Humidity Theory: Understanding Humidity

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Product Manager, Industrial Instruments
http://go.vaisala.com/humiditycalculator/5.0

<table>
<thead>
<tr>
<th>Ambient conditions</th>
<th>Value</th>
<th>Unit/Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>21</td>
<td>°C</td>
</tr>
<tr>
<td>Pressure</td>
<td>1013.3</td>
<td>mbar</td>
</tr>
<tr>
<td>Gas type</td>
<td>Air</td>
<td></td>
</tr>
<tr>
<td>Psychrometer</td>
<td>Standard</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fill in the known parameter to calculate other values</th>
<th>Value</th>
<th>Unit/Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity (%RH)</td>
<td></td>
<td>%RH</td>
</tr>
<tr>
<td>Dewpoint</td>
<td>-2.8964</td>
<td>°C</td>
</tr>
<tr>
<td>Parts per million (ppm)</td>
<td>4949.6</td>
<td>PPMmol</td>
</tr>
<tr>
<td>Absolute humidity (a)</td>
<td>3.6761</td>
<td>g/m³</td>
</tr>
<tr>
<td>Mixing ratio (x)</td>
<td>3.0786</td>
<td>g/kg</td>
</tr>
<tr>
<td>Water content (w)</td>
<td>233.82</td>
<td>lb/MMscf</td>
</tr>
<tr>
<td>Vapor pressure (pv)</td>
<td>4.9905</td>
<td>mbar</td>
</tr>
<tr>
<td>Wet bulb</td>
<td>18.032</td>
<td>°C</td>
</tr>
<tr>
<td>Enthalpy</td>
<td>28.944</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>Entrope</td>
<td>-2.4525</td>
<td>°C</td>
</tr>
<tr>
<td>Saturation vapor pressure (pws)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific Volume</td>
<td>24.952</td>
<td>m³/kg</td>
</tr>
</tbody>
</table>

[Image of a humidity calculator webpage]
Content

- Theory, terms and definitions
  - Evaporation and condensation, equilibrium
  - Vapor pressure, saturation vapor pressure
  - Relative humidity, dew point temperature, frost point temperature
  - Other humidity variables: Wet-bulb temperature, mixing ratio
- Choosing the correct instrument
How does humidity affect your day?
Theory, terms and definitions
Concepts

- Humidity
- Vapor pressure, partial pressure
- Evaporation, condensation, equilibrium
- Saturation vapor pressure
- Relative humidity
- Dew point temperature
What is humidity

- Humidity is dissolved water
- Humidity is in gas phase
- Moisture - wetness of the solid material

If you can see it, it is not humidity
The water molecule

- Polarity – uneven distribution of electrical charge, causing attraction between molecules
Vapor pressure

- Molecules in gas phase are in constant random motion
- This motion exerts **pressure**
  - The more molecules, higher the vapor pressure
- The energy of the molecules depends not only on the amount, but also **temperature**
Partial pressure of water

- The total pressure is the sum of the partial pressures of the components in the gas (Dalton’s law)

- The partial pressure exerted by water vapor is called the vapor pressure $P_w$

500 hPa Air + 500 hPa Water = 1000 hPa (14.5 PSIA) total

$P_{tot} = P_1 + P_2 + P_3\ldots$

= $P_{air} + P_{water}$
Example: Water in a Closed Container

- **Evaporation:** As a result of the random movement of molecules, some molecules have enough energy to escape through the water film.

- **Condensation:** As a result of random movement of molecules, some move so slow they get trapped back in water.

- **Equilibrium:** With time, rate of evaporation equals rate of condensation.
The Effect of Temperature

Notice the impact of **temperature** on equilibrium vapor pressure as it goes from 50 to 104 °F!
Saturation vapor pressure

- The equilibrium of water vapor in a closed container is the **saturation vapor pressure** in that particular temperature
  - Condensation rate equals evaporation rate
  - Air cannot hold any more water vapor

**Saturation vapor pressure is highly temperature dependent**

![Graph showing the relationship between temperature and saturation vapor pressure](attachment:image)
The humidity variables I know or use:

A. Relative humidity
B. Vapor pressure
C. Dew-point/Frost-point temperature
D. Mixing ratio
E. Absolute humidity
F. Wet-bulb temperature
G. Water content [lb/MMscf, g/Nm³]
H. PPM (parts per million)
Relative Humidity

The proportion of water vapor pressure ($P_w$) to the maximum vapor pressure in the given temperature [$P_{ws}(t)$]

$$\%RH = \frac{\text{Vapor pressure}}{\text{Saturation vapor pressure at the particular temperature}}$$
Example

- Let’s assume we have vapor pressure of 100 hPa

  ..And temperature 100 °C
  \[ \text{RH} = \frac{100}{1013} = \approx 10 \% \]

  ..And temperature 60 °C
  \[ \text{RH} = \frac{100}{200} = \approx 50 \% \]

  ..And temperature 45,8 °C
  \[ \text{RH} = \frac{100}{100} = \approx 100 \% \]
Relative humidity is by definition relative to

A. Absolute amount of water in the air
B. Temperature
C. Total pressure of the system
When temperature of a gas sample is increased

A. Relative humidity increases
B. Dew point temperature decreases
C. Relative humidity decreases
Dew Point Temperature

- Dew point temperature is the temperature, where the vapor pressure would equal to saturation vapor pressure.
- This is the temperature, where the given humidity level condenses by effect of temperature.
- Proportional to amount of water vapor.
Dew point temperature only depends on

A. Amount of water vapor in the air
B. Vapor pressure
C. Temperature
Impact of pressure

- Let’s assume a closed container with water vapor pressure of 10 hPa (0.145 PSIA) dew point temperature of 7 °C (44.6 °F) and total pressure of 1 bar (14.5 PSIA)

- When we compress the gas isothermally to 4 bars (58 PSIA), the vapor pressure increases linearly

- As a result, the vapor pressure would be 40 hPa (0.58 PSIA) and corresponding dew point temperature 28 °C (82.4 °F). Under room temperature, condensation would occur.

