

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

Eq. 1065.644-1

Where:

 V_{vac} = geometric volume of the vacuum-side of the sampling system. R = molar gas constant. p_2 = vacuum-side absolute pressure at time t_2 . T_2 = vacuum-side absolute temperature at time t_2 . p_1 = vacuum-side absolute pressure at time t_1 . T_1 = vacuum-side absolute temperature at time t_1 . t_2 = time at completion of vacuum-decay leak verification test. t_1 = time at start of vacuum-decay leak verification test.

Example:

 $V_{\text{vac}} = 2.0000 \text{ L} = 0.00200 \text{ m}^3$ $R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K}) = 8.314472 (\text{m}^2 \cdot \text{kg})/(\text{s}^2 \cdot \text{mol} \cdot \text{K})$ $p_2 = 50.600 \text{ kPa} = 50600 \text{ Pa} = 50600 \text{ kg}/(\text{m} \cdot \text{s}^2)$ $T_2 = 293.15 \text{ K}$ $p_1 = 25.300 \text{ kPa} = 25300 \text{ Pa} = 25300 \text{ kg}/(\text{m} \cdot \text{s}^2)$ $T_1 = 293.15 \text{ K}$ $t_2 = 10:57:35 \text{ a.m.}$ $t_1 = 10:56:25 \text{ a.m.}$

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

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

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

[79 FR 23795, Apr. 28, 2014]

§ 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. Paragraph (d) of this section provides an equation for determining dewpoint from relative humidity and dry bulb temperature measurements.

The equations for the vapor pressure of water as presented in this section are derived from equations in "Saturation Pressure of Water on the New Kelvin Temperature Scale" (Goff, J.A., Transactions American Society of Heating and Air-Conditioning Engineers, Vol. 63, No. 1607, pages 347-354). Note that the equations were originally published to derive vapor pressure in units of atmospheres and have been modified to derive results in units of kPa by converting the last term in each equation.

(a) *Vapor pressure of water.* Calculate the vapor pressure of water for a given saturation temperature condition, T_{sat} , as follows, or use good engineering judgment to use a different relationship of the vapor pressure of water to a

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given saturation temperature condition:

(1) For humidity measurements made at ambient temperatures from (0 to 100)

°C, or for humidity measurements made over super-cooled water at ambient temperatures from (–50 to 0) °C, use the following equation:

$$\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}}\right) - 5.02800 \cdot \log_{10}\left(\frac{T_{\text{sat}}}{273.16}\right) + 1.50475 \cdot 10^{-4} \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{T_{\text{sat}}}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}}\right)} - 1\right) - 0.2138602$$

Eq. 1065.645-1

Where:

$p_{\text{H}_2\text{O}}$ = vapor pressure of water at saturation temperature condition, kPa.

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

Example:

$T_{\text{sat}} = 9.5 \text{ °C} = 282.65 \text{ K}$

$$\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left(1 - \frac{273.16}{282.65}\right) - 5.02800 \cdot \log_{10}\left(\frac{282.65}{273.16}\right) + 1.50475 \cdot 10^{-4} \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{282.65}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{282.65}\right)} - 1\right) - 0.2138602$$

$\log_{10}(p_{\text{H}_2\text{O}}) = 0.074297$

$p_{\text{H}_2\text{O}} = 10^{0.074297} = 1.186581 \text{ kPa}$

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

$$\begin{aligned} \log_{10}(p_{\text{H}_2\text{O}}) &= -9.096853 \cdot \left(\frac{273.16}{T_{\text{sat}}} - 1 \right) - 3.566506 \cdot \log_{10} \left(\frac{273.16}{T_{\text{sat}}} \right) \\ &+ 0.876812 \cdot \left(1 - \frac{T_{\text{sat}}}{273.16} \right) - 0.2138602 \end{aligned}$$

Eq. 1065.645-2

Example:

$$T_{\text{ice}} = -15.4 \text{ }^\circ\text{C} = 257.75 \text{ K}$$

$$\begin{aligned} \log_{10}(p_{\text{H}_2\text{O}}) &= -9.096853 \cdot \left(\frac{273.16}{257.75} - 1 \right) - 3.566506 \cdot \log_{10} \left(\frac{273.16}{257.75} \right) \\ &+ 0.876812 \cdot \left(1 - \frac{257.75}{273.16} \right) - 0.2138602 \end{aligned}$$

$$\log_{10}(p_{\text{H}_2\text{O}}) = -0.798207$$

$$p_{\text{H}_2\text{O}} = 10^{-0.79821} = 0.159145 \text{ kPa}$$

(b) *Dewpoint.* If you measure humidity as a dewpoint, determine the amount of water in an ideal gas, $x_{\text{H}_2\text{O}}$, as follows:

$$x_{\text{H}_2\text{O}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad \text{Eq. 1065.645-3}$$

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

Example::

$p_{\text{abs}} = 99.980 \text{ kPa}$
 $T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ }^\circ\text{C}$

Using Eq. 1065.645-1,

$p_{\text{H}_2\text{O}} = 1.186581 \text{ kPa}$
 $x_{\text{H}_2\text{O}} = 1.186581/99.980$
 $x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$

(c) *Relative humidity.* If you measure humidity as a relative humidity, $RH\%$, determine the amount of water in an ideal gas, $x_{\text{H}_2\text{O}}$, as follows:

$$x_{\text{H}_2\text{O}} = \frac{RH\% \cdot p_{\text{H}_2\text{O}}}{P_{\text{abs}}} \quad \text{Eq. 1065.645-4}$$

