Welcome
Vaisala Humidity 101 – Humidity Theory, Terms & Definitions

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Agenda

1. Why does it help to understand humidity?
2. Dalton’s Law
3. Vapor pressures
4. Relative humidity
5. Td, x, ppm, Tw, h
- Exists in the three phases
- Which phase depends on the amount of thermal energy that is present
Humidity

1. Generally, some measure of the water vapor content of air.
Dalton’s Law

“The total pressure of a gas is equal to the sum of the different gases’ partial pressures”

\[ P_t = P_1 + P_2 + \ldots + P_n \]

air around us

\[ P_t = P_{N_2} + P_{O_2} + P_w + P_{\text{misc.}} \]

English chemist, meteorologist, physicist
(1766 – 1844)
Practical Example of Dalton’s Law

Nitrogen ..................... 77%
Oxygen ..................... 21%
Water vapor ............. 1%
Other gases ........... 1%

1000 mbar = 770 mbar + 210 mbar + 10 mbar + 10 mbar

How does this change in Denver?

\[ P_t = 840 \text{ mbar} \]

\[ \begin{align*}
647 &\text{ N}_2 + 177 \text{ O}_2 + 8 \text{ P}_w + 8 \text{ Other}
\end{align*} \]

\[ P_t = P_w + P_{\text{dry}} \]
Definitions

Psychrometry
Partial Pressure of Water Vapor (psi, mbar, hPa, inhg…)

**P_w**

“The key parameter that affects all other humidity parameters”

Note: The only two properties that can affect a change in **P_w**
- adding or removing water vapor
- changes in system pressure
Saturation Vapor Pressure (psi, mbar, hPa, in hg…)

On the saturation curve

- evaporation and condensation are in equilibrium and occur at the same rate
- $P_w = P_{ws}$
- dewpoint = temperature
- wet bulb = dry bulb
- RH = 100%

Note: The only property that affects $P_{ws}$ is temperature
**P_{ws} Saturation Vapor Pressure**

$P_{ws}$ - maximum vapor pressure or amount of water vapor that can exist at a given temperature. Expressed in units of pressure.

$P_{ws} = 480$ mbar
Relative humidity is the ratio of water vapor partial pressure present in a gas \((P_w)\) to the saturation vapor pressure of water at that temperature \([P_{ws}(t)]\)

or

The amount of water vapor present in air (gas) expressed as a percentage of the amount needed for saturation at the same temperature.
Bucket Analogy

\[ P_{ws} = \text{bucket size or max amount of water} \]
\[ P_w = \text{amount of water in the bucket} \]

Relative fill = 1/1
100%

Relative fill = 1/10
10%

Relative fill = 1/5
20%
Relative humidity

\[ \%RH = 100 \times \frac{P_w}{P_{ws}(t)} \]

\[ \%RH = 100 \times \frac{200}{480} = 42\% \]

Note: Relative humidity is strongly proportional to temperature and its measurement is very sensitive to temperature differences.
Temperature and Relative Humidity

\[
\%RH = 100 \times \frac{P_w}{P_{ws}(t)}
\]
Temperature and Relative Humidity

\[ \% \text{RH} = 100 \times \frac{P_w}{P_{ws}(t)} \]
Temperature and Relative Humidity – Rule of Thumb #1

Rule of Thumb #1*

- As temperature increases, air becomes drier (RH decreases)
- As temperature decreases, air becomes wetter (RH increases)

• drier and wetter are relative terms; applies to a closed system where pressure and water vapor content do not change
What about pressure and Relative Humidity?

Recall Dalton’s Law of Partial Pressures \( P_t = P_w + P_{dry} \)

If double total pressure;
then \( 2(P_t) = 2(P_w + P_{dry}) = 2P_w + 2P_{dry} \)
so \( P_w \) changes proportionately to overall pressure changes

*remember that \( P_{ws} \) remains unchanged because \( T \) is unchanged*
Pressure and Relative Humidity

\[ P_t = 1000 \text{ mbar} \]

We double the total pressure so \[ P_t = 2000 \text{ mbar} \]

What happens to \( P_w \) \( P_{ws} \)?
Pressure and Relative Humidity – Rule of Thumb #2

Rule of Thumb #2*

- As pressure decreases, air becomes drier (RH goes down)
- As pressure increases, air becomes wetter (RH goes up)

* drier and wetter are relative terms; applies to a closed system where temperature and water vapor content do not change
Relative humidity is the common parameter in HVAC applications where comfort balanced with efficiency is the main concern.
The temperature to which a given portion of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur

The temperature at which a moist gas is saturated with respect to a plane surface of pure liquid water
Dewpoint

\[ T_d = \frac{T_n}{m} \left( \log \left( \frac{P_w}{A} \right) + 1 \right) \]

- changes with water vapor
- changes with pressure

Note: Dewpoint is not a temperature dependent parameter
Beer temperature = 38F

Td = 20F

Glass temperature above the dewpoint – no condensation
Beer temperature = 38°F

Glass temperature below the dewpoint – condensation appears

Td = 45°F
Dewpoint & Pressure
Rule of Thumb

Rule of Thumb

- As pressure increases, dewpoint temperature rises, air becomes more moist (RH increases)
- As pressure decreases, dewpoint temperature goes lower, air becomes drier (RH decreases)

• drier and wetter are relative terms; applies to a closed system where water vapor content does not change
The temperature to which a given portion of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur.

The temperature at which a moist gas is saturated with respect to a plane surface of pure ice.

Note: $T_{d/f}$ is a Vaisala term which means dewpoint above 32°F and frostpoint 32°F and below.
# Dewpoint versus Frostpoint

<table>
<thead>
<tr>
<th>Frostpoint</th>
<th>Dewpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.10° C</td>
<td>-0.11° C</td>
</tr>
<tr>
<td>-5.00° C</td>
<td>-5.64° C</td>
</tr>
<tr>
<td>-10.00° C</td>
<td>-11.23° C</td>
</tr>
<tr>
<td>-20.00° C</td>
<td>-22.25° C</td>
</tr>
<tr>
<td>-30.00° C</td>
<td>-33.09° C</td>
</tr>
<tr>
<td>-40.00° C</td>
<td>-43.74° C</td>
</tr>
<tr>
<td>-50.00° C</td>
<td>-54.24° C</td>
</tr>
<tr>
<td>-60.00° C</td>
<td>-64.59° C</td>
</tr>
<tr>
<td>-70.00° C</td>
<td>-74.88° C</td>
</tr>
<tr>
<td>-80.00° C</td>
<td>-85.29° C</td>
</tr>
<tr>
<td>-90.00° C</td>
<td>-96.37° C</td>
</tr>
</tbody>
</table>

Diagram:

```
<table>
<thead>
<tr>
<th>AIR evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR evaporation</td>
</tr>
<tr>
<td>condensation</td>
</tr>
<tr>
<td>ICE</td>
</tr>
</tbody>
</table>
```
Td/f – gives you dewpoint at 32 degrees (F) and above and frostpoint below 32 degrees (F)

Td – gives you dewpoint across the entire range of temperatures and assumes supercooled water below 32 degrees (F)
Application Example - compressed air

Dewpoint is the common parameter for measurement in compressed air systems and plastics production feed drying.
Mixing Ratio or Humidity Ratio (g/kg, gr/lb)

-the ratio of the mass of water vapor per unit mass of dry air to which it is associated

\[ X = B \frac{P_w}{(P_{\text{tot}} - P_w)} \]

\[ B = 621.9907 \text{ g/kg} \]

Note: mixing ratio is an absolute measure, not affected by temperature or pressure
Application Example – drying process

Mixing ratio can be used as a measure to help determine drying time where moisture content of a product is important like paper drying or dog biscuit drying.
ppm\textsubscript{v} ppm\textsubscript{w} \hspace{1cm} \text{parts per million (volume/weight)}

ppm\textsubscript{v} \hspace{1cm} \text{volume of water vapor per total volume of dry gas}

\[ \text{PPM}_v = \frac{P_w}{(P_{\text{tot}} - P_w)} \times 10^6 \]

ppm\textsubscript{w} \hspace{1cm} \text{mass of water vapor per total mass of dry gas}

\[ \text{PPM}_m = \frac{M_w P_w}{M_d (P_{\text{tot}} - P_w)} \times 10^6 \]

Note: ppm is an absolute measure, not affected by temperature or pressure
Mw is molecular mass of water ; Md is molecular mass of dry air
### ppm\(_v\) and ppm\(_w\)

<table>
<thead>
<tr>
<th>Td/f</th>
<th>PPM(_w)</th>
<th>PPM(_v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40.00</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>-35.00</td>
<td>24</td>
<td>39</td>
</tr>
<tr>
<td>-30.00</td>
<td>42</td>
<td>67</td>
</tr>
<tr>
<td>-25.00</td>
<td>69</td>
<td>111</td>
</tr>
<tr>
<td>-20.00</td>
<td>113</td>
<td>181</td>
</tr>
<tr>
<td>-15.00</td>
<td>181</td>
<td>290</td>
</tr>
<tr>
<td>-10.00</td>
<td>284</td>
<td>456</td>
</tr>
<tr>
<td>-5.00</td>
<td>439</td>
<td>706</td>
</tr>
</tbody>
</table>

\[
\text{PPM}_v = \frac{P_w}{(P_{tot} - P_w)} \times 10^6
\]

\[
\text{PPM}_m = \frac{M_w P_w}{M_d (P_{tot} - P_w)} \times 10^6
\]

\[M_w/M_d = .621980\]
Application Example – glove box

ppm is sometimes used in dry environments where very precise absolute measurement is required such as in a glove box or clean room.
Absolute Humidity \((g/m^3, \, gr/ft^3, \, lbs/MMcf)\)