Compressing until vapor pressure reaches saturation: ”squeezing” water out in compression dryers.
Frost Point Temperature

- Frost point temperature is the temperature, where the water vapor condenses directly to solid ice, or frost
- Relevant in dry conditions where saturation temperatures are well below freezing point
Frost point temperature

Temperature -2°C (28.4°F)

- Saturation vapor pressure over ice is slightly lower than over supercooled water
  - Water molecules in ice form a rigid lattice
  - Lower rate of evaporation
  - Lower saturation vapor pressure

- In most cases frostpoint is more useful with freezing saturation temperatures as it represents the natural saturation temperature

\[ P_w = 5.3 \text{ hPa} \quad \text{or} \quad P_w = 5.1 \text{ hPa} \]

\[ = 0.08 \text{ PSIA} \quad \text{or} \quad = 0.07 \text{ PSIA} \]
How much do frost point and dew point differ?

- The difference is ~10% of indication

- Vaisala products output Tdf, which is dew point when saturation temperature is above freezing point, and frost point when saturation temperature is below freezing point
When measuring dew point, what does not induce a change in the reading:

A. Changing pressure of the gas sample
B. Changing temperature of the gas sample
C. Changing amount of water vapor in the gas sample
Wet-bulb temperature

- Evaporation involves change in energy
- Evaporation process involves cooling effect
- Rate of evaporation is governed by relative humidity
- Wet-bulb represents the lowest achievable temperature by means of evaporation of water
- Dry- and wet-bulb temperatures are tabulated for conversion to RH

A psychrometer in a climate chamber
Mixing ratio

- Gives the mass of water vapor divided by total gas mass
- Independent on temperature or pressure

- Typical applications:
  - process control, drying
  - Mass balance calculations
  - Processes where pressures and temperatures vary from one stage to another

*Mixing ratio represents the mass fraction of water in the gas*
Ppm (Parts Per Million)

- Vaisala products output ppm –value per dry bases
  - Amount of water divided by amount of dry air
  - Volumetric (ppmv) and by-weight (ppmm) numbers available

- Mostly used in trace humidity measurements

- Note – exponential relation to wet basis ppm number (amount of water divided by total amount of wet gas)
Theory in practice
Measurements under high humidity-
Case example: Ceramics drying kiln
Normal probe in high humidity application (ceramics dryer)

![Graph showing relative humidity (RH) over time. The graph indicates a curve that drops from 100% RH to approximately 20% RH within 50 hours. The curve has two distinct dips near 45 hours, and the probe remains at 20% RH after 50 hours. The graph is labeled with 'RH [%] without warmed probe' and has a note 'Probe in saturation' at the top left corner.]
Warmed Probe Technology

- With additional T-probe; temperature elevated from ambient
  - Without additional T-probe (heated dew point measurement) seeks to 70..80 %RH

- Constant heating; affects the filter

- **XHEAT** for rapid condensation recovery

Whole probe heated above ambient
a must in a fuel-cell applications
dew-point and T back-calculated to Relative humidity
How does probe warming work?

\[
T_{\text{ambient}} = 14 \, ^\circ\text{C} \, (57.2\, ^\circ\text{F})
\]
\[
\text{RH}_{\text{ambient}} = 97\% \, \text{RH}
\]

\[
T_{\text{ambient}} = 14 \, ^\circ\text{C} \, (57.2\, ^\circ\text{F})
\]

\[
T_{\text{sensor}} = 16 \, ^\circ\text{C} \, (60.8\, ^\circ\text{F})
\]
\[
\text{RH}_{\text{sensor}} = 83 \, \%
\]
\[
\text{RH} \, \text{at} \, 14\, ^\circ\text{C} = 97 \, \% \, \text{RH}
\]
**HMT337 warmed probe**

- Condensation problem solved
- Better quality
- Better yield
Practical control application in a ceramics dryer
A customer case

- Ceramics dryer
- Control options
  - No control
  - Indirect control by feed rate
  - Humidity based control

Control variables: temperature and humidity mixing ratio

\[ t = 130..140 \, ^\circ\text{C} \]
\[ x = 100 \, \text{g/kg} \quad (t_d = 53 \, ^\circ\text{C}) \]

\[ \text{RH} = 5 \% \]
Another supplier said..

- Brand X distributors proposed solution:

"calibration at process temperature will provide the necessary accuracy"

Specified accuracy at 23°C: 0.8 %RH
Accuracy of control

- T = 130 °C
- RH = 5 % +/- 3%
  - Brand X specified repeatability short-term: 0,5 %RH
  - Brand X hysteresis: 1,5 %RH
  - Brand X estimated drift in 1 year: 2 %RH

x = 100 +/- 80 g/kg  Another brand

- DMT345 specified accuracy full scale:
  Td = 53 +/- 2 °C

x = 100 +/- 10 g/kg  VAISALA

RH inaccuracy multiplies in high temperatures for calculated variables
DMT345 for high temperatures

- DRYCAP180S sensor
- High dew point measurements up to 140 °C dry-bulb
- Low dew-point applications (ovens and similar) up to 100 °C dry-bulb temperature
- Installation flange and long probe provide easy installation through insulation materials
What should be considered when measuring elevated or variable temperatures?

