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Humidity measurement in steam oven for cooking applications by means of lambda sensor

Eric Georgin – eric.georgin@cetiat.fr

EMPIR
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Outline

Context and needs

What is Lambda sensor ?

Experimental work

Results

Conclusion

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 "

Context and needs

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, au gratin, and sous vide cooking.
- The operating modes can be distinguished during cooking or preparing:
  - Convection mode: mode that cooks and processes food by forcing hot air;
  - Low-temperature steam in moist, saturated air;
  - Steam mode: mode that cooks and processes food by saturated and superheated steam in a non-pressurized atmosphere;
  - Combination mode: a mixture of convection mode and steam mode

Context and needs

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

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

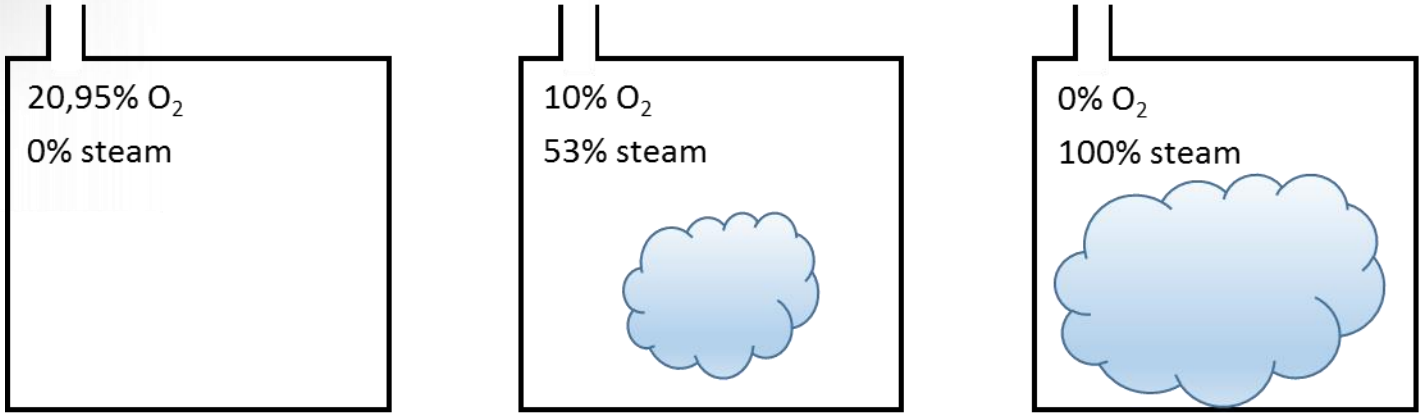
Context and needs

Issue with current standards:

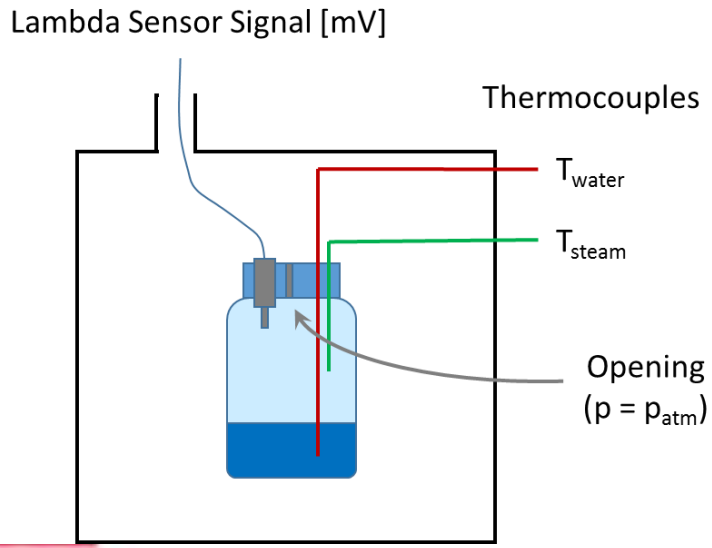
- Humidity measurement is missing (ASTM&DIN)
- Water pans test medium (DIN)
  - Not representative of real food behavior
- Potatoes test medium (ASTM):
  - Season dependent
  - Not standard
  - Waste of food

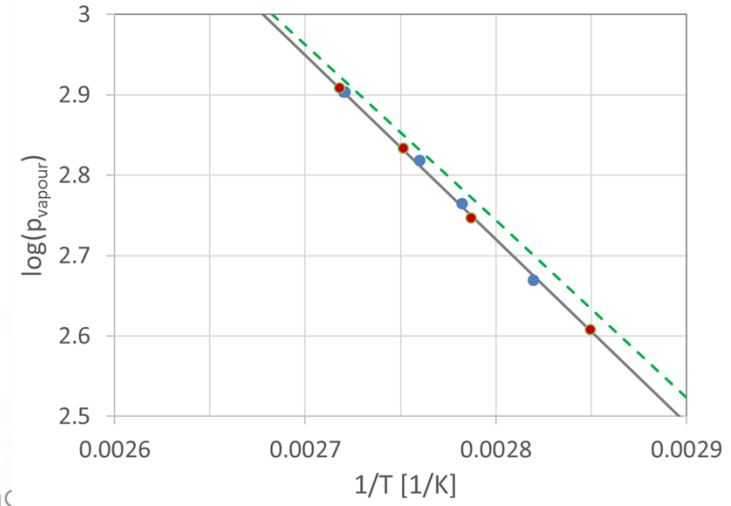
Context and needs

How measure humidity in steam mode ?



