2018/07/12

Process humidity measurements at high temperature

The use of lambda sensor for measuring humidity

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

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Outline

Context and needs

What is Lambda sensor ?

Experimental work

Results

Conclusion

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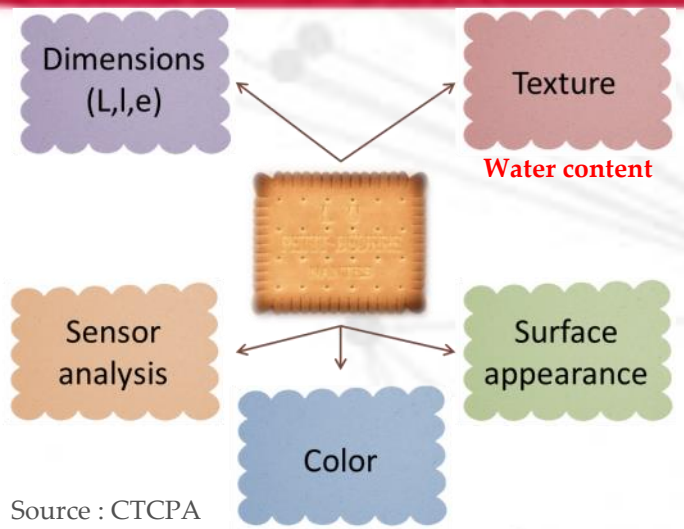
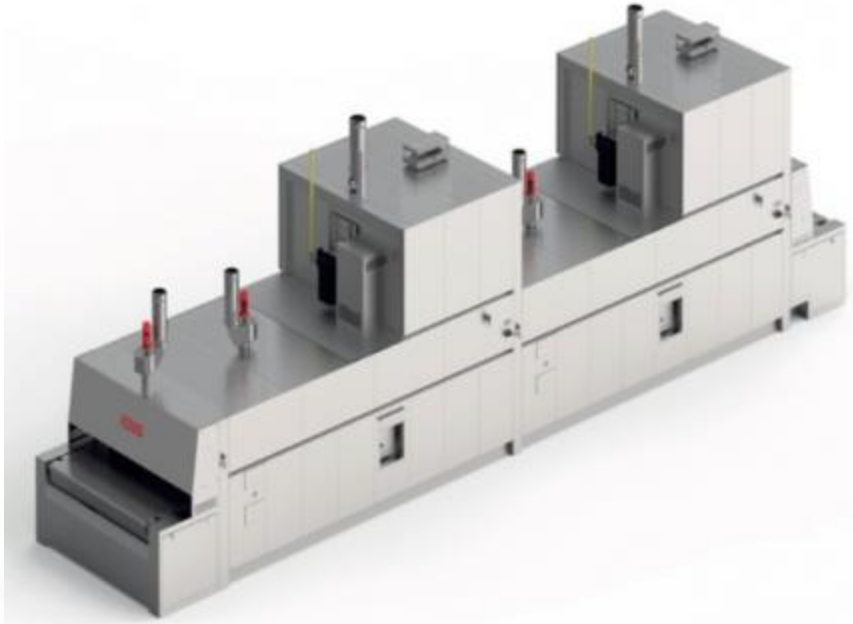
Context and needs

Baking process applied to cookies

- Water content inside the cookies
- Tunnel oven
- Improve tunnel oven by
  - Understanding aeraulic (flow)
  - Measuring temperature profile
  - Measuring humidity profile



Source : CTCPA



Source : http://www.ageniaa.com/fr/p-four-tunnel-de-cuisson-boulangerie-patisserie-cyclothermique-sdi-pharos--p214.html

Context and needs

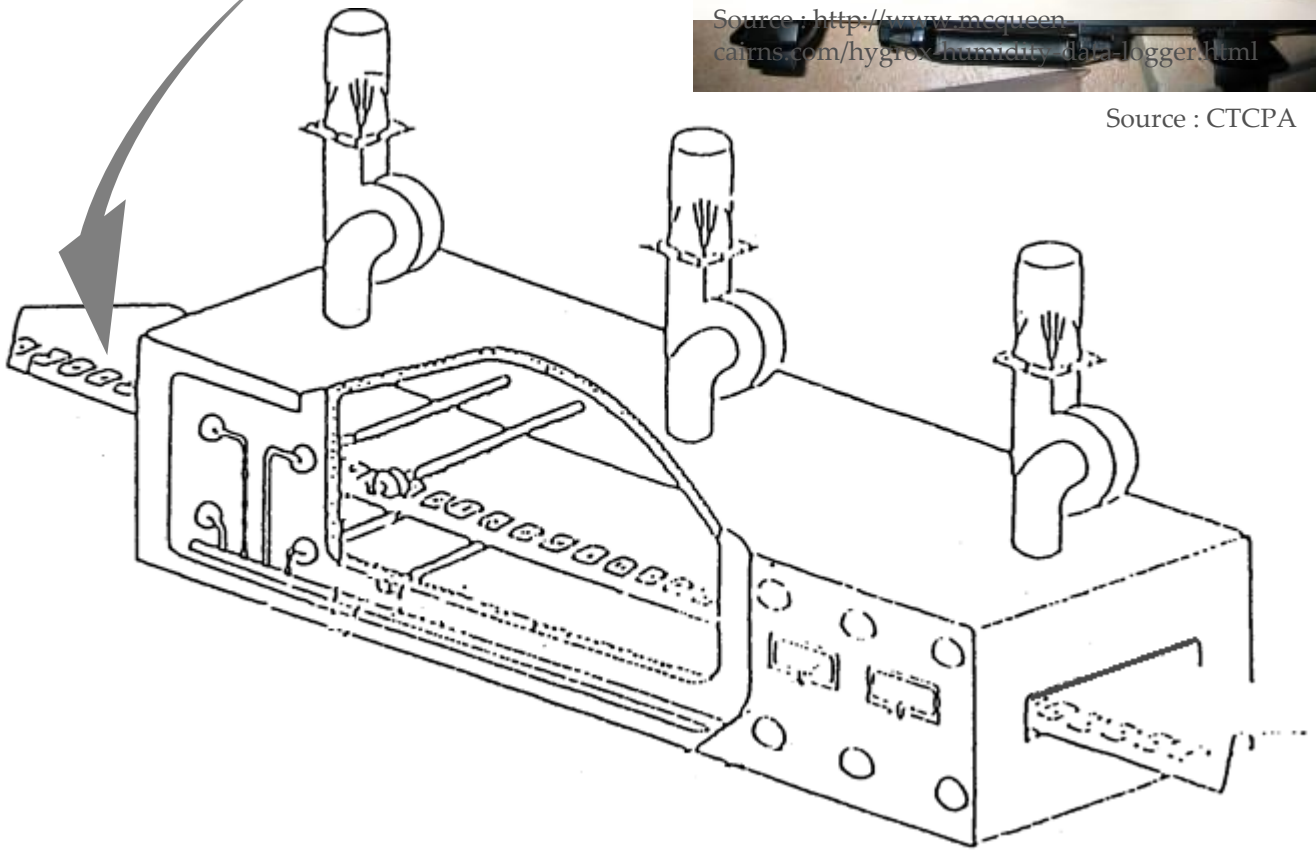
Baking process applied to cookies

- Tunnel oven & baking process, key parameters
  - Baking time
  - Temperatures
  - Extraction flow

- Sensors
  - Temperature sensor : thermocouple
  - Humidity sensor : zirconium oxyde (lambda sensor)

Source : http://www.mcqueen-cairns.com/hygrox-humidity-data-logger.html

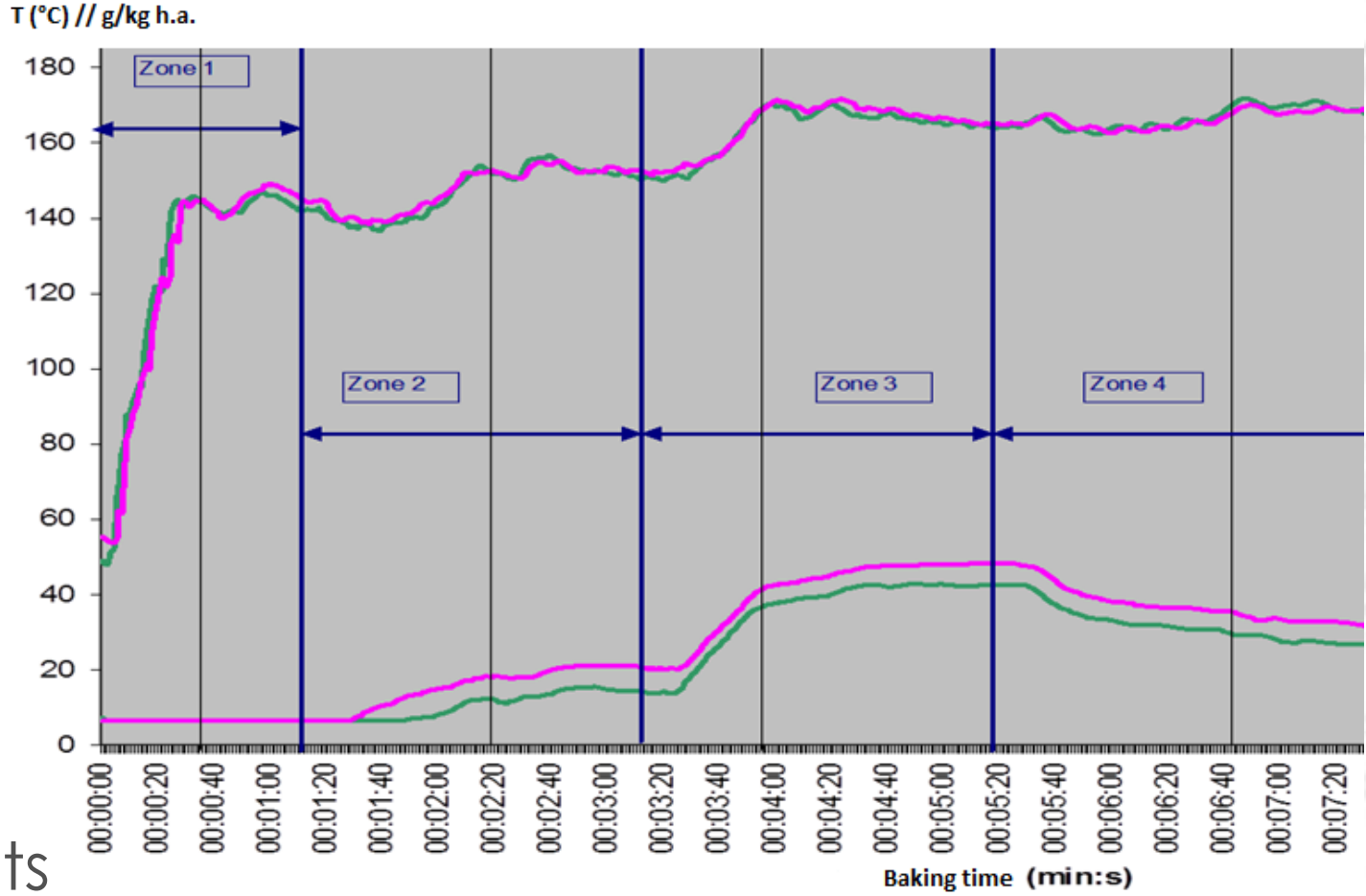
Source : CTCPA



Context and needs

Baking process applied to cookies

- Experimental datas
- Balance:
  - Mass
  - Momentum
  - Energy



Purpose

- Need of calibration for comparing theory and measurements

Context and needs

CENELEC's ICT activities can be subdivided through different key concepts

- " Homegrown work "
  - CLC/TC 59X "Performance of household and similar electrical appliances"
    - CLC/TC/59X/WG18 "Electric ovens for commercial use"

Project

- "A new European standard for energy efficiency in professional ovens steam mode "

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Context and needs

What is a professionnal oven ?