- What is the maximum temperature at the measurement position?
- Is the instrument specified for accuracy in my temperature range?
- What is the instrument’s accuracy in terms of the engineering unit I am using?
Cooling towers and wet-bulb temperature
Practical issues

- Maintenance
  - Scaling
    - Reduced performance
    - Make-up water
  - Pumps and fans

- Control
  - Temperature set-point
    - Generally optimal 2..3 °C above the wet-bulb temperature
    - Too small approach leads to excessive evaporation and windage loss
Unshielded installation with low quality sensor

- Radiated heat +3 °C (5.4 °F)
- Drift of the sensor +/- 5 %RH
- Wet-bulb temperature +2 °C (+3.6 °F)

75 %RH calibration after outdoor testing

Impossible to control accurately for optimizing approach (2..3 °C)
A good installation with a high-quality sensor

Radiated heat +0.2 °C

Drift of the RH sensor +/- 2 %RH

Wet-bulb temperature +/- 0.3 °C

White top surface on each plat reflects heat

Black bottom surface on each plate effectively emits any absorbed heat
In the set-up below, the theoretical low limit of beverage’s temperature is (use humidity calculator)

A. 25.0 °C (77.0 °F)
B. 20.1 °C (68.2 °F)
C. 14.5 °C (58.1 °F)
D. Don’t know, it’s gone already!
End of part 1
Humidity measurement technologies
History of Humidity Measurement
## Comparison of traditional technologies

<table>
<thead>
<tr>
<th></th>
<th>Mechanical</th>
<th>Psychrometer</th>
<th>Chilled mirror</th>
<th>Resistive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range minimum</strong></td>
<td>10 %</td>
<td>15 %</td>
<td>-95 .. -20 °C Tf</td>
<td>5 %</td>
</tr>
<tr>
<td><strong>Range max</strong></td>
<td>100 %</td>
<td>100 %</td>
<td>&lt; 100 °C Td</td>
<td>100 %</td>
</tr>
<tr>
<td><strong>Accuracy typ.</strong></td>
<td>+/-5%</td>
<td>+/-2..5 %</td>
<td>~1 %RH</td>
<td>+/-5%</td>
</tr>
<tr>
<td><strong>Hysteresis</strong></td>
<td>Very high</td>
<td>None</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>Very poor</td>
<td>Poor</td>
<td>Very good</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Maintenance need</strong></td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Response time</strong></td>
<td>Very slow</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Temp. range</strong></td>
<td>Room temp.</td>
<td>0..100 °C</td>
<td>Room temp</td>
<td>Up to 100 °C</td>
</tr>
</tbody>
</table>
Performance

- Chilled mirror hygrometer
- Laboratory reference etc.
- Requires maintenance
- Accuracy: +/- 0.1 °C in dew point (+/- 0.1..0.9 %RH at room temp)

- HMP7 Relative Humidity and Temperature probe with capacitive HUMICAP sensor
- Field instrument for industrial use
- No regular maintenance need
- Accuracy: +/- 0.8 %RH at room temperature
Radio sonde

- Measurements in atmosphere up to 30 km above sea level with 5 m/s vertical speed
- RH range 0..100 %RH
- Rapid changes up and down
- Temperature +60..-90 °C
- Cloud layer
Vaisala innovation: Capacitive thin-film polymer sensor

- Vaisala founded by prof. Vilho Väisälä in 1940’s

- Humicap invented in 1973
  - For radiosonde application
  - Current de facto technology

- Later on productized for industrial applications
Vaisala HUMICAP®

The sensor capacitance responds directly to changes in **relative humidity**

**Operating range:**
Relative humidity 0..100 %RH
Temperature -40..+180 °C

Withstands chemicals
Withstands wetting
Fast response time
Low hysteresis
Theory of operation

Overlap

Upper Electrode

Lower Electrode

Thin-Film Polymer

Glass Substrate

Distance $d$

Dielectric with Permittivity $\varepsilon$

Conductive Plate with Area $A$

Lead $+Q$

Lead $-Q$
HUMICAP sensor is sensitive to changes in

A. Dew point temperature
B. Vapor pressure
C. Relative humidity
HUMICAP® vs DRYCAP®

- Capacitive humidity sensors are sensitive to relative humidity as the primary physical variable.
- HUMICAP® withstands continuous high humidity and immersion 0..100 %RH.
- DRYCAP® is optimized for low humidity measurements, generally for < 10 or 5 %RH.
  - In general, when frost point is below 10 °C.
HUMICAP® sensor types

- HUMICAP180
- HUMICAP180R
- HUMICAP180L2
- HUMICAP180V
- HUMICAP R2 and R2C

Composite temperature sensor for chemical purge

C for Composite
Humicap180RC
Humicap180C
Humicap180VC
Which sensor should I use?

- **HUMICAP180R**
  - R for Robust
  - General purpose

- **HUMICAP180**
  - Previous generation
  - Faster response time under low temperatures

- **HUMICAP180L2**
  - Optimized for measurement of humidity in oil medium

- **HUMICAP R2**
  - General purpose
  - Latest generation, like Humicap180R but with improved corrosion resistance

- **HUMICAP180V**
  - For applications where the sensor is exposed to hydrogen peroxide
HUMICAP® robustness

Saturated Isopropyl Alcohol exposure

Drift at 75 %RH [%RH]

Duration [days]

Humicap180R 75 %RH

Another sensor at 75 %RH
Sensor purge

- Regeneration of the sensing element by brief heating
- Evaporates volatile contaminants from the active polymer
HUMICAP® stability

- Three Humicap180R sensors in outdoor test
- Drift less than 1 %RH over full range
- 1000 days test

Three sensors in outdoor test located in Southern Finland
Full Temperature Range Linearity

Calibration at 70 °C

Deviation from reference [%RH]

Reference %RH

Vaisala HUMICAP
Brand X
Brand Y

© Vaisala
Response time

- The response time of the sensor is ~15 s in room temperature and still air.

- **Diffusion** – temperature
- **Gas exchange** – flow
- **Temperature** – thermal mass

*Diffusion time multiplies by factor of ~2 for every 10 °C decrease in temperature.*

*Humicap180 is slightly faster for diffusion than Humicap180R*

**HUMICAP®180R**

T90 with filters/slow moving air:
- open grid 17 s
- steel netting 50 s
- sintered filter 60 s

Typical time constant of bare chip at 20°C: 10s
End of part 2
Calibration and traceability
Why knowing calibration, measurement uncertainty and traceability is important?

