Humidity Calibration - Simple and Accurate

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Introduction

In a strong growing market for humidity sensor elements and humidity transmitters, respectively, it is from great importance to have accurate and traceable methods for calibrating and adjusting of humidity measuring systems. So there is a need for systems which are able to perform relative humidity with high stability and accuracy. Also short stabilisation time and easy handling are requests to such a „humidity generator“.

Actually, the well known concentrated and non concentrated salt solutions are most common for this purpose, but certainly they cannot fulfil the increasing requests in accuracy and stability. Commercially available climate chambers are also partly used for this purpose, but usually they don't have the requested stability and accuracy. Additionally there is the disadvantage of the need to build in usually the whole sample under test which makes it more difficult to readjust the sample.

Humidity reference systems used in standardisation institutes like PTB or NBS show much more accuracy and stability [1],[2]. In this case air or nitrogen with pressure p_1 is saturated to nearby 100 %rh at a temperature $T > T_1$ and then condensed due to a dew point temperature T_1 . As a result you get gas with pressure p_1 and dew point temperature T_1. Now the gas is expanded to pressure p_2 at a temperature T_2 .and let into a test chamber. From the relation of p_1,T_1 to p_2,T_2 the performed relative humidity in the test chamber can be calculated. Such a two pressure - two temperature generator (2p2T-generator) can show the highest available accuracy to perform relative humidity , if it is constructed properly, but it needs a rather high apparatus consumption.

Two pressure generator

Our main goal was to simplify the working principle and the construction of a standard 2p2T-generator in such a way that we get a simple humidity generator easy to handle with less but sufficient accuracy and stability.

At a 2p2T generator in the first (saturation) chamber the saturation partial pressure of vapour is given as

$$e'_{ws}(p_1,T_1) = e_{ws}(T_1) \cdot f(p_1,T_1)$$

$e_{ws}'(p,T)$
saturation vapour pressure at a certain gas pressure p at temperature T . It has an approximately exponential behaviour in temperature and gives the maximum possible vapour pressure at this temperature in a real gas.
$e_{ws}(T)$
saturation vapour pressure in the pure phase at temperature T, it corresponds to the saturation vapour pressure in an ideal gas.
f(p,T)
enhancement factor, describes the real gas behaviour of the used gas. Usually the vapour pressure in a gas is a little bit higher than in the pure phase. E.g. in air or nitrogen at 1 bar the enhancement factor is approximately 1.004

The values for $e_{ws}(T)$ and f(p,T) can be calculated using e.g. formulas from Sonntag[4] and Hyland[5]

Now the gas is expanded into the second (test-) chamber to a pressure p_2 . In this chamber due to Dalton's law you will get a vapour pressure

$$e'_2 = e'_{ws}(p_1,T_1) \cdot \frac{p_2}{p_1}$$

The saturation vapour pressure in the (test-) chamber 2 is given as

$$e'_{ws}(p_2,T_2) = e_{ws}(T_2) \cdot f(p_2,T_2)$$

Relative humidity rh is defined as ratio between the actual vapour pressure e to saturated vapour pressure e_{ws} at a certain temperature .

$$rh = \frac{e}{e_{ws}}$$

In our case we get

$$rh = \frac{e'_2}{e'_{ws}(p_2, T_2)} = \frac{e'_{ws}(p_1, T_1)}{e'_{ws}(p_2, T_2)} \cdot \frac{p_2}{p_1}$$

There are two ways to simplify the 2p2T generator. The first way is to keep the pressure constant

$p = p_1 = p_2 = const$

and we will get in the case of a **2-temperature generator**

$$rh = \frac{e'_{ws}(p, T_1)}{e'_{ws}(p, T_2)}$$

Here the temperature T_1 is equal to the dew point temperature T_d corresponding to the relative humidity rh at temperature T_2. Setting $T = T_2$ we can write

$$rh = \frac{e'_{ws}(p, T_d)}{e'_{ws}(p, T)}$$

A 2-temperature generator is a very simple concept and fundamentally works like a reversed dew point mirror, but it has a main disadvantage. You have to stabilise temperature very accurately and any change in relative humidity needs a change in temperature which takes a lot of time for stabilisation.

