CONTROLLING HIGH-HUMIDITY APPLICATIONS

with dew point temperature

White Paper

VAISALA

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The benefits of dew point temperature as a control parameter

Dew point temperature is a useful parameter in many industrial applications. It is often used to measure dryness in, for example, plastics manufacturing and applications that use dried compressed air, where the relative humidity (RH) is typically below 10%RH.

Unlike RH, dew point temperature is not dependent on temperature variations. Let's take the example of a cleanroom where the control target is set to 40%RH with allowed noise of 2%RH at a temperature of 20 °C (68 °F) ± 1 °C (33.8 °F). As humidifying or drying may change the temperature, and heating or cooling will change the RH, achieving stable conditions may be difficult using RH as the humidity control parameter. The solution is to use dew point temperature as the control parameter instead.

Another use case is applications such as fuel cells, where high humidity is essential to maximize the efficiency and lifetime of the cell. In such applications, the condensation that forms on the measurement sensor can make it impossible to take measurements until the sensor is sufficiently dry. This can be avoided by using measurement instruments with sensor-heating technology, which can keep the humidity sensor at a temperature higher than the dew point temperature to prevent condensation forming. This increases the lifetime of the sensor and ensures reliable and repeatable dew point temperature measurement even in a condensing environment.

But why measure the dew point temperature if the relative humidity can be measured directly with the sensor? Relative humidity is an output parameter that is dependent on temperature measurement, which means that if sensor-heating technology is used, the temperature reading of the probe will be distorted. Because of this, the true temperature of the environment can be measured using a separate instrument or by entering the temperature data into the Modbus register. Probe heating has no effect on the dew point temperature measurement, which is why it can be selected as the output parameter.

Calculating relative humidity from dew point and dry bulb temperature with and without considering process pressure

In this section we present two ways to calculate relative humidity using the dew point temperature. The first is a simplified method that does not take into account the process pressure or the enhancement factor. The equation works at atmospheric pressure, where the gas is nitrogen or air. Another way to calculate the relative humidity is to take all the factors into account, in which case process pressure and the enhancement factor are also considered.

Calculation formula where process pressure is not considered

RH is defined at all temperatures and pressures as the ratio of the water vapor pressure (e_w) to the saturation water vapor pressure over water (e_{ws}) at the gas temperature and pressure. It can be calculated using the formula [1].

$$RH = \frac{f(T_d, p)e_w(T_d)}{f(T, p)e_{ws/is}(T)} \cdot 100\,\%RH \approx \frac{e_w(T_d)}{e_{ws/is}(T)} \cdot 100\,\%RH \text{ , where} \qquad (1)$$

e_w = water vapor pressure, Pa
e_{ws} = saturated water vapor pressure (over water), Pa
e_{is} = saturated water vapor pressure (over ice), Pa
f = enhancement factor

Water vapor pressure (e_w) and saturated water vapor pressure (e_{ws}/e_{is}) are the most important factors in the calculation because they can be used to derive other parameters using functions, iterative procedures, or auxiliary parameters (temperature and pressure).

In this paper, we calculate RH using dew point and ambient temperature utilizing Sonntag's equation [2]. This equation is valid in the temperature range -100 °C ... +100 °C (-212 °F ... +212 °F) and at ambient pressure. Also note that in equation [2] temperatures are defined in Kelvins.

$$\left.\begin{matrix} e_{ws}(T_K) \\ e_{is}(T_K) \end{matrix}\right\} = a_0 \times \exp\left[\frac{a_1}{T_K} + a_2 + a_3 T_K + a_4 T_K^2 + a_5 \ln(a_6 \times T_K)\right] \text{, where} \qquad (2)$$

$$e_w(T_{dK}) = a_0 \times \exp\left[\frac{a_1}{T_{dK}} + a_2 + a_3 T_{dK} + a_4 T_{dK}^2 + a_5 \ln(a_6 \times T_{dK})\right] \text{, where} \qquad (2)$$

T_{dK} = dew point temperature, K
T_K = temperature, K
a_n = coefficients (see. Table 1)

Table 1. Numerical values for coefficients a0 … a6

Coefficients a_n	Over water (P_{ws}) (0 … 100 °C)	Over Ice (P_{is}) (-100 … 0 °C)
a_0	1 Pa	1 Pa
a_1	-6.0969385E+03 K	-6.0969385E+03 K
a_2	2.12409642E+01	2.932707E+01
a_3	-2.711193E-02 K^{-1}	1.0613868E-02 K^{-1}
a_4	1.673952E-05 K^{-2}	1.3198825E-05 K^{-2}
a_5	2.433502	-4.9382577E-01
a_6	1 K^{-1}	1 K^{-1}

Example:

Calculating relative humidity when T = 25 °C (77 °F) and Td = 20 °C (68 °F):

1. Convert temperature from Celsius or Fahrenheit to Kelvins

Celsius:

$$\boldsymbol{T} = 25\,°\text{C} => \boldsymbol{T_K} = 25 + 273.15 = 298.15\ \text{K}$$

$$\boldsymbol{T_d} = 68\,°\text{F} => \boldsymbol{T_{dK}} = 20 + 273.15 = 293.15\ \text{K}$$