- **Uncertainty** is numerical quality of a measurement, with respect to the international measurement system

- **Traceability** means the documented path from the instrument to the international measurement system

*Measurements without traceability and uncertainty are worthless*

Either the lorry driver or the bridge builder did not meet the traceability requirements in the measurement
I take care of calibrations by

A. Not applicable
B. My equipment is not calibrated
C. Own calibration laboratory
D. Third-party calibration laboratory
E. Field-checks
F. Other
Traceability and calibration
Traceability

“Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty”
International System of Units: SI
Système international d’unités

SI base units

- Length: 1 metre
- Mass: 1 kilogram
- Time: 1 second
- Electric current: 1 Ampere
- Temperature: 1 Kelvin
- Amount of substance: 1 mole
- Luminous intensity: 1 candela

*Measurement standard, in which all traceable measurements can be traced*
Simplified example: Traceability of Vaisala RH instrument

- **SI units**
  - **NIST**
    - Accredited laboratory
    - Primary standard SPRT reference
    - Working standard PRT reference
  - **MIKES**
    - Triple-point cell of water
  - **MIKES**
    - Pressure primary standard

- **Temperature**
- **Calculated RH**
- **Pressure**

**Unit under test**

**Accredited laboratory**

**National laboratory**

**Accredited laboratory**

**Vaisala Measurement Standards Laboratory**

**Vaisala operations**

SI units

Temperature

Calculated RH

Pressure

Unit under test
What is calibration?

- **Calibration** means comparing the instrument reading with a reference (a calibration standard)
- Quality of calibration is defined by the following
  - The *competence* of the laboratory
  - The *management system* of the laboratory
  - The *methods* used by the laboratory
  - The *equipment* and the references of the laboratory

By definition, every measurement has some degree of uncertainty.

Calibration is a way to validate and maintain the performance of a measurement instrument.
What is adjustment?

- Adjustment is correcting the instrument to minimize deviation from the calibration reference.

- Normal service procedure is calibration ("as-found") and adjustment + calibration ("as-left").
  - This is sometimes called "Calibration"
Types of adjustment: Offset
Types of adjustment: Linear adjustment
Multi-point correction

Necessary when sensor is non-linear and further linearization is required
Things to ask

What does your quality system require?

What does your application require?
Quality Management System

- **ISO9001**: Quality Management Systems – Requirements
  - ISO9001 clause 7.6: Control of measurement and monitoring equipment
  - ISO10012:2003: Measurement management systems - Requirements for measurement processes and measuring equipment
- **ISO17025:2005**: General requirements for the competence of testing and calibration laboratories
- **AQAP (NATO Allied Quality Assurance Program) 2110**: Design, development, production, sales and service of instruments, systems, solutions and information for environmental and industrial applications
How often to calibrate?

- Calibration interval is subject to the operating conditions
  - Humidity/temperature
  - Chemical contaminants

- As-found certificates help in determining suitable calibration interval

Calibration interval recommendation

- 6 months
- 2.5 years
- 1 year
- 5 years

* +/- 1.2 %RH accuracy requirement
** +/- 3.5 %RH accuracy requirement
*** HMP7 with probe warming recommended
What options do I have for calibration?

- Field calibration
  - Reference instrument
  - Portable calibrator
- Laboratory calibration
  - In-house
  - Service
- Factory service

Quality of calibration:

- Competences
- Management system
- Methods
- Equipment and the references
Calibration interval is defined by

A. The manufacturer of the instrument
B. The quality policy
C. Calibration laboratory’s recommendation
Options for calibration: Field Calibration
Single point or multi-point

**Single-point**
- When stable condition
- When not close to extremes of measurement range

**Multi-point**
- When relative humidity changing on wide range
- When measuring close to extremes of the measurement range
Field calibration references

Handheld Single-point

HMK15 Salt calibrator Multi-point

Humidity generator Multi-point
HMK15 salt calibrator

- Intrinsic reference based on known property of saturated salt solutions generating known relative humidity levels
- Uncertainty 1.2..2 %RH
- Batch traceable

Applicable standards:
- ASTM E104-85
- DIN 5008
- JIS Z8806

<table>
<thead>
<tr>
<th>Salt</th>
<th>Equilibrium RH at 20 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiCl</td>
<td>11.3 %RH</td>
</tr>
<tr>
<td>MgCl</td>
<td>33.1 %RH</td>
</tr>
<tr>
<td>NaCl</td>
<td>75.5 %RH</td>
</tr>
<tr>
<td>K2SO4</td>
<td>97.6 %RH</td>
</tr>
</tbody>
</table>
HMK15 salt calibrator

- A reference instrument can be used as a reference for additional accuracy or traceability reasons

Common mistakes:
- Insufficient stabilization time
- Temperature gradients
- Adjustment in too narrow RH range
Options for calibration:

Laboratory calibration
Laboratory calibration

- Reduces uncertainty components from calibration
  - Constant and controlled environment

- Multi-point calibration possible
  - For wide-span applications and validating linearity

- Special calibrations
  - RH calibrations under different temperatures
  - Accredited calibrations
Accredited calibration?

- Accredited calibration laboratory is running a Quality Measurement System in compliance to ISO/IEC 17025, ANSI/NCSL Z540 or other standard
  - Management system
  - Technical requirements

- Professionally made and validated uncertainty calculations
- Verified traceability to international standards
- Use of accepted and agreed methods
- Competence of personnel
- Independence of the organization
- Privacy of data and records
What Type of Calibration Do I Need?

Does your company’s Quality Management Standards (QMS) require an ISO17025 Accredited Calibration?

No

Yes

I don’t know

Will you need to defend or demonstrate proper calibration procedures to assure the quality of test results?

No

Yes

Do you require processes such as management review, internal audits, customer complaints and contract reviews which are verified as traceable to a recognized national or international standard?

ISO/IEC 17025

Accredited Calibration

ISO 9001

Standard Calibration with fixed calibration points

Custom Point Calibration for specific calibration points within the instrument's measurement range
Which option works best for you?

- **Field calibration**
  - Own staff or sourced

- **In-house laboratory**
  - Manage your own lab, training, standards, traceability, documentation...

- **External service provider**
  - Evaluating service provider, auditing

- **Quality Management System (QMS) requirements**
- **Number of points needed**
- **Humidity range**
- **Temperature range**
- **Accuracy requirement**

- **Factory calibration**
  - Highest quality references
  - Calibration + Adjustment
  - Functional check
  - Small repairs included
  - No worries
Case example
Case example: "spot-check" calibration: In spec or not?