How calibrate the sensor ?





What is Lambda sensor ?

Lambda sensor

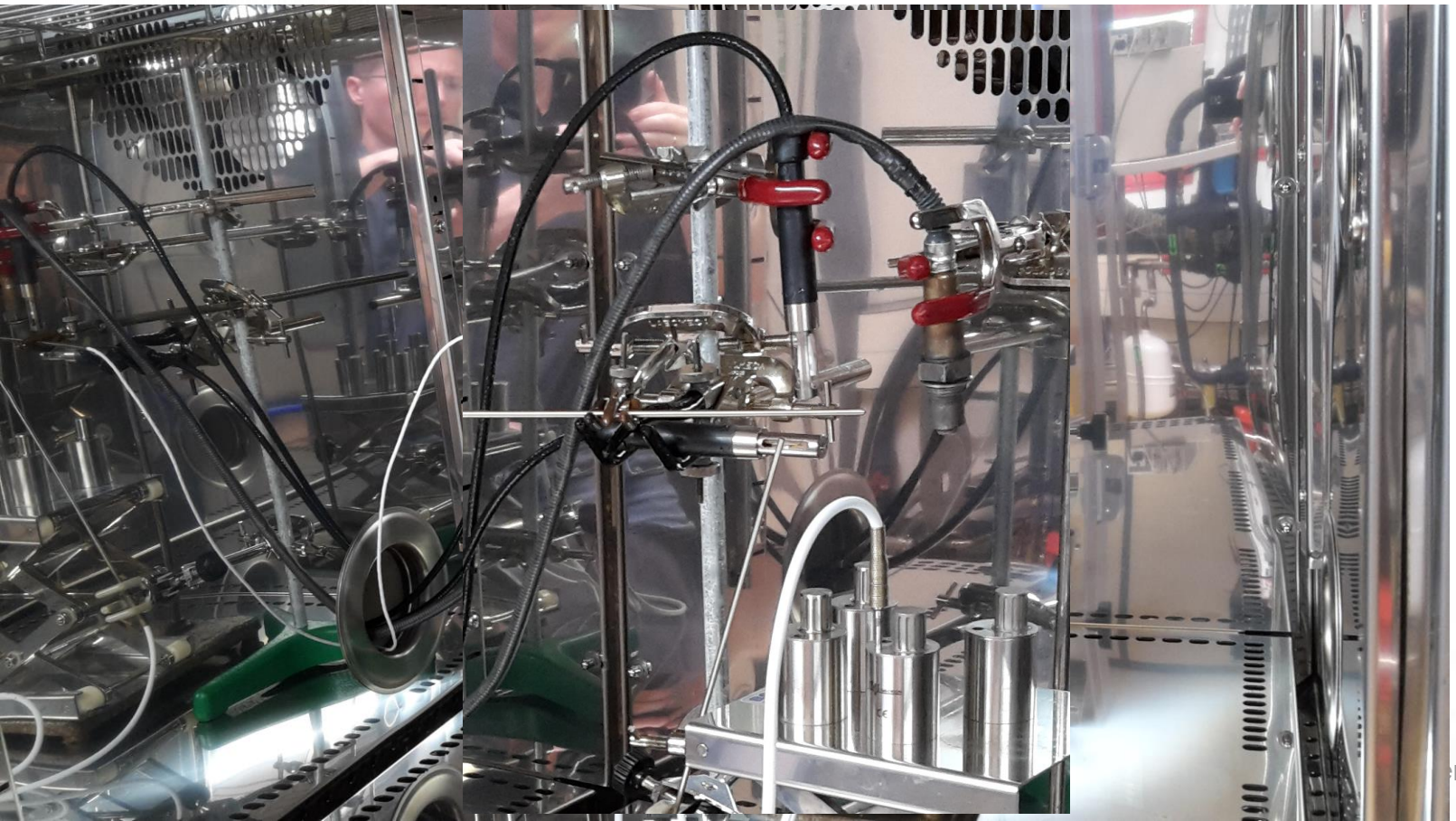
- is a planar ZrO_2 dual cell limiting current sensor with integrated heater
- is designed to measure the proportion of oxygen in exhaust gases of automotive engines

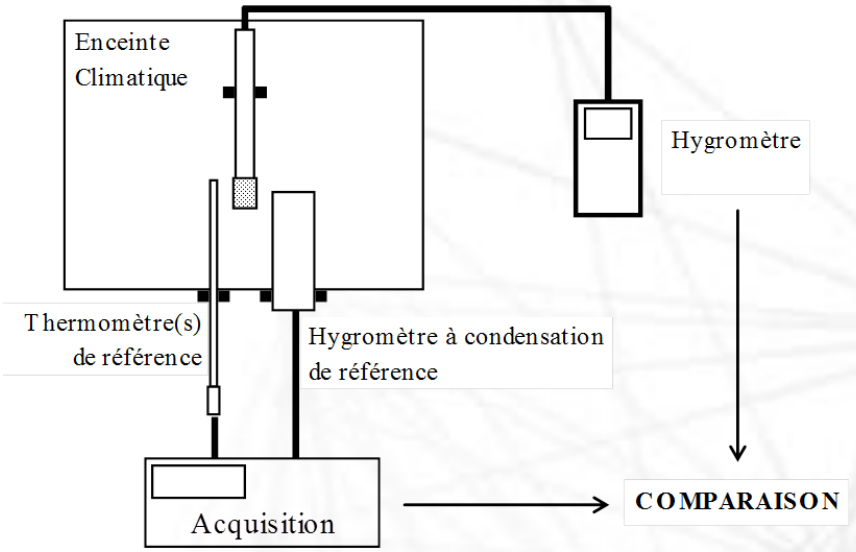
$$x_{oxygen}[\%] = \frac{V_\lambda}{k} \; where \; k = 0{,}4$$