- the mass of water vapor per unit volume of moist air
- the density of the water vapor

\[ A = C \frac{P_W}{T} \quad (g/m^3), \text{where} \]

\[ C = \text{constant} \quad 216.679 \, \text{gK/J} \]

\[ P_W = \text{vapour pressure in hPa} \]

\[ T = \text{temperature in K} \]
Application Example – natural gas

Absolute humidity is the common parameter for measurement of moisture content in natural gas (in the U.S.)
the temperature indicated by a thermometer sheathed in a wet cloth as air is passed over it
Application Example
– evaporative cooler or swamp cooler

By comparing the wet bulb temperature to the dry bulb temperature we can determine cooling capacity of an evaporative cooler.
Enthalpy \( (\text{kJ/kg}; \text{btu/lb}) \)

- Measure of the total energy in a moist gas
- Heat content
- Sum of the latent heat + sensible heat

Figure 6-2.—Relationship between temperature and the amount of heat required per pound (for water at atmospheric pressure).
Application Example - HVAC

Enthalpy is a useful measurement for determining HVAC equipment size and efficiency.
Psychrometric Terms

- relative humidity
- partial pressure of water vapor
- saturation pressure
- dewpoint/frostpoint
- absolute humidity
- mixing ratio/humidity ratio
- wet bulb temperature
- ppm
- ppm
- enthalpy

<table>
<thead>
<tr>
<th>Term</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity</td>
<td>RH</td>
<td>[%RH]</td>
</tr>
<tr>
<td>Partial pressure of water vapor</td>
<td>(P_w)</td>
<td>[mbar; in. Hg, etc.]</td>
</tr>
<tr>
<td>Saturation pressure</td>
<td>(P_{ws})</td>
<td>[mbar; in. Hg, etc.]</td>
</tr>
<tr>
<td>Dewpoint/frostpoint</td>
<td>(T_{d/f})</td>
<td>[°C; °F]</td>
</tr>
<tr>
<td>Absolute humidity</td>
<td>(a)</td>
<td>[g/m(^3); gr/ft(^3)]</td>
</tr>
<tr>
<td>Mixing ratio/humidity ratio</td>
<td>(x)</td>
<td>[g/kg; gr/lb]</td>
</tr>
<tr>
<td>Wet bulb temperature</td>
<td>(T_w)</td>
<td>[°C; °F]</td>
</tr>
<tr>
<td>Enthalpy</td>
<td>(h)</td>
<td>[kJ/kg; Btu/lb]</td>
</tr>
</tbody>
</table>
Summary

1. Water vapor theory
2. Dalton’s law of partial pressures
3. $P_w$ & $P_{ws}$
4. $RH = \frac{P_w}{P_{ws}}$
5. Temperature and RH – Rule of thumb
6. Pressure and RH – Rule of thumb
7. Absolute parameters – $x$, ppm
Vaisala Humidity Resources

- On-line Humidity Calculator  [www.vaisala.com/humiditycalculator](http://www.vaisala.com/humiditycalculator)
- Psychrometric Chart - [http://forms.vaisala.com/forms/RequestPsychChart](http://forms.vaisala.com/forms/RequestPsychChart)
- Humidity Conversion Formulas  - [http://forms.vaisala.com/forms/humidity_conversion](http://forms.vaisala.com/forms/humidity_conversion)

For expert assistance with your humidity measurement
Request info:  [Click here](http://forms.vaisala.com/forms/RequestContact) to fill out ‘Request Contact’ form
Direct telephone:  800-408-9454
Website:  [www.vaisala.com](http://www.vaisala.com)
Next Webinar – Humidity Sensor Technology - Tutorial

Wednesday, June 26th, 9:30AM MDT
- Humidity Sensor Technology

For full Webinar Schedule info please [click here](#).

Everyone who registered for Humidity Theory will get the invitation for Sensor Technology.

You will receive a follow up email with all of the resource links & link to recording.
Thank you!
This concludes the webinar.

Follow-up email will arrive shortly with the resource links & further contact information.