Field calibration (spot check) of a wall-mount RH/T transmitter

- Device under test (DUT):
  - Temperature [°C]: 22.1 (71.8°F)
  - Relative Humidity [%RH]: 57.6

- Reference instrument:
  - Temperature [°C]: 21.87 (71.37°F)
  - Relative Humidity [%RH]: 55.10
### Should it be adjusted?

<table>
<thead>
<tr>
<th></th>
<th>DUT</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp [°C/°F]</td>
<td>22.1 / 71.8</td>
<td>21.87 / 71.37</td>
</tr>
<tr>
<td>RH [%RH]</td>
<td>57.6</td>
<td>55.10</td>
</tr>
</tbody>
</table>

**A. Yes**  
**B. No**
Steps of uncertainty estimation

- Recognize the relevant uncertainty components
- Estimate the standard uncertainty of each component
- Express the model equation
  - Calculate the sensitivity coefficients
- Calculate the expanded uncertainty
Uncertainty components of temperature calibration

- What are the uncertainty components?
  - Related to the reference?
    - Calibration correction
    - Calibration uncertainty
    - Stability
    - Resolution

- Related to the device under test?
  - Resolution

- Related to the set-up?
  - Humidity spatial distribution
  - Humidity temporal distribution
  - Temperature spatial distribution
  - Temperature temporal distribution
Source of information: Datasheet

### Relative Humidity

<table>
<thead>
<tr>
<th>Measurement range</th>
<th>0 ... 100 %RH, non-condensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy including non-linearity, hysteresis and repeatability, defined as ±2 standard deviation limits:</td>
<td></td>
</tr>
<tr>
<td>At +15 ... +25 °C (+59 ... +77 °F)</td>
<td>±1 %RH (0 ... 90 %RH)</td>
</tr>
<tr>
<td></td>
<td>±1.7 %RH (90 ... 100 %RH)</td>
</tr>
<tr>
<td>Factory calibration uncertainty (+20 °C / +68 °F)</td>
<td>±0.6 %RH (0 ... 40 %RH)</td>
</tr>
<tr>
<td></td>
<td>±1.0 %RH (40 ... 97 %RH)</td>
</tr>
<tr>
<td>Typical long-term stability</td>
<td>better than 1 %RH / year</td>
</tr>
</tbody>
</table>

### Temperature

![Temperature Chart]

- **Measurement range**: -5 ... +55 °C (+23 ... +131 °F)
- **Accuracy at +20 ... +30 °C (+68 ... +86 °F)**: ±0.2 °C (± 0.36 °F)
Uncertainty of temperature?

- Reference: Vaisala HM70 handheld
  - Accuracy: 0.1 °C
  - Calibration correction: -0.01 °C
  - Calibration uncertainty: 0.1 °C
  - Stability: 0.05 °C
  - Resolution: 0.01 °C

- Set-up and DUT?
  - Temperature spatial: 0.5 °C
  - Temperature temporal: 0.1 °C
  - Temperature stabilization: 0.05 °C
  - DUT resolution: 0.1 °C

Self-heating effect: Two wall-mount transmitters side-by-side (Vaisala GMW95R on the right)
Model equation and uncertainty

- Correction = Reference value – Indication of DUT
- Uncertainty = Uncertainty of the reference + Uncertainty of the DUT
  - Uncertainties sum up quadratically
  - Distribution of the uncertainty varies. Different shapes of distribution are scaled to normal distribution equivalents:

  - **Normal distribution**: The uncertainty has some likely value and a spread around that
    - E.g. Repeatability of a measurement
  - **Flat distribution**: The uncertainty is evenly distributed between some values
    - E.g. Resolution of the measurement
  - **U-shaped distribution**: The uncertainty component is likely to be at the extremes
    - E.g. Thermostat controlled temperature
# Uncertainty budget for temperature

<table>
<thead>
<tr>
<th>Group</th>
<th>Uncertainty component</th>
<th>Symbol</th>
<th>Value [°C]</th>
<th>Related uncertainty</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference instrument</td>
<td>Reference indication</td>
<td>Tref</td>
<td>21.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calibration correction</td>
<td>( \delta T_{\text{calibration correction}} )</td>
<td>-0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ref specified accuracy</td>
<td>( \delta T_{\text{specified accuracy}} )</td>
<td>0.1</td>
<td>0.1</td>
<td>From datasheet</td>
</tr>
<tr>
<td></td>
<td>Ref calibration uncertainty</td>
<td>( \delta T_{\text{calibration uncertainty}} )</td>
<td>0.1</td>
<td>0.1</td>
<td>From datasheet</td>
</tr>
<tr>
<td></td>
<td>Ref long-term stability</td>
<td>( \delta T_{\text{stability}} )</td>
<td>0.05</td>
<td>0.05</td>
<td>From datasheet</td>
</tr>
<tr>
<td></td>
<td>Ref resolution</td>
<td>( \delta T_{\text{resolution}} )</td>
<td>0.005</td>
<td></td>
<td>Uncertainty of resolution is half of the specified value</td>
</tr>
<tr>
<td>Device under Test</td>
<td>DUT Indication</td>
<td>T_DUTIndication</td>
<td>22.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DUT resolution</td>
<td>( \delta T_{\text{DUT resolution}} )</td>
<td>0.1</td>
<td></td>
<td>Uncertainty of resolution is half of the specified value</td>
</tr>
<tr>
<td>Setup</td>
<td>Spatial temperature distrib.</td>
<td>( \delta T_{\text{spatial}} )</td>
<td>0.5</td>
<td></td>
<td>Incl. Self heating of DUT, cold wall, draft, radiated temperature</td>
</tr>
<tr>
<td></td>
<td>Temporal stability</td>
<td>( \delta T_{\text{temporal stability}} )</td>
<td>0.1</td>
<td></td>
<td>Different response time of sensors</td>
</tr>
<tr>
<td></td>
<td>Stabilization time</td>
<td>( \delta T_{\text{stabilization}} )</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difference of indications</td>
<td></td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Correction</td>
<td></td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Expanded uncertainty</td>
<td></td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Model equation

\[
R_{\text{correction}} = R_{\text{Tref}} \times (R_{\text{Tcalibration correction}} + \delta R_{\text{specified accuracy}} + \delta R_{\text{calibration uncertainty}} + \delta R_{\text{resolution}}) / (\delta R_{\text{stability}} + \delta R_{\text{stabilization}}). R_{\text{DUT}}(R_{\text{H calibration resolution}})
\]