- An appliance that cooks and processes foods, in which one or more of the following methods are undertaken:
  - baking, blanching, frying, steaming, proofing, roasting, rethermalizing, toasting, ...

- The operating modes can be distinguished during cooking or preparing:
  - Convection mode
  - Low-temperature steam in moist, saturated air
  - Steam mode, saturated and superheated steam in a non-pressurized atmosphere;
  - Combination mode: convection mode and steam mode

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Context and needs

Whait is a professionnal oven ?

Context and needs

Purpose:

- Steam mode : issues with current standards
- How to measure humidity : lambda sensor & lambda sensor calibration procedure
- Experimental work : “steam mode” experiences with different loads

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Context and needs

Why should they measure humidity ?

- To heat up 1 l of water from 25 °C to 100 °C it is needed 87 Wh, to transform 1 l of water @ 100 °C in steam it is needed 631 Wh
  - It is a lot of energy !

- The energy consumption results evaluated alone are not significant

	Q [Wh]	water consumption [l]	Relative humidity [%]
Producer 1	1101	1,28	97,1
Producer 2	2577	20,03	98,25
Producer 3	1926	10,19	89,54
Producer 4	1369	1,6	83,1

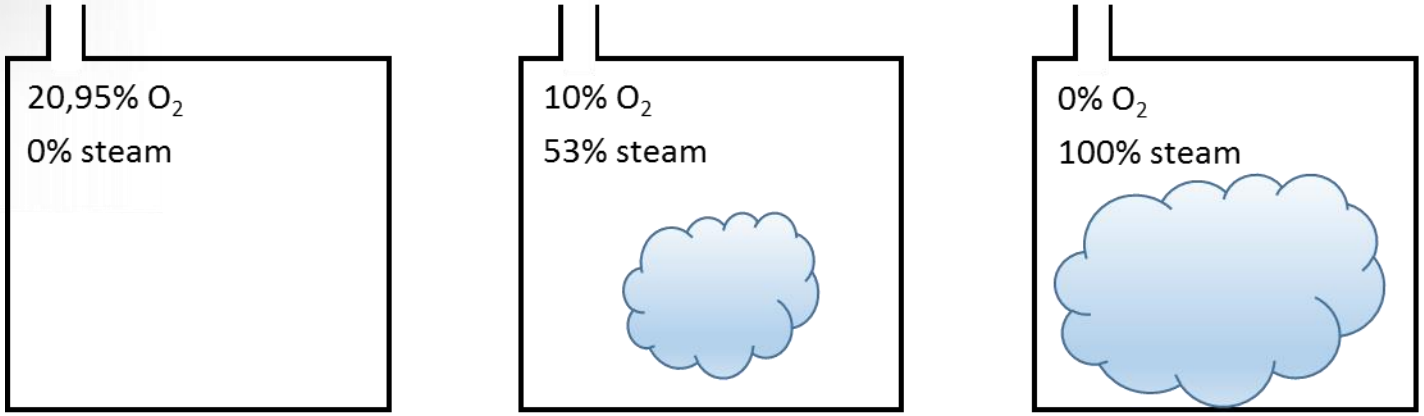
Context and needs

Issue with current standards:

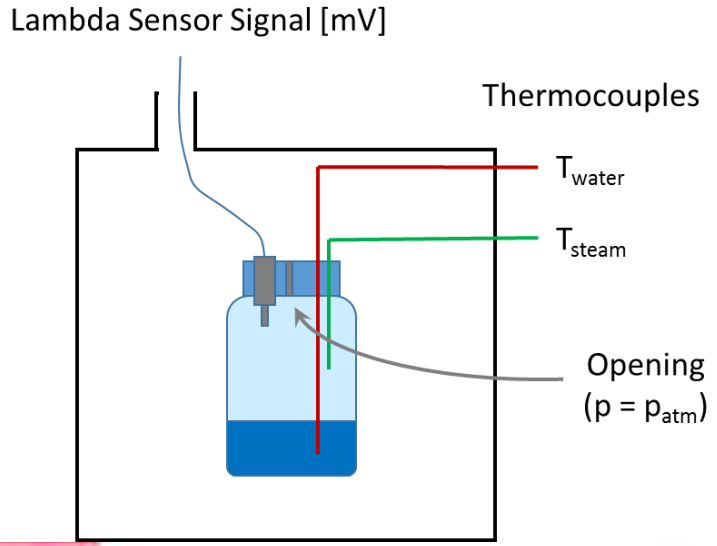
- Humidity measurement is missing (ASTM&DIN)
- Water pans test medium (DIN)
  - Not representative of real food behavior
- Potatoes test medium (ASTM):
  - Season dependent
  - Not standard
  - Waste of food

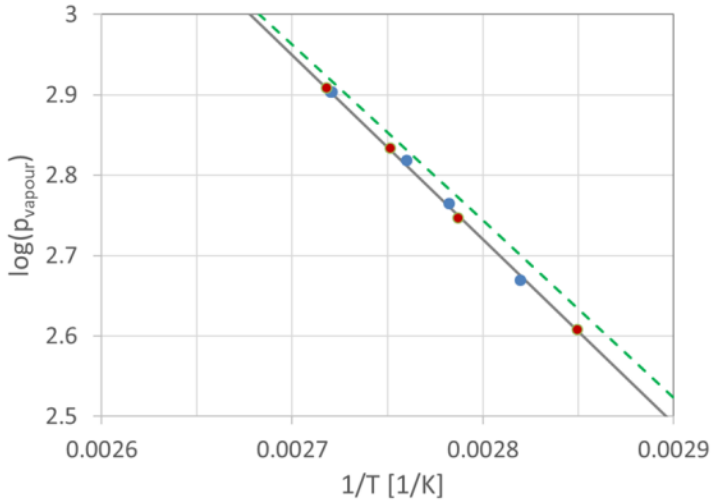
Context and needs

How measure humidity in steam mode ?



How calibrate the sensor ?





What is Lambda sensor ?

Lambda sensor

- is a planar ZrO_2 dual cell limiting current sensor with integrated heater
- is designed to measure the proportion of oxygen in exhaust gases of automotive engines

$$x_{oxygen}[\%] = \frac{V_\lambda}{k} \; where \; k = 0{,}4$$

$$p_{vap}^{\lambda} = p \cdot \left(1 - \frac{x_{oxygen}[\%]}{20.95}\right) = e'_{h2o\,\lambda}$$

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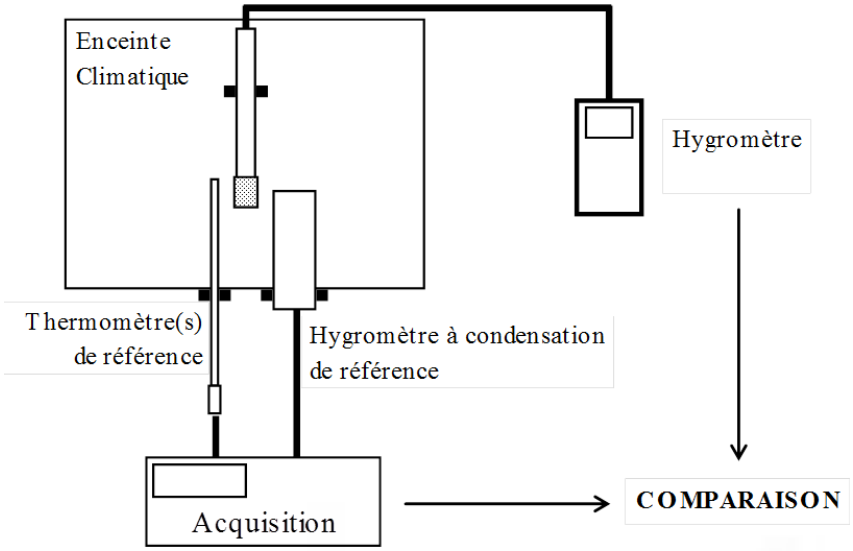
Experimental work

Compare (& validate) « classical » humidity calibration rig with experimental setup



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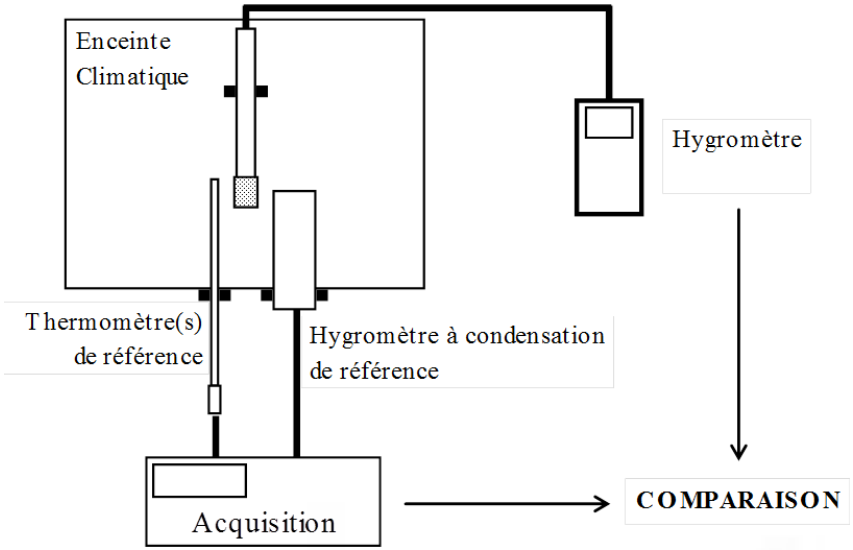

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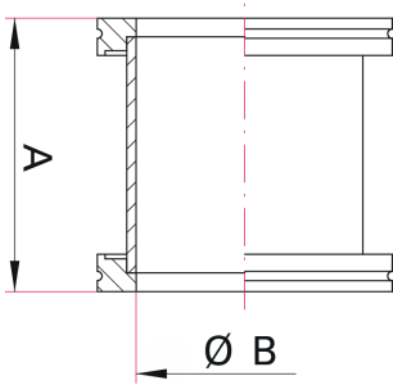
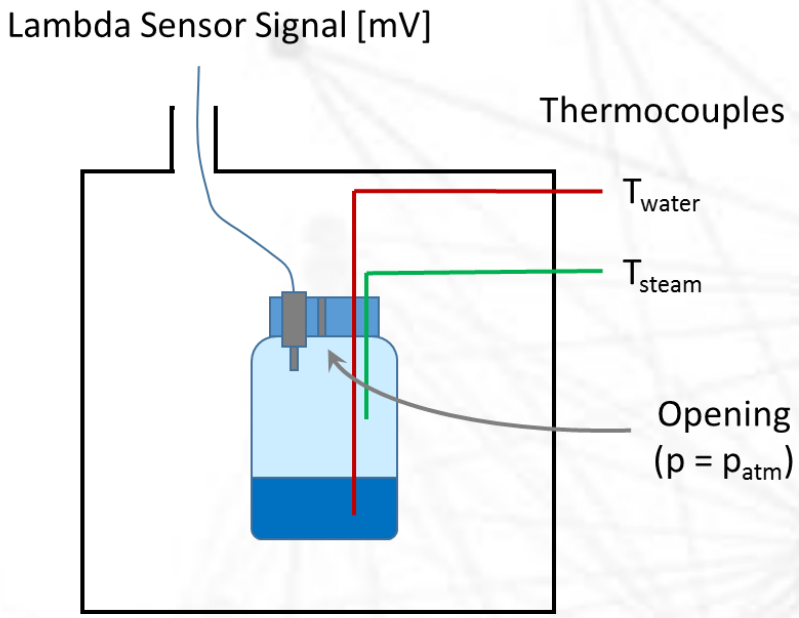


A = 138 mm
B = 153 mm



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Experimental work

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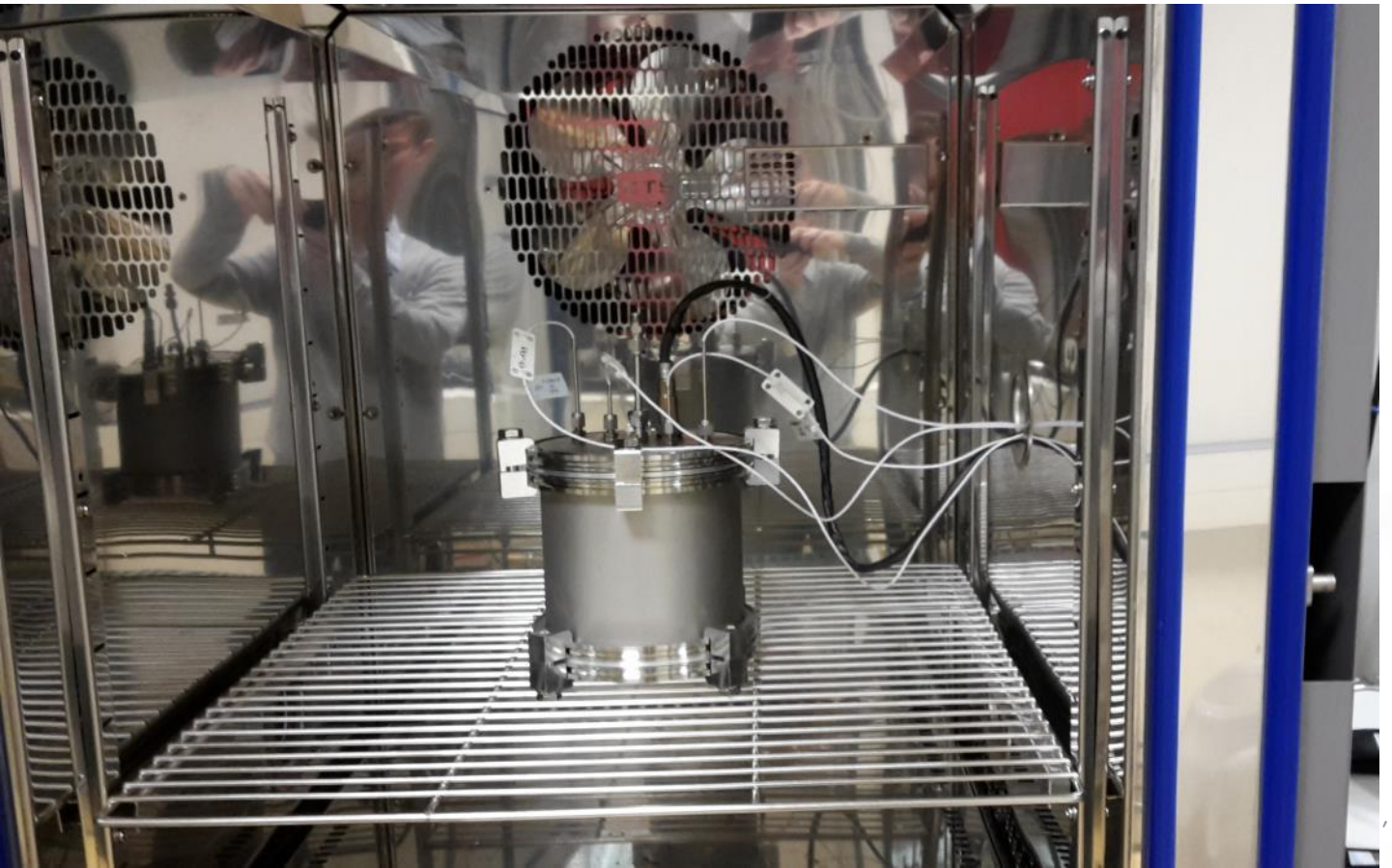

Experimental work

Calibration programm :

- « classical » humidity calibration rig
  - Dry temperature & relative humidity (dewpoint)
    - @ 95 °C : 56 %rh (80 °C), 68 %rh (85 °C), 83 %rh (90 °C)

- Experimental setup
  - Dry temperature inside the experimental chamber
    - @ 80 °C, 85 °C, 90 °C, 95 °C, 97 °C
- Proposed protocol has been (almost) followed

- 4 Lambda sensors : λ1, λ2, λ3, λ4
- Repeatability with λ2, λ3 with « classical » calibration

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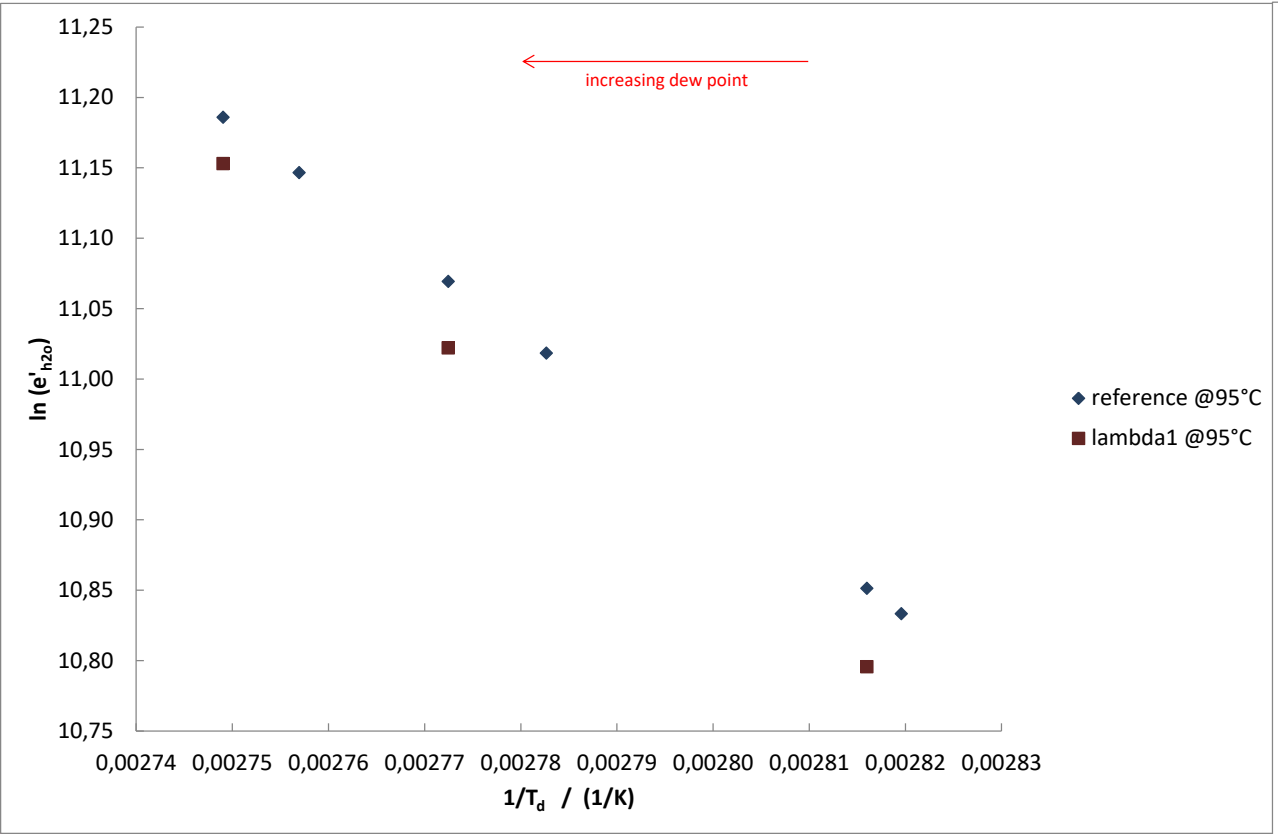
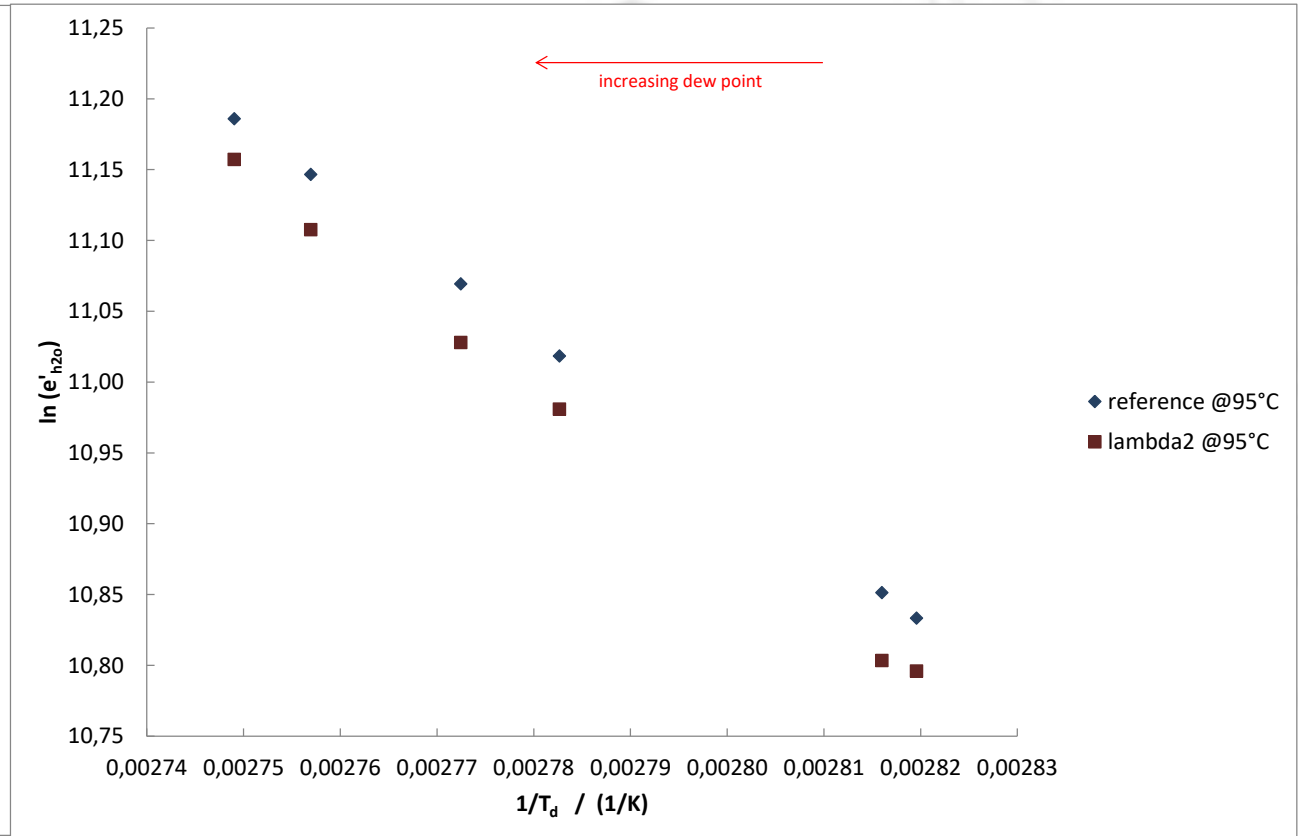
Results

