Gas humidity

ELEC-5710 Sensors and Measurement Methods
2017

What is humidity?
Water vapor in gas or in other substances
• In gas: Humidity
• In other substances: Water content

Described with different quantities:
• Absolute humidity
• Mass mixing ratio
• Specific humidity
• Relative humidity

Absolute humidity (AH) and Relative humidity (RH)
• The mass of water vapor in a certain volume of gas:

\[ AH = \frac{m_v}{V} \]

• Known also as volumetric humidity
• Absolute humidity changes as a function of temperature and pressure
  – The quantity does not fit well to situations where temperature changes a lot
  – Sometimes (incorrectly) absolute humidity refers to mass ratios
• Relative humidity, expressed as a percent, measures
  the current absolute humidity relative to the maximum
  (highest point) for that temperature.
Mass ratios

- **Specific humidity** is the mass of water vapour in relation to the total mass
  \[ SH = \frac{m_v}{m_t} \]
  \[ m_v + m_g = m_t \]
- **Mass mixing ratio** is the mass of water vapour in relation to the mass of dry gas
  \[ MR = r = \frac{m_v}{m_g} \]
- Temperature does not affect mass ratios (unless condensation happens)

Dalton’s law of partial pressures

\[ P_{\text{av}} = P_N + P_O + P_{H_2O} + P_{CO_2} + \ldots \]

Saturated water vapour

- Pressure is at the highest
- Equilibrium with planar water or icy surface
- Temperature drops \( \rightarrow \) condensation
- Pressure rises \( \rightarrow \) condensation
- Dew point: \( t_d \)
Pressure of saturated water vapour in air

Relative humidity (RH)

- Vapour pressure ratio to saturated vapour pressure at the same temperature
  \[ RH = \phi = \frac{P_{(H_2O)}}{P_{(H_2O)\text{sat}}} \times 100\% = \frac{MR}{MR_\text{sat}} \times 100\% = \frac{SH}{SH_\text{sat}} \times 100\% \]

- Reveals how close the dew point is
- Important at weather forecasts
- Affects human's comfort
  - Thermal regulation of a body, high dew point less comfortable
The effect of temperature to relative humidity

![Graph showing the effect of temperature on relative humidity]

**Hygrometer**

- Most accurate result by measuring dew point
  - Detecting the phase change of water
- The effect of water vapour to electrical, mechanical and optic properties of a material
Detecting the phase change of water: Optical dew point sensor

- A mirror is cooled to the dew point
- The deposit of moisture on the mirror surface is kept constant by controlling the Peltier element
- The deposit of moisture is measured optically and the signal then controls the Peltier element

The uncertainty of the device is 0.1-0.3 °C

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Detecting the phase change of water: Optical dew point sensor

+ Accurate
+ Wide range (-80 °C … +100 °C)
+ Stable
- Expensive
- The mirror needs regular cleaning
- Slow
Detecting the phase change of water:

Psychrometer

- Two temperature sensors: dry and wet
- Water evaporates from the wet side and drops its temperature
- Wet side cools to "wet bulb temperature"

Temperature range > 0 °C
- Uncertainty even 2 %RH
- Long-term stability
- Wide humidity range (1-100 %RH)
- Withstands exposure to water
  - Air flow
  - Maintenance (adding distilled water, changing sock)

Detecting the phase change of water:

Other dew point sensors

Instead of optical detection:
- Quartz crystal microbalance, QCM (change of frequency)
  - Especially below 0 °C
  - Relatively new method, not widely in use
- Thermic (change of heat flux)
  - Especially high humidities and temperatures
  - Not produced anymore?
- Impedance
  - Normal humidity zone
  - Fast
Detecting the phase change of water: Surface acoustic wave dew point sensor (SAW)

- Surface acoustic wave damps when ice or water is formed on a surface of a sensor
- Vaisala has been the only manufacturer; not produced anymore

Capasitive polymer sensors

- The most common RH sensor type
- Measurement range even 0-100 %RH
- Uncertainty at best 2 %RH
- Wide temperature range: -40 ... +80 °C

- Easy to use, small scale
- Withstands exposure to water (after that requires a calibration)
- Fast, sensitive, wide temperature range

- Relatively poor stability
- Hysteresis
- Temperature dependency (temperature sensor in the same device)
- Individuality (necessity to calibrate)
**Other sensor types**

- **Resistive sensors**
  - Conducting polymers
  - Usually less sensitive and accurate than capacitive

- **Mechanical**
  - Thermohygrographs, hair tension hygrometers
  - No longer in use

**Other sensor types**

- **Optical**
  - Spectroscopic:
    - air absorption
  - Fiber optical:
    - moisture detector

- **Mechanical properties**
  - Quartz crystal microbalance (QCM)