Uncertainty in Humidity Measurement

Helping you make a better measurement.
Webinar Presenters

Bruce McDuffee

Michael Boetzkes
Agenda

• Terms & Definitions
• Understand the Uncertainty of Your Instrument
• Understanding the Uncertainty on the Calibration Certificate
• How to Avoid the Dreaded O.O.T.
• Final Q&A
Terms & Definitions
The Truth About Measurement

- There is no such thing as a true or perfect measurement.
- A proper measurement result is incomplete without a statement of uncertainty.
- Knowing the uncertainty helps us determine the fitness of the measurement.
- Understanding uncertainty is the first step to reducing it.
Accuracy

“closeness of agreement between a measured quantity value and a true quantity value of a measurand”

- **Measurand** - quantity intended to be measured
- **Measured Quantity Value** - quantity value representing a measurement result
- **True Quantity Value** - quantity value consistent with the definition of a quantity
- **Quantity Value** - number and reference together expressing magnitude of a quantity, for example 5 °C, 543 meters
Error

• Error is the difference between the measured value and the ‘true value’ of the thing being measured.

• Like ‘accuracy’, it is qualitative, not quantitative
Uncertainty

• “Uncertainty is the quantification of the doubt about the measurement result.”
• “A calculated statement concerning the level of confidence in a reported measurement.”

Statement of Uncertainty:

50 %RH ± 1 %RH k=2
Understanding the Uncertainty of the Humidity Instrument
Calculating the Instrument Uncertainty

- Instrument Calibration
- Resolution
- Long term drift
- Temperature effects
- Hysteresis
- Linearity (accuracy)
- Sensitivity to contamination
Calculating the Instrument Uncertainty

\[ U = k \sqrt{u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + \ldots} \]

<table>
<thead>
<tr>
<th>Uncertainty Contributor</th>
<th>Uncertainty (U)</th>
<th>Distribution</th>
<th>Divisor</th>
<th>Standard Uncertainty (u)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>0.8 %RH</td>
<td>Rectangular</td>
<td>1.732</td>
<td>0.462</td>
<td>From Data Sheet</td>
</tr>
<tr>
<td>Calibration Uncertainty</td>
<td>0.5 %RH</td>
<td>Normal</td>
<td>2</td>
<td>0.250</td>
<td>From Calibration Certificate</td>
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<tr>
<td>Annual Drift</td>
<td>1.0 %RH</td>
<td>Rectangular</td>
<td>1.732</td>
<td>0.577</td>
<td>From Data Sheet</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level of Confidence</th>
<th>Coverage Factor (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.27%</td>
<td>1</td>
</tr>
<tr>
<td>90%</td>
<td>1.645</td>
</tr>
<tr>
<td>95%</td>
<td>1.96</td>
</tr>
<tr>
<td>95.45%</td>
<td>2</td>
</tr>
<tr>
<td>99%</td>
<td>2.576</td>
</tr>
<tr>
<td>99.73%</td>
<td>3</td>
</tr>
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</table>

Combined Uncertainty 0.780

Expanded Uncertainty k=2 \( \pm 1.6 \%RH \)
Impact of the Instrument Uncertainty

• Each instrument is unique in behavior
• Environmental factors can change drift characteristics
• Understand the impact of calibrations

Understand total instrument performance!
Comments & Questions

If we don’t get to your question today, we’ll respond via email after the webinar.
Calibration Certificate Uncertainty
# Divided Flow System with Chilled Mirror

Test Point: 80 %RH at 23 °C  
Temperature Sensitivity: 4.96 %RH/°C

<table>
<thead>
<tr>
<th>Reference</th>
<th>Uncertainty Source</th>
<th>Value</th>
<th>Units</th>
<th>Distribution</th>
<th>Divisor</th>
<th>Standard Uncertainty</th>
<th>Sensitivity Coefficient</th>
<th>Standard Uncertainty (%RH)</th>
<th>% of Total Expanded Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chilled Mirror Uncertainty</td>
<td>0.05</td>
<td>°C</td>
<td>Normal</td>
<td>2</td>
<td>0.025</td>
<td>4.96</td>
<td>0.124</td>
<td>18%</td>
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<td>Chilled Mirror Drift (1 year)</td>
<td>0.04</td>
<td>°C</td>
<td>Rectangular</td>
<td>1.732</td>
<td>0.023</td>
<td>4.96</td>
<td>0.115</td>
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<td>Temperature Uncertainty</td>
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<td>°C</td>
<td>Normal</td>
<td>2</td>
<td>0.004</td>
<td>4.96</td>
<td>0.018</td>
<td>3%</td>
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<tr>
<td>4</td>
<td>Repeatability of humidity</td>
<td>0.10</td>
<td>%RH</td>
<td>Normal</td>
<td>1</td>
<td>0.100</td>
<td>1</td>
<td>0.100</td>
<td>14%</td>
</tr>
<tr>
<td>5</td>
<td>Chamber temperature gradients</td>
<td>0.05</td>
<td>°C</td>
<td>Rectangular</td>
<td>1.732</td>
<td>0.029</td>
<td>4.96</td>
<td>0.143</td>
<td>20%</td>
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<tr>
<td>6</td>
<td>Temperature stabilization</td>
<td>0.01</td>
<td>°C</td>
<td>Rectangular</td>
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<td>4.96</td>
<td>0.014</td>
<td>2%</td>
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<td>7</td>
<td>Temperature repeatability</td>
<td>0.05</td>
<td>°C</td>
<td>Normal</td>
<td>1</td>
<td>0.050</td>
<td>4.96</td>
<td>0.248</td>
<td>35%</td>
</tr>
<tr>
<td>8</td>
<td>Humidity stabilization</td>
<td>0.05</td>
<td>%RH</td>
<td>Rectangular</td>
<td>1.732</td>
<td>0.029</td>
<td>1</td>
<td>0.029</td>
<td>4%</td>
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<tr>
<td>9</td>
<td>Humidity fluctuations</td>
<td>0.05</td>
<td>%RH</td>
<td>Rectangular</td>
<td>1.732</td>
<td>0.029</td>
<td>1</td>
<td>0.029</td>
<td>4%</td>
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**Temperature Sensitivity:** 4.96 %RH/°C

**Standard Uncertainty:** 0.350

**Expanded Uncertainty (95% confidence level):** 0.70
Divided Flow System with Internal Probe

Test Point: 80 %RH at 23 °C
Temperature Sensitivity: 4.96 %RH/°C

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<td>Reference Probe Uncertainty</td>
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<td>%RH</td>
<td>Normal</td>
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<td>1</td>
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<td>34%</td>
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<td>1</td>
<td>0.014</td>
<td>1%</td>
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<td>Repeatability of humidity</td>
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Standard Uncertainty: 0.854
Expanded Uncertainty (95% confidence level): 1.71
Why is Uncertainty Important

• Required for Metrological Traceability

• Insight into the quality of the calibration

• Makes the difference between instrument meeting manufacturer specification or not!

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Combined Uncertainty: 0.818
Expanded Uncertainty k=2: ±1.7 %RH

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Combined Uncertainty: 1.130
Expanded Uncertainty k=2: ±2.3 %RH
Taking Uncertainty into Account

- Uncertainty of measurement leads to risk of False Accept
- Guardband methods available to define and limit the risk
- Creates 3rd option for result: Indeterminate
How to Avoid the Dreaded OOT
Causes of OOT

• Instrument/Sensor Drift
• Accuracy specification used instead of 1-year uncertainty
• Previous calibration was not suitable

Typically can be traced back to an error in or lack of uncertainty analysis!
Avoiding OOT

• Know the sensitivities of the instrument
• Use the Long Term Uncertainty as the acceptance limit
• Ensure appropriate calibration provider can provide suitable calibration uncertainties
Takeaways

1. Instrument performance is more than just an accuracy specification
2. Two instruments of the same model can have different measurement uncertainties
3. OOT results can be reduced by understanding the instrument uncertainty
Comments & Questions

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Measurement Academy

- Resources for making a better measurement
  - Psychrometric charts
  - Technical notes
  - Humidity calculator
  - Application notes
  - More

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