Partial pressure of water /« classical » humidity calibration rig

$$x_{oxygen}[\%] = \frac{V_\lambda}{k} \; where \; k = 0{,}4 \qquad p_{vap}^{\lambda} = p \cdot \left(1 - \frac{x_{oxygen}[\%]}{20.95}\right) = e'_{h2O\,\lambda}$$





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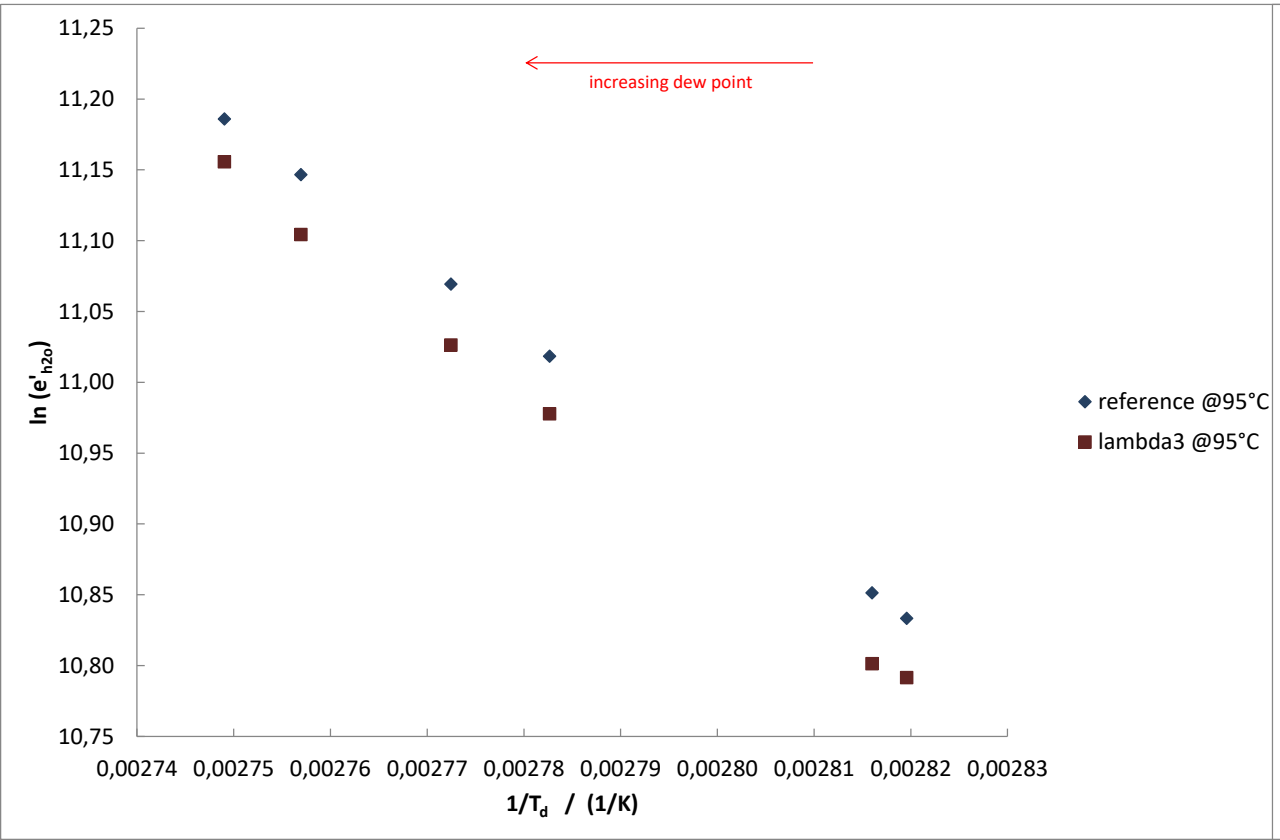