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

Experimental work

Compare "classical" humidity calibration rig and experimental setup proposed in the standard





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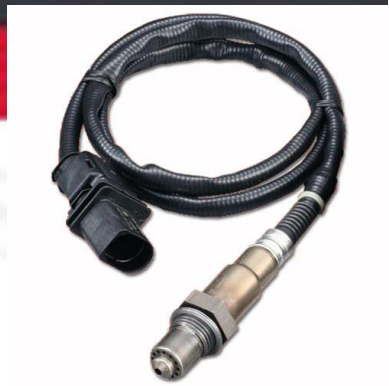
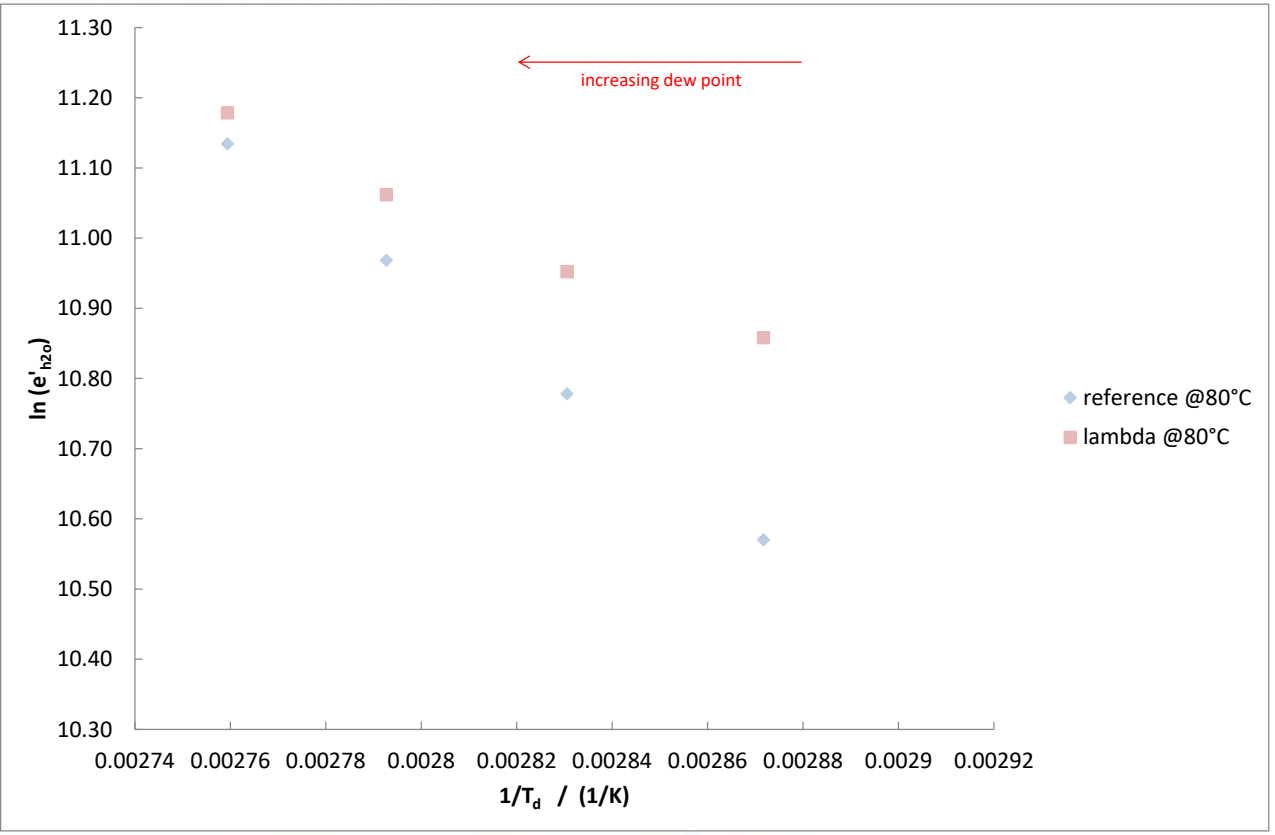
Experimental work

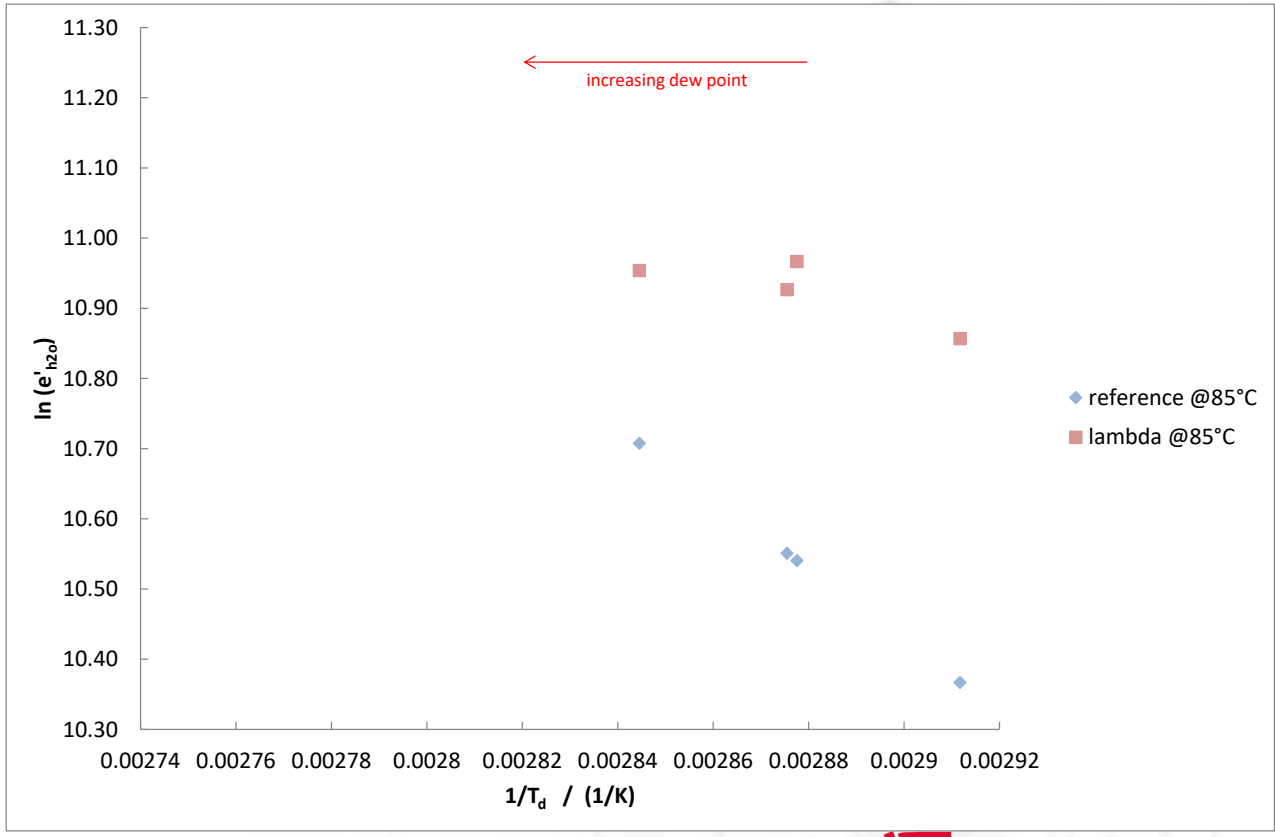
Calibration programm :

- @ 80 °C : 66 %rh (70,06 °C), 80 %rh (74.24 °C); 96 %rh (79 °C)
- @ 85 °C : 64 %rh (74°C), 70 %rh (75,78 °C), 80 %rh (79,02 °C), 96 %rh (83,96°C)
- @ 90 °C : 53 %rh (74,07 °C), 65%rh (79 °C), 80%rh (83.81 °C), 96 %rh (88,93 °C)
- @ 95 °C : 44 %rh (74,05 °C), 54 %rh (79 °C), 66 %rh (84,02 °C), 81 %rh (89,15 °C)

Results







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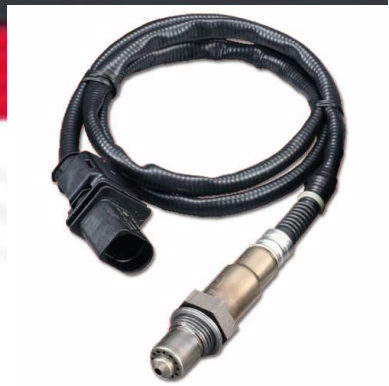
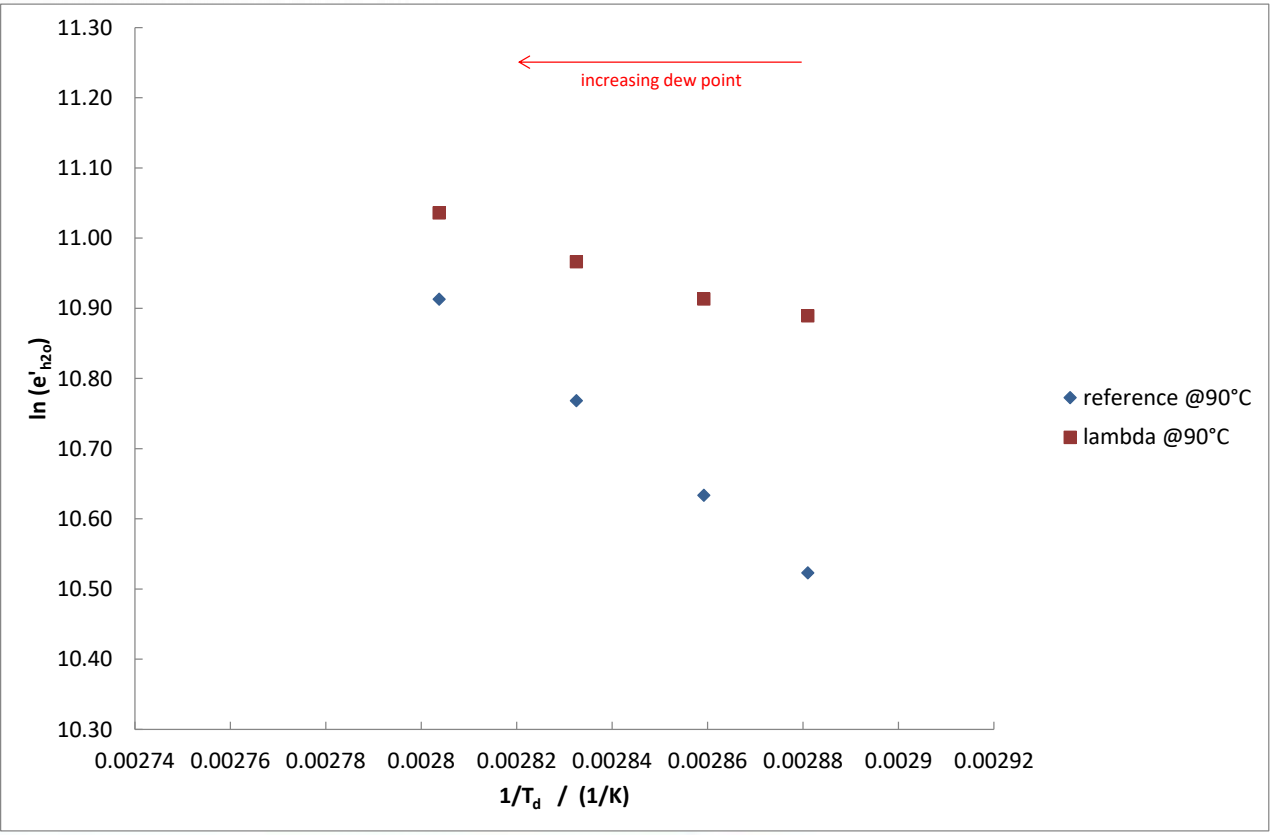
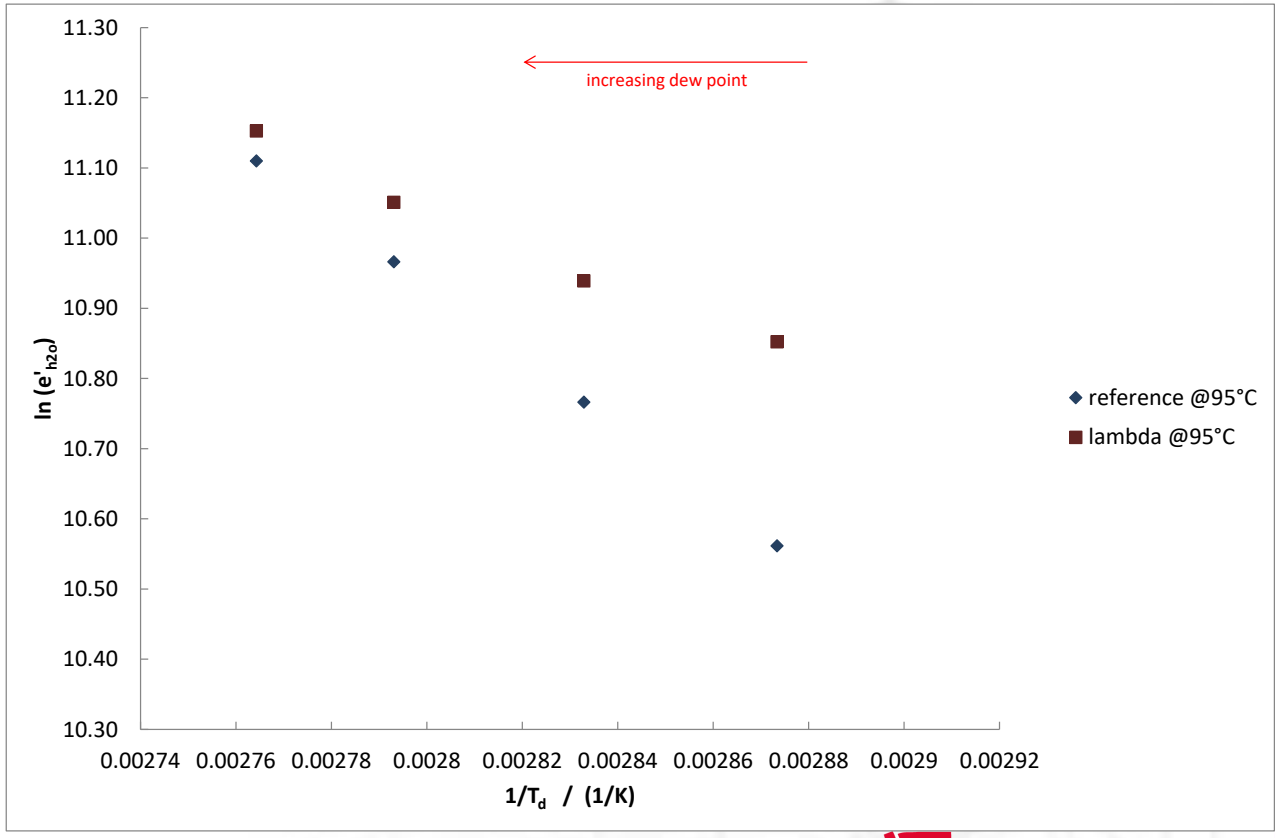
Results