<table>
<thead>
<tr>
<th>Uncertainty component</th>
<th>Symbol</th>
<th>Extended uncertainty ( k = 2 )</th>
<th>Distribution type</th>
<th>Scaling factor</th>
<th>Standard uncertainty</th>
<th>Sensitivity coefficient</th>
<th>One-sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref specified accuracy</td>
<td>( \delta T_{\text{specified accuracy}} )</td>
<td>0.1</td>
<td>Norm</td>
<td>2</td>
<td>0.050</td>
<td>1.0 °C/°C</td>
<td>0.050</td>
</tr>
<tr>
<td>Ref calibration uncertainty</td>
<td>( \delta T_{\text{calibration uncertainty}} )</td>
<td>0.1</td>
<td>Norm</td>
<td>2</td>
<td>0.050</td>
<td>1.0 °C/°C</td>
<td>0.050</td>
</tr>
<tr>
<td>Ref long-term stability</td>
<td>( \delta T_{\text{stability}} )</td>
<td>0.05</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.029</td>
<td>1.0 °C/°C</td>
<td>0.029</td>
</tr>
<tr>
<td>Ref resolution</td>
<td>( \delta T_{\text{resolution}} )</td>
<td>0.005</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.003</td>
<td>1.0 °C/°C</td>
<td>0.003</td>
</tr>
<tr>
<td>DUT resolution</td>
<td>( \delta T_{\text{DUT resolution}} )</td>
<td>0.05</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.029</td>
<td>1.0 °C/°C</td>
<td>0.029</td>
</tr>
<tr>
<td>Spatial temperature distrib.</td>
<td>( \delta T_{\text{spatial}} )</td>
<td>0.5</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.285</td>
<td>1.0 °C/°C</td>
<td>0.285</td>
</tr>
<tr>
<td>Temporal stability</td>
<td>( \delta T_{\text{temporal stability}} )</td>
<td>0.1</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.550</td>
<td>1.0 °C/°C</td>
<td>0.550</td>
</tr>
<tr>
<td>Stabilization time</td>
<td>( \delta T_{\text{stabilization}} )</td>
<td>0.05</td>
<td>U-dist</td>
<td>0.71</td>
<td>0.071</td>
<td>1.0 °C/°C</td>
<td>0.071</td>
</tr>
<tr>
<td>Total 1-sigma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.314</td>
</tr>
</tbody>
</table>

Rounding error: -4%
Do we need to adjust for temperature?

<table>
<thead>
<tr>
<th>Referenced T [°C]</th>
<th>Device T [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20.5</td>
</tr>
<tr>
<td>21</td>
<td>21.5</td>
</tr>
<tr>
<td>22</td>
<td>22.5</td>
</tr>
<tr>
<td>23</td>
<td>23.5</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

Influence on total calibration uncertainty
Uncertainty of Relative Humidity calibration

- Reference: Vaisala HM70 handheld
  - Accuracy: 1.0 %RH
  - Calibration correction: -0.6 %RH
  - Calibration uncertainty: 0.6 %RH
  - Resolution: 0.1 %RH
  - Long-term stability: 1.0 %RH

- Set-up and DUT?
  - Temperature equilibrium: 0.6 °C
  - RH difference spatial/temporal: 0.1 %RH
  - RH stabilization time: 0.1 %RH
RH sensitivity coefficient for temperature

- Relative Humidity has non-linear dependency on temperature
  - The magnitude of the dependency differs with the RH and temperature condition

- Sensitivity coefficient tells how the uncertainty in a variable is reflected to the uncertainty of another variable

- Solved algebraically or numerically
# Uncertainty budget for Relative Humidity

<table>
<thead>
<tr>
<th>Group</th>
<th>Uncertainty component</th>
<th>Value</th>
<th>Related uncertainty</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference instrument</strong></td>
<td>Reference indication</td>
<td>55.1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calibration correction</td>
<td>-0.6</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specified accuracy</td>
<td>0.6</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calibration uncertainty</td>
<td>0.1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ref resolution</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reference drift</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td><strong>Device under Test</strong></td>
<td>DUT indication</td>
<td>52.8</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DUT resolution</td>
<td>0.1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td><strong>Set-up</strong></td>
<td>Temperature equilibration</td>
<td>0.3</td>
<td></td>
<td>Incl. Spatial distribution, temporal stability, stabilization time</td>
</tr>
<tr>
<td></td>
<td>Microclimate</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH stabilization time</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model equation

\[
\text{RH}_{\text{correction}} = \text{RH}_{\text{ref}} + (\text{RH}_{\text{calibration correction}} + \delta\text{RH}_{\text{specified accuracy}} + \delta\text{RH}_{\text{calibration uncertainty}} + \delta\text{RH}_{\text{resolution}} + \delta\text{RH}_{\text{stability}} + \delta\text{RH}_{\text{stabilization}}) \cdot (\text{RH}_{\text{indication}} + \delta\text{RH}_{\text{DUT resolution}})
\]

