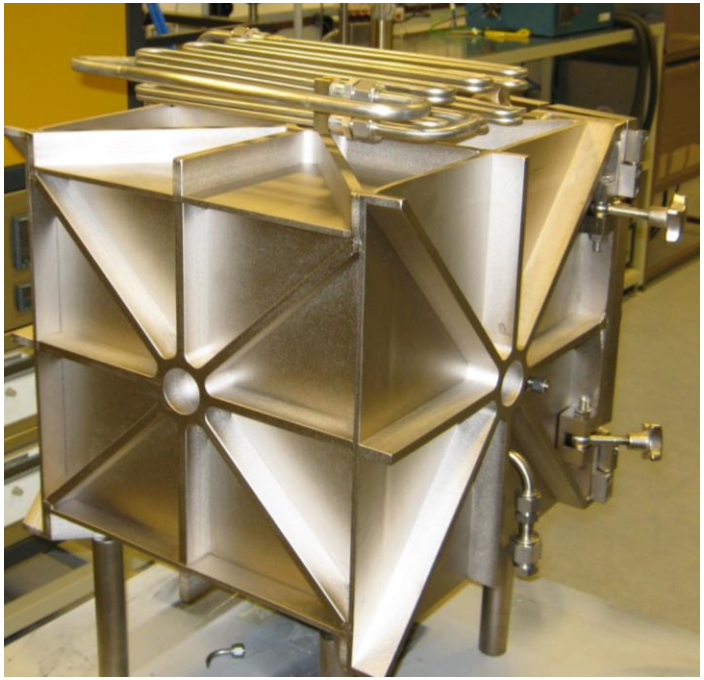


Climatic Chamber for dew-point temperatures up to 150 ºC

A. Peruzzi and R. Bosma

Outline

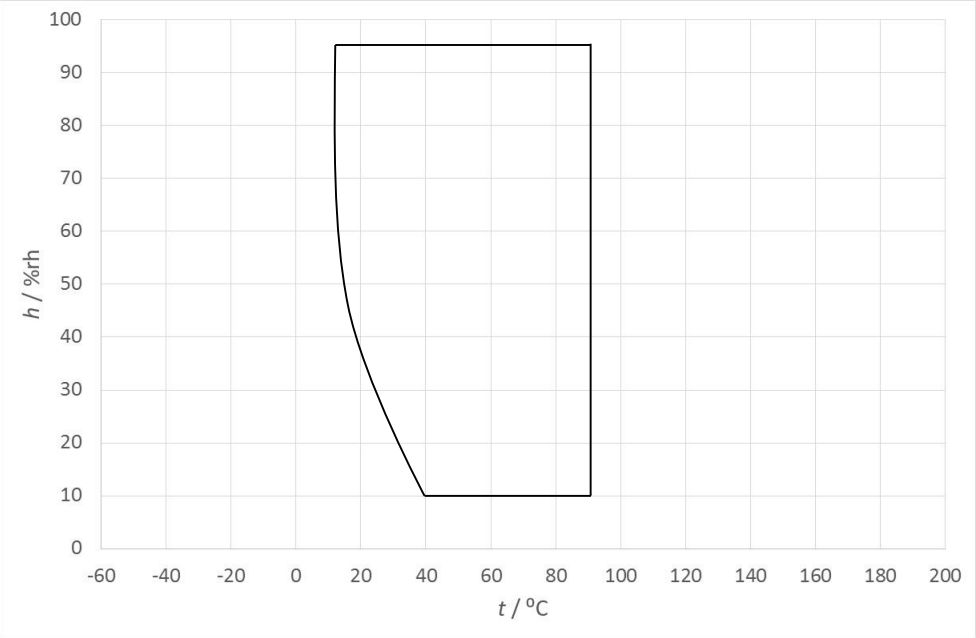
- Extension of relative humidity CMCs…
- … by incremental developments…
- … starting from the available commercial climatic test chamber…
- … ending with a set up allowing relative humidity calibrations at:
  - temperatures up to 180 °C
  - dew-point temperatures up to 150 °C
  - pressures up to 600 kPa
- Tests on impedance and acoustic sensors

Climatic Test Chambers

- Commercial Climatic Chambers:
  - Temperature range: -75 °C up to 180 °C
  - Humidity range: limited (10 °C up to 95 °C)
  - Pressure range: limited (mostly only atmospheric)
  - Test space volume: large

VSL climatic test chamber

- Heraeus HC4033:
  - Temperature range: -40 °C up to 180 °C
  - Humidity range: 10 °C up to 95 °C
  - Pressure range: only atmospheric
  - Test space volume: 650 x 645 x 745 mm^3



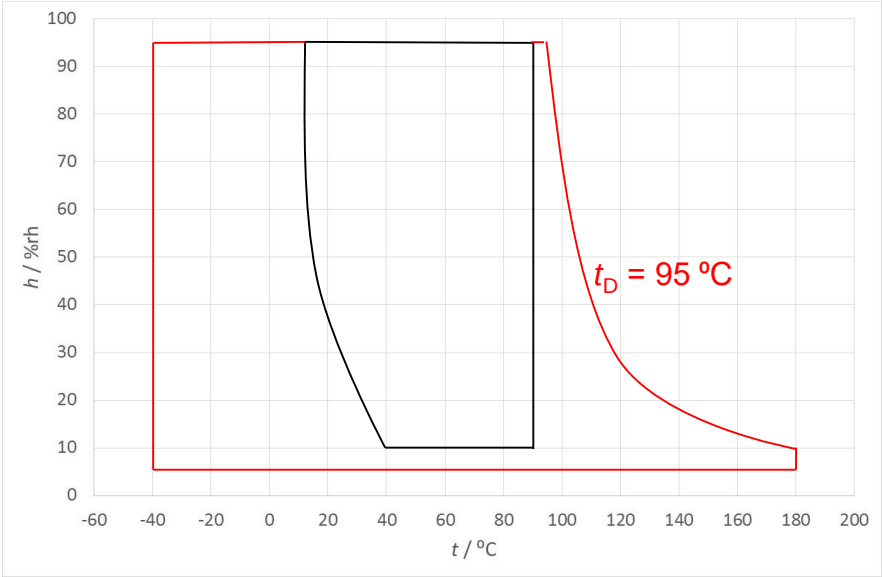
Extension of CMCs

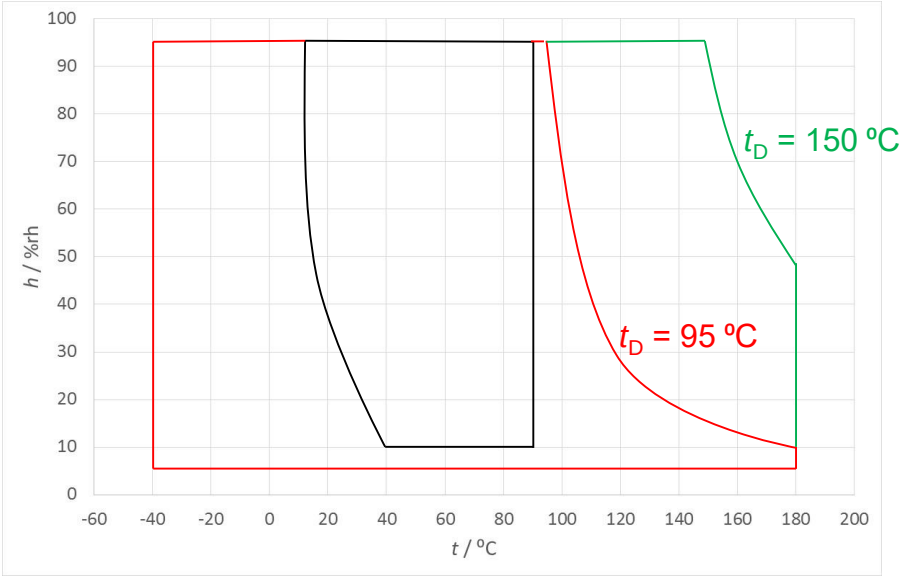
➢ Through incremental developments (from 2011 to 2015):

- Sub-chamber in the chamber test space
- External saturator
- Test space volume: 300 x 300 x 300 mm^3
- Temperature range: -40 °C to 180 °C
- Pressure range: 50 kPa to 600 kPa
- Dewpoint temperature: -64 °C to 95 °C

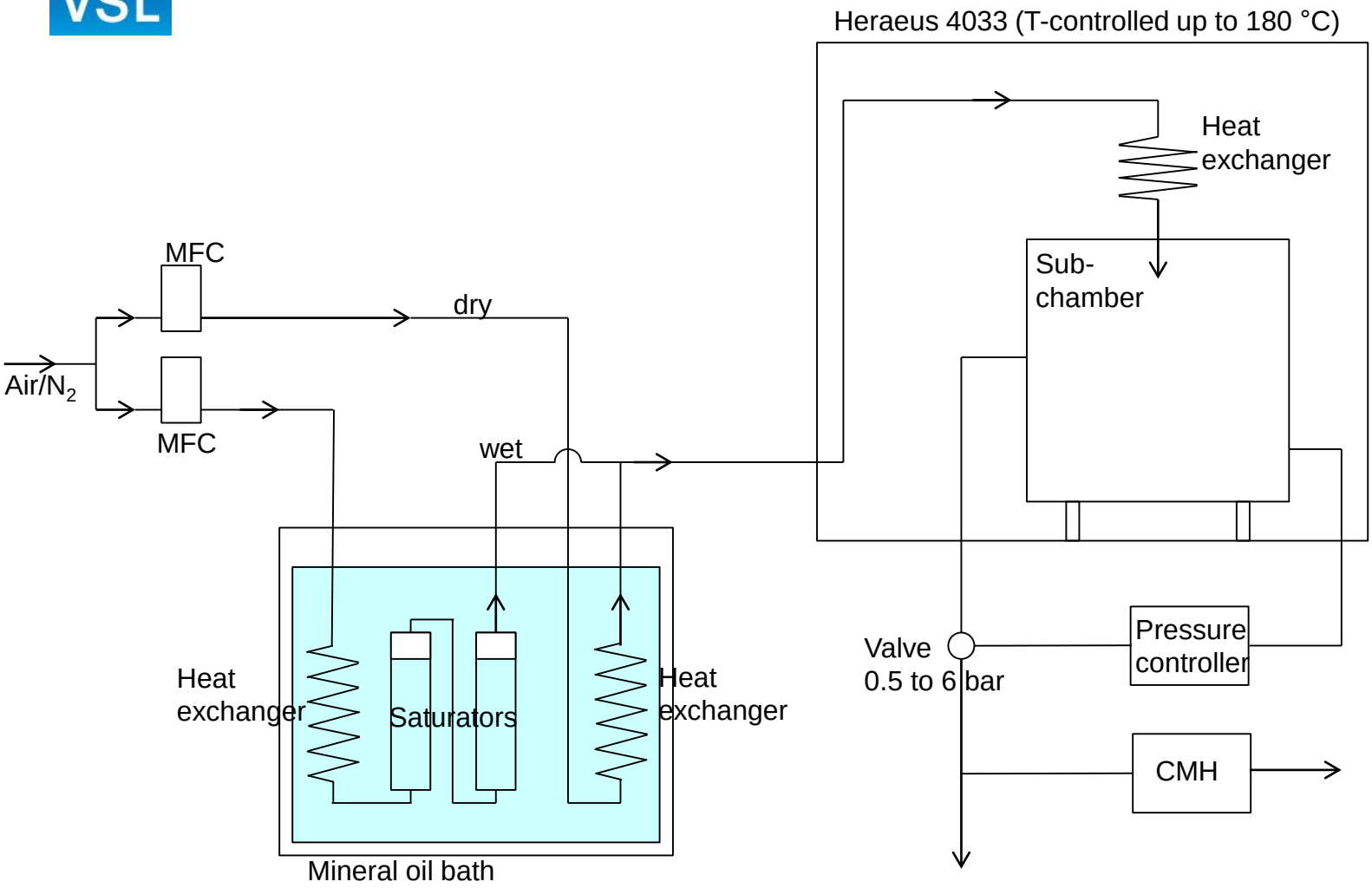
➢ Last development (2015-2017):

