Relative humidity at temperatures up to 180 °C and pressures up to 600 kPa

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Outline

- ✓ Humidity at high temperatures
- ✓ Modifications of the facility since 2013
- ✓ Validation at pressure
- ✓ Drift and pressure sensitivity of thermistors
- ✓ Future work : dew-point temperatures above 95 °C

Humidity at high temperature

Drying is estimated to cost European industry around 30 000 M€ per year in associated energy costs. Every 0.1 % improvement in drying efficiency due to better process control could save around 30 M€/year. Monitoring humidity under transient conditions and at temperatures above 100 °C is a key factor in controlling drying processes. Thus, by improving the reliability of these humidity measurements annual savings of millions of euros can be achieved in Europe

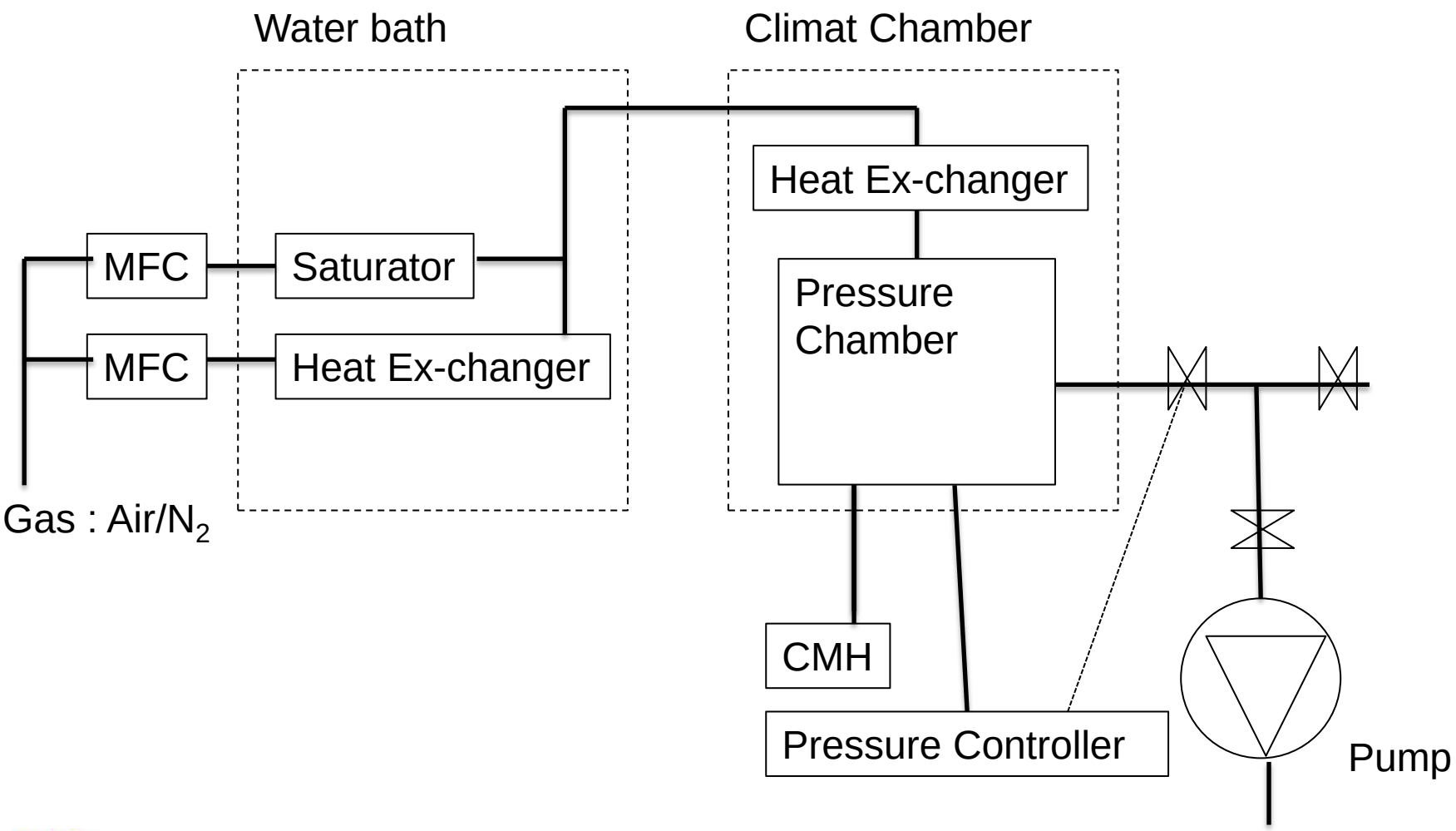
Source : EMPIR HIT 14IND11 HIT

Wood drying

Paper drying (1970's)