Fahrenheit:

$$\boldsymbol{T} = 77\,°\text{F} => \boldsymbol{T_K} = \frac{77 + 32}{1.8} + 273.15 = 298.15\ \text{K}$$

$$\boldsymbol{T_d} = 68\,°\text{F} => \boldsymbol{T_{dK}} = \frac{68 + 32}{1.8} + 273.15 = 293.15\ \text{K}$$

2. Calculate RH using formulae [1] and [2].

$$RH = \frac{P_w(T_{dK})}{P_{ws}(T_K)} \cdot 100\%rh \qquad (1)$$

$$RH = \frac{a_0 \times \exp\left[\frac{a_1}{T_{dK}} + a_2 + a_3 T_{dK} + a_4 T_{dK}^2 + a_5 \ln(a_6 \times T_{dK})\right]}{a_0 \times \exp\left[\frac{a_1}{T_K} + a_2 + a_3 T_K + a_4 T_K^2 + a_5 \ln(a_6 \times T_K)\right]} \cdot 100\%rh \qquad (1) + (2)$$

Place the coefficients a0-a6 and temperatures in the equation, giving us
RH = 73.80 %

Calculation formula where process pressure is considered

Water vapor pressure describes a situation where at least two components form a gas mixture. Thus, the gas cannot be considered an ideal gas and an enhancement factor (f) is introduced to correct the non-ideality effects of humid gases.

For atmospheric pressure and vacuum pressures this effect is typically negligible, but as the gas pressure increases so do the non-ideality effects. In a pressurized process, an enhancement factor (f) must be added to the water vapor pressure equation so that the pressure range 0 … 2 MPa can be covered. Note that equations [3], [4], [4.1], and [4.2] use Celsius scaling instead of Kelvin.

$$\left.\begin{matrix} P_w(T_d) \\ P_{ws}(T) \\ P_{is}(T) \end{matrix}\right\} = e_w/e_{ws}/e_{is} \cdot f(T/T_d, P)\,, where \qquad (3)$$

f = enhancement factor
p = total pressure, Pa
T = temperature, °C
T_d = dew point temperature, °C

The enhancement factor (f) for air pressures greater than 1100 hPa is typically determined using the formula developed by Lewis Greenspan [4]. The coefficients used in this white paper [5] have been calculated by Bob Hardy. Note that the values of this formula are valid for CO_2-free moist air. In general, these values are valid for nitrogen and air, but if the carrier gas is something else, for example CO_2 or CH_4, the formula is no longer valid.

$$f(T,P) = exp[\alpha(T) \cdot (1 - \frac{P_{ws/is}}{P}) + \beta(T) \cdot (\frac{P}{P_{ws/is}} - 1)], where \qquad (4)$$

$$\alpha(T) = \sum_{i=0}^{3} \alpha_i \cdot T^i \qquad (4.1)$$

$$\beta(T) = exp[\sum_{i=0}^{3} \beta_i \cdot T^i] \qquad (4.2)$$

Coefficients α0 … α3 ja ß0 … ß3 can be found from Table 2:

Table 2. Numerical values for coefficients α0 … α3 and β0 … β3 [5]

Coefficients α_n & β_n	Over water (0 … 100 °C)	Over Ice (-100 … 0 °C)
α_0	3.5362400E-04	3.64449000E-04
α_1	2.9328363E-05 °C^{-1}	2.9367585E-05 °C^{-1}
α_2	2.6168979E-07 °C^{-2}	4.8874766E-07 °C^{-2}
α_3	8.5813609E-09 °C^{-3}	4.3669918E-09 °C^{-3}
β_0	-1.07588000E+01	-1.07271000E+01
β_1	6.3268134E-02 °C^{-1}	7.6215115E-02 °C^{-1}
β_2	-2.5368934E-04 °C^{-2}	-1.7490155E-04 °C^{-2}
β_3	6.3405286E-07 °C^{-3}	2.4668279E-06 °C^{-3}

Calculate and convert humidity parameters with your smartphone

The Vaisala Humidity Calculator simplifies complex humidity calculations and conversions. It helps you calculate several humidity parameters based on only one known value and tolerance. You can make unit conversions, see the effects of changing ambient conditions such as temperature and pressure, and adjust ambient conditions accordingly. The calculator can be used via web browser on your smartphone or laptop.

You can find the calculator at
www.vaisala.com/humiditycalculator

What to consider when selecting measurement instruments for high-humidity measurement applications

The standards for the features and functionalities of your measurement instruments should be kept high as measurement accuracy and stability have a significant impact on process and end-product quality.

Here are some questions to ask when choosing measurement instruments:

- Is the measurement technology reliable and developed in the manufacturer's own cleanroom?
- Do the measurement instruments conform to global standards?
- Is there a product available that includes sensor-heating technology?
- Does the IP rating of the instrument match your needs?
- Do the available measurement parameters and output options match your needs?
- Is the manufacturer trustworthy and able to provide ongoing support ?
- Is the manufacturer able to serve you globally with quick deliveries when needed?
- Is the manufacturer able to develop their product ecosystem to meet your needs in the long run?

Find measurement instruments that meet your requirements by visiting
www.vaisala.com
or by contacting your local Vaisala representative.

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