The second way to simplify a 2p2T-generator is to keep the two temperatures equal

$T = T_1 = T_2$

and we will get in the case of a **2-pressure generator**

$$rh = \frac{e'_{ws}(p_1, T)}{e'_{ws}(p_2, T)} \cdot \frac{p_2}{p_1} = \frac{e_{ws}(T) \cdot f(p_1, T)}{e_{ws}(T) \cdot f(p_2, T)} \cdot \frac{p_2}{p_1} = \frac{p_2}{p_1} \cdot \frac{f(p_1, T)}{f(p_2, T)}$$

As the enhancement factor f(p,T) depends only a little on temperature, especially when you are using the humidity generator in e restricted temperature range from 10 to 30°C, you can neglect the temperature dependence of f(p,T)

$$\frac{f(p_1, T)}{f(p_2, T)} ====> \frac{f(p_1)}{f(p_2)}$$

Finally the relative humidity depends only on the pressure ratio with a small pressure depending real-gas correction

$$rh = \frac{p_2}{p_1} \cdot \frac{f(p_1)}{f(p_2)}$$

HUMOR 10 humidity generator

The two pressure humidity generator HUMOR 10 consists of two chambers, one built within the other (s.fig. 1)

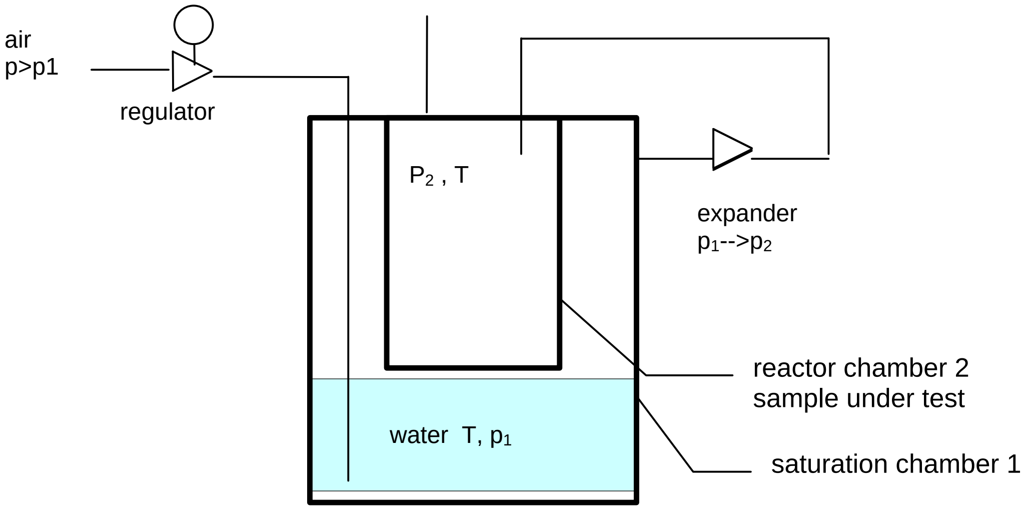

Fig. 1 : Schematic construction of the two pressure reactor HUMOR 10

Air or nitrogen with pressure p_1 is let into chamber 1 and humidified to a saturation vapour pressure e_{ws} corresponding to the temperature of the chamber and the water, respectively
Now the humidified air is expanded to pressure p_2 and let into chamber 2 and a relative humidity rh is performed which depends mainly on the ratio p_2/p_1.

By changing the inlet pressure p_1 by the regulator the relative humidity in chamber 2 can be varied. During operation the pressures in chamber 1 and 2 are measured and the actual relative humidity is calculated using the formula above and given on a display. (s. fig.2)

Fig. 2 : HUMOR 10 2-pressure humidity generator

The performed relative humidity by HUMOR 10 is practically independent from the environmental temperature and depends only on the pressures p2 and p1 . The only assumption is an equal temperature of chamber 1 , chamber 2 and the water inside chamber 1. This can be achieved by the thermal high conductive construction of the HUMOR 10.

Constructing a 2-pressure generator the main problems are to avoid condensation in the expansion part of the construction and to keep the gas stream constant independent from the pressure ratio.
The first point is solved by a heating which keeps the expansion part approximately 5°C above the generator temperature. The second point is solved by an expansion in two steps from p_1 to p_2 . First the gas is expanded by a regulater from p1 to $p_z = p_2$+150 mbar . From p_z to p_2 the gas is expanded by a throttle valve. As a consequence the gas stream is determined by the pressure difference between p_z and p_2 and not by the difference between p_1 and p_2 .

Accuracy :
The accuracy of the HUMOR 10 primarily depends on the pressure measurement . To improve the accuracy the humidity generator can be compared with a certified dew point mirror and the deviation can be stored as correction function to the microprocessor of the HUMOR 10. Finally we can achieve an accuracy which depends only on the used humidity reference. (s.fig. 3)

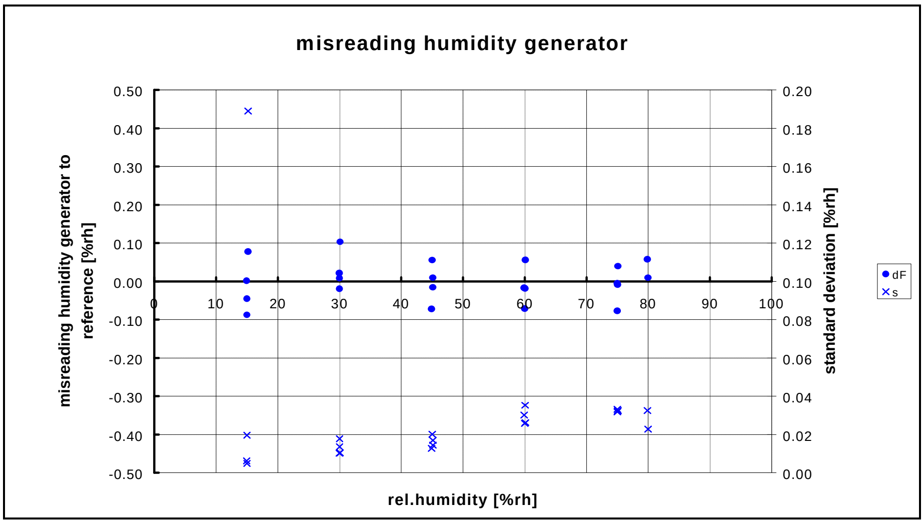

Fig.3 : Accuracy of HUMOR 10 in comparison with a certified dew point mirror

Stability
A performed humidity of 75%rh was compared with a certified dew point mirror over a period of 150 hours. (s.fig. 4) An accuracy of -0.09 ± 0.06(s) %rh was coming out.

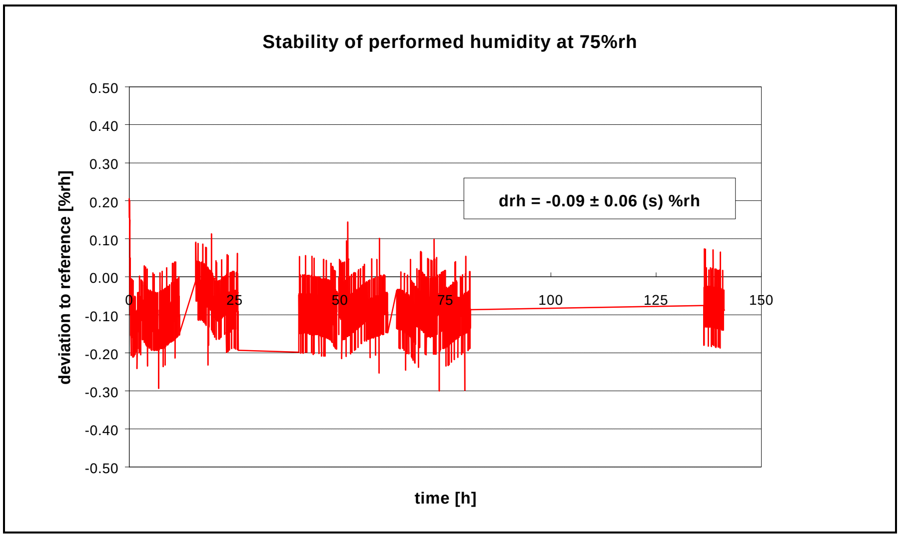

Fig. 4 : Stability of performed humidity in comparison with a dew point reference

For a period of one year a stability better than 0.5%rh is expected.

All accuracy measurements with the HUMOR 10 have one problem : The stability and accuracy (after correction) of the HUMOR 10 is usually comparable or better than available references. Therefore in most cases it is impossible to decide whether you are measuring the accuracy of the generator or that of the reference.

Response

The response of the HUMOR 10 on changing rel.humidity depends only on how fast you can change the pressure in chamber 1 (s.Fig.1). Practically a change from 75%rh to 25% takes a time below 1 min. Fig. 5 shows the deviation of the HUMOR 10 from the final value in comparison with a reference dew point mirror. Again there is the problem that the dew point mirror is much slower than the humidity generator and shows some oscillations in the first minutes.

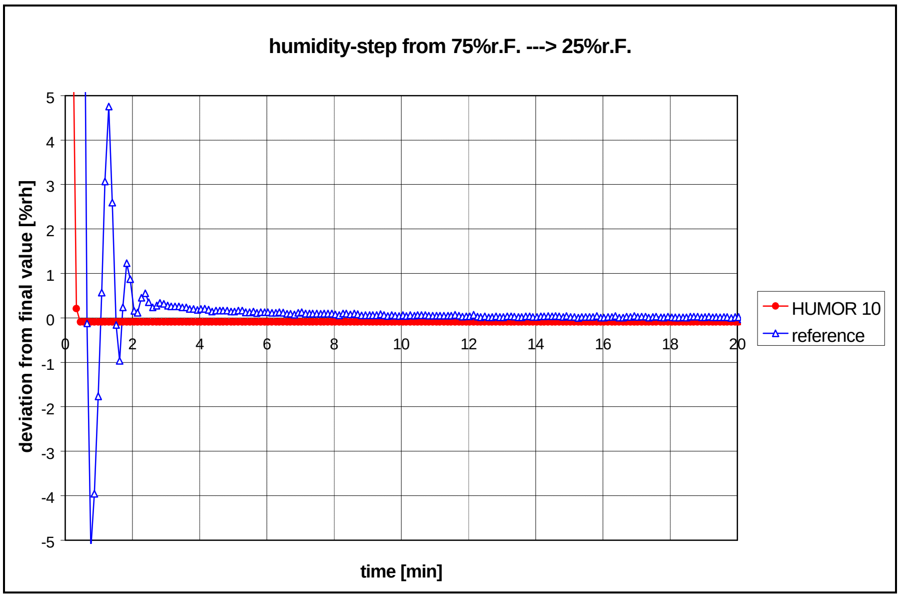

Fig. 5 : Deviation from final value after a change in performed humidity from 75%rh to 25%rh in comparison with a dew point-mirror

Environmental conditions

The performed humidity by the HUMOR 10 doesn't depend on the environmental temperature. The only required condition is a good temperature uniformity of the chambers of the generator. In fig. 6 the deviation of the performed humidity of 75%rh is shown during an environmental temperature step from 25°C to 40°C and from 10°C to 25°C. Again the problem is the accuracy of the dew point reference, especially in the first minutes after the temperature step.

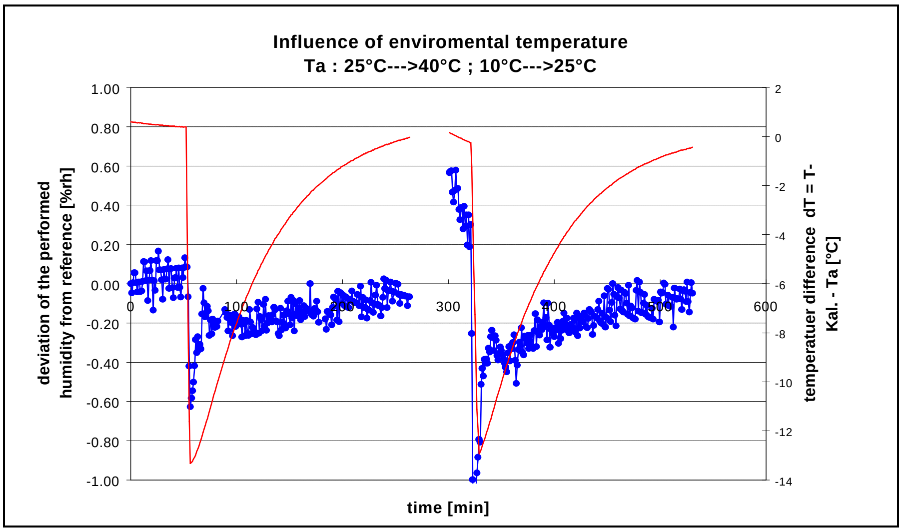

Fig.6 : Accuracy of the performed humidity of 75%rh under changing environmental temperature conditions. In the chart there is also drawn the temperature-difference between environmental temperature T_a and the HUMOR temperature T_{cal}

Literature

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