- Dewpoint temperature: up to 150 °C



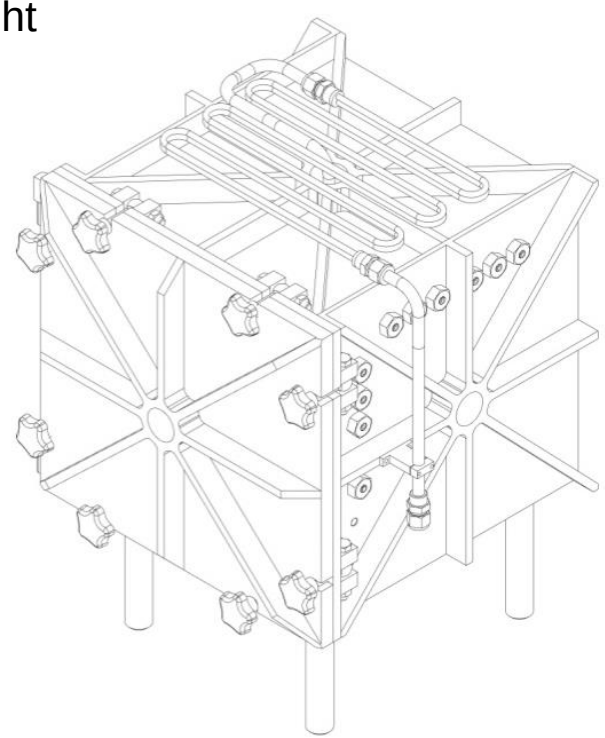


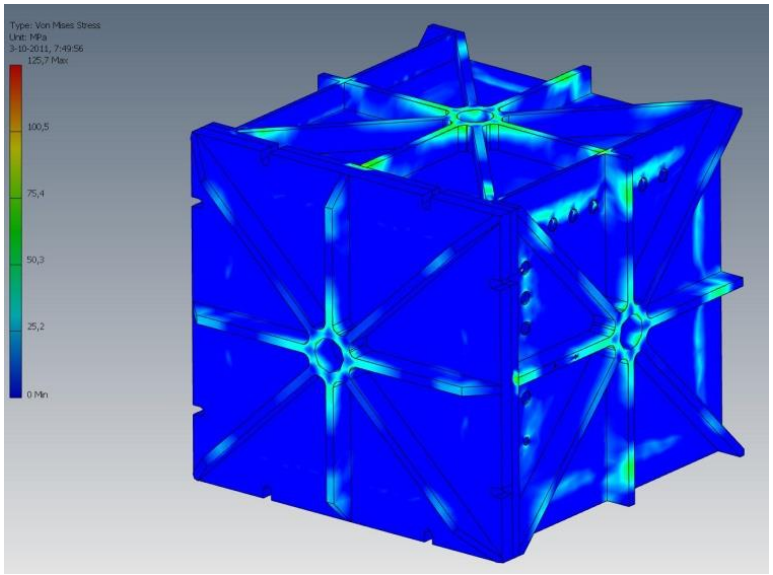
Sketch of the set-up



Sub-chamber: design

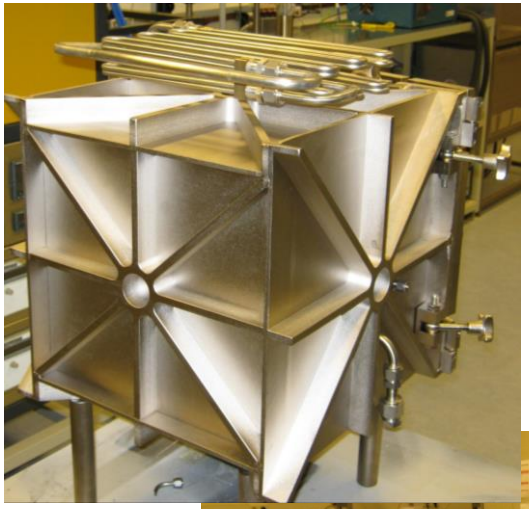
- Specifications:
- Size: fits in HC 4033 test volume
- Temperature range: -40 °C to 180 °C
- Pressure range: up to 600 kPa
- Corrosion resistant (high humidity at high temperature)
- Leak tight

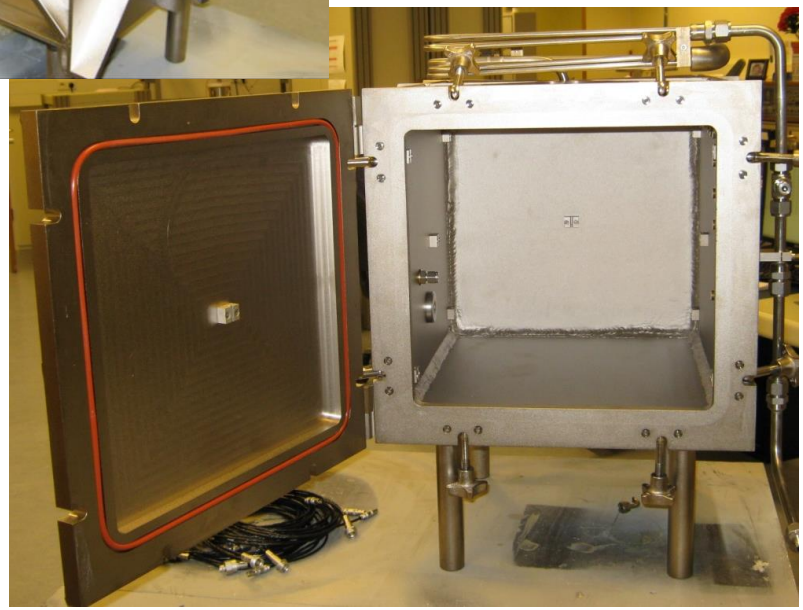




Von Mises stress plot

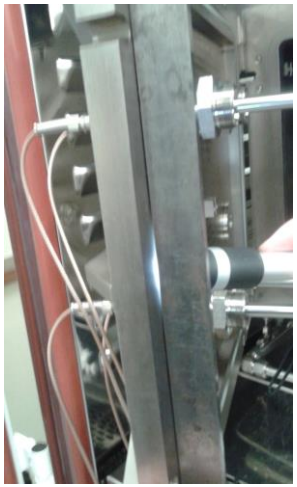
Sub-chamber: realization



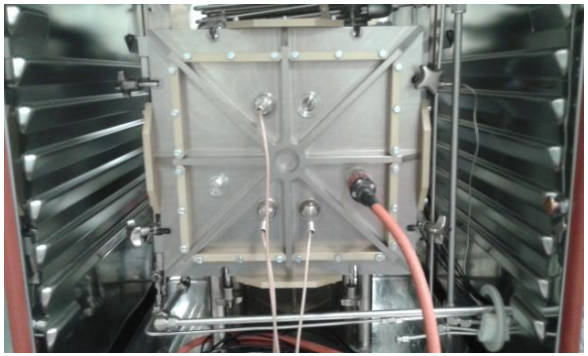


Sub-chamber: modeling versus real world

Deformation of chamber door



Door reinforced with extra ribs



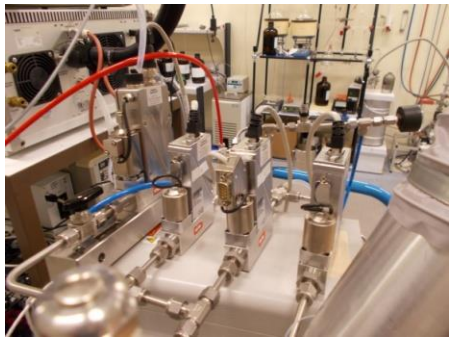
500 kPa over 30 cm x 30 cm ≈ 4500 kg

Saturator in liquid bath

2 containers with 50 cm water column

Mineral oil bath for dew-point temperatures up to 150 °C

Saturators automatic refill from external containers at 23 °C.
(11 l water, allowing 24 hours operation at 150 °C and 95% rh)



Flow mixing using mass flow controllers

Heated valve at exit of pressure chamber

Tests at 550 kPa and 150°C

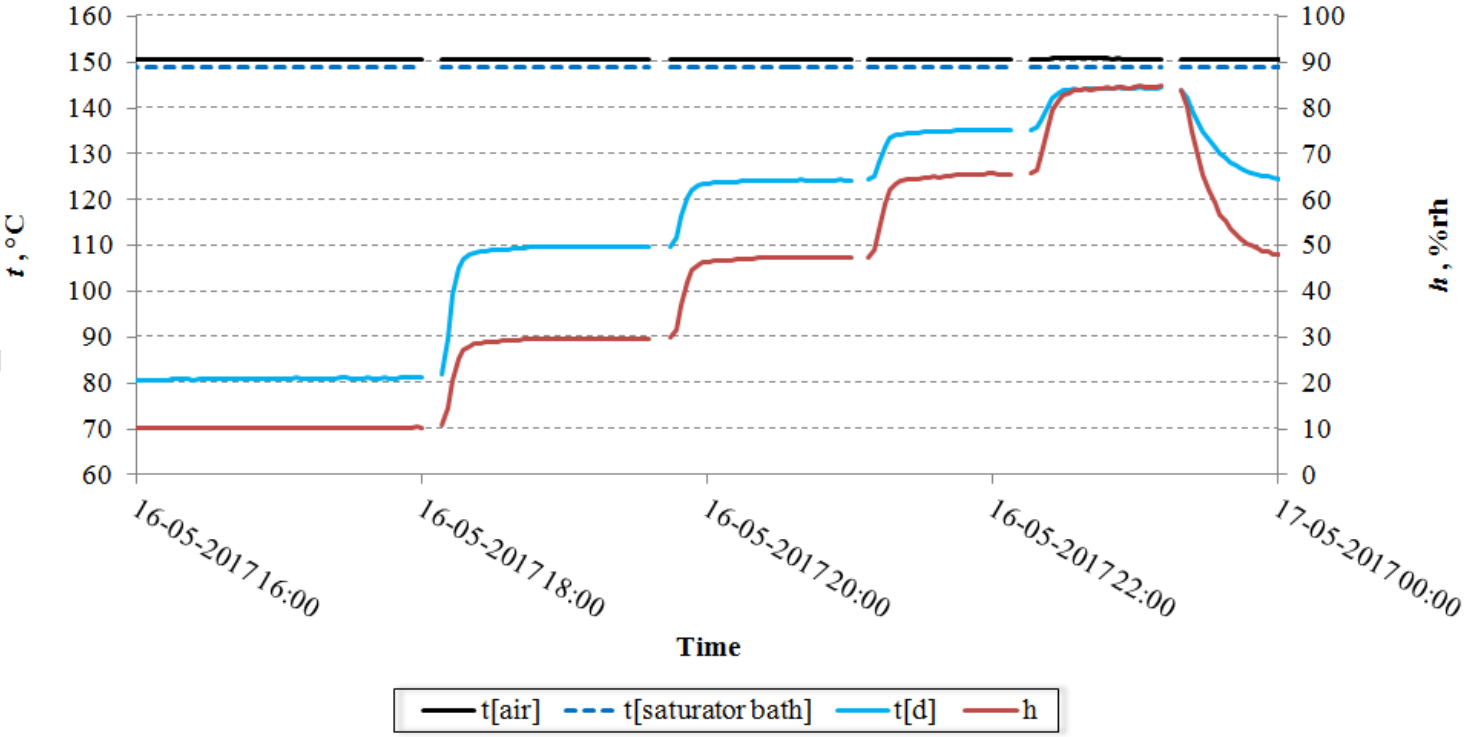
t_{HC4033} set to 150 ºC

$p_{sub\text{-}ch}$ = 550 kPa

t_{bath} = 150 ºC

t_D and h varied by changing the mixing ratio of dry and wet flow rates

t_{air} measured with thermistors



t_{air} measured with thermistors

t_d measured with CMH on expanded gas

EA-accreditation

Annex to ISO/IEC 17025:2005 declaration of accreditation for registration number: **K 999**

of **VSL**
(KvK nummer 27228703)

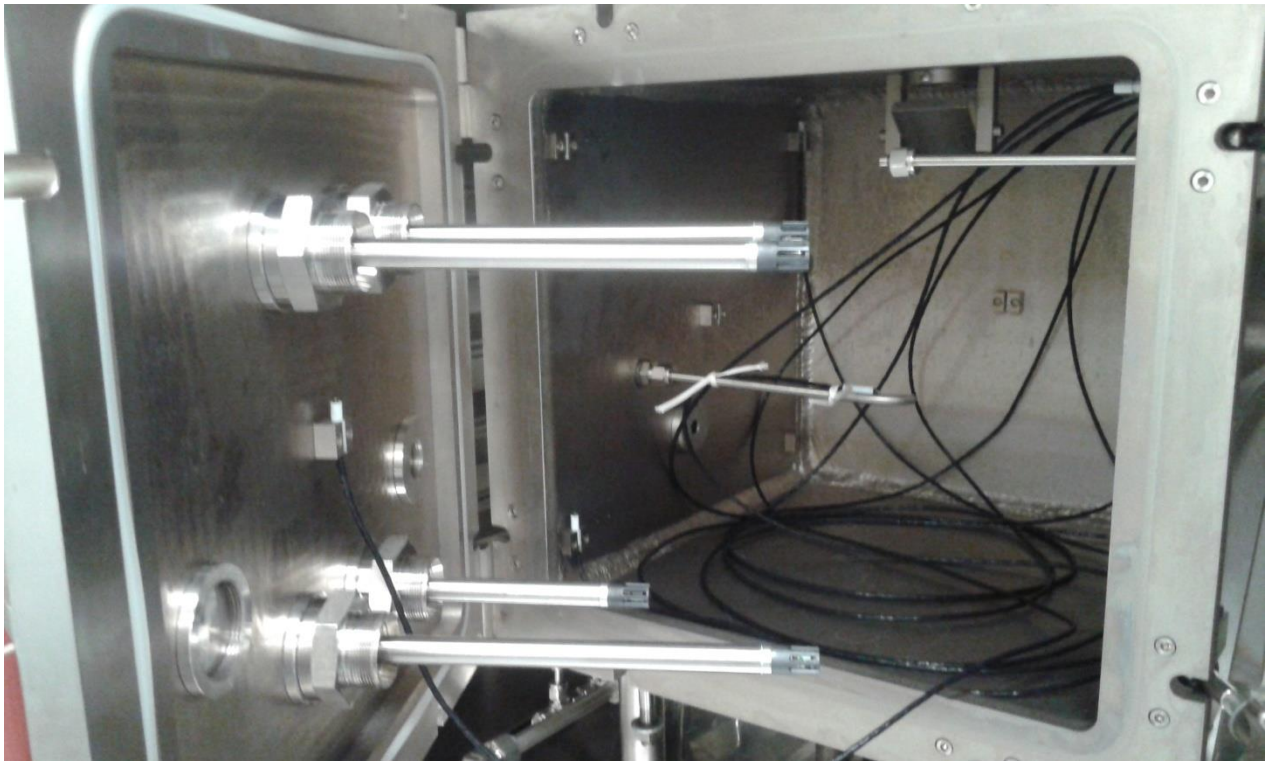
This annex is valid from: **03-10-2016** to **01-11-2017** Replaces annex dated: **09-12-2015**

RH 00		Humidity		
HCS code	Quantity, Instrument, Measure	Measuring range	CMC*	Remarks
RH 10	Dew point meters	-83 °C – -70 °C 0.1 MPa	0.06 °C	Against primary generator in two pressure mode with air and nitrogen
		-70 °C – -50 °C 0.1 MPa – 0.6 MPa	0.04 °C	Against primary generator in single pressure mode with air and nitrogen
		-50 °C – -41 °C 0.1 MPa – 0.6 MPa	0.04 °C	
		-41 °C – +15 °C 0.1 MPa – 6.0 MPa	0.04 °C	
		15 °C – 50 °C 0.1 MPa	0.04 °C	
		50 °C – 65 °C 0.1 MPa	0.05 °C	
		65 °C – 95 °C 0.1 MPa	0.05 °C - 0.1 °C	
		-50 °C – -15 °C 0.1 MPa - 0.5 MPa	0.04 °C	Against primary generator in single pressure mode with methane as carrier gas
		-15 °C – +8 °C 0.1 MPa – 3.0 MPa	0.04 °C	
		8 °C - 15 °C 0.1 MPa – 6.0 MPa	0.04 °C	
		-30 °C – +65 °C	0.10 °C	By comparison with air
RH 13	Relative Humidity sensors	-10 °C – +70 °C 10 %rh – 95 %rh	0.3 %rh – 0.8 %rh	By comparison in climatic chamber at atmospheric pressure with air
		-40 °C – +5 °C 1 %rh – 97 %rh	0.4 %rh – 0.8+(5-t/°C)*0.5) %rh	By comparison in climatic chamber between 50 kPa(a) and 600 kPa(a) with air
		5 °C – 180 °C 1 %rh – 97 %rh, t_{dmax} = 95 °C	0.4 %rh – 0.8 %rh	
RH 14	Trace humidity meters	0.3 µmol/mol – 10 000 µmol/mol 0.1 MPa	0.3 % – 2.0 %	Against primary generator in two pressure mode with air and nitrogen

CALIBRATION
RvA K 999

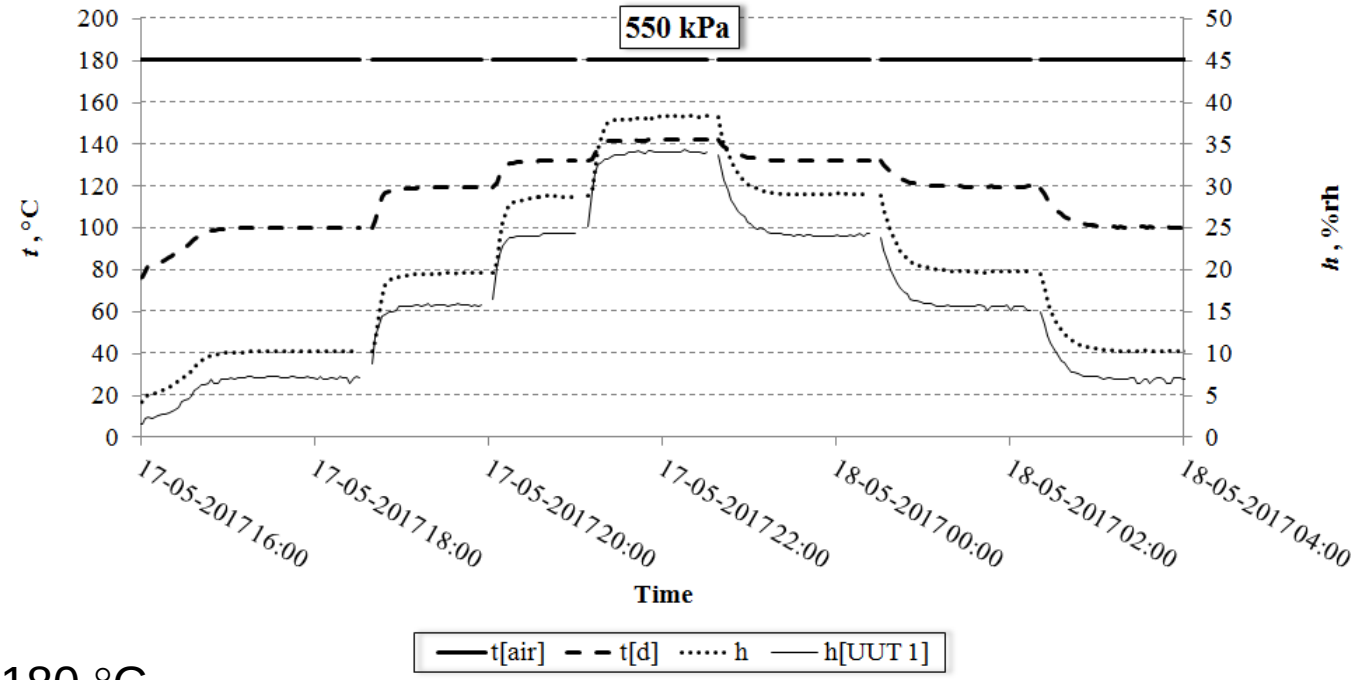
- Accreditation since 2015:
  - Temperature: up to 180 °C
  - Pressure: up to 600 kPa
  - $t_{d,max}$ = 95 °C
- Accreditation from January 2018:
  - Temperature: up to 180 °C
  - Pressure: up to 600 kPa
  - $t_{d,max}$ = 150 °C

Tests on impedance sensors



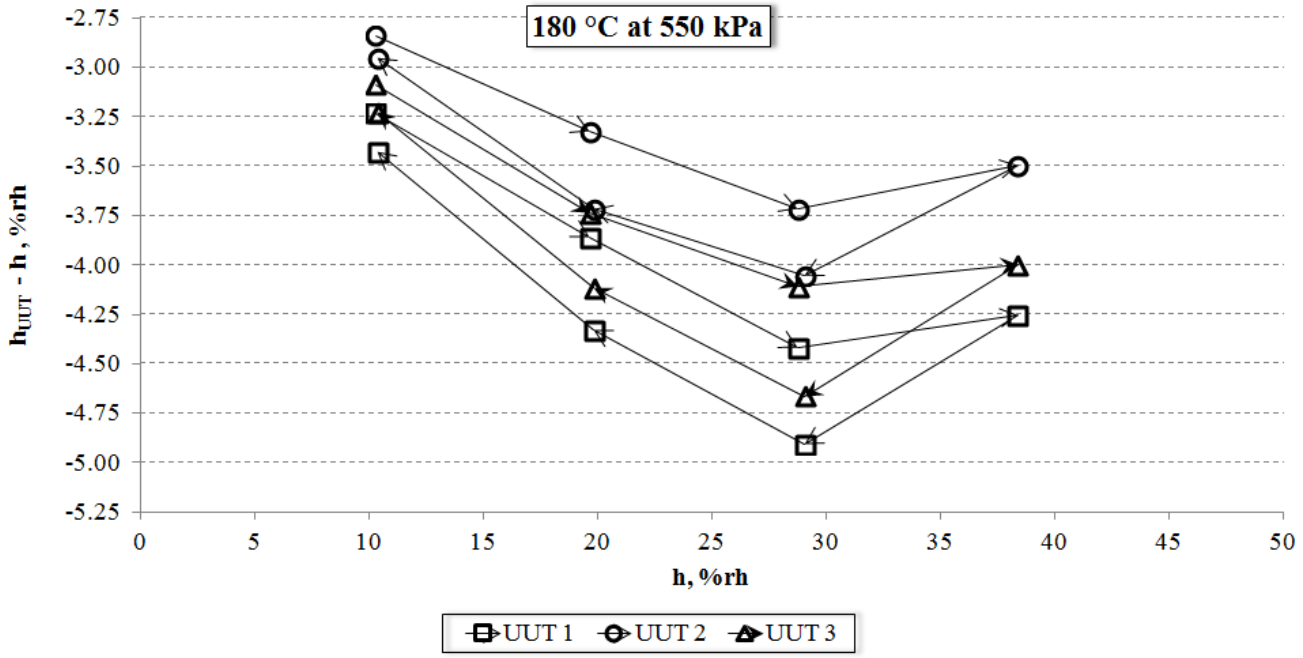
- Michell Benelux DT722
- 5 sensors tested
- 7 measurement runs
- $t_{air,max}$ = 180 °C $t_{d,max}$ = 144 °C p_{max} = 550 kPa

Tests with Michell DT722



- t_{air} = 180 °C
- p = 550 kPa
- h = 5 … 38 %rh
- t_d = 80 … 140 °C

Tests with Michell DT722



- 3 sensors at t_{air} = 180 °C and p = 550 kPa:
  - Deviation of humidity indication from reference humidity: < 5 %rh
  - Hysteresis: < 0.5 %rh

Determination of correction function

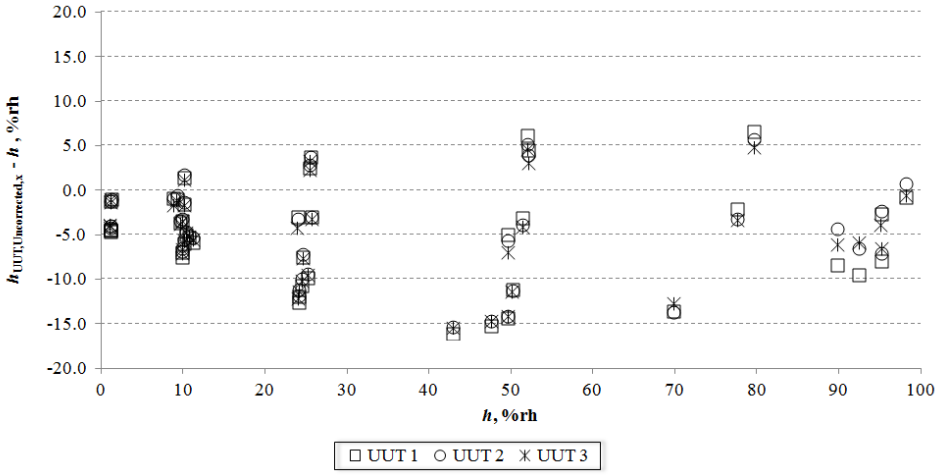
- Data set:
  - 3 sensors,
  - p = 400 kPa
  - t_{air} from 20 °C to 180 °C
  - Scatter up to 23 %rh

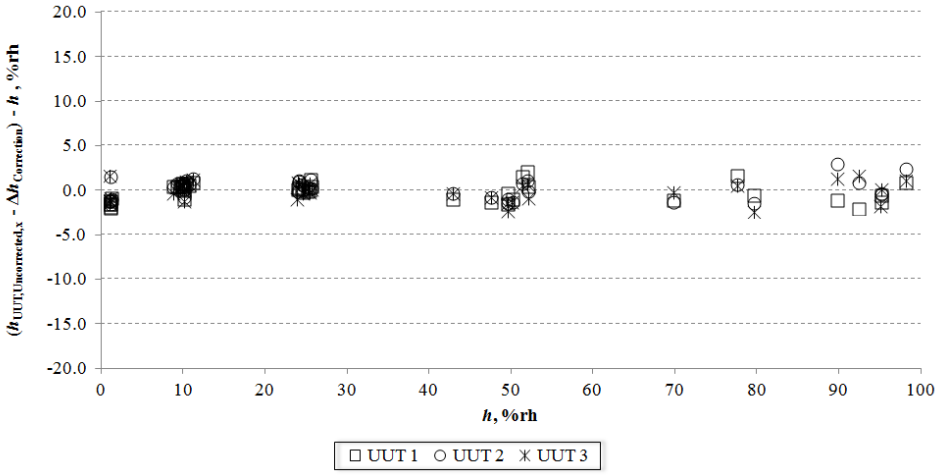
- Collective correction function:

$$\Delta h_{corr}\,(h,t) = \sum_i a_i\,t^i + \left(\sum_i b_i\,t^i\right)h + \left(\sum_i c_i\,t^i\right)h^2$$

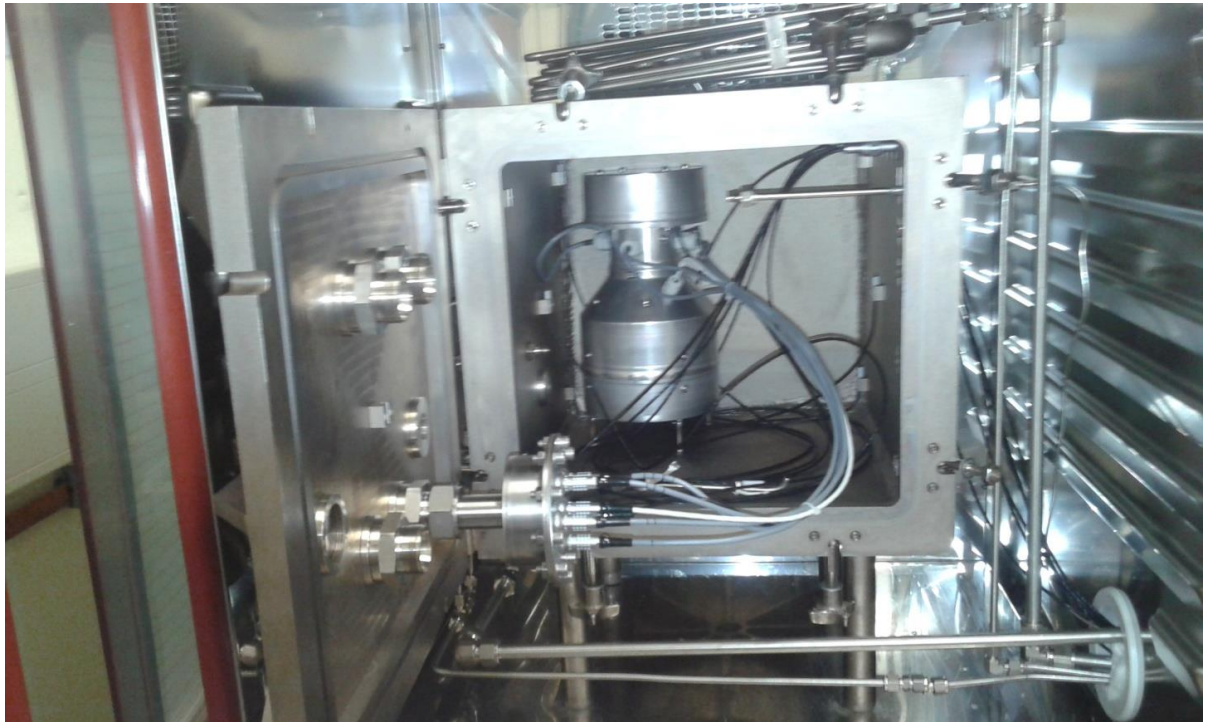
i = 0, 1, 2

- After applying the collective correction function:
  - The scatter is reduced to < 5 %rh with a standard deviation of 1.2 %rh





Tests with Innovation Handling HT-183



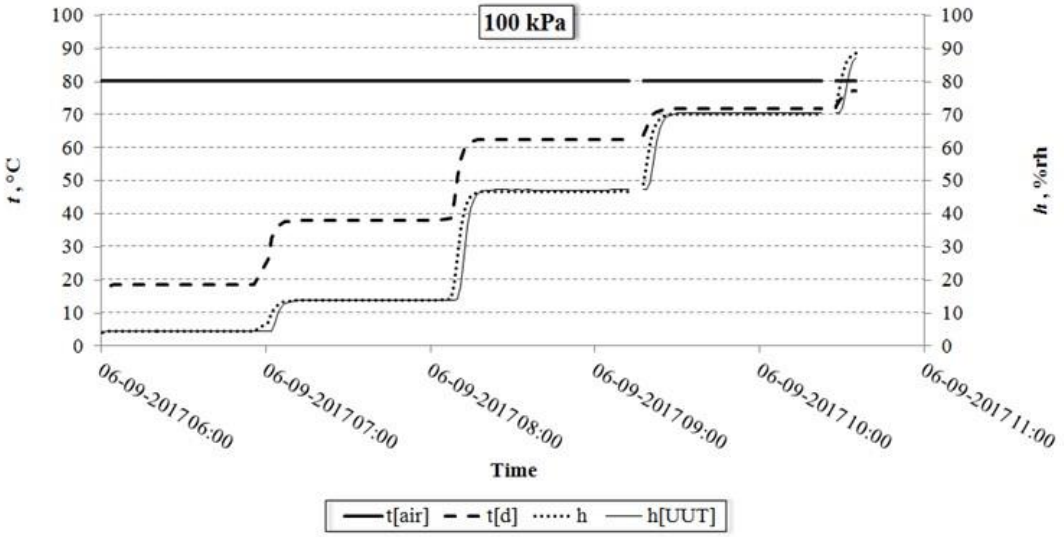
- The device measures temperature t_{air} and the speed of sound v and calculates from them the relative humidity h

- 2 devices and 6 measurement runs

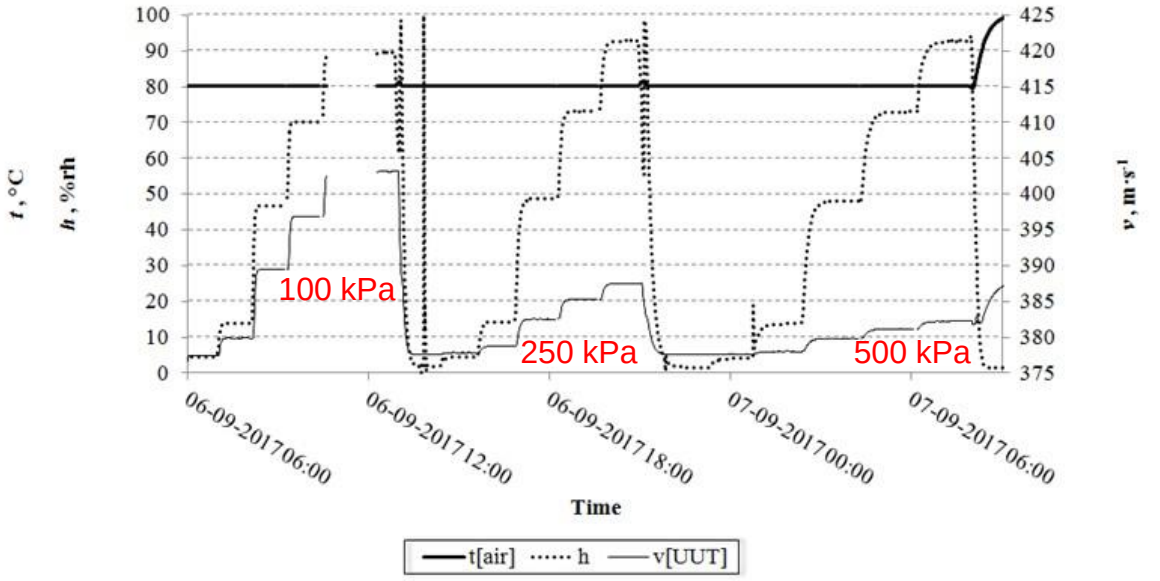
- $t_{air,max}$ = 120 °C ; $t_{d,max}$ = 117 °C ; p_{max} = 500 kPa

Tests with Innovation Handling HT-183

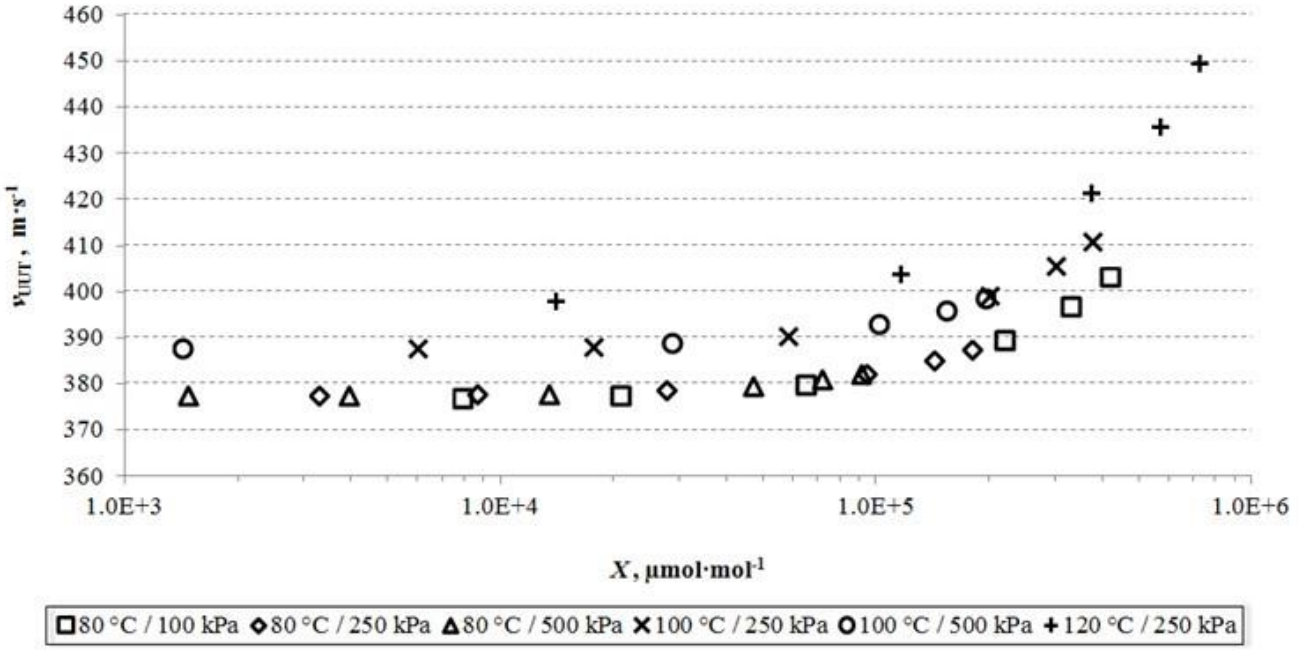
- t_{air} = 80 °C
- p = 100 kPa
- Deviation from reference less than 0.5 %rh



- t_{air} = 80 °C
- p_{max} = 100 kPa, 250 kPa and 500 kPa
- For the same change in h, the corresponding change in v decreases with increasing pressure



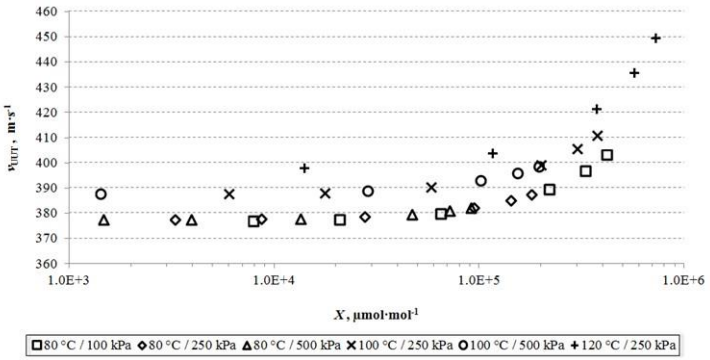
Speed of sound: results



- Speed of sound indicated by the device as a function of water mole fraction X, temperature t_{air} and pressure p

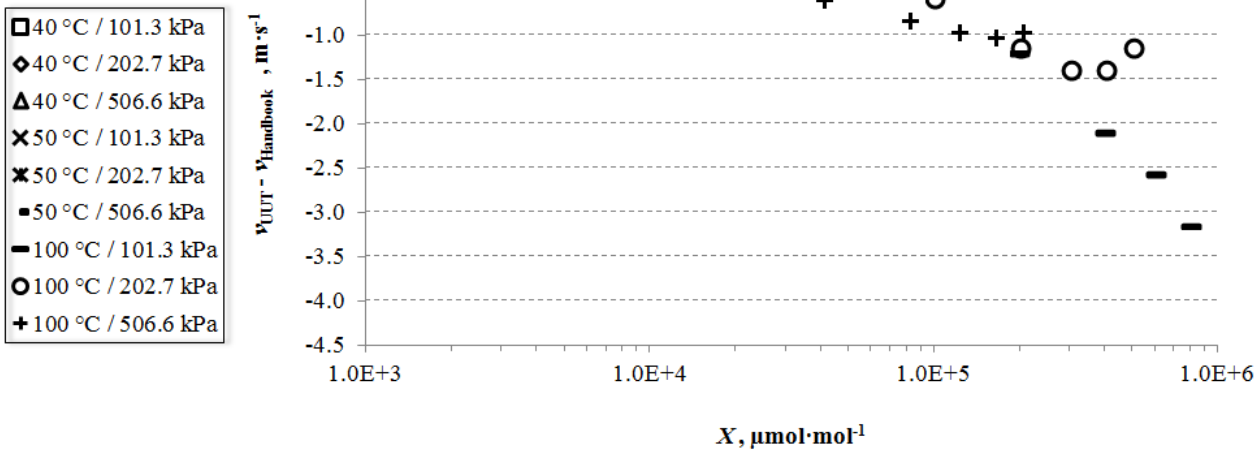
- p = 100 kPa, 250 kPa and 500 kPa

Speed of sound: analysis



- Fitting equation: $v_{UUT} = \sum_{i=0}^{2} a_i\, t^i + \sum_{i=0}^{2} b_i\, X^i$
- Experimental standard deviation: 0.4 m·s^{-1}
- Compared to literature (Zuckerwar, 2002) in ranges 40 ºC ≤ t_{air} ≤ 100 ºC, p ≤ 500 kPa
- At low temperature the fitted equation agrees with literature within 0.5 m·s^{-1} (up to 3 m·s^{-1} at high temperature)

- Discrepancies could be explained by:
  - CO_2 content with respect to literature
  - 78 cm channel vs free space (literature)



Conclusion

- Relative humidity set-up for temperatures up to 180 °C, dew-point temperatures up to 150 °C and pressures up to 600 kPa.

- The setup was used to:
  - Test impedance sensors
  - Determine the temperature correction function of impedance sensors
  - Test acoustic sensors
  - Determine the speed of sound in air up to 120 °C and 500 kPa