Spray-dryer: Milk powder, Pharmaceutical products, Ceramics, etc

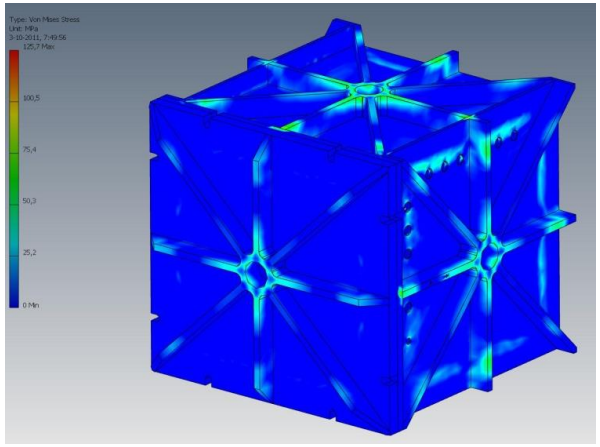
Design facility

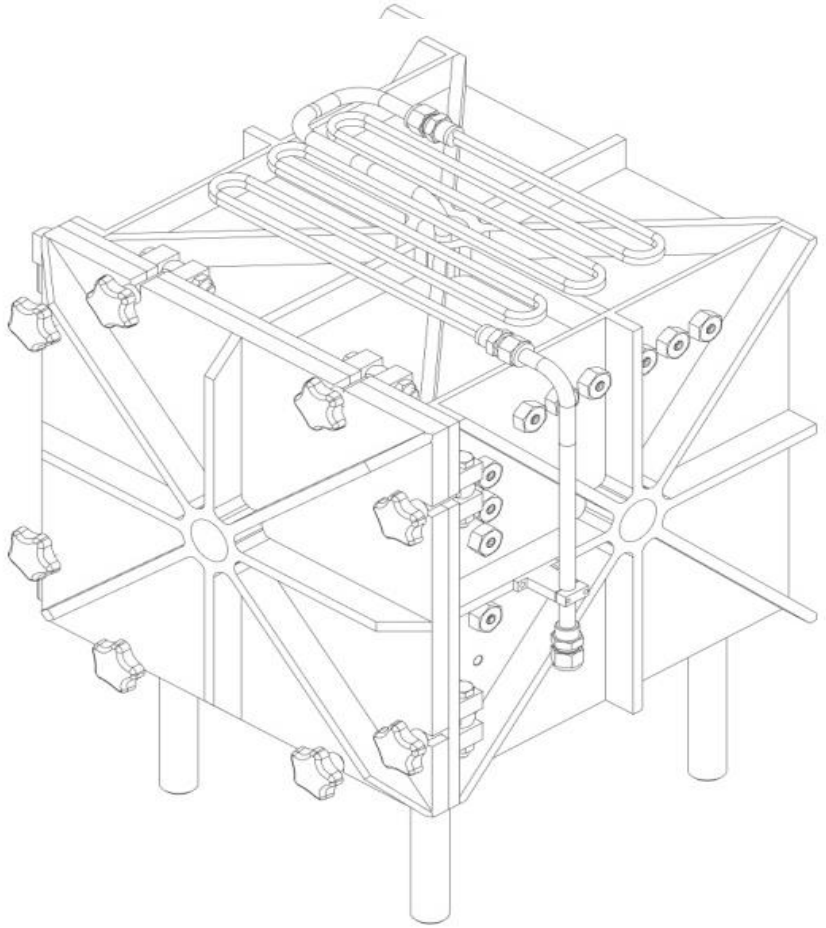


Design Chamber in Chamber

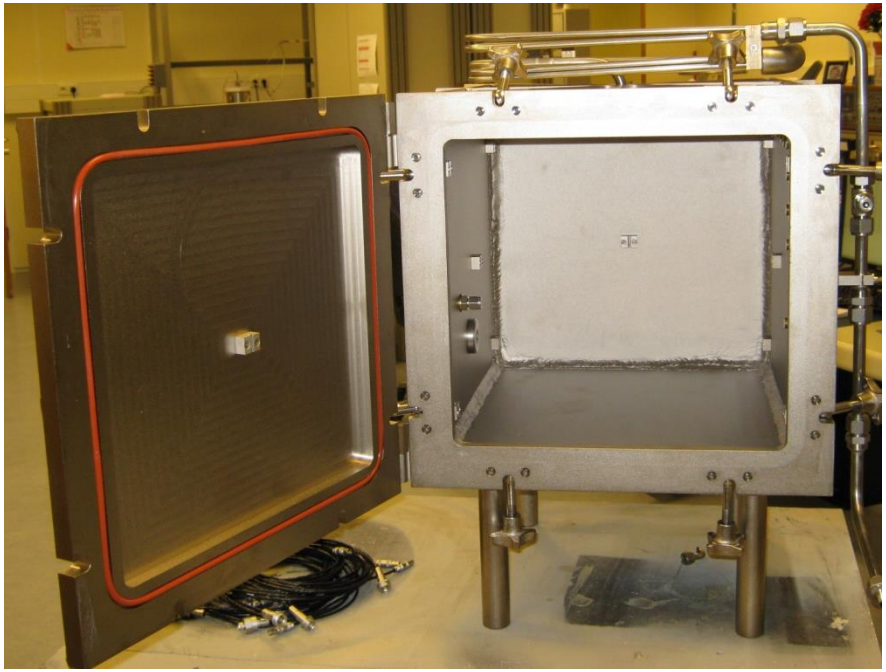
Specifications Chamber 2011:

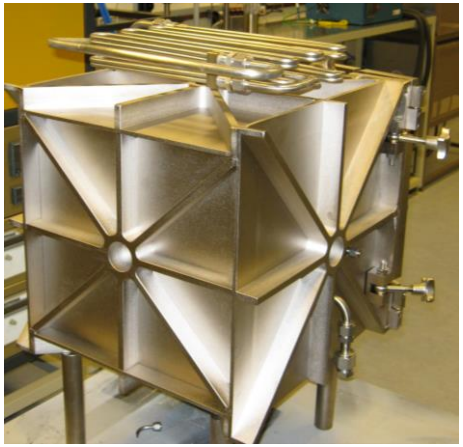
- ❑ Fits inside HC 4033 Chamber
- ❑ Range -40 °C to 180 °C
- ❑ Corrosion resistant (high humidity at high temperature)
- ❑ Leak tight
- ❑ Pressure up to 600 kPa





Realization in 2011

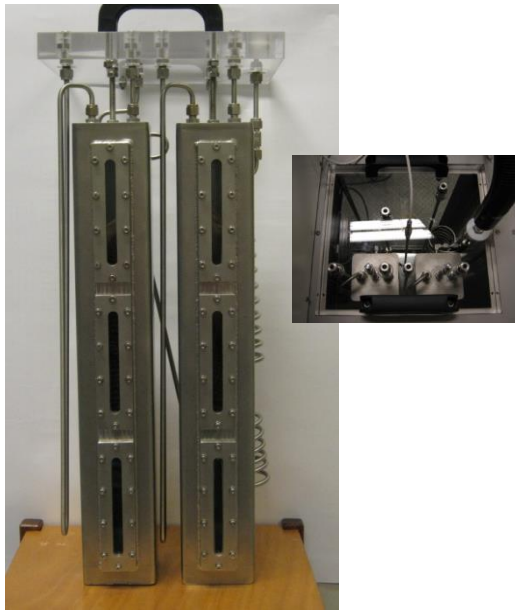




Modification of saturator

2013 →

2014 →



Glass cylinder for use at atmospheric pressure; water level 28 cm

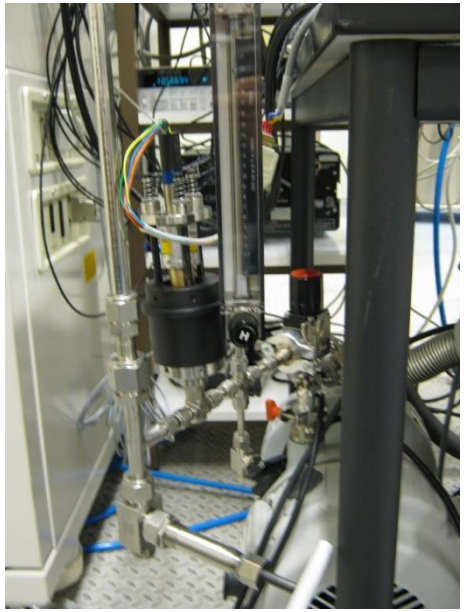
Steel container for use up to 600 kPa (Pre-Sat of HTS); water level 28 cm

Two steel container for use up to 600 kPa; water level 50 cm.

$\eta > 97\ \%$ at 20 $l \cdot min^{-1}$

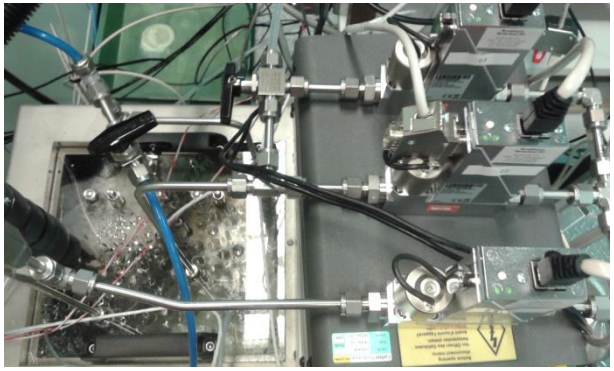
Saturator in water bath → temperature up to 95 °C

Modification Q_v/P-Control



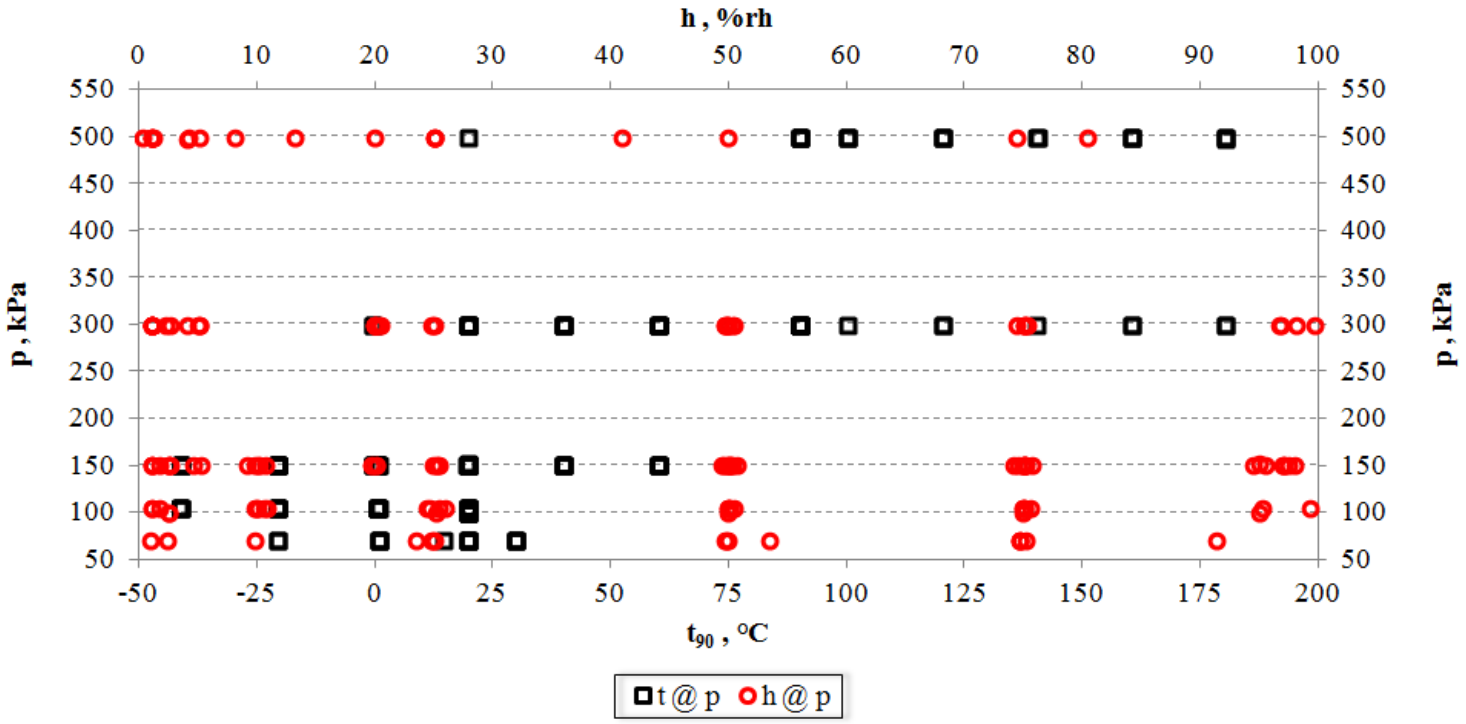
Rota-meters and home-built valve control

2014



Mass flow controllers and commercial pressure controller

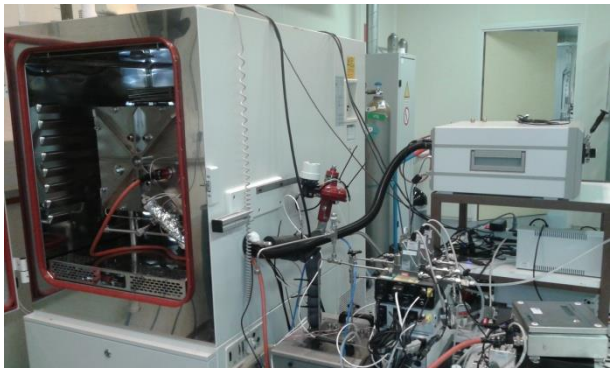
Validation of pressure range



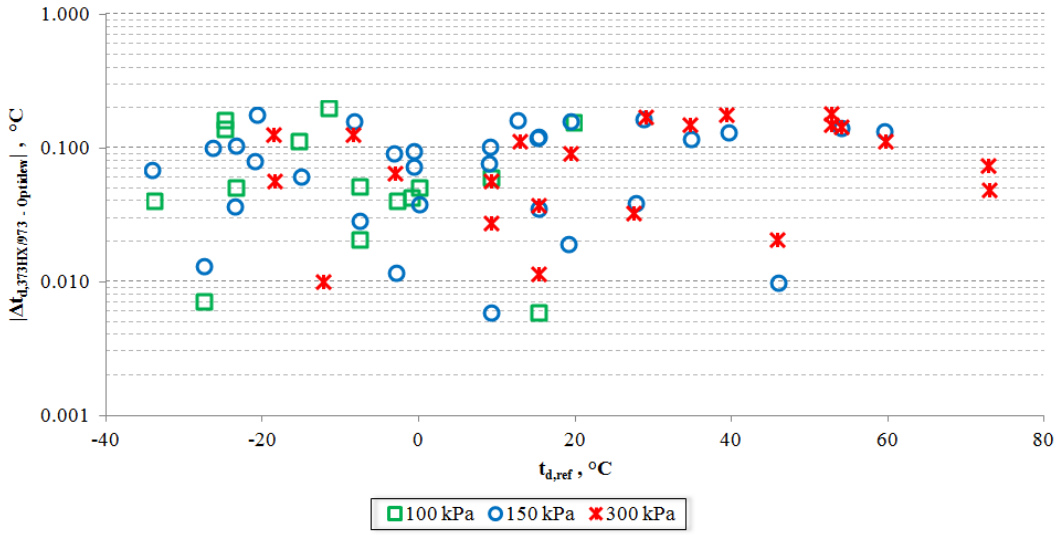
Validated from -40 °C to 180 °C, 1 %rh to 98 %rh and 70 kPa to 500 kPa

Validation Humidity

Optidew in door of chamber

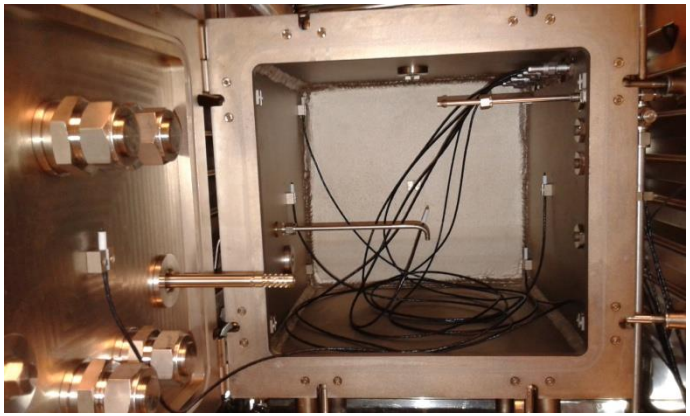


373 HX via sample tube outside chamber

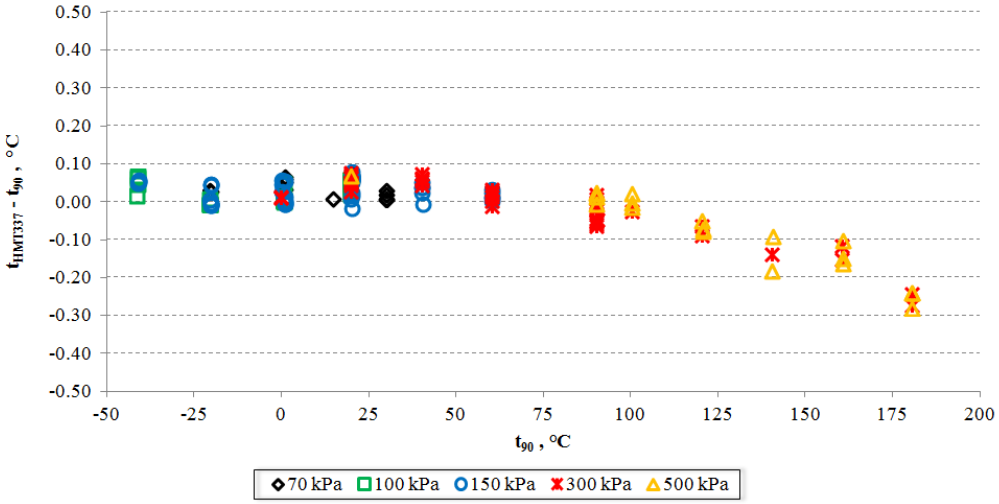


No influence of pressure on difference between CMH's

Validation Temperature

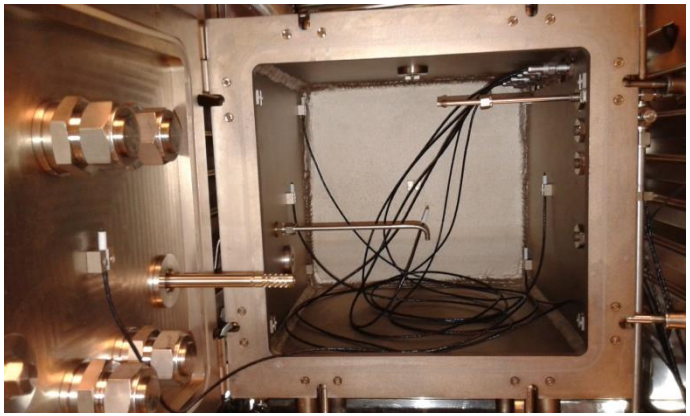


- HMT337 in door of chamber
- 6 thermistors in chamber

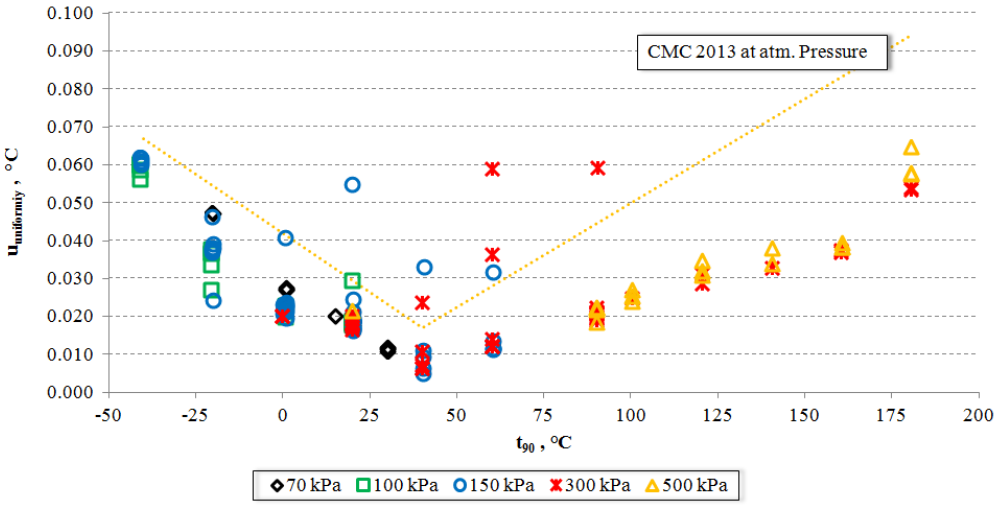


No influence of pressure on difference between temperatures

Validation Uniformity

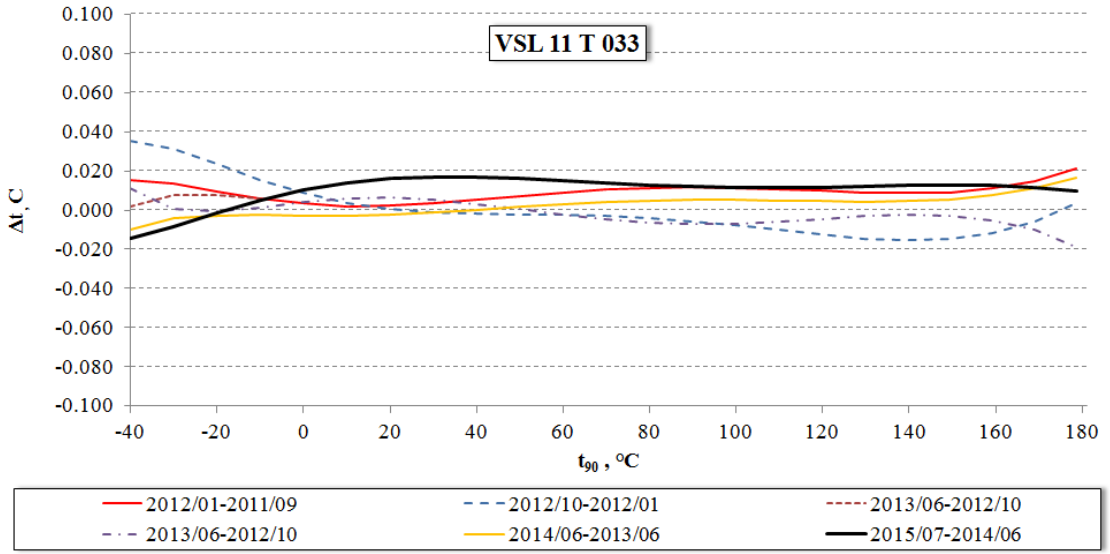


- 6 thermistors in chamber

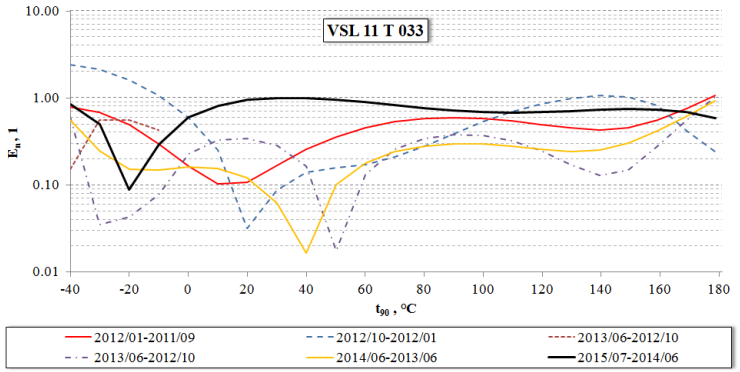


No influence of pressure on uncertainty component for temperature uniformity

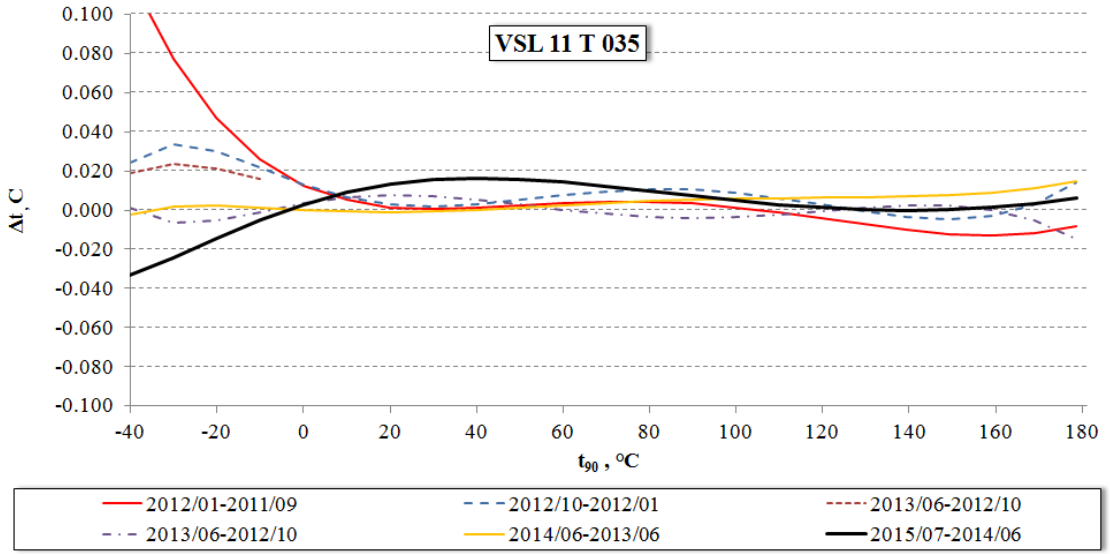
Drift of thermistors (1)



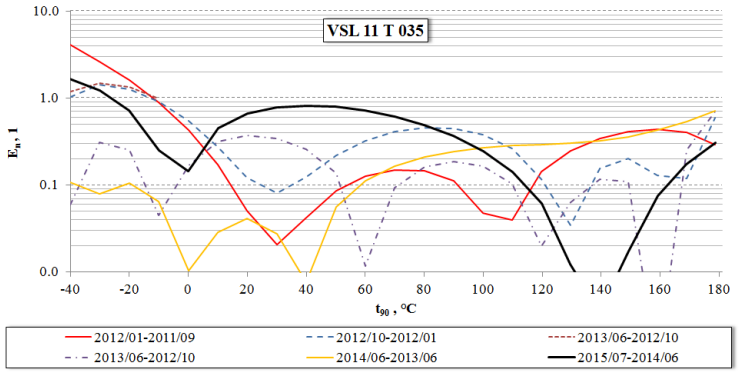
- 7 calibrations between September 2011 and July 2015
- u(cal) between 6 mK and 7 mK (N=5)
- Differences increase at low temperature (high resistance)



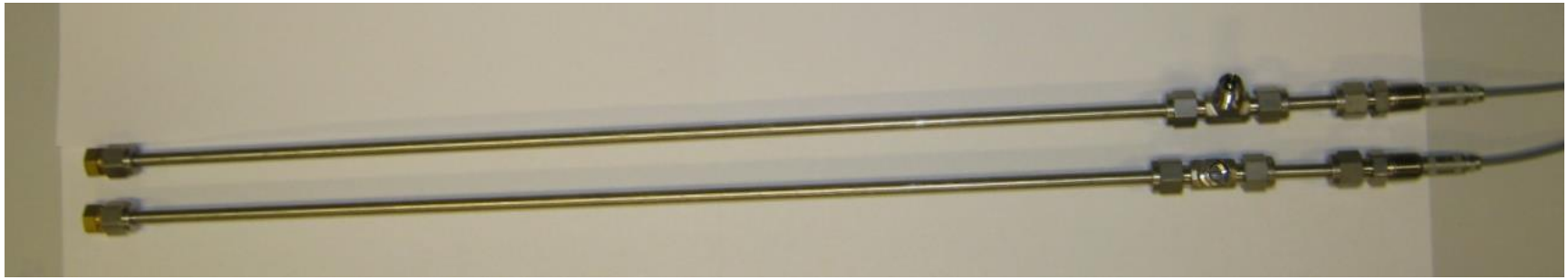
Drift of thermistors (2)



- 7 calibrations between September 2011 and July 2015
- u(cal) between 6 mK and 12 mK (N=5)
- Differences increase at low temperature (high resistance)

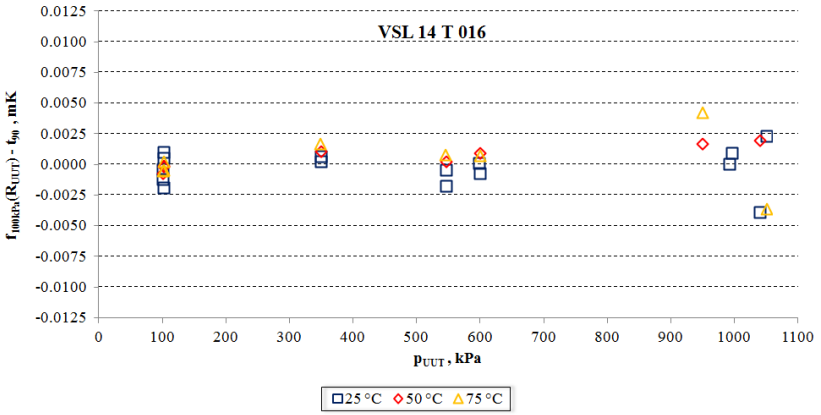


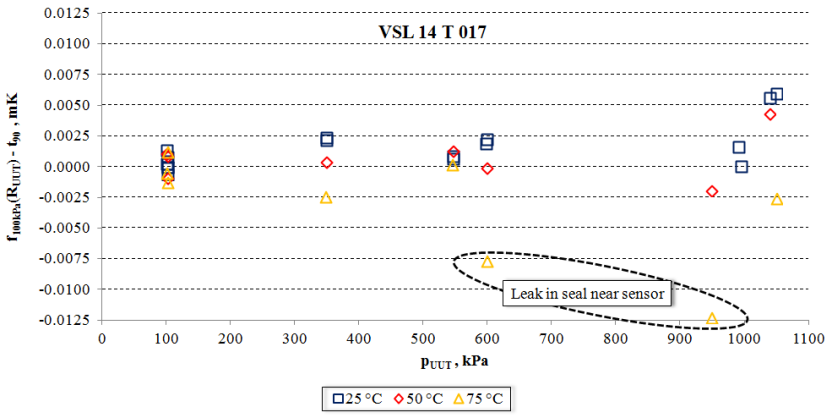
Pressure dependence thermistor (1)



- 2 thermistors sealed in tube and submerged in water bath
- Function t = f(R) measured at 100 kPa
- $R_{UUT,i}$,$p_{UUT,i}$ measured with air in tube pressurized up to 1 MPa

Pressure dependence thermistor (2)



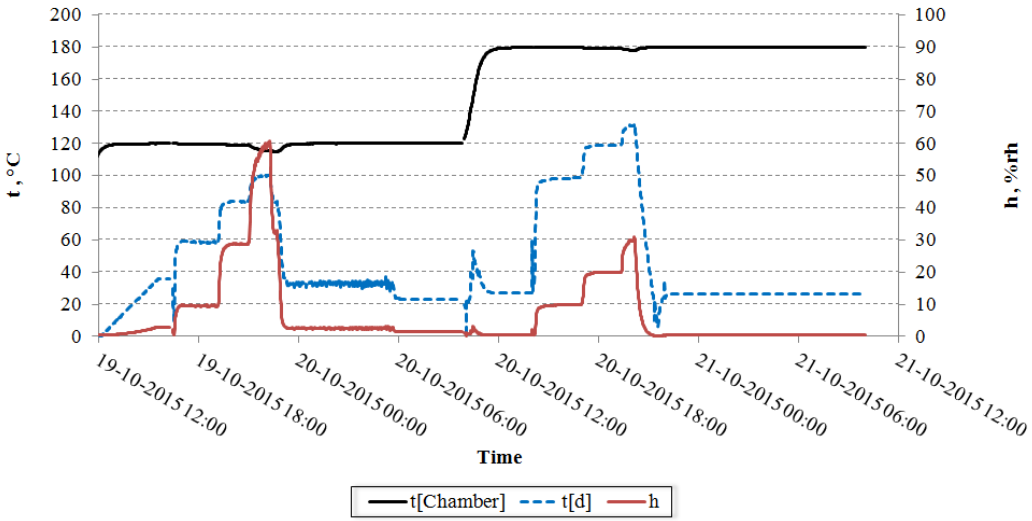


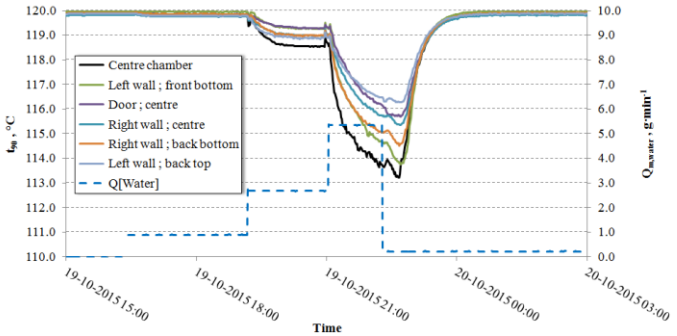
- Pressure sensitivity measured at 25 °C, 50 °C and 75 °C
- Uncertainty in temperature u(t) = 2.5 mK
- Up to 600 kPa no pressure sensitivity detectable

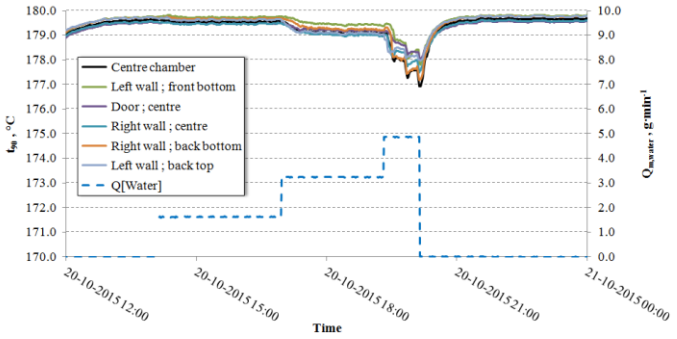
Preliminary work on t_d > 95 °C

- Coriolis mass flow controller up to 10 ml·min$_{-1}$
- 11 litre water container pressurized to 1 MPa
- Different ways of injecting water in dry gas tested
  - injecting direct in the dry gas stream
  - pre-heat the water before injecting
  - using small saturator (horizontal/vertical)

Results direct water injection

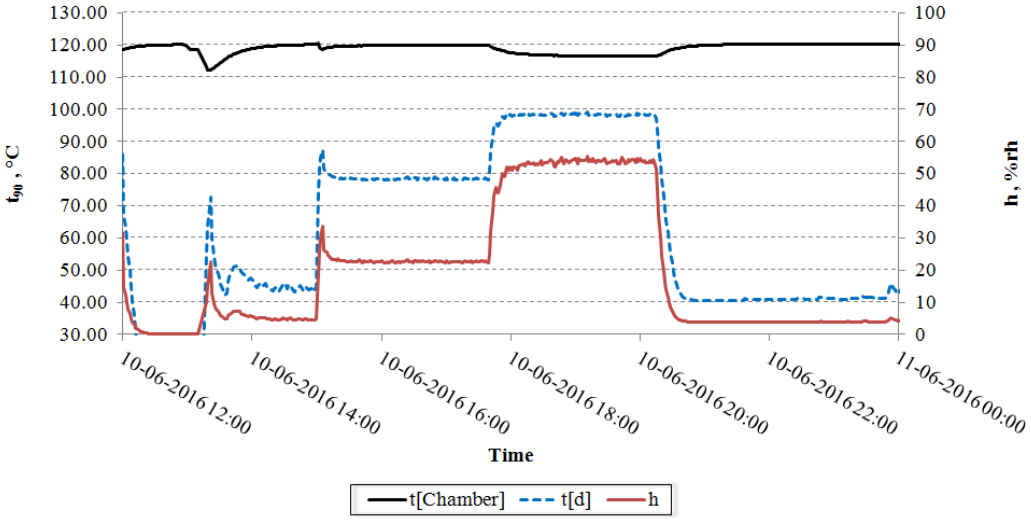


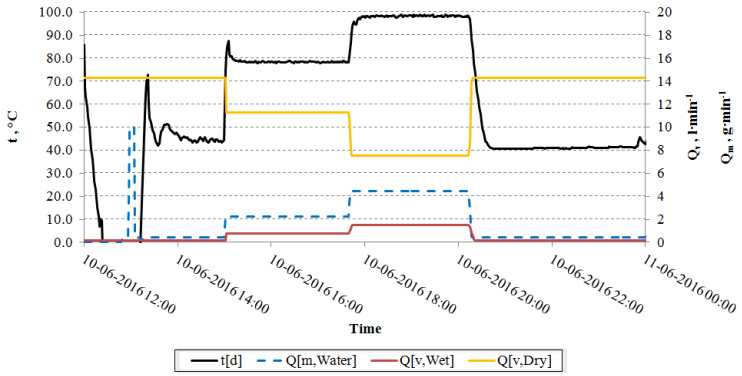


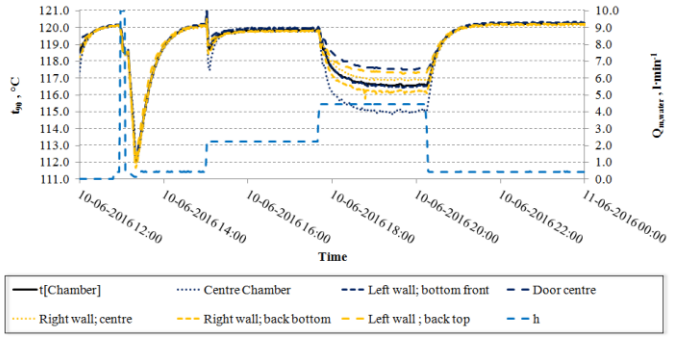


- Simple principle
- Achieved t_d =130 °C
- Large effect on pressure chamber temperature

Results saturator







- Less simple principle
- More stable dew-point temperature
- Still large effect on temperature

Conclusion

- Pressurizing the chamber does not affect the performance of the facility
- Thermistors can be used at high temperature and humidity with small drift
- Thermistors can be used up to 600 kPa without additional uncertainty

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States