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

Example:

RH% = 50.77%
 $p_{\text{abs}} = 99.980 \text{ kPa}$
 $T_{\text{sat}} = T_{\text{amb}} = 20 \text{ }^\circ\text{C}$
 Using Eq. 1065.645-1,
 $p_{\text{H}_2\text{O}} = 2.3371 \text{ kPa}$
 $x_{\text{H}_2\text{O}} = (50.77\% \cdot 2.3371)/99.980$
 $x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$

(d) *Dewpoint determination from relative humidity and dry bulb temperature.*

This paragraph (d) describes how to calculate dewpoint temperature from relative humidity, RH%. This is based on ‘‘ITS-90 Formulations for Vapor Pressure, Frostpoint Temperature, Dewpoint Temperature, and Enhancement Factors in the Range -100 to +100 °C’’ (Hardy, B., The Proceedings of the Third International Symposium on Humidity & Moisture, Teddington, London, England, April 1998). Calculate $p_{\text{H}_2\text{Osat}}$ as described in paragraph (a) of this section based on setting T_{sat} equal to T_{amb} . Calculate $p_{\text{H}_2\text{Oscaled}}$ by multiplying $p_{\text{H}_2\text{Osat}}$ by RH%. Calculate the dewpoint, T_{dew} , from $p_{\text{H}_2\text{O}}$ using the following equation:

$$T_{\text{dew}} = \frac{2.0798233 \cdot 10^2 - 2.0156028 \cdot 10^1 \cdot \ln(p_{\text{H}_2\text{O}}) + 4.6778925 \cdot 10^{-1} \cdot \ln(p_{\text{H}_2\text{O}})^2 - 9.2288067 \cdot 10^{-6} \cdot \ln(p_{\text{H}_2\text{O}})^3}{1 - 1.3319669 \cdot 10^{-1} \cdot \ln(p_{\text{H}_2\text{O}}) + 5.6577518 \cdot 10^{-3} \cdot \ln(p_{\text{H}_2\text{O}})^2 - 7.5172865 \cdot 10^{-5} \cdot \ln(p_{\text{H}_2\text{O}})^3}$$

Eq. 1065.645-5

Where:

$\ln(p_{\text{H}_2\text{O}})$ = the natural log of $p_{\text{H}_2\text{Oscaled}}$, which is the water vapor pressure scaled to the

relative humidity at the location of the relative humidity measurement, $T_{\text{sat}} = T_{\text{amb}}$.

Example:

RH % = 39.61 %

$T_{\text{sat}} = T_{\text{amb}} = 20.00 \text{ }^\circ\text{C} = 293.15\text{K}$

Using Eq. 1065.645-1,

$p_{\text{H}_2\text{Osat}} = 2.3371 \text{ kPa}$

$p_{\text{H}_2\text{Oscaled}} = (39.61 \% \cdot 2.3371) = 0.925717 \text{ kPa} = 925.717 \text{ Pa}$

$$T_{\text{dew}} = \frac{2.0798233 \cdot 10^2 - 2.0156028 \cdot 10^1 \cdot \ln(925.717) + 4.6778925 \cdot 10^{-1} \cdot \ln(925.717)^2 - 9.2288067 \cdot 10^{-6} \cdot \ln(925.717)^3}{1 - 1.3319669 \cdot 10^{-1} \cdot \ln(925.717) + 5.6577518 \cdot 10^{-3} \cdot \ln(925.717)^2 - 7.5172865 \cdot 10^{-5} \cdot \ln(925.717)^3}$$

$T_{\text{dew}} = 279.00 \text{ K} = 5.85 \text{ }^\circ\text{C}$

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[73 FR 37327, June 30, 2008, as amended at 73 FR 59331, Oct. 8, 2008; 75 FR 23048, Apr. 30, 2010; 76 FR 57456, Sept. 15, 2011; 79 FR 23796, Apr. 28, 2014]

§ 1065.650 Emission calculations.

(a) *General.* Calculate brake-specific emissions over each applicable duty cycle or test interval. For test intervals with zero work (or power), calculate the emission mass (or mass rate), but do not calculate brake-specific emissions. For duty cycles with multiple test intervals, refer to the standard-setting part for calculations you need to determine a composite result, such as a calculation that weights and sums the results of individual test intervals in a duty cycle. If the standard-setting part does not include those calculations, use the equations in para-

graph (g) of this section. This section is written based on rectangular integration, where each indexed value (*i.e.*, “*i*”) represents (or approximates) the mean value of the parameter for its respective time interval, delta-*t*. You may also integrate continuous signals using trapezoidal integration consistent with good engineering judgment.

(b) *Brake-specific emissions over a test interval.* We specify three alternative ways to calculate brake-specific emissions over a test interval, as follows:

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

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

Example:

$m_{\text{NOx}} = 64.975 \text{ g}$
 $W = 25.783 \text{ kW} \cdot \text{hr}$
 $e_{\text{NOx}} = 64.975/25.783$
 $e_{\text{NOx}} = 2.520 \text{ g}/(\text{kW} \cdot \text{hr})$

(2) For discrete-mode steady-state testing, you may calculate the brake-

specific emissions over a test interval using the ratio of emission mass rate to power, as described in paragraph (e) of this section, using the following equation:

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

(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 (f) of this section. You may also use this approach for laboratory testing, consistent with good engineering judgment. Good engineering judgment dictates that this method not be used if there are any work flow paths described in §1065.210 that cross the system boundary, other than the primary output shaft (crankshaft). 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: