e-newsletter n°2

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Measuring humidity with lambda sensor ??

Introduction what is lambda sensor ?

The so called "lambda sensor" is usually used for detecting and for measuring the presence of oxygen in exhaust gases of engines. The output signal of "lambda sensor" is a tension, or a current, related to the quantity of oxygen that is present in the exhaust gases.

Thus "lambda sensors" are used to monitor the level of unburned oxygen in the exhaust gases. The amount of oxygen that is left in the exhaust following combustion is a good indicator of the relative richness or leanness of the fuel mixture.

The name lambda sensor refers to the stoichiometric air/fuel ratio, also written the Greek letter lambda (λ) : if $\lambda>1$ the engine has a lean mixture, if $\lambda<1$ the engine has a rich mixture.

This sensor is also designated by the name "oxygen sensor"; the sensing element is mainly composed by a ceramic material called zirconium dioxide (ZrO_2). At high temperatures, typically above 650 °C, zirconium dioxide exhibits two phenomena:

- ZrO_2 partly dissociates to produce oxygen ions; when a voltage is applied ions can be transported through the material
- ZrO_2 behaves like a solid electrolyte for oxygen, *i.e.*, if gradient of oxygen pressure occurs on both side of an ZrO_2 element, generate an electrical potential named Nernst voltage

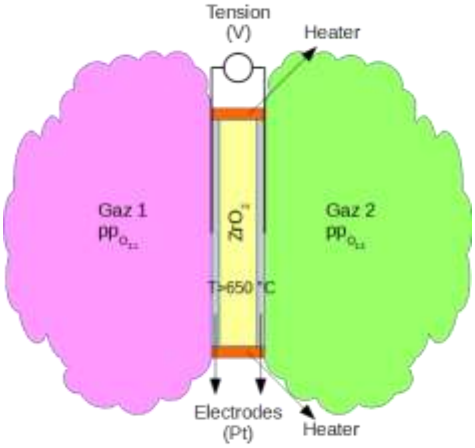

Figure 1 – Nernst cell

Depending on the generation of the sensor and the manufacturers, the measuring cell may be composed by

- one zirconium dioxide (ZrO_2) coated with a thin porous layer of platinum which serve as electrodes – also called Nernst Cell
- two zirconium dioxide (ZrO_2) coated with a thin porous layer of platinum which serve as electrodes – also called Nernst Cell and Pump Cell

Thus zirconium dioxide (ZrO_2) enables to measure partial pressure of oxygen (pp_{O2}) in a gas or mixture of gases. The analog signal output is a function of pp_{O2}, nevertheless the end user should take care of

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- the total pressure : a change in total pressure leads to a change of partial pressure of oxygen
- the influence of other chemical species in the gas mixture, such as humidity, which may change partial pressure of oxygen as well

LSU 4.9 lambda sensor by BOSCH

In the framework of studies at high temperatures and very high humidity, air almost saturated in humidity, LSU 4.9 lambda sensor by BOSCH has been used. This sensor requirse an ETAS CBS100 cable and a DC power supply of 12V. The cable output is a voltage signal V_λ in the range 0-10V and it is proportional to the oxygen concentration x_{oxygen} according to:

$$x_{oxygen}\,[\%] = \frac{V_\lambda}{k}$$

It is assume that the k coefficient is constant within the operating range.

How is it possible to determine humidity ?

In order to determine the partial pressure of water vapour from the lambda sensor, e^{λ}_{vapour}, the following equation is used:

$$e^{\lambda}_{vapour} = p_{tot} \cdot \left(1 - \frac{x_{oxygen}}{20{,}95}\right)$$

Where p_{tot} is the total pressure of the gas mixture and the assumption of a concentration of 20,95 % in O2 is achieved in the studied dry gas mixture.

It turns out that the k coefficient is not constant along the operating range and may be corrected after thanks to a calibration process and by using the following equation

$$k' = \frac{V_\lambda}{20{,}95 \cdot \left(1 - \frac{e'_{vapour}}{p_{tot}}\right)}$$

A classical calibration by comparison has been used in order to determine the k' coefficient.

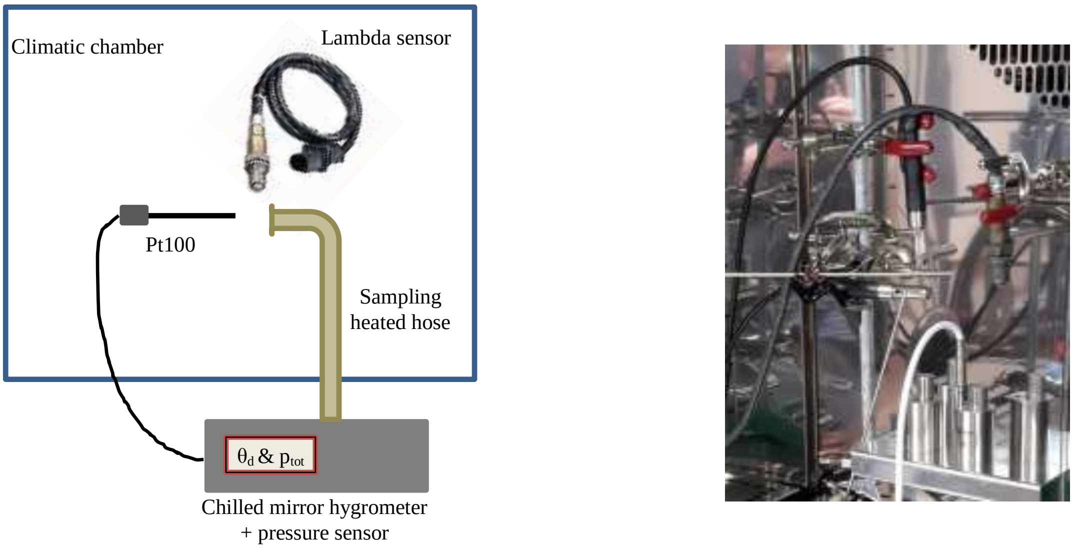

Figure 2 – calibration by comparison

Thus a climatic chamber is used as humid air generator, and thanks to the use of a chilled mirror measures the dew point temperature, combined with dry temperature measurement from a Pt100 temperature probe and a pressure sensor, all of them traceable to SI units, it is possible to evaluate the theoretical of e'_{vapour}. Then e^{λ}_{vapour} and e'_{vapour} can be compared and k' coefficient might be determined.

The following calibration program has been applied :
@ 80 °C : 66 %rh (θ_{dew}=70,06 °C), 80 %rh (θ_{dew}=74.24 °C); 96 %rh (θ_{dew}=79 °C)
@ 85 °C : 64 %rh (θ_{dew}=74°C), 70 %rh (θ_{dew}=75,78 °C), 80 %rh (θ_{dew}=79,02 °C), 96 %rh (θ_{dew}=83,96°C)
@ 90 °C : 53 %rh (θ_{dew}=74,07 °C), 65%rh (θ_{dew}=79 °C), 80%rh (θ_{dew}=83.81 °C),96 %rh (θ_{dew}=88,93 °C)
@ 95 °C : 44 %rh (θ_{dew}=74,05 °C), 54 %rh (θ_{dew}=79 °C), 66 %rh (θ_{dew}=84,02 °C), 81 %rh (θ_{dew}=89,15 °C)

The calibration results are presented below :

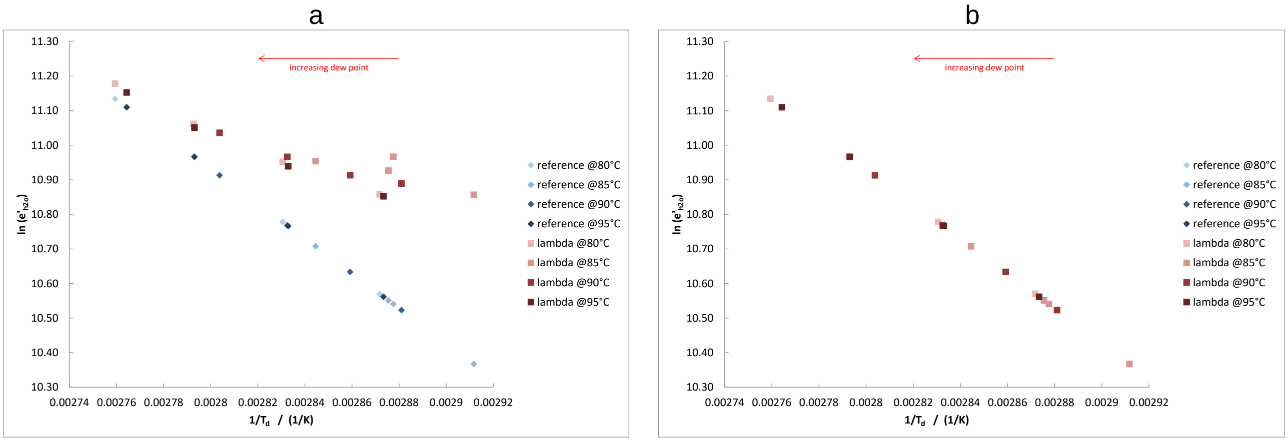

Figure 3 – a) results with $k = 0{,}4$; b) results with k' obtained from calibration

Further information are available here.