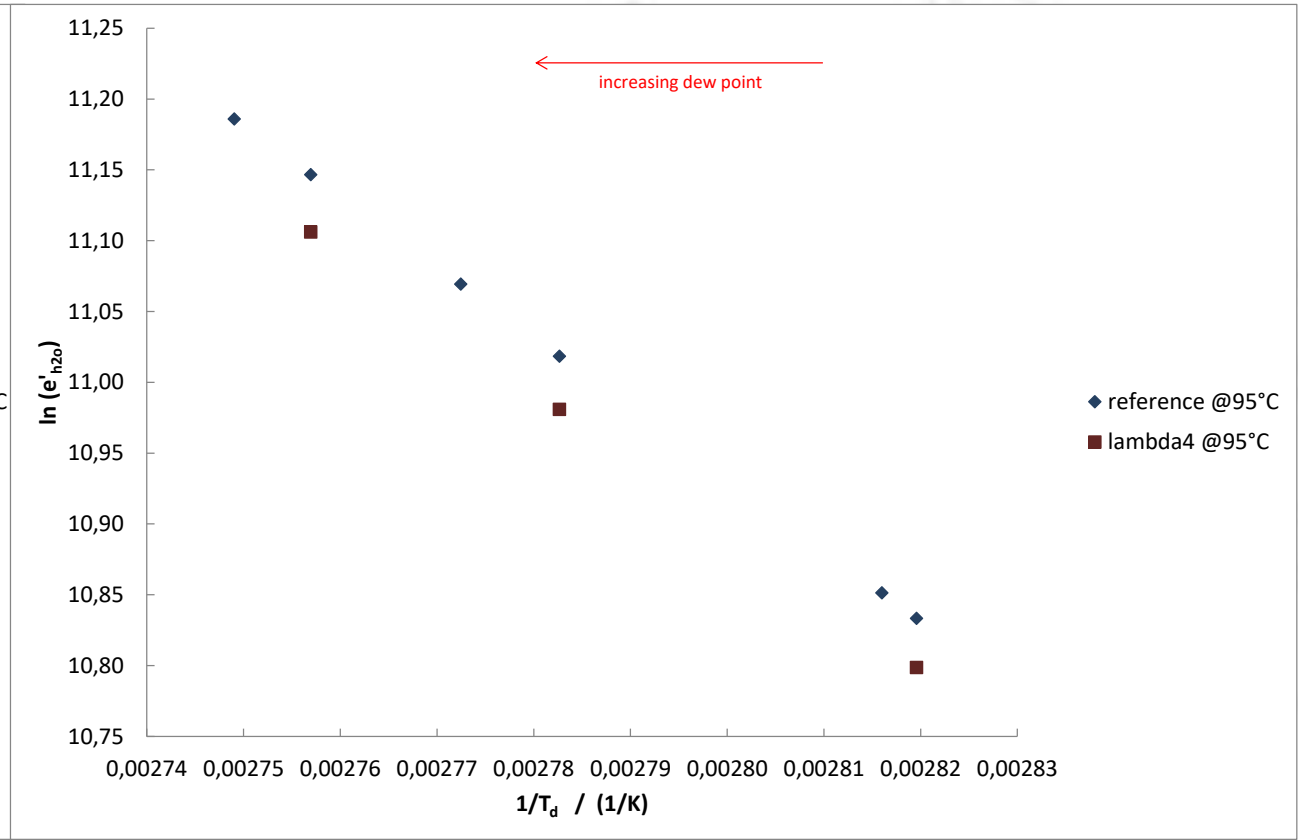

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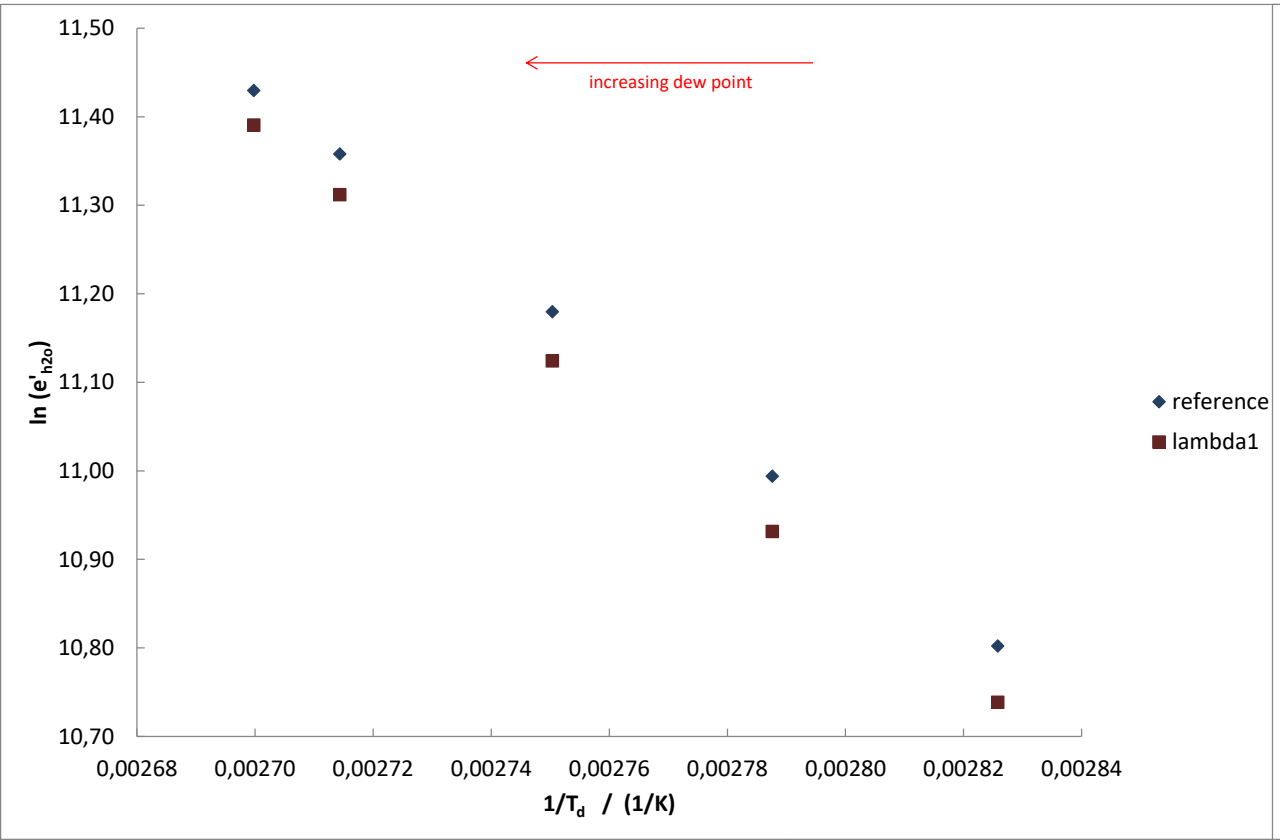

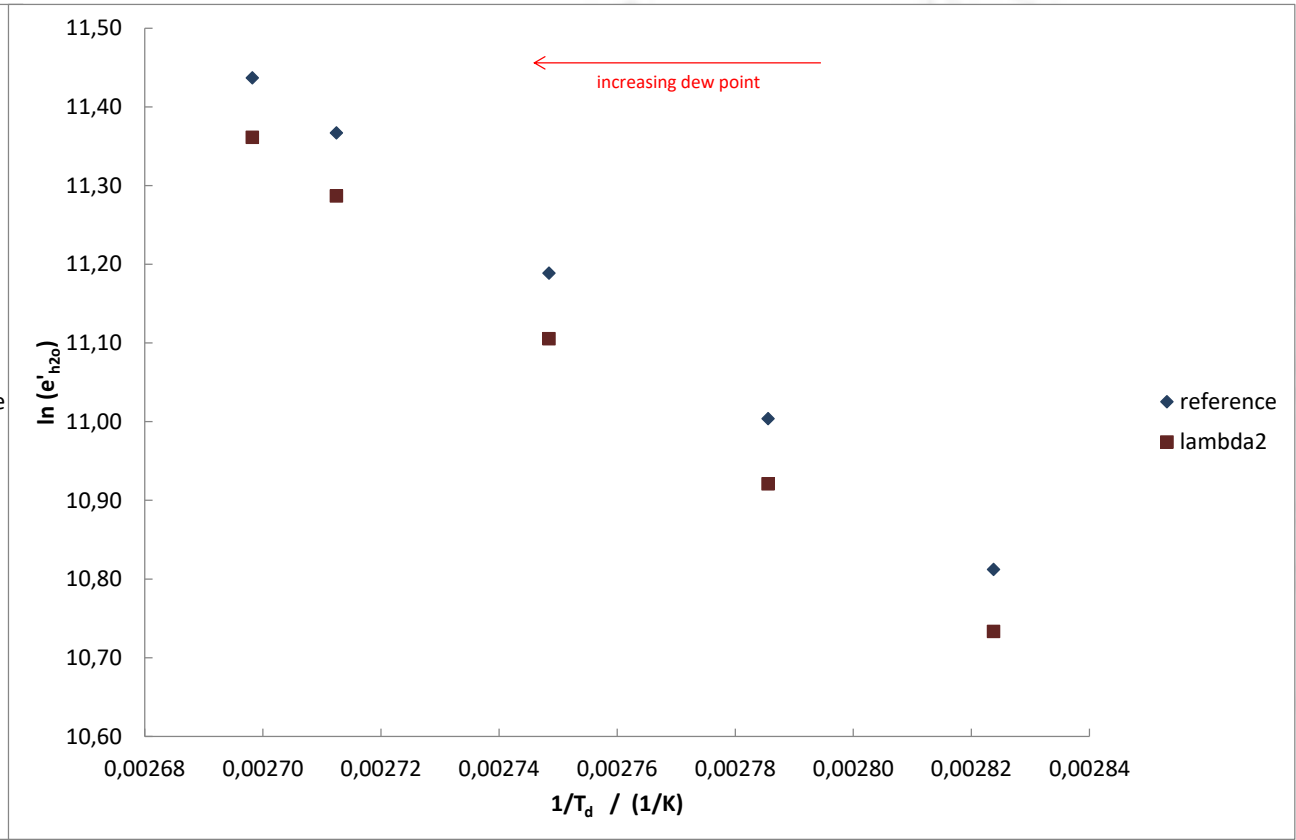

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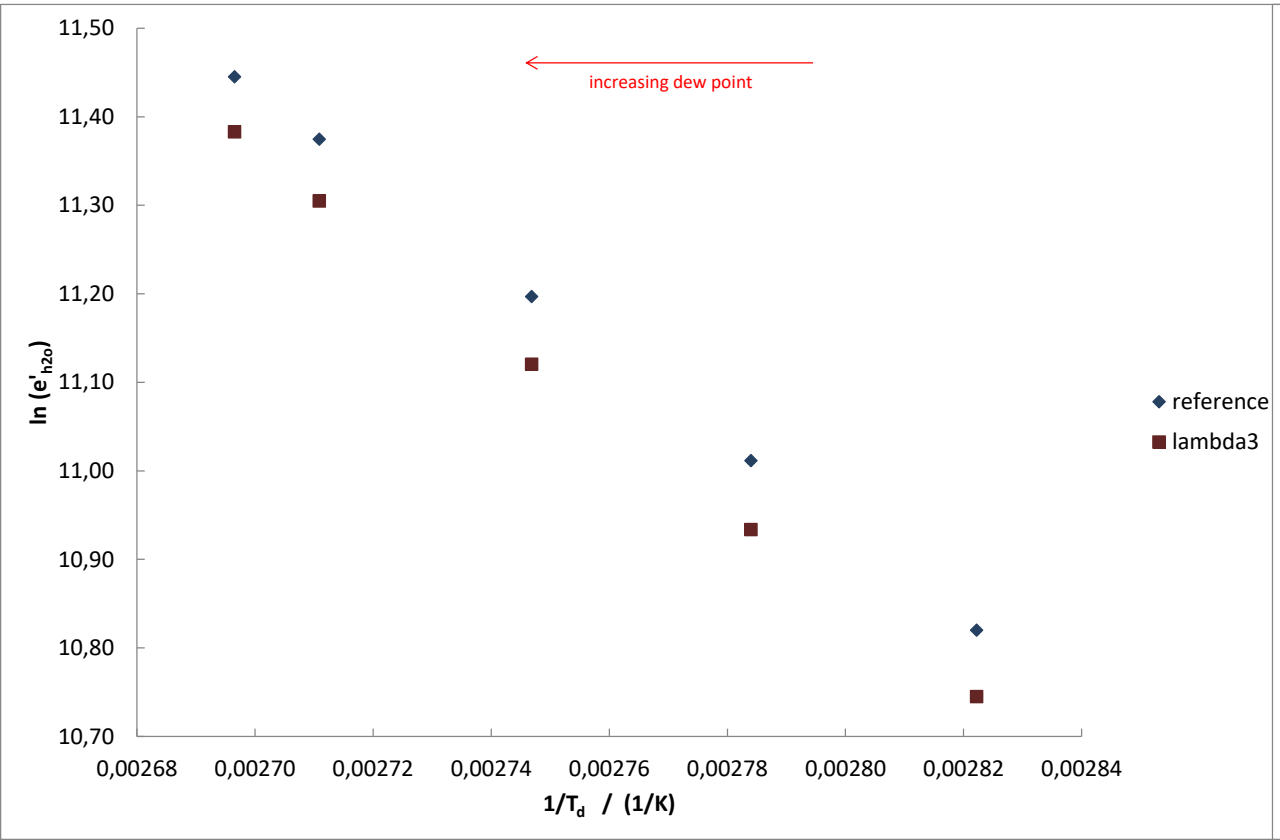
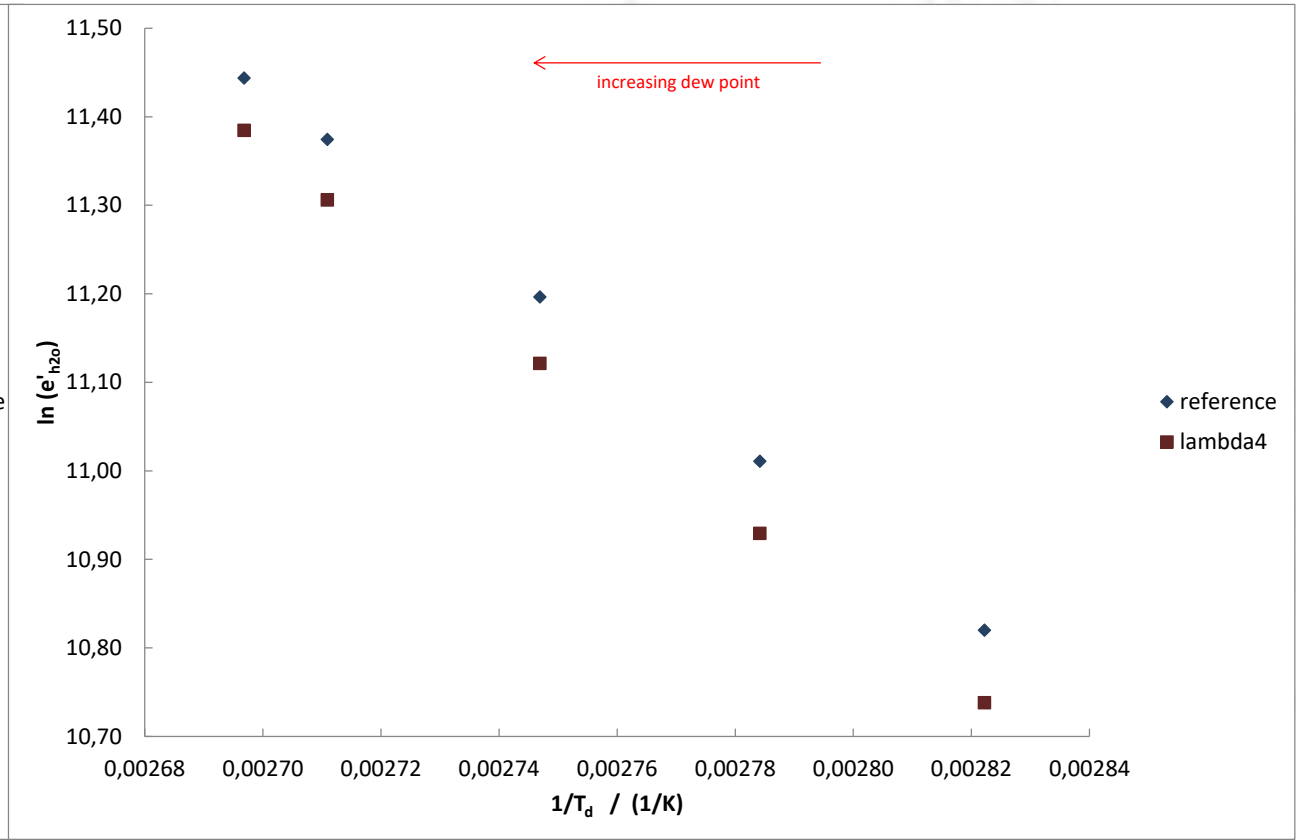
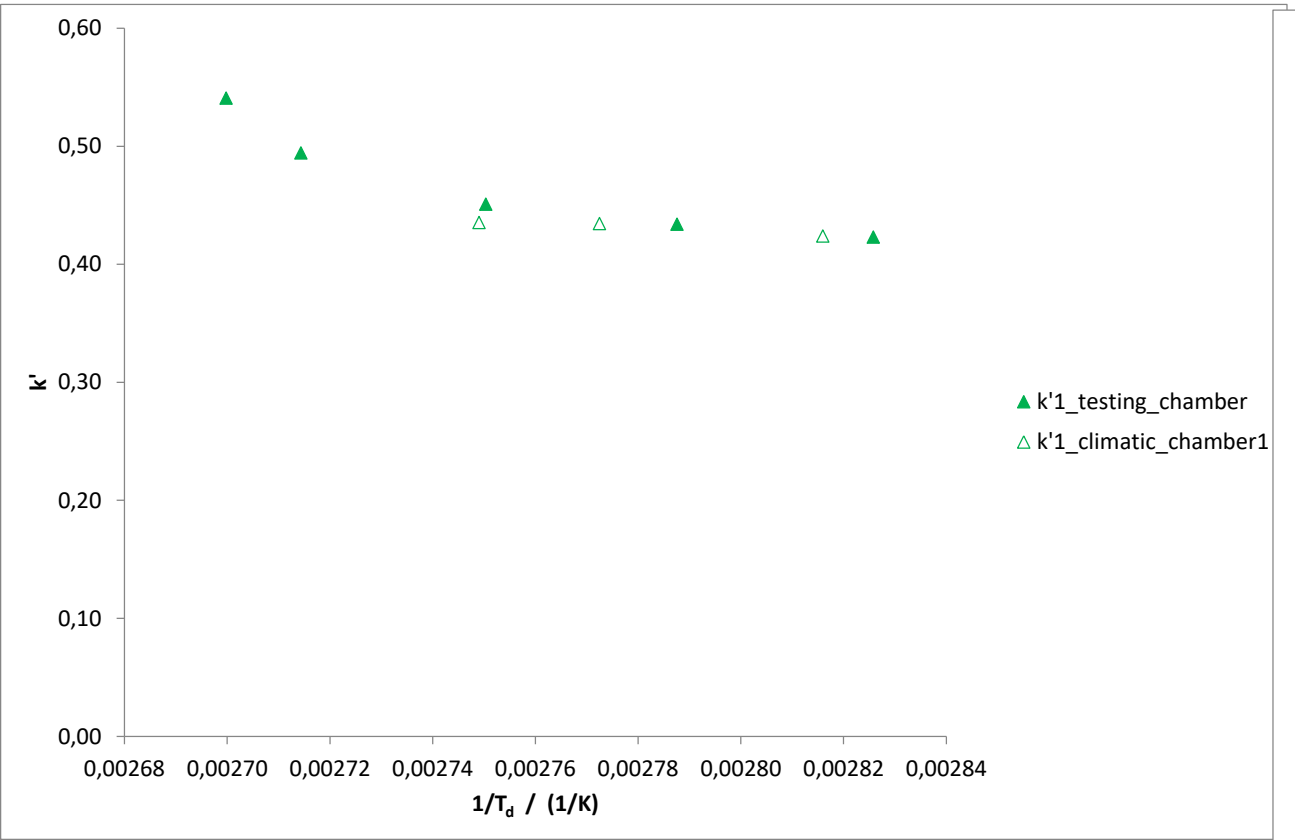


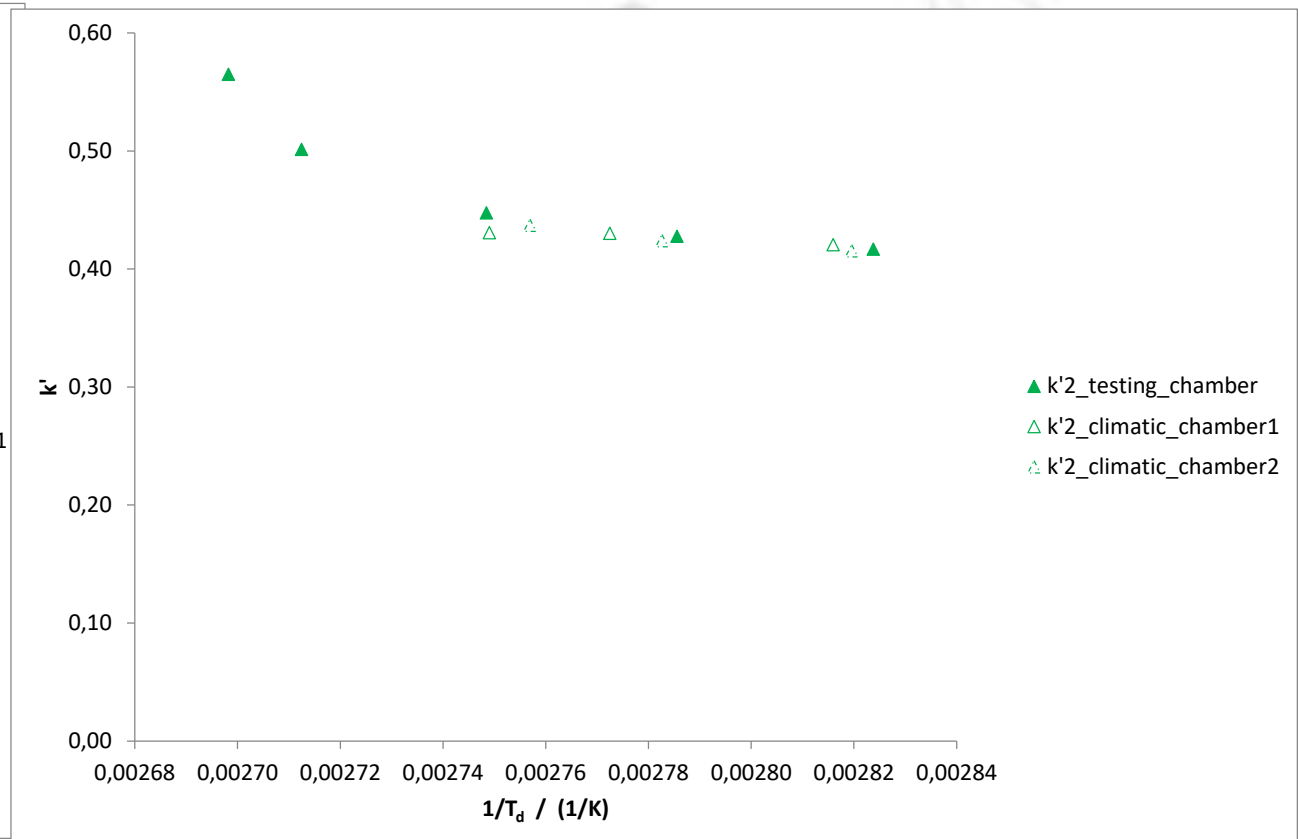


Results

Correction of k factor; k' determination

$$k' = \frac{V_{out}}{20.95 \cdot \left(1 - \frac{p_{th}}{p}\right)} = \frac{V_{out}}{20.95 \cdot \left(1 - \frac{e'_{h2O}}{p}\right)}$$