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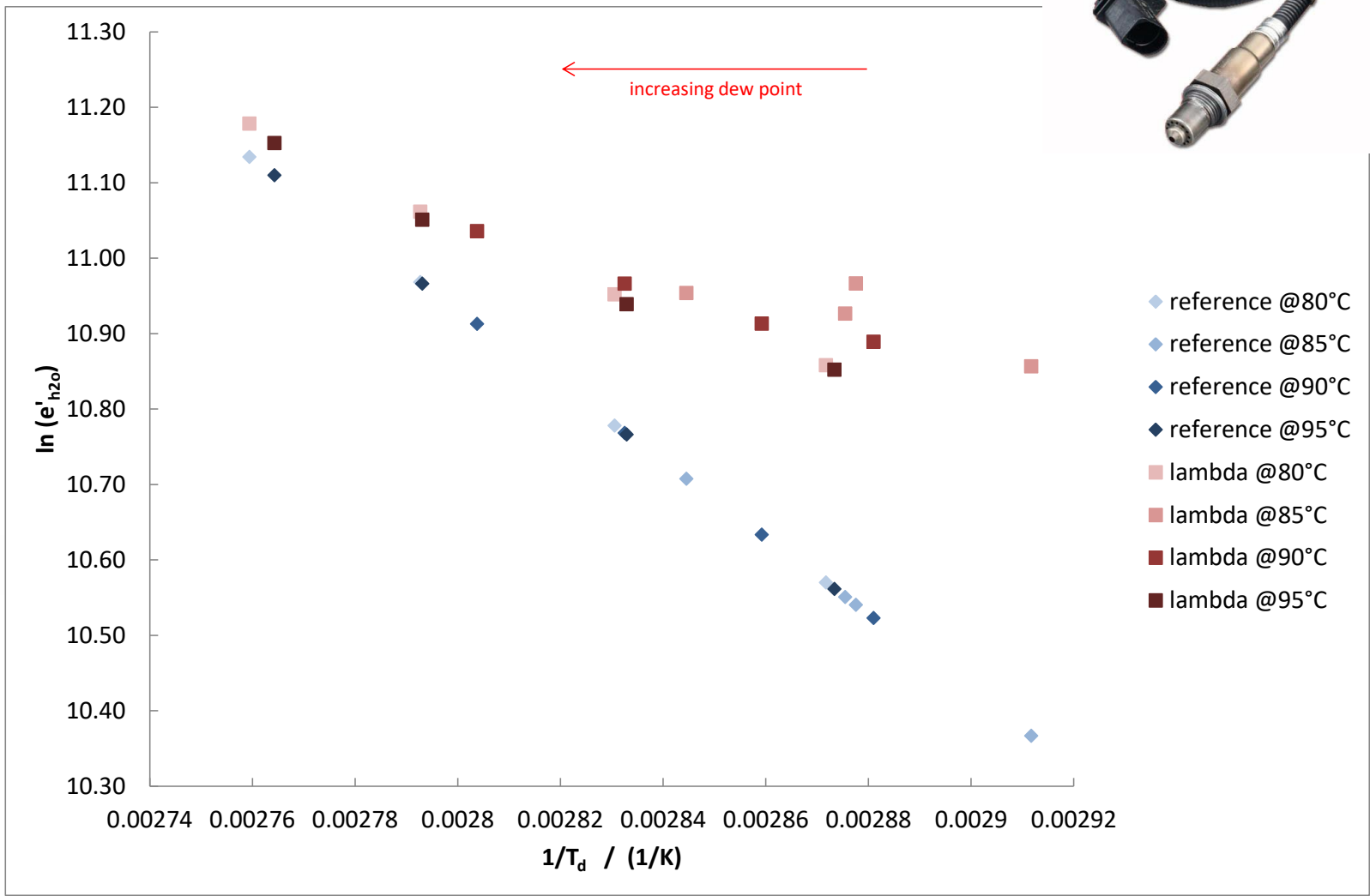
Results

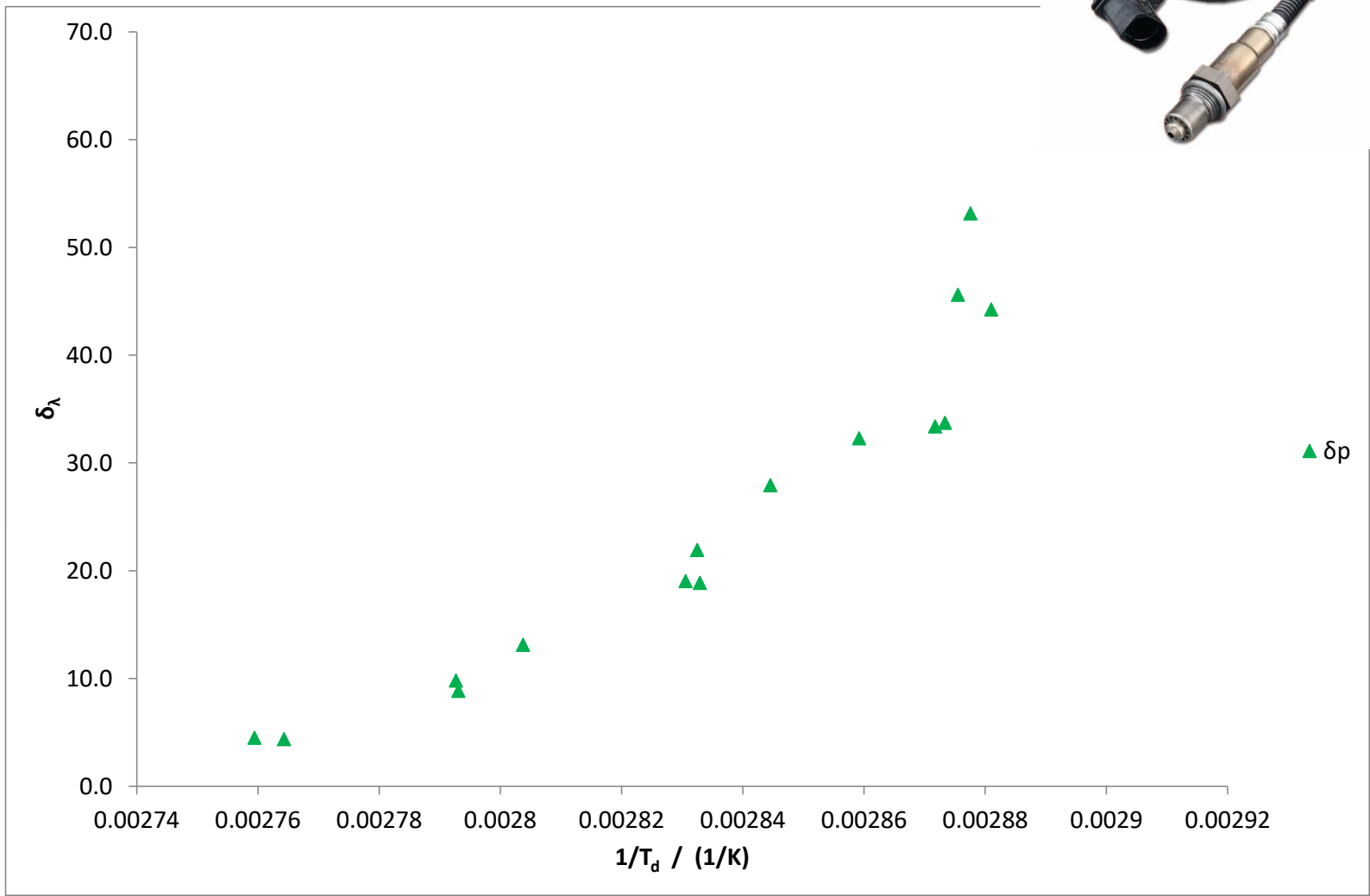
$$x_{oxygen}[\%] = \frac{V_\lambda}{k} \; where \; k = 0{,}4$$

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



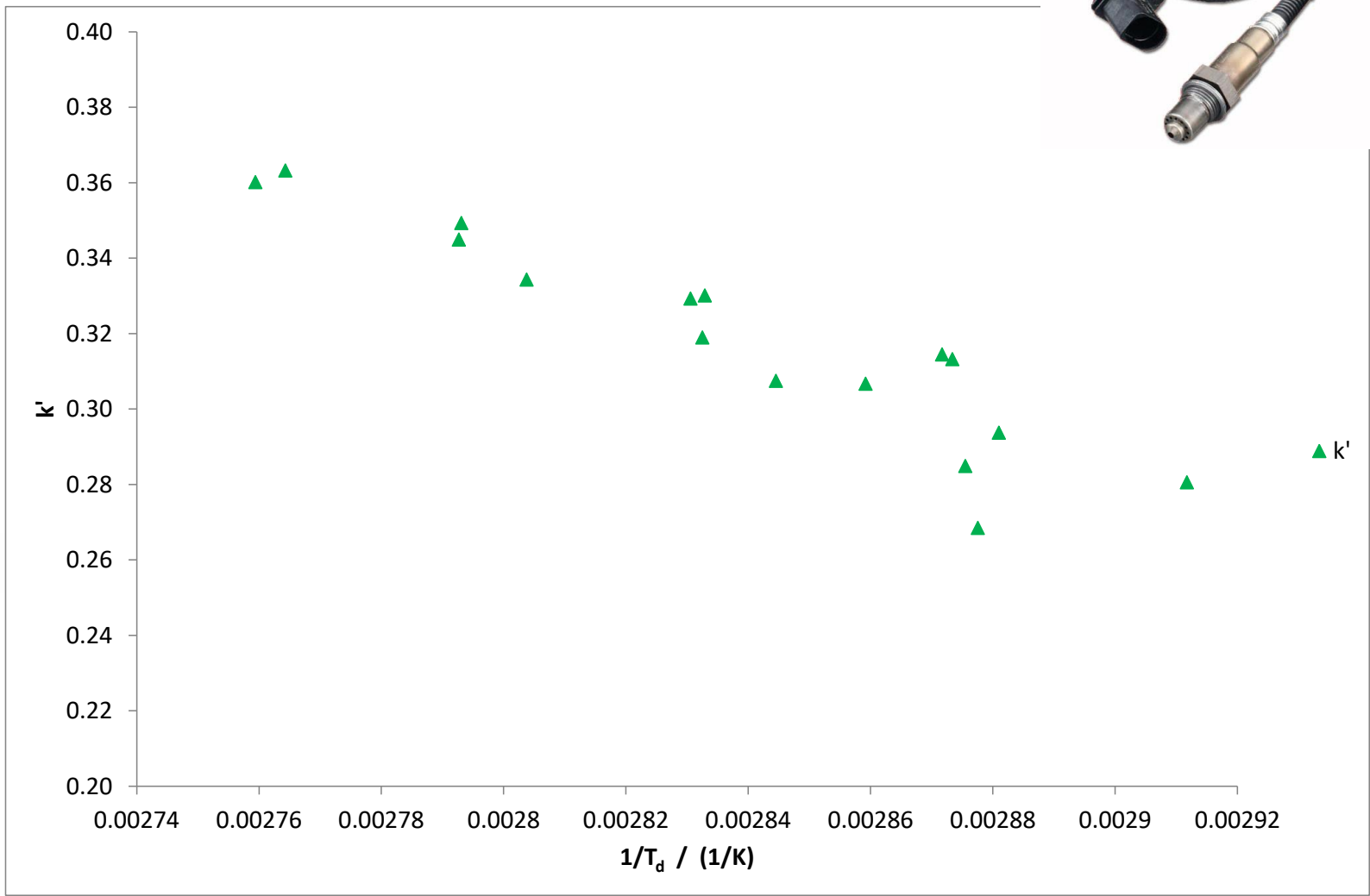
Results

$$\delta_p = \frac{p_{vap}^{\lambda} - p_{th}}{p_{th}} \cdot 100\%$$



Results

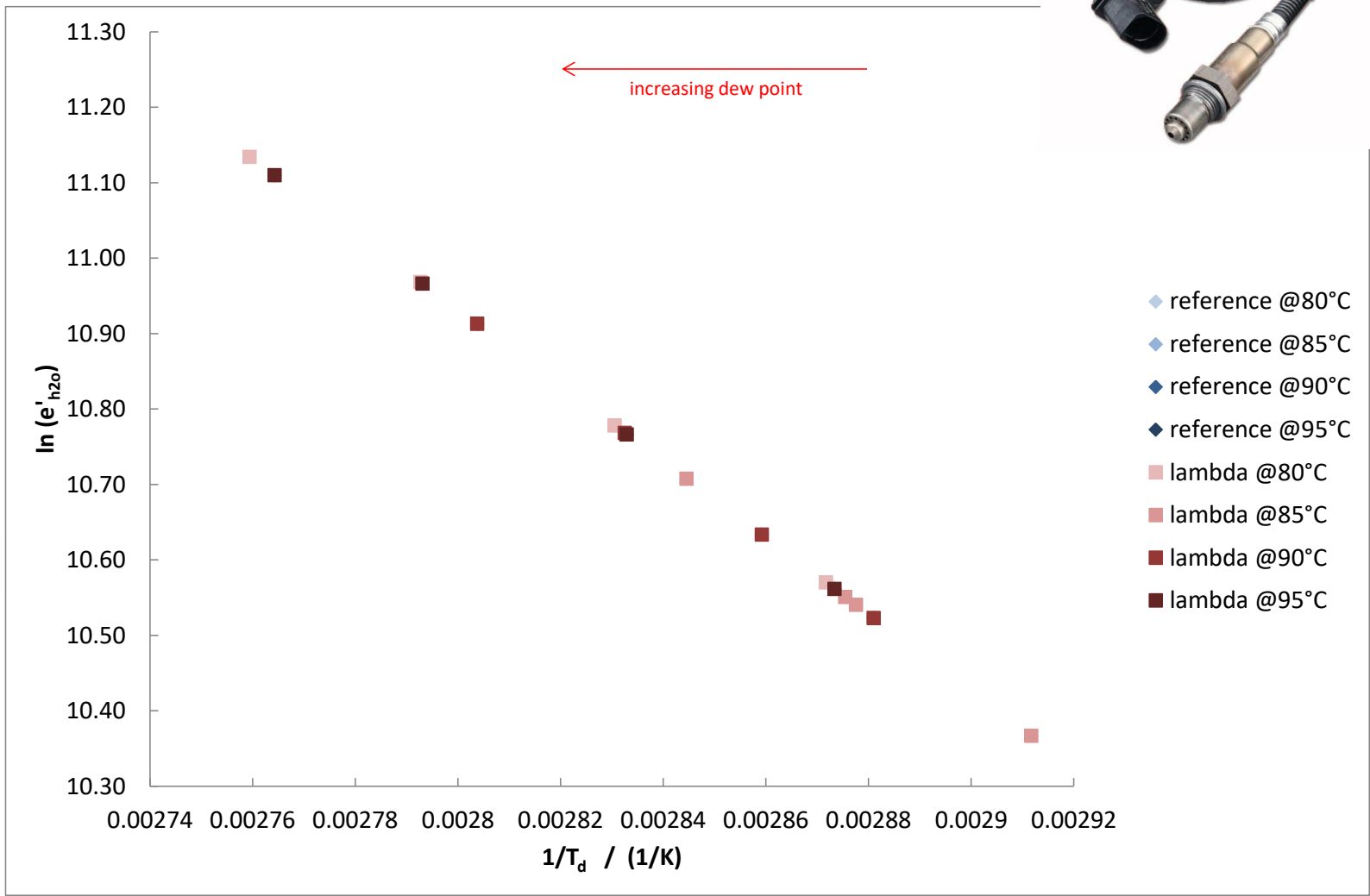
$$k' = \frac{V_\lambda}{20.95 \cdot \left(1 - \frac{p_{th}}{p}\right)} = \frac{V_\lambda}{20.95 \cdot \left(1 - \frac{e'_{h2O}}{p}\right)}$$



Results

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

$$p^{\lambda}_{vap\ corr} = p \cdot \left(1 - \frac{V_\lambda}{20.95 \cdot k'}\right) = e'_{h2O\ \lambda\ corr}$$



Conclusion

Achievement:

- Calibration, by comparison, of a lambda sensor in "classical way" ($\theta_{\text{dry temperature}} < +100\ °C$)
- Large deviation of the sensor at relatively low temperature and low humidity
- Adjustment of the response by computing k'

Futur work

- Higher temperatures to be investigated
- Additional lambda sensors to be tested (interchangeability ?)
- Comparison of "classical" calibration and method proposed in the new standard
- Uncertainty budget

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Domaine scientifique de la Doua
25 avenue des Arts – BP 52042
69003 VILLEURBANNE CEDEX - FRANCE

Mail : information@cetiat.fr
Tél : 04 72 44 49 00
Fax : 04 72 44 49 49