<table>
<thead>
<tr>
<th>Uncertainty component</th>
<th>Symbol</th>
<th>Distribution type</th>
<th>Scaling factor</th>
<th>Standard uncertainty</th>
<th>Sensitivity coefficient</th>
<th>One-sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified accuracy</td>
<td>$\delta$RH$_{\text{specified accuracy}}$</td>
<td>Normal</td>
<td>2</td>
<td>0.500</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
<tr>
<td>Calibration uncertainty</td>
<td>$\delta$RH$_{\text{calibration uncertainty}}$</td>
<td>Normal</td>
<td>2</td>
<td>0.300</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
<tr>
<td>Ref resolution</td>
<td>$\delta$RH$_{\text{resolution}}$</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.029</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
<tr>
<td>Reference drift</td>
<td>$\delta$RH$_{\text{drift}}$</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.577</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
<tr>
<td>DUT resolution</td>
<td>$\delta$DUT$_{\text{resolution}}$</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.029</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
<tr>
<td>Temperature equilibration</td>
<td>$\delta$Total</td>
<td>Normal</td>
<td>2</td>
<td>0.151</td>
<td>-3.3</td>
<td>%RH / °C</td>
</tr>
<tr>
<td>Microclimate</td>
<td>$\delta$RH$_{\text{stability}}$</td>
<td>Uniform</td>
<td>1.73</td>
<td>0.058</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
<tr>
<td>RH stabilization time</td>
<td>$\delta$RH$_{\text{stabilization}}$</td>
<td>Uniform</td>
<td>2.45</td>
<td>0.041</td>
<td>1.0</td>
<td>%RH / %RH</td>
</tr>
</tbody>
</table>

Total 1-sigma: 0.97 Rounding error

Expanded uncertainty: 2 4%
Should we adjust for Relative Humidity?

Reference drift  Uncertainty in temperatures  Specified accuracy

Calibration uncertainty  Microclimate  RH stabilization time  Ref resolution  DUT resolution

Influence on total calibration uncertainty

Chart Title
What uncertainty to expect with RH calibration?

- Field check: +/- 2..5 %RH
- HMK15: +/- 1.2..2 %RH
- NIST: Hybrid humidity generator: +/- 1 %
- Vaisala factory calibration: +/- 0.6.. 1.0 %
End of part 3
Dew point in compressed air
Compressed Air

Compressed air is often called the fourth utility in industry, right behind water, electricity and natural gas.

Where is it measured?

- Energy storage:
  - Instrument air for tools, robots, pneumatic actuators..
  - Trains: brakes, couplings, pneumatic doors..
  - Vortex cooling
- Conveyor media for powder, granulate or aerosol
  - Spray painting
- Drying, bottling, spraying, coating, packaging, cleaning..
- Medical air, diving, firefighting equipment..
Why Measure Dew Point?

- Dryer performance monitoring
  - Condition monitoring
- Dryer switching endpoint
  - Time controlled vs dew point demand controlled
  - Efficiency
- Compressed air quality at point of use
  - Quality assurance
When RH is ~1 %RH
±2 °C Td = ±0.2 %RH
±5.6°F Td = ±0.2 %RH

When RH is ~5 %RH
±2 °C Td = ±1 %RH
±5.6°F Td = ±1 %RH
How dew point sensor works?

- All capacitive and resistive solid state sensors are based on equilibration of humidity between the surroundings and the sensor.

- Similar operation with humidity sensors.

- When relative humidity and temperature are known, the dew point temperature can be calculated.
**Vaisala dew point technology**

- DRYCAP sensor is optimized for sensitivity in low humidity ranges by a special engineered polymer
- Sensor purge function always included
- Unique auto-calibration function
  - Sensor responds to very small changes in relative humidity
  - Sensitivity combined with robustness by autocalibration functionality:
    - Sensor detects a stable process condition (RH and temperature)
    - Heat-up and correction when necessary

*Autocalibration allows the benefits of the polymer technology together with the high sensitivity needed in the low humidity range*
Auto-calibration

1. Auto-calibration start:
   Sensor warmed
   RH value decreases when T increases

2. Sensor starts to cool down after short warming.
   RH reading starts to increase.

3. RH and T values logged during cooling phase

4. When drawing a straight line through the collected RH&T points the offset correction value is determined.

5. Auto-calibration ends:
   Sensor is cooled and normal measurement mode is activated using the correction value

6. After set interval (once/hour) auto-calibration repeated
DRYCAP sensor for low humidity

- Tolerates wetting, recovers perfectly
- Tolerates contaminants: Compressor oils, volatile organics
- Fast response time
- No drifting – recommended calibration interval 2 years
- Small hysteresis
- ISO9001 calibrated at factory
Compressed Air Systems

**Basics:** The air contains water as water vapor. The water may cause problems in the compressed air system – condensation and corrosion in the distribution system and quality problems at the point of use.

**Challenge:** Energy efficient control of dryers requires measurement with combination of both sensitivity and robustness - a difficult combination for conventional measurement technologies.

**Solution:** Vaisala DRYCAP sensors for low humidity measurements and the unique autocalibration function.
Compressed Air
Compressed Air

DRYING

REGENERATING
Analyzing correct operation of the dryer by dew point measurement

- Dryer operates normally
  - Regeneration cycles

- Dryer is loaded too early
  - Air leak into the dryer
  - Regeneration cycle not complete?
  - Contaminated desiccant?
Desiccant dryer condition monitoring

- **Dryer does not work**
  - Regeneration does not work
  - Severely contaminated desiccant

- **Regenerated dryer does not work**
  - Insufficient cooling time
Process Pressure vs. Ambient

- **Measurement process at pressure**
  - + typically true specified dew point
    - Value that user wants to know e.g. in dryers
  - + no sampling system needed
  - + effect of pressure fluctuation is marginal. Example:
    - \( T_d = -40 \, ^\circ\text{C} \) at \( p = 7\text{bar} \) =>
    - \( T_d = -40.6 \, ^\circ\text{C} \) at \( p = 6.5\text{ bar} \)
  - System shut down needed in case of sensor change
    - Solution available: use of pressurized sampling cell DSC74 with quick connector
  - installation place and direction critical
    - sensor warming may not be able to keep sensor dry in most harsh conditions

- **Measurement at ambient pressure**
  - + line pressure fluctuation has no effect
  - + easy to remove instrument for service
  - + protects sensor against humidity peaks (not typically necessary for DRYCAP®)
  - dew point not in the user specified pressure
    - depends on the application
  - - sampling system with needle valve and venting coil needed
    - Solution available: Sampling cell DSC74B/C
Sampling Cells

DMT242SC
- G3/8", G1/4" ISO (inlet, outlet)
- G1/2" for probe

DMT242SC2
- Like above, but with 1/4" swagelok fittings

DSC74C
- For pressurized air, quick connector and leak screw
- Pressurized measurement

DSC74C
- For measurement in atmospheric pressure
- Fixed leak screw 3 ..1.0 bar

DMCOIL
- For venting the sample out in low dew point measurements
Portable Dewpoint

Vaisala DSS70A
Requirements for Accurate Switchpoint Control?

Stability at -40°C/-40°F frost point

Stability at -10°C/14°F frost point

- tolerates getting wet
- minimal drifting
- fast response time
- immune to contamination

2 long, 2-year calibration interval

Difference to reference (°C)

Years

Stability at -40°C/-40°F frost point

Difference to reference (°C)

Years

1st DMT242
2nd DMT242
Dew point error at constant temperature

Overshoot

Undershoot

Vaisala DRYCAP180U: DMT152
Vaisala DRYCAP180D: DMT143
Sensor B
Sensor C
Sensor D
Sensor F
Sensor G
Sensor H
Temperature dependency at -50°C / -58 °F dew point level

Dew point error, °C

Temperature of environment, °C

Vaisala DRYCAP180U:
DMT152

Sensor B
Sensor C
Sensor D
Sensor E
Sensor F

Vaisala DRYCAP180D:
DMT143

Sensor H
Sensor I
Sensor J
Sensor K
Short-term stability

Vaisala DRYCAP180U: DMT152

Sensor B

Sensor C

Sensor D

Sensor E

Vaisala DRYCAP180M: DMT143

Sensor G

Sensor H
End of part 4
How do you decide what instrument to purchase?
(choose top 3 in order)

A. Referral from a colleague
B. Web research
C. Magazines
D. Vendor websites
E. Vendor salesperson
Follow the Manufacturer's Instructions

- Read the Manual
- Use the Technical Support
- Use the Application Engineers
- Use the Sales Engineers
Follow the Manufacturer's Instructions

**Proper installation**

- Must be mounted in area where air or gas is representative of the process or environment

- Air should flow around or past the sensor
  - good air flow is an advantage; it ensures that the probe and ambient air are at the same temperature & ensures that the measurement is representative of the space

- Avoid anomalous sources of heat or cold; i.e. sunlight
Follow the Manufacturer's Instructions

**Probe installation**
- horizontal is preferred; bend in the cable
- allow for temperature and pressure fittings
- use insulation and sample line heating
- ensure representative sample of air with flow preferred

Follow the Manufacturer's Instructions
Ensure a proper calibration

- Is the calibration within the recommended interval?
- Is it traceable?
- Is there a valid certificate available?
- Does the calibration comply with your requirements?
Keep records

- Record of calibration
- Record of adjustments
- Record of repairs
- Out of tolerance results
- Record of any damage to the instrument
Spot-check performance

- Check at intervals between calibrations
- Check before and after any event that may stress the instrument
  - Transportation
  - Packaging or shipping
- Check against one or, even better, two other instruments
Be knowledgeable about the parameter

\[ ax \times ppm \times T_d \times T_w \times h \times RH \]

- Know what parameter you are measuring and be aware of the potential effects of the environment around the point of measure.
  - sensor type
  - gas effect
    - CO2, pure hydrogen, other high concentrations of gas
  - temperature & pressure effect
  - is output parameter measured or calculated
Be knowledgeable about the parameter

Polymer & organic sensors measure RH

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

Saturation Curve

Note: at 20°C a temperature difference of just 1°C may add 3% error to the RH measurement
Be knowledgeable about the parameter

How is the parameter determined?

- Is it measured directly or calculated?
- Does the calculation require pressure input?
- Is the calculation dependent on temperature?
- Dew point or Frost point? (for example)
- Pressure dew point or atmospheric dewpoint?
- Mixing ratio or ppm calculation require actual pressure input (for example)

\[
Td_{pre} = \frac{T_s}{x = B^*P_W(P_{tot} - P_W)}
\]

\[
\text{PPM}_v = \frac{P_w}{(P_{tot} - P_w)} \times 10^8
\]
Be aware of potential external factors

- Do not introduce external factors that will affect the measurement
  - direct sunlight
  - body heat and humidity
  - non-representative sources of heat
  - stagnant and/or non representative air samples
  - temperature leakage
Be aware of potential external factors
Be aware of potential external factors

Anomalous Sources of Heat or Cold

25C  10C
77F  50F
Be aware of potential external factors

**Temperature Leakage**

- If the temperature of the process is considerably higher than that of the environment, the whole probe and preferably a part of the cable must be in the process.

![Diagram showing temperature leakage](image)

- 80°C / 176°F
- 70%RH
- [adds 3.2% error]

- 22°C / 72°F
Be aware of potential external factors

Temperature leakage

- Less critical, but enough difference where you want the whole portion of the metal probe inside the process and the cable sealed.

22°C 72°F

28°C 82°F
Be aware of potential external factors

Temperature leakage
- Very large differences require heavy insulation

180°C/356°F 85%RH
Be aware of potential external factors

Temperature
- From room to high temperature high humidity chamber

Testing chamber

104°F
60% RH
$T_d = 87°F$

What is the dew point?

70°F ambient temp

You must **PRE-HEAT** the probe!!
Be aware of potential external factors

Water Vapor Pressure

Testing chamber

120°F
TD = -76°F
ppmv = 11

What is the ppmv?

80°F @ 35%RH

What is TD? 50°F
What is ppmv? 12,000 ppmv
Summary – Good Measurement Practice

- 7 Points
1. Choose the correct instrument
2. Follow the manufacturers instructions
3. Ensure a proper calibration
4. Keep records
5. ‘Spot-check’ performance
6. Be knowledgeable about the parameter
7. Be aware of potential external factors
Was this Measurement Practice section beneficial?

A. Very beneficial
B. Somewhat beneficial
C. Neutral
D. Minimally beneficial
E. Not at all beneficial
End of part 5