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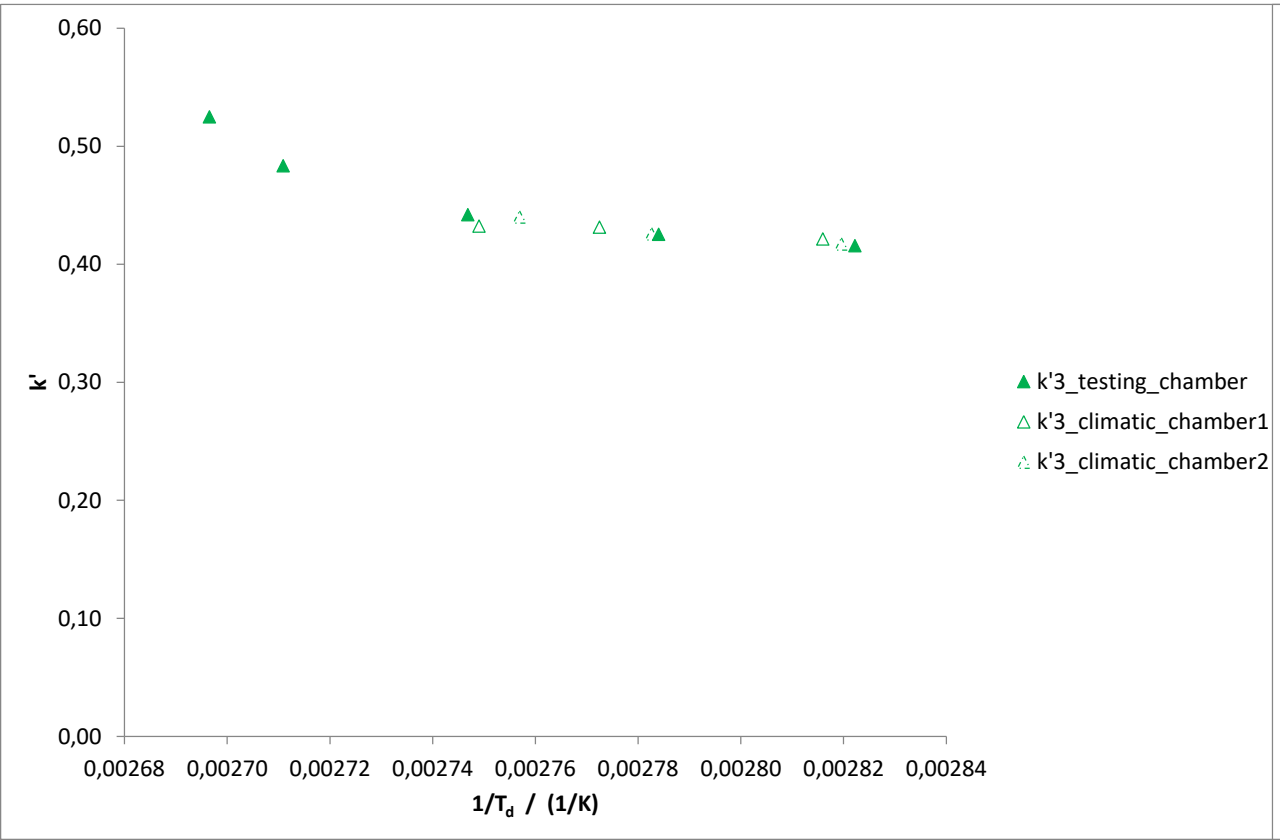

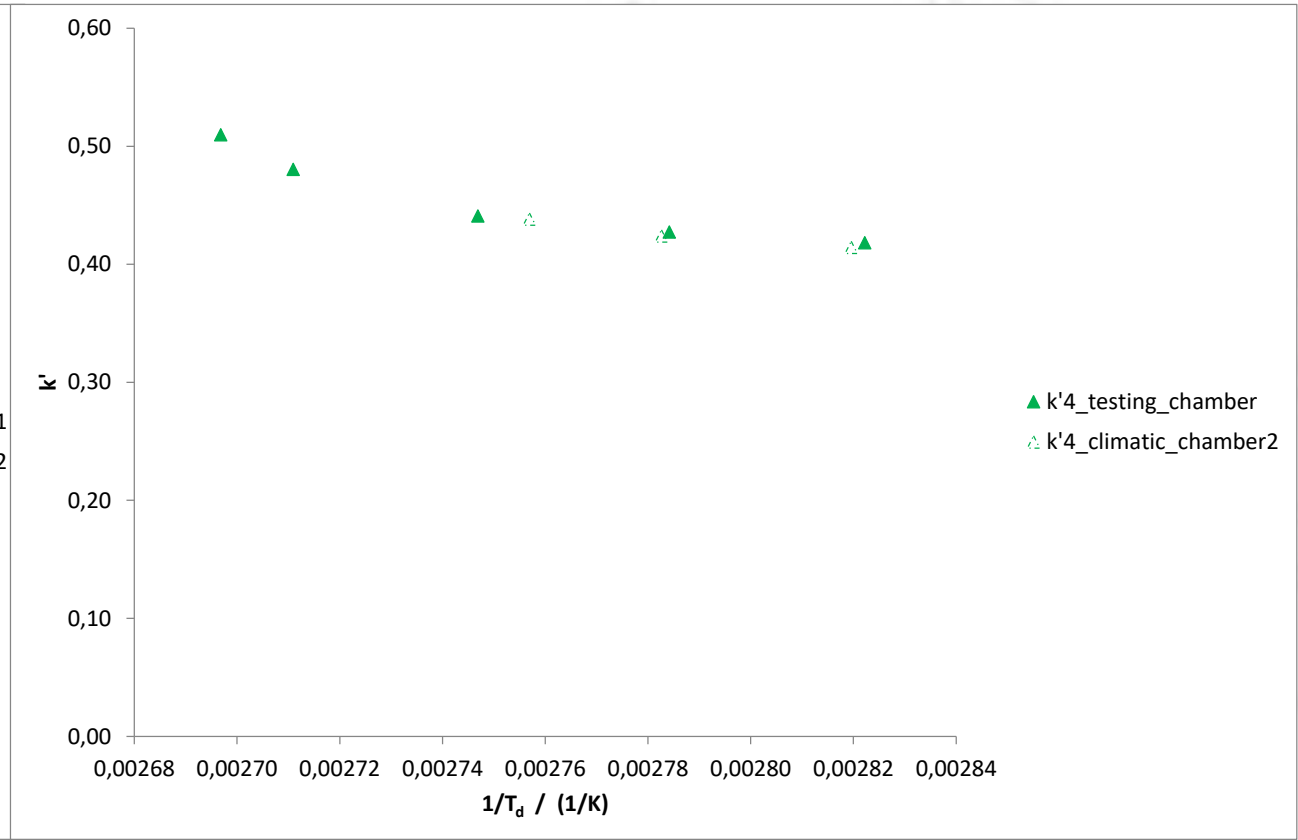

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Partial pressure of water (corrected)

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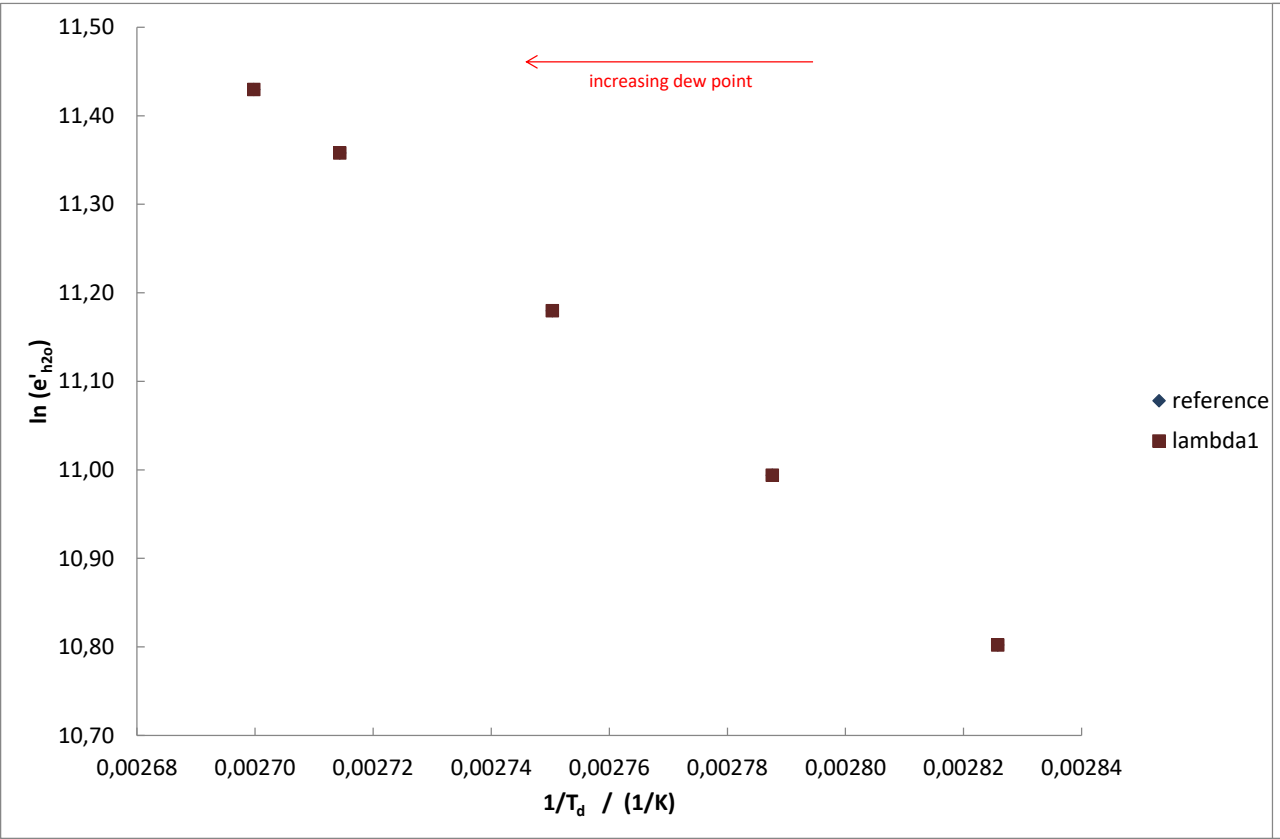

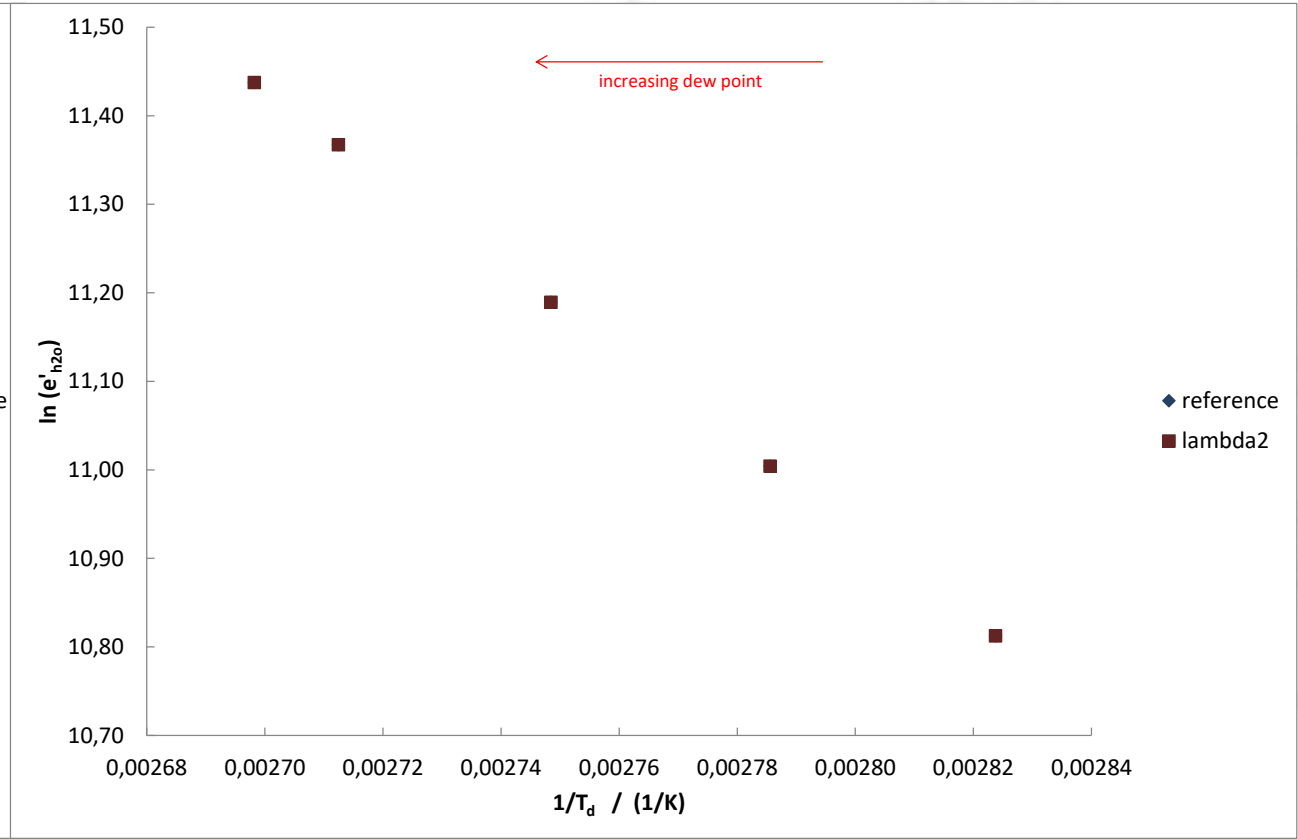

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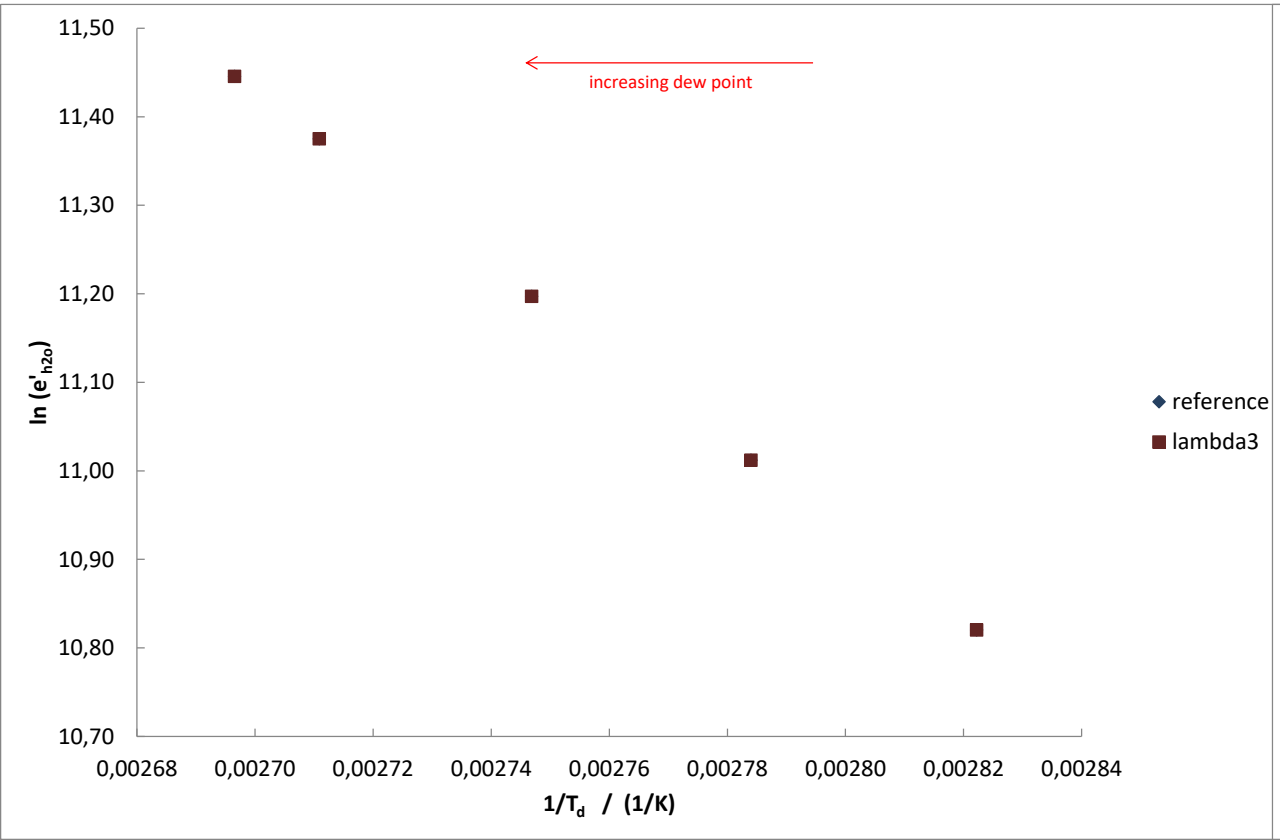

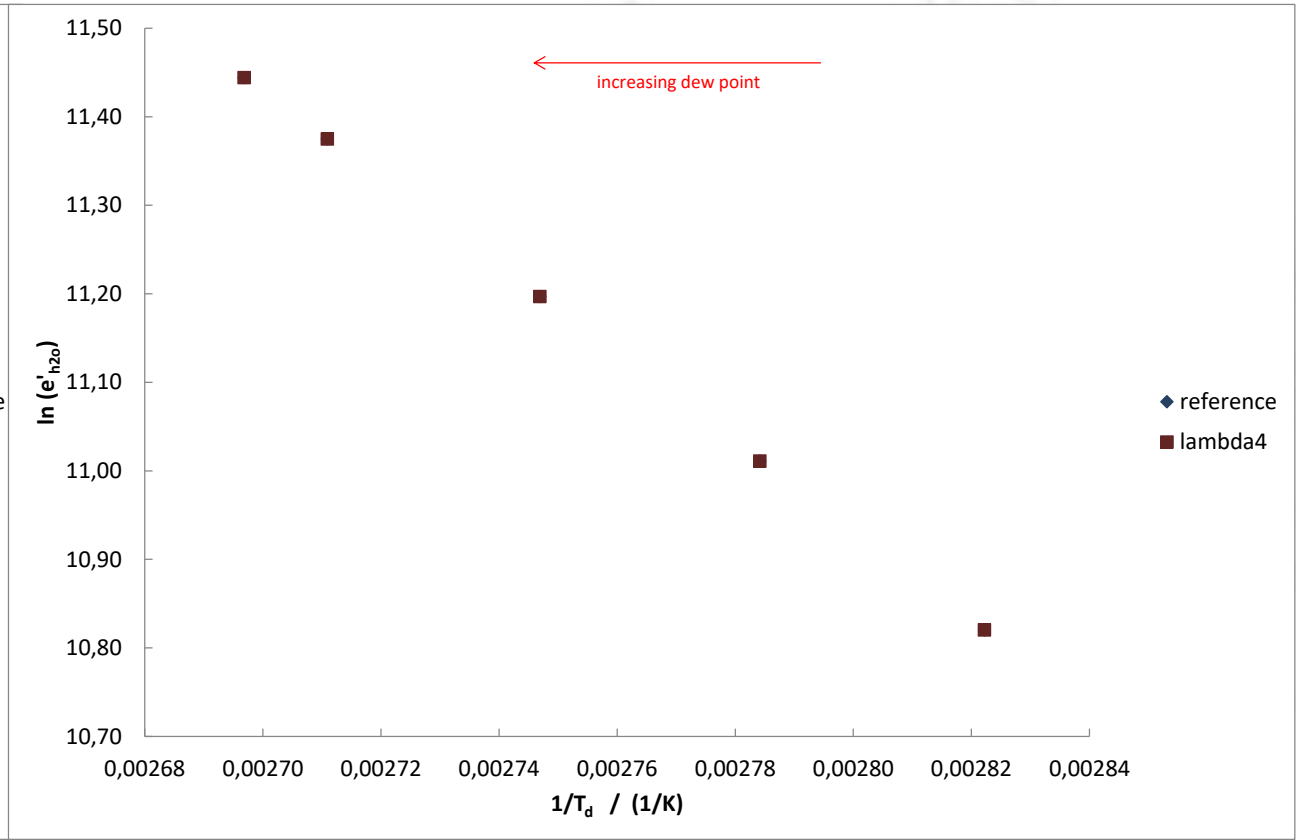

Conclusion

Comparison between « classical » humidity calibration rig And experimental setup

- Good agreement between both methods
- Based on k'and corrected partial pressure

Lamda sensors

- Good interchangeability
- Good repeatability

Expression of amont of water in the oven

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Conclusion

Experimental setup designed at CETIAT

- Homogeneity in temperature
  - Air : ≤ 0,05 °C
  - Water : ≤ 0,03 °C
  - Air-Water : ≈ 2 °C
- Stability at equilibrium : $\sigma_{15\ min} \leq 0{,}03$ °C
- Time for reaching equilibrium : ≈ 2h
- Level of water remained almost constant
- Not sensitive to lambda sensor's heating
- Hypothesis of full saturation according to the applied procedure

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Conclusion

Next steps

- Repeatability / reproducibility with lambda sensors
- Drift / ageing of lambda sensors
- Uncertainty budget
- Inter Laboratories Comparison (among participants)
- Decrease the size of the chamber

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