

BASIC HUMIDITY DEFINITIONS

Dalton's Law

P_m

John Dalton was first to surmise that the **total pressure** (P_m) exerted by a mixture of gases or vapors is the sum of the pressures of each gas if it were to occupy the same volume by itself. The pressure which each gas exerts is called its **partial pressure**. If P_x , P_y , and P_z represent the respective partial pressures of gases X, Y, and Z in a mixture, Dalton's law states:

$$P_m = P_x + P_y + P_z + \dots$$

The concept of Dalton's law is often overlooked in considering problems in humidity measurement, because one forgets that the "water" in a gas is actually a gas itself and must be treated in accordance with the gas laws. Air must be considered a mixture of gases – oxygen, nitrogen, and water vapor (neglecting the minor constituents). All discussions and definitions of humidity can be reduced to discussions and definitions of water vapor pressure.

Saturation Vapor Pressure Dew Point

P_{ws}

Saturation vapor pressure P_{ws} is the maximum water vapor pressure that can exist at a given temperature.

Dew Point

DP

Dew point (DP) is that unique temperature to which the air (or any gas) must be cooled in order that it shall be saturated with respect to **water**.

Frost Point

FP

Frost point (FP) is that unique temperature to which the air (or any gas) must be cooled in order that it shall be saturated with respect to **ice**.

Note: the dew point or frost point DEFINES the partial pressure of water vapor in the gas.

Relative Humidity

RH

Relative humidity (RH) is the ratio of the actual vapor pressure (P_w) in the gas mixture to the saturation vapor pressure (P_{ws}), with respect to water, at the prevailing dry

bulb temperature. Relative humidity is expressed as a percentage.

$$RH = \frac{P_w}{P_{ws}} \times 100$$

Example 1.

If the dew point = 10°C and the dry bulb = 25°C:

$$RH = \frac{P_w \text{ at } 10^\circ\text{C}}{P_{ws} \text{ at } 25^\circ\text{C}}$$

$$RH = \frac{12.272 \text{ mb}}{31.671 \text{ mb}} = 38.7\%$$

If the frost point = -45°C and the dry bulb = -40°C:

$$RH = \frac{P_w \text{ at } -45^\circ\text{C}}{P_{ws} \text{ at } -40^\circ\text{C (with respect to water)}}$$

$$RH = \frac{0.1111 \text{ mb}}{0.1891 \text{ mb}} = 58.8\%$$

Example 2.

If the dew point = 50°F and the dry bulb = 90°F:

$$RH = \frac{P_w \text{ at } 50^\circ\text{F}}{P_{ws} \text{ at } 90^\circ\text{F}}$$

$$RH = \frac{.03624 \text{ inHg}}{1.422 \text{ inHg}} = 25.5\%$$

If the frost point = -50°F and the dry bulb = -40°F:

$$RH = \frac{P_w \text{ at } -50^\circ\text{F}}{P_{ws} \text{ at } -40^\circ\text{F (with respect to water)}}$$

$$RH = \frac{1.990 \times 10^{-3} \text{ inHg}}{5.584 \times 10^{-3} \text{ inHg}} = 35.6\%$$

NOTE: RH is arbitrarily defined with respect to water even though it seems that it should be with respect to ice at -40°C (-40°F).

Parts Per Million by Volume

PPMV

Parts per million by volume (PPM_v) is the ratio of the partial pressure of water vapor to the partial pressure of the dry gas.

Example 1.

If the frost point = -60°C and system total pressure (P_m) is 1013 mb:

$$\begin{aligned} \text{PPM}_v &= \frac{\text{Parts}}{\text{Million}} \\ &= \frac{P_w \text{ at } -60^\circ\text{C}}{P_m - P_w \text{ at } -60^\circ\text{C}} \times 10^6 \\ &= \frac{10.80 \times 10^{-3} \text{ mb}}{1013 \text{ mb} - (10.8 \times 10^{-3}) \text{ mb}} \times 10^6 \\ &= 10.7 \text{ PPM}_v \end{aligned}$$

Example 2. (English Units)

If frost point = -70°F and P_m is 29.92 inHg:

$$\begin{aligned} \text{PPM}_v &= \frac{\text{Parts}}{\text{Million}} \\ &= \frac{P_w \text{ at } -70^\circ\text{F}}{P_m - P_w \text{ at } -70^\circ\text{F}} \times 10^6 \\ &= \frac{4.974 \times 10^{-4} \text{ inHg}}{29.92 - (4.974 \times 10^{-4}) \text{ inHg}} \times 10^6 \\ &= 17 \text{ PPM}_v \end{aligned}$$

Parts Per Million by Weight

PPMW

Parts per million by weight of dry gas (PPM_w) is identical to PPM_v except that the weight ratio changes with the molecular weight of the carrier gas.

