$  equal to  $x_{\text{H}_2\text{Oexh}}$ . If you use a sample dryer upstream of storage media, you must be able to demonstrate that the sample dryer is removing water continuously (*i.e.*,  $x_{\text{H}_2\text{Oexh}}$  is higher than  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$  throughout the test interval).

(c) For a concentration measurement where you did not remove water, you may set  $x_{\text{H}_2\text{O}[\text{emission}]_{\text{meas}}}$  equal to  $x_{\text{H}_2\text{Oexh}}$ . You may determine the amount of water at the flow meter,  $x_{\text{H}_2\text{Oexh}}$ , using any of the following methods:

(1) Measure the dewpoint and absolute pressure and calculate the amount of water as described in §1065.645.

(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: