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CALIBRATION OF SMALL RELATIVE HUMIDITY SENSORS

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Abstract: The authors' laboratory is accredited for calibration by comparison of contact thermometers and calibration baths and furnaces in the range from -55 °C to 1250 °C. The accreditation was granted to the laboratory in January 1997 as the first temperature calibration laboratory in Slovenia. It also became a holder of national standards for thermodynamic temperature thus providing the traceability of temperature in Slovenia. There are many thermometers and relative humidity sensors made combined as thermo-hygrographs. These applications serve mainly for monitoring environmental conditions at various places. Their users usually need to know their performance therefore they need calibration certificates of an accredited laboratory for these thermo-hygrographs as an evidence of traceability. Since there are quite a few demands to calibrate both a temperature and a humidity sensor, and there is no other laboratory accredited for calibration of relative humidity sensors in Slovenia, we have decided to set-up the facility for calibration of small relative humidity sensors. The decision based also on relative affinity between thermodynamic temperature and relative humidity.
Keywords: relative, humidity calibration, traceability

1 INTRODUCTION

Because an industry expressed quite a few demands for traceable measurement of relative humidity it was decided that in the previously accredited temperature laboratory the accreditation should be extended also to the calibration of relative humidity sensors. Therefore a small relative humidity generator was introduced and evaluated according to our own procedure developed, [1]. As a reference instrument a dew-point sensor was introduced, which is traceable to the international standards. A relatively simple set-up is presumably capable of covering approximately 50% of Slovenian needs for traceable calibrations in the field of relative humidity. Limiting factors are very small dimensions of a chamber in the relative humidity generator and its very limited temperature range from 20 °C to 26 °C. The first factor makes impossible the calibration of non-electronic, usually mechanical thermo-hygrographs or hygrographs, which measurements are based on stretching of a horse hair. The second factor prevents calibration of relative humidity sensors, which are capable to measure relative humidity at other than room temperatures. With respect to the current situation and demands from pharmaceutical, food, wood industry and various calibration or testing laboratories, the laboratory has already taken further steps to cover the rest of the requirements and practically satisfy all the country's needs.

2 EQUIPMENT

The facility besides the laboratory room, which is the same for temperature calibrations, is rather moderate since it comprises a small relative humidity generator with a chamber dimensions only (14 x 6 x 6) cm, a reference dew-point meter and a reference thermometer. The complete set-up is shown in Figure 1. A chamber of the humidity generator is covered with a plastic plate. We made a few plates more so that we are able to bore such openings into plates, which fit particular relative humidity sensors. The reference dew-point meter is connected to the humidity generator and according to its feedback the humidity generator generates a set relative humidity inside the chamber. The humidity generator uses a divided flow to generate a relative humidity. Relative humidity is controlled by the time proportioning a fraction of a constant flow of dry air stream through a saturator and into a mixing chamber. The saturated air rejoins the remaining dry air and mixes to the desired relative humidity value before flowing into the test chamber. As a desiccant, the humidity generator is using anhydrous $CaSO_4$. When it becomes saturated its color turns to pink and has to be dried at 220 °C in an electric oven.

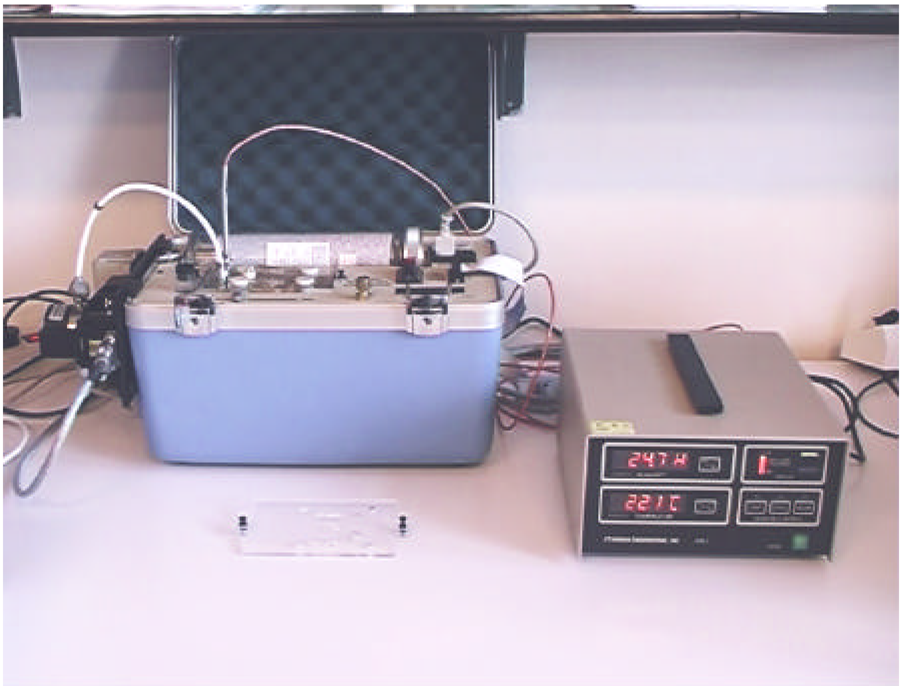

Figure 1. Measurement set-up for calibration of small relative humidity sensors

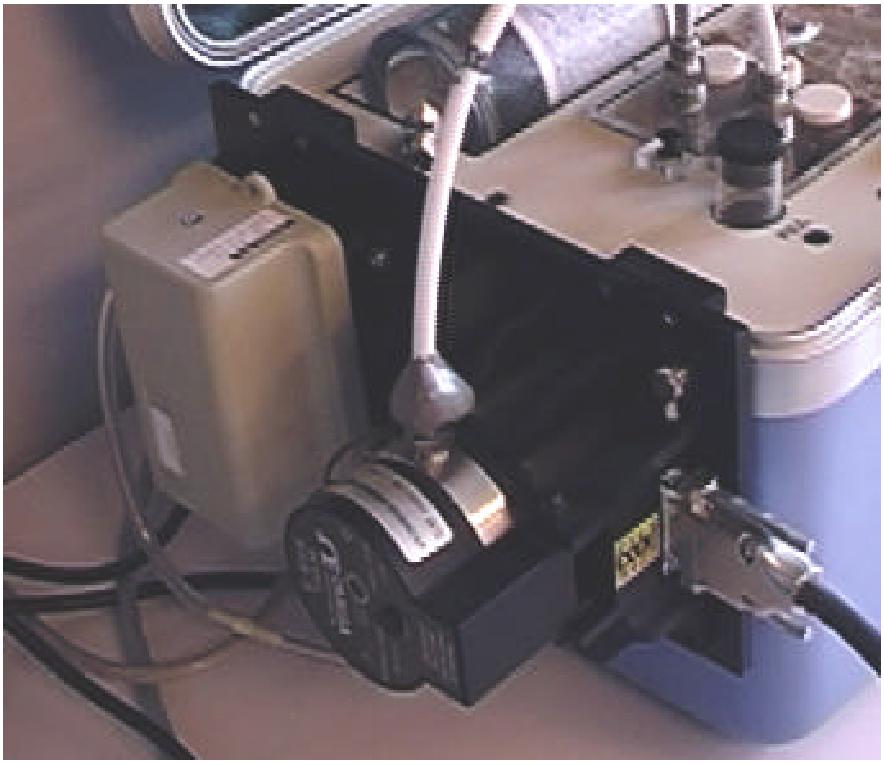

Figure 2. The reference dew point sensor

3 UNCERTAINTY, BEST MEASUREMENT CAPABILITY AND TRACEABILITY

The uncertainty budget in calibration of a relative humidity sensor consists of the following contributions: the uncertainty due to repeatability of an unit under test (u_{repeat}), the uncertainty of the humidity test chamber (u_{chamber}), the uncertainty of the reference dewpoint meter ($u_{\mathrm{RHB\text{-}S}}$), and the uncertainty of reading of a relative humidity sensor (u_{reading}). The total uncertainty of calibration of a relative humidity sensor (unit under test) is determined by the equation:

$$u_{\text{total}} = \sqrt{u_{\text{repeat}}^2 + u_{\text{chamber}}^2 + u_{\text{RHB-S}}^2 + u_{\text{reading}}^2} \tag{1}$$

While the uncertainties due to repeatability and reading are based on calibration measurements, and the uncertainty of the reference dew point sensor is obtained from its calibration certificate, the uncertainty of the chamber has to be determined by the calibration laboratory itself. The main task is to objectively determine the uncertainty of relative humidity due to temperature gradients inside the chamber $\{u_T(x)\}$, and the uncertainty due to time instability of a relative humidity set $\{u_T(t)\}$. The uncertainty of the chamber is therefore calculated as:

$$u_{\text{chamber}} = \sqrt{u_T^2(t) + u_T^2(x)} \tag{2}$$

There is no ideally stable environment. Inside the test chamber conditions are constantly fluctuating. Fluctuation of temperature is often more important then fluctuation of humidity since there is a strong influence of temperature on relative humidity. Since the temperature gradients in the air are quite fast, we had to measure them with thermometers that have an appropriate response time (short time constant).

Stability of temperature is measured at the same time as temperature gradients inside the chamber. It is determined as the greatest difference observed by measuring the time deviation of temperature with a reference thermometer placed in a geometrical center of the chamber. The difference has to be multiplied by $1/\sqrt{3}$ according to [2]. A temperature value is converted to a relative humidity value with a help of the equation (3) and (4) as described in [3], and taken as the uncertainty of relative humidity due to temperature gradients.

$$\ln e_w(T_d) = -6096.9385 \cdot T_d^{-1} + 21.2409642 - 2.711193 \cdot 10^{-2} \cdot T_d + 1.673952 \cdot 10^{-5} \cdot T_d^2 + 2.433502 \cdot \ln T_d \tag{3}$$

$$\textit{relative humidity}\,[\%] = \frac{e_w}{e_s} \cdot 100 \tag{4}$$

In equation (3) e_w means a vapor pressure of water (in pascal), and T_d (in kelvin) is a dew point temperature. In equation (4) e_w is the actual vapor pressure of water and e_s is the saturation vapor pressure of water at prevailing temperature and barometric pressure.

Humidity gradients are consequence of temperature gradients in the chamber, therefore temperature is measured with five thermometers at different positions. One thermometer is placed in a geometrical center of the chamber and is considered as the reference. Other four thermometers are placed into holes, which are near to the corners of the chamber. Two thermometers at one side of the reference thermometer are placed 1 cm and 5 cm from the bottom of the chamber, respectively. Other two thermometers on the other side of the reference thermometer are placed at the same heights. Position of thermometers regarding one chamber diagonal has to increase (1 cm, 3 cm, 5 cm), and decrease (5 cm, 3 cm, 1 cm) regarding another chamber diagonal. Two measurements have to be taken at one relative humidity set, so that the heights of thermometers on each chamber diagonal are once increasing and once decreasing. Measurements have to be taken at three different values of humidity: 5%, 50%, 95%. The greatest difference between reference thermometer and other thermometers is observed, multiplied by $1/\sqrt{3}$ (according to the document EAL-R2), converted to a relative humidity value according to the equation (3), and taken as the uncertainty due to temperature gradients inside the chamber.

Table 1. The best measurement capability of the LMK

quantity	standard uncertainty	probability distribution	sensitivity coefficient	uncertainty (value in % r.h.)
u_{repeat}	0,1 °C	normal	6% r.h./°C at 95% r.h.	0,6
u_{chamber}				
$u_T(t)$	0,1 °C	rectangular	6% r.h./°C at 95% r.h.	0,6/√3
$u_T(x)$	0,4 °C	rectangular	6% r.h./°C at 95% r.h.	2,4/√3
$u_{\text{RHB-S}}$				
u_{DT}	0,2 °C	rectangular	6% r.h./°C at 95% r.h.	1,2
u_{AT}	0,2 °C	rectangular	6% r.h./°C at 95% r.h.	1,2
u_{reading}	Digital: 0,1% r.h. Analog: 1% r.h.	rectangular	1,0	Digital: 0,1/√3 Analog: 1·(1/5)/√3
u_{total}				3,0

Once the chamber is evaluated all uncertainty contributions are known and the best measurement capability can be determined and presented in the Table 1.

The traceability of relative humidity in Slovenia is presented in Figure 3. Our reference dew point sensor is traceable to the international standard at the NMi, Delft, The Netherlands. The thermometer for measuring an ambient temperature is calibrated in our laboratory.

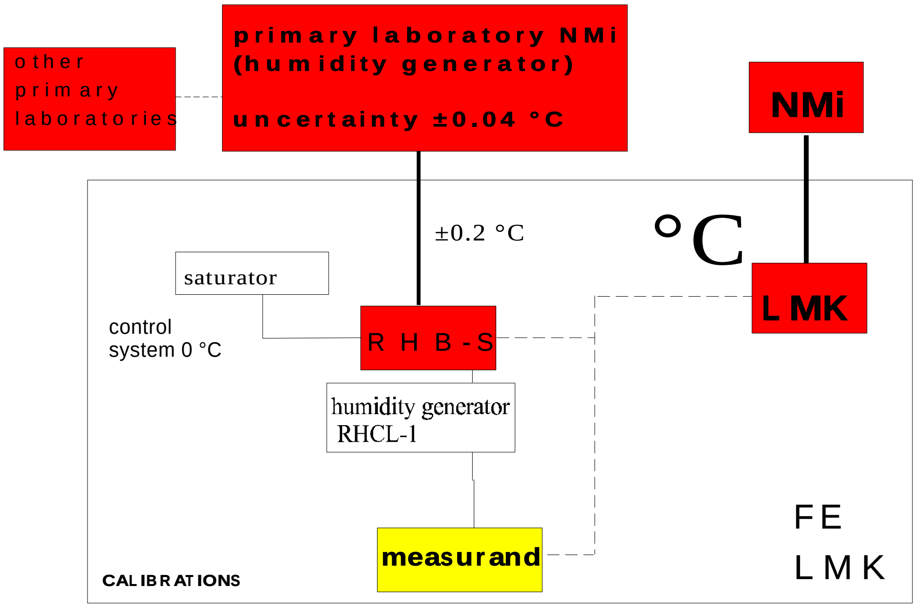

Figure 3. Traceability scheme of relative humidity in Slovenia

5 CONCLUSIONS AND FURTHER DEVELOPMENT

With a relatively simple equipment an useful and necessary calibration set-up was established for calibration of small relative humidity sensors. Achieved uncertainty is not of the highest performance but still good enough to cover most of the Slovenian needs in the field of relative humidity around the ambient temperature. To cover also other needs a humidity generator with the temperature range from –10 °C to 70 °C and bigger chamber is being introduced as well as a high precision dew point sensor. An aimed uncertainty is 2% of relative humidity or less, depending on the temperature range. Traceability will remain related to the temperature and to the international standards.

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