Example 1.

If the frost point = -60°C and the carrier gas is hydrogen:

$$\text{PPM}_w = \text{PPM}_v \times \frac{\text{Molecular weight of water}}{\text{Molecular weight of carrier gas}}$$

$$= 10.7 \times \frac{18}{2} = 96.3 \text{ PPM}_w$$

Example 2.

If the frost point = -70°F and system total pressure is 14.7 PSIA, and the carrier gas is hydrogen:

$$\begin{aligned} \text{PPM}_w &= \text{PPM}_v \times \frac{\text{Molecular weight of water}}{\text{Molecular weight of carrier gas}} \\ &= 16.7 \times \frac{18}{2} = 150.3 \text{ PPM}_w \end{aligned}$$

Molecular weight of common gases:

Acetylene	26	Helium	4
Air	29	Hydrogen	2
Ammonia	17	Methane	16
Argon	43	Nitrogen	28
Carbon dioxide	44	Oxygen	32
Carbon monoxide	28	Sulfur Dioxide	64
Ethylene	28	Water	18

Dew Point / Frost Point Relationships

FPR

Below 0°C (32°F), dew point hygrometers measure the frost point temperature rather than the dew point. The tables below permit conversion from dew to frost point. For a more accurate conversion, consult Table 102 of the Smithsonian Meteorological Table.

Degrees Celsius							
FP	DP	FP	DP	FP	DP	FP	DP
0.0	0.0	-12.0	-13.4	-24.0	-26.2	-36.0	-39.4
-1.0	-1.2	-13.0	-14.5	-25.0	-27.7	-37.0	-40.5
-2.0	-2.3	-14.0	-15.6	-26.0	-28.8	-38.0	-41.6
-3.0	-3.4	-15.0	-16.7	-27.0	-29.9	-39.0	-42.6
-4.0	-4.5	-16.0	-17.8	-28.0	-30.9	-40.0	-43.7
-5.0	-5.6	-17.0	-18.9	-29.0	-32.0	-41.0	-44.7
-6.0	-6.8	-18.0	-20.0	-30.0	-33.0	-42.0	-45.8
-7.0	-7.9	-19.0	-21.1	-31.0	-34.1	-43.0	-46.8
-8.0	-9.0	-20.0	-22.2	-32.0	-35.2	-44.0	-47.9
-9.0	-10.1	-21.0	-23.3	-33.0	-36.2	-45.0	-49.0
-10.0	-11.2	-22.0	-24.4	-34.0	-37.3	-46.0	-50.0
-11.0	-12.3	-23.0	-25.5	-35.0	-38.4		

REFERENCE: Smithsonian Meteorological Tables, Sixth Revised Edition, List, Robert J., Publication No. 4014, Smithsonian Institution, Washington, D.C.

As the total pressure of a gas sample changes, the partial pressures of the gases comprising the total pressure change in the same ratio.

Example 1.

If frost point = -60°C and the system total pressure is 1013 mb what is the frost point at 21 bar?

$$\frac{P_w \text{ at } -60^\circ\text{C}}{1.013 \text{ bar}} = \frac{\text{Vapor Pressure at New Frost Point}}{21 \text{ bar}}$$

$$P_w \text{ at new frost point} = \frac{(10.8 \times 10^{-6}) \times 21 \text{ bar}}{1.013 \text{ bar}} = .000223 \text{ bar}$$

From the Vapor Pressure Tables (over ice), **the new Frost Point = -35.2°C.**

Example 2.

If the frost point = -70°F and the system total pressure is 14.7 PSIA, what is the frost point at 84.7 PSIA?

$$\frac{P_w \text{ at } -70^\circ\text{F}}{14.7 \text{ PSIA}} = \frac{P_w \text{ at new frost point}}{84.7 \text{ PSIA}}$$

$$P_w \text{ at new frost point} = \frac{4.974 \times 10^{-4} \text{ inHg} \times 84.7 \text{ PSIA}}{14.7 \text{ PSIA}} = 2.87 \times 10^{-3} \text{ inHg}$$

From the Vapor Pressure Tables (over ice) **the new frost point = -44.5°F.**

Rule of Thumb: If you increase the total pressure of a system, the dew/frost point temperature will increase. If you decrease the total pressure of a system, the dew/frost point temperature will decrease.

Equivalent Dewpoint